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BENEFIT AND NET BENEFIT ANALYSIS OF ALTERNATIVE NATIONAL AMBIENT AIR QUALITY STANDARDS FOR PARTICULATE MATTER

VOLUME III

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Prepared for:

Benefits Analysis Program
Economic Analysis Branch
Strategies and Air Standards Division
Office of Air Quality Planning and Standards

U.S. ENVIRONMENTAL PROTECTION AGENCY
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BENEFIT AND NET BENEFIT ANALYSIS OF ALTERNATIVE NATIONAL AMBIENT AIR QUALITY STANDARDS FOR PARTICULATE MATTER

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EPA PERSPECTIVE

There has been growing concern with the effectiveness and burden of regulations imposed by the Federal government. In order to improve the process by which regulations are developed, Executive Order 12291 was issued. The order requires that Federal agencies develop and consider, to the extent permitted by law, Regulatory Impact Analyses (RIA) for the proposal and promulgation of regulatory actions which are classified as major. According to the order, a significant component of the RIA is to be an economic benefit and benefit-cost analysis of the regulatory alternatives considered. Under the Clean Air Act, the Administrator of EPA may not consider economic and technological feasibility in setting National Ambient Air Quality Standards (NAAQS). Although this precludes consideration of benefit cost analyses in setting NAAQS, it does not necessarily preclude consideration of benefit analyses for that purpose.

In full support of the Executive Order, the EPA commissioned Mathtech, Inc. to accomplish an economic benefit and benefit-cost analysis of some of the alternatives that were thought likely to be considered in the development of proposed revisions to the NAAQS for particulate matter (PM). The report, entitled "Benefit and Net Benefit Analysis of Alternative National Ambient Air Quality Standards for Particulate Matter," documents the results of the contractor's study. One of the major objectives of the study was to give a better understanding of the complex technical issues and the resource requirements associated with complying with the spirit of the Order for the NAAQS program. In order to achieve this objective, the contractor was given a wide range of latitude in the use of data, analytic methods, and underlying assumptions.

It is important to stress that the benefit analysis portion of the Mathtech study has not had a role to date in the development of proposed revisions to the NAAQS for particulate matter. Staff recommendations currently under consideration are based on the scientific and technical information contained in two EPA documents. They are the "Air Quality Criteria for Particulate Matter and Sulfur Oxides" and the "Review of the National Ambient Air Quality Standards for Particulate Matter: Assessment of Scientific and Technical Information, OAQPS Staff Paper." These documents have undergone extensive and rigorous review by the public and the Clean Air Scientific Advisory Committee in accordance with the Agency's established scientific review policy. Although the Mathtech study reflects the "state-of-the-art" in particulate matter benefit analysis, the approach and results have not been subjected to a comparable extensive peer review process. In addition, some EPA staff have raised questions regarding the approach taken in the analysis and the significance of the results for standard setting purposes under the Act. These circumstances do not necessarily preclude use of the benefit analysis in some manner after appropriate peer review and further consideration of the questions that have been raised.

PREFACE

This report was prepared for the U.S. Environmental Protection Agency by Mathtech, Inc. The report is organized into five volumes containing a total of 11 sections as follows:

ACKNOWLEDGMENTS

While preparing this report, we had the benefit of advice, comments and other assistance from many individuals. Allen Basala, the EPA Project Officer, and James Bain, former Chief of the Economic Analysis Branch (EAB), were especially helpful. They provided both overall guidance on project direction as well as technical review and comment on the report. Others in EAB who assisted us included Thomas Walton, George Duggan, and John O'Connor, the current Chief of EAB.

Others within EPA/OAQPS who reviewed parts of the report and assisted in various ways included Henry Thomas, Jeff Cohen, John Bachman, John Haines, Joseph Padgett, and Bruce Jordan.

Several individuals within EPA/OPA also provided comments or assistance at various stages of the project. These included Bart Ostro, Alex Cristofaro, Ralph Luken, Jon Harford, and Paul Stolpman.

Others outside EPA who reviewed parts of the report and provided comments included V. Kerry Smith, Paul Portney, Lester Lave, Eugene Seskin, and William Watson. Other Mathtech staff who assisted us in various ways were Donald Wise, Gary Labovich, and Robert J. Anderson. We also appreciate the assistance of Al Smith and Ken Brubaker of Argonne National Laboratory who conducted the parallel analysis of control costs and air quality impacts.

Naturally, it was not possible to incorporate all comments and suggestions. Therefore, the individuals listed above do not necessarily endorse the analyses or conclusions of the report.

The production of a report this length in several draft versions, each under a tight time constraint, is a job which taxes the patience and sanity of a secretarial staff. Carol Rossell had this difficult task and managed ably with the assistance of Deborah Piantoni, Gail Gay, and Sally Webb. Nadine Vogel and Virginia Wyatt, who share the same burden at EAB, also assisted us on several occasions.

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SUMMARY OF RESULTS

One method that has been used to estimate the benefits of air quality improvements has involved the analysis of residential property value differentials. The underlying hypothesis in this method is that residential property values will reflect not only housing quality but also site-specific attributes such as location, neighborhood characteristics, availability of services, and environmental amenities including air quality. Under this hypothesis, property value differentials attributable to air quality differences reflect the household's economic valuation of air quality and therefore can be used to estimate the economic value of improvements in air quality.

The purpose of this section is to develop estimates of the benefits resulting from reductions in the ambient level of suspended particulates based on the results of representative studies employing the property value technique. Because property value differentials can measure only the effects of air pollution that are perceived by the household, it should be mentioned that the types of benefits that are measured in this section are any perceived health, physical property, aesthetic, or psychic benefits that can be attributed to residing in an area with relatively clean air. Consequently, it is likely that the benefits estimated in this section will be larger than the benefits estimated in Section 7 for household soiling and materials damage. It is unclear, however, whether the estimates presented in this section will exceed the health benefits presented in Sections 3 and 4.

The benefits in this section were estimated using the same air quality data and air quality standards used throughout this study -- implementation of four particulate matter with a diameter of 10 μm (PM10) and two total suspended particulate (TSP) standards in counties where air quality data are available. The resulting estimates under these alternative standards are summarized in Table 5-1. The benefits reported in this table are reported in terms of the discounted present value in 1982 of a stream of benefits occurring between the year of standard attainment and 1995.* These benefit estimates are stated in 1980 dollars and assume a 10 percent discount rate. As Table 5-1 indicates, under the most lax PM10 standard of an annual arithmetic average (AAM) of 70 $\mu g/m^3$ and a 24-hour expected value (EV) of 250 $\mu g/m^3$, the discounted present value of benefits range from $3.4 to $11.4 billion and include a point estimate of $6.9 billion. The most stringent of the PM10 standards -- an AAM of 55 $\mu g/m^3$ and a 24-hour EV of 150 $\mu g/m^3$ results in benefits ranging from $7.6 to $25.4 billion with a point estimate of $15.3 billion. The current primary standard of 75 $\mu g/m^3$ annual geometric mean (AGM) and 260 $\mu g/m^3$ 24-hour maximum value not to be exceeded more than once a year for TSP are estimated to result in benefits ranging from $11.2 to $37.3 billion and include a point estimate of $22.4 billion.

The benefits estimated in this section should be considered to be general approximations of the household benefits resulting from the attainment of alternative particulate matter standards for the following reasons:

- Since property value differentials only reflect the value of <u>perceived</u> differences in air quality levels, any unperceived benefits resulting from air quality improvements will not be captured in the estimates reported in this section. Consequently, the benefits reported in this section are underestimates of the total benefits of reductions in the ambient level of particulate matter.

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* The year of standard attainment for PM10 standards is 1989. The year of standard attainment for TSP standards is 1987.

Table 5-1

PROPERTY VALUE BENEFITS OF ATTAINING ALTERNATIVE PARTICULATE MATTER STANDARDS*

(Billions of 1980 Dollars)

Standard**	Minimum	Point Estimate	Maximum
PM10 - 70 $\mu g/m^3$ AAM and 250 $\mu g/m^3$ 24-hour EV	$ 3.4	$ 6.9	$11.4
PM10 - 55 $\mu g/m^3$ AAM	6.0	11.9	19.9
PM10 - 55 $\mu g/m^3$ AAM and 250 $\mu g/m^3$ 24-hour EV	6.0	12.0	20.0
PM10 - 55 $\mu g/m^3$ AAM and 150 $\mu g/m^3$ 24-hour EV	7.6	15.3	25.4
TSP - 75 $\mu g/m^3$ AGM and 260 $\mu g/m^3$ 24-hour MAX	11.2	22.4	37.3
TSP - 150 $\mu g/m^3$ 24-hour MAX	14.9	29.7	49.6

* Benefits are stated in terms of the discounted present value in 1982 and assume a 10 percent discount rate. Benefits for the PM10 standards are accumulated from 1989 to 1995, while the benefits for the TSP standards are accumulated from 1987 to 1995.

** AAM = annual arithmetic mean; AGM = annual geometric mean; EV = expected value; MAX = maximum value not to be exceeded more than once a year.

- The results of studies on specific cities in the early 1960's and 1970's are used to estimate the benefits of pollution reductions occurring between 1987 and 1995 for the counties included in this analysis. If the valuation of air quality improvements has changed significantly since that time, or if the valuation of air quality improvements differs between cities and counties, the use of these studies' results can only be considered as approximations of the benefits of attaining alternative particulate matter standards.

- The assumptions of the hedonic technique are assumed to hold in the property value market. The effect of this assumption is unknown.
- The average of the particulate matter readings within a county is taken as representative of the level of exposure of all households within a county. The effect of this assumption on the estimated benefits is unknown.
- The marginal willingness to pay for air quality improvements of households residing in single-family units is assumed to be representative of all households. The effect of this assumption is unknown.
- The marginal willingness to pay for air quality improvements is assumed to decline at a constant rate as air quality improves. The effect of this assumption is unknown.

GENERAL BACKGROUND

The analysis of residential property value differentials has been widely used for estimating the benefits of reductions in air pollution levels. This method assumes that the benefits of living in a clean air environment are capitalized into property values. In other words, what people are willing to pay for air quality improvements can be measured by the observed differences in the value of residential properties that are identical in every respect except air pollution exposure.

Since this method focuses on the decisions made in the housing market, the household does not need to know the technical relationship between air pollution and physical damage. The household, however, must be able to perceive the effect of different levels of air quality, and make decisions in the housing market based on that perception. Consequently, the types of benefits that are measured through the property value method are any <u>perceived</u> health, physical property, aesthetic, or psychic benefits that are the result of <u>residing</u> in an area with relatively clean air. Because some of the effects of air pollution are probably not perceived by households, one of the disadvantages of property value studies is that they cannot provide estimates of all the benefits accruing to households that result from air quality improvements. For example, health effects that are not perceived by the household will not be captured by residential property values. Another disadvantage is that residential property value studies may only provide estimates of benefits that occur at home. For example, benefits of air quality improvements that occur at recreation areas and the workplace may not be measured by residential property value differentials.*

One of the major advantages of property value differential analysis is the ability to capture the value that households place on the aesthetic and psychic amenities of the place where they reside. Neither health studies nor physical property dose-response functions measure the aesthetic benefits of improvements in air quality. In addition, property value studies can reflect the choice of substitute activities and goods that are used as a means of offsetting the effects of pollution. For example, if the members of a household substitute indoor activities for outdoor activities on certain days because of poor air quality, this reduced flow of services from the property would be reflected in a lower property value. It is possible, however, that the purchase of goods to offset the effect of pollution may result in an enhancement of the property value in a polluted area. If central air conditioning, for example, is bought by a household in order to offset the effects of pollution, the value of that house is higher relative to an identical home without air conditioning that is exposed to the same level of pollution. This can be correctly reflected in property value differentials if air conditioning is identified as one of the attributes of housing.

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* It is possible that property values, in addition to reflecting the value individuals place on amenities at the home, may also reflect the value placed on amenities at the workplace since once an individual makes a residential location decision, the choice of other locational amenities, such as those at the worksite, are limited. See Cropper (1).

METHODOLOGY

The use of property value differentials as a means of determining the willingness to pay for air quality improvements has its underpinnings in the hedonic price technique. This technique was originally developed by L. M. Court (2). Griliches and Adelman (3), Griliches (4), Ohta and Griliches (5), Kain and Quigley (6), and others have used the technique to estimate the value of changes in the quality of consumer goods. Generally stated, the hedonic technique examines the functional relationship between the price of a good and its characteristics.* It has been used extensively as a means of estimating the marginal willingness to pay for environmental quality [Harrison-Rubinfeld (7); Nelson (8)]. In these studies, housing values are regressed on a set of housing characteristics which includes a measure of air quality.

Before explaining the hedonic technique, it is necessary to address the question of whether predicted changes in property values are accurate measures of the total benefits of air quality improvements. Using a model of locational choice, Polinsky and Shavell (9) have shown that predicted property value changes are accurate measures of these benefits only under certain rather stringent assumptions. Their explanation proceeds as follows:

Assume that there is a city inhabited by individuals with identical utility functions and equal incomes.** People work in the center of the city and reside in the area surrounding the center city. Air quality (AQ) at a specific location increases with distance (d) from the center city.

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* See Chapter 1 of Griliches (4) for a summary of the hedonic price technique.

** The model can be generalized to reflect the possibility that there is more than one utility function and unequal incomes within the city. In this case, there would be i consumer groups (i = 1,n) where each member of the i^{th} group would have identical utility functions and incomes. This would only serve to complicate the analysis without changing the results. If incomes are endogenous to the model, however, the following results will be altered.

Travel cost (T) to the center city is also an increasing function of d. Utility in this city is a function of the consumption of household services (H), a composite good (X), and the level of air quality [AQ(d)]:

$$U = U\left(H, X, AQ(d)\right) \tag{5.1}$$

The consumer desires to maximize his utility subject to the budget constraint:

$$Y = p(d)H + X + T(d) \tag{5.2}$$

where Y = money income.

p(d) = per unit price of housing services at a location with distance (d) from the center city.

H = household services.

X = the composite good with price equal to 1.

T(d) = commuting costs to the center city.

By solving the first-order conditions of the utility maximization problem, Equation (5.1) can be stated in terms of an indirect utility function -- utility as a function of the demand functions for H, X, and AQ:

$$U = I[p(d), Y-T(d), AQ(d)] \tag{5.3}$$

Under the assumption of unrestrained and costless mobility throughout the city, and identical utility functions and income, a common equilibrium level of utility, U^*, will be obtained. At U^*, no individual can increase his utility level by moving.

$$U^* = I[p(d), Y-T(d). AQ(d)] \tag{5.4}$$

Implicit in this relation is the equilibrium housing function:

$$p(d) = P[U^*, Y-T(d). AQ(d)]. \tag{5.5}$$

It is important to note that the equilibrium price of housing is a function of U^* as well as Y-T(d) and AQ(d).

In Polinsky and Shavell's paper, Equation (5.5) is used to explain the conditions under which a new property value schedule can be predicted from a change in air quality. If it is assumed that the city is small and there is perfect and costless mobility among cities, then U^* will be the same across all cities and exogenous to the small city. If air quality improves within the small city, U^* will not change and the change in property value is only dependent on the characteristics of d. A regression equation specifying the relationship between p(d) and d can be used in this case to predict the change in property values resulting from a given change in air quality. If the city is either large, or there is imperfect mobility among cities, then U will be endogenous. If air quality improves within the city, U will be affected. In this case, the new property value schedule cannot be predicted without first using a general equilibrium model to determine the new level of U resulting from the change in air quality.

In general, therefore, property value equations that estimate the change in property value for a given change in air quality can be used to predict the new property value schedule for such changes only if the following assumptions are met:

- The geographical area under consideration must be small.
- There must be perfect mobility throughout, and into and out of, the geographical area.
- There must be no changes in input and output prices.

The hedonic technique, however, does not attempt to predict a new property value schedule resulting from a change in air quality, but rather estimates the marginal willingness to pay for air quality improvements by observing the housing market in equilibrium. In this method, the implicit price of air quality is identified by examining the differentiated prices within the housing market that result from variations in existing air quality. Since the housing market is in equilibrium, the implicit price of air quality can be shown to be equal to the marginal willingness to pay for air quality. The hedonic technique is therefore useful in predicting the benefits of marginal changes in air pollution. Given certain conditions, the implicit prices estimated by the hedonic technique and other relevant variables can be used to estimate the inverse demand function for air quality.* Through the estimation of this demand curve, the benefits of non-marginal changes in air quality can also be predicted.

The general form of a hedonic equation relates the price of a good to the characteristics of that good. As applied to the housing market, this can be expressed as:

$$R_i = r(S_i, N_i, Q_i) \tag{5.6}$$

where R_i = price of the i^{th} residential location.

S_i = a vector of structural characteristics of the i^{th} location.

N_i = a vector of neighborhood characteristics of the i^{th} location.

Q_i = a vector of environmental characteristics of the i^{th} location with one element in the vector being air quality (q_1).

Note that housing price in the hedonic equation is a function only of the characteristics of the house, not of the household.

The assumptions that are necessary in order for the hedonic equation to estimate the marginal willingness to pay for air quality improvements are:

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* In a recent study, Palmquist (9) has found that without strong assumptions, it is not possible to identify the demand curve for a housing characteristic, such as air quality, with data from one city. Palmquist has suggested that the demand curve can be identified by using data from a number of cities.

- The housing market must be in equilibrium.
- Individuals must be able to perceive the characteristics and attributes of housing.
- A complete range of houses with alternative characteristics must be available.

The partial derivatives of property value with respect to the housing characteristics are interpreted as the marginal implicit prices or the additional amount that must be paid for a house with one more "unit" of a particular characteristic, <u>ceteris</u> <u>paribus</u>. Since one of the assumptions of the property value model is that the housing market is in equilibrium, the marginal implicit price is therefore equal to the marginal willingness to pay for that characteristic. In terms of the partial derivative of property value with respect to air quality ($\partial R_i/\partial q_1$), an estimate of the equilibrium willingness to pay for marginal air quality improvements is obtained.

In order to see why the partial derivatives of the housing equation variables are equal to the equilibrium marginal willingness to pay for housing characteristics, it is helpful to develop a model of consumer choice following Rosen (11).*

Assume that there is a consumer whose utility is dependent on the consumption of a composite good (X) and a vector of housing characteristics (H) where air quality (h_1) is an element in the vector:

$$U = U(X, h_1, \ldots, h_n) \tag{5.7}$$

The consumer has income (y) which can be expressed as:

* Rosen's paper dealt with both the consumption and production of a good that could be defined in terms of its attributes and characteristics. Since the hedonic price technique only reveals the equilibrium outcome of demand and supply conditions and not the underlying demand and supply functions, and since the purpose of this paper is to estimate the willingness to pay for air quality improvements, we will limit our discussion to the consumer allocative decisions made for housing.

$$y = X + p(H) \tag{5.8}$$

where $p(H)$ = price of housing.

X = the composite good with price equal to 1.

Setting up the Lagrangian, the consumer maximizes U subject to his budget constraint. The first order conditions can be expressed as:

$$\partial U/\partial X = \lambda \quad \text{and} \quad \partial U/\partial h_i = \lambda \partial p(H)/\partial h_i \tag{5.9}$$

where λ = the Lagrangian multiplier.

By combining equations, it is found that in equilibrium the marginal rate of substitution between each housing characteristic and the composite good is equal to the partial derivative of the price of housing with respect to that particular characteristic (i.e., the implicit price of the characteristic estimated by the housing equation):

$$(\partial U/\partial h_i)/(\partial U/\partial X) = (\partial p(H)/\partial h_i) \; . \tag{5.10}$$

If X is thought of as money (the price of a dollar is equal to \$1.00), equilibrium is achieved when the marginal rate of substitution between h_i and money is equal to the marginal implicit price of h_i. Since the marginal rate of substitution between h_i and money can also be viewed as the marginal payment for h_i with money, the equilibrium conditions can be expressed as equating the marginal willingness to pay for h_i (with money) with its marginal implicit price.

The equating of the marginal implicit price and the marginal willingness to pay can also be explained by viewing equilibrium in terms of a particular h_i. Assume that there is a level of consumer utility, u, that can be defined by the function:

$$U(y - \theta; h_1, \ldots, h_n) = u \tag{5.11}$$

where $y - \theta = X$.

For a given u, Equation (5.11) can be thought of as an indifference curve relating the tradeoff between h_i and X. A bid function:

$$\theta(h_1, \ldots, h_n; u,y) \tag{5.12}$$

can be derived from Equation (5.11) which relates the alternative expenditures a consumer is willing to make for h_i given a certain level of utility and income. By totally differentiating (5.11), we find that:

$$\partial U/\partial X(dy - d\theta) + \partial U/\partial h_1 dh_1 + \ldots + \partial U/\partial h_n dh_n = du \tag{5.13}$$

Given the assumption of a fixed level of utility and income, $du = 0$ and $dy = 0$. If $dh_k = 0$ for $k \neq i$, Equation (5.13) reduces to:

$$\partial\theta/\partial h_i = (\partial U/\partial h_i)/(\partial U/\partial X) \quad . \tag{5.14}$$

Viewing a particular h_i,h_1 as air quality, Equation (5.14) shows that the marginal rate of substitution between air quality and X (money) is equal to the marginal implicit bid for air quality ($\partial\theta/\partial h_1$) at a given level of utility and income.

Figure 5-1 shows the bid function of consumer j for air quality while holding everything else constant, $\theta^j(h_1, h_2^*, \ldots, h_n^*; u^*, y^*)$. There are a number of different bid functions reflecting the different levels of tastes, preferences, and income of consumers. This function shows the willingness to pay (bid) for air quality in terms of the amount of money (X) foregone, <u>ceteris paribus</u>. The minimum implicit prices revealed in the market that must be paid for different levels of air quality while holding h_2 through h_n constant is shown by $p(h_1, h_2^*, \ldots, h_n^*)$. Equilibrium is reached when $\theta^j(h_1, h_2^*, \ldots, h_n^*; u^*, y^*)$ is tangent to $p(h_1, h_2^*, \ldots, h_n^*)$; i.e., where the marginal willingness to pay for air quality is equal to its marginal implicit price.

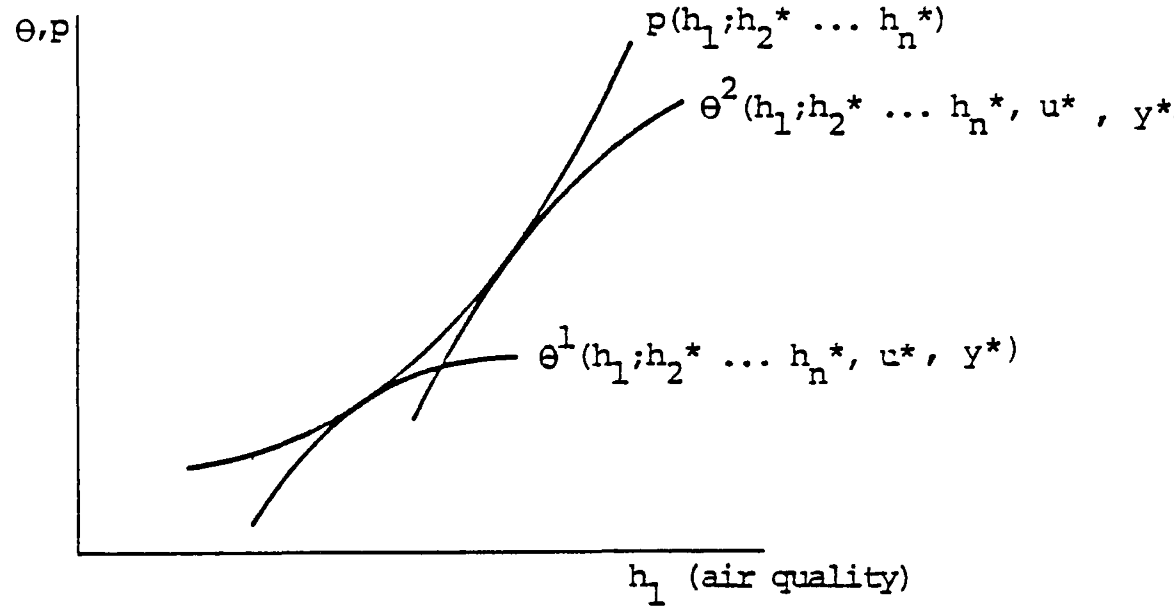

Figure 5-1. Implicit price schedule and bid functions.

Since the hedonic equation can be expressed by $p(h_1, \ldots, h_n)$, the marginal implicit price schedule for air quality ($\partial p(H)/\partial h_1$) can be easily obtained by taking the derivative of the hedonic housing equation with respect to air quality (see Figure 5-2). Assuming that the housing market is in equilibrium and following the above explanation, this schedule will also trace out the loci of marginal willingness to pay equilibria for different levels of air quality by consumers with different bid functions. Note that unless all consumers have identical bid functions (i.e., identical utility functions and incomes), the hedonic technique yields only the equilibrium marginal willingness to pay of consumer j with bid function θ^j. This is only one point on consumer j's demand price function for h_1 while holding utility constant (i.e., the inverse compensated demand function). Consequently, $\partial p(H)/\partial h_1$ is not the inverse compensated demand function for air quality and, in most cases, can only be used to approximate the benefits of marginal improvements in air quality. In order to accurately estimate the demand curve for air quality and predict the benefits of non-marginal changes in air quality when consumers do not have identical utility functions and incomes, additional information and steps are needed.

In this section, the hedonic studies that have measured the relationship between residential property values and particulate matter will be reviewed. The ultimate purpose of this review is to determine which of these studies can be used to estimate some of the economic benefits resulting from decreases in the ambient level of particulate matter. The studies used in this section meet the following specific criteria:

- Each study uses a properly specified hedonic model and attempts to include as many of the characteristics of the residential property as possible.
- The relationship observed between particulate matter and residential property value is plausible in terms of the underlying theoretical construct.
- The results can be used to estimate the benefits of particulate matter reductions.

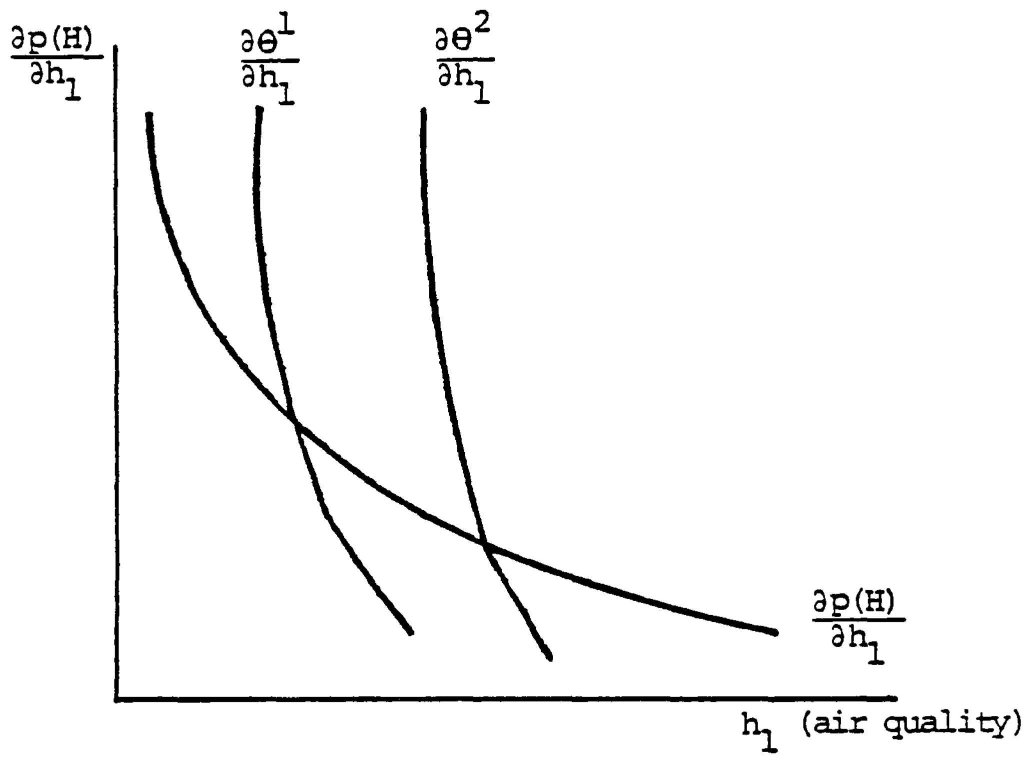

Figure 5-2. Marginal implicit price schedule and demand price functions.

The next subsection will contain a review of the pertinent residential property value studies. This will be followed by a subsection discussing the limitations of the hedonic price technique. The next subsection will contain the methods used to calculate the benefits of reductions in the ambient level of particulate matter. It will also contain the benefits under alternative particulate matter standards. Finally, the section will be ended with conclusions.

LITERATURE REVIEW

As previously mentioned, all of the studies that will be reviewed in this section examine the relationship between residential property values and some measure of particulate matter. The measure of particulate matter most commonly used in these studies are sulfates (SO_4), total suspended particulates (TSP), and dustfall. Consequently, studies including any of these pollutants will be examined.

The first study undertaken to measure the relationship between property values and the level of air quality was done by Ridker and Henning (12). Using 1960 cross-sectional census tract data from the St. Louis metropolitan area, the effect of air pollution levels on property values was estimated using regression analysis. The dependent variable was the median value (estimated by owner) of owner-occupied single-family housing units, and the independent variables included those reflecting location characteristics (e.g., accessibility to highway, travel time to central business district), property characteristics (e.g., median number of rooms, houses per mile), neighborhood characteristics (e.g., school quality, persons per housing unit), median family income, and an air pollution variable (an index indicating the presence of SO_2, SO_3, H_2S, H_2SO_4, and in some cases dustfall). Different linear specifications were tried and a significant negative relationship was found between the dependent variable and the air pollution variable. From these results, they concluded that property values could be expected to rise at least $83.00 and more probably

$245, if the measurement of SO_3 were to drop by 0.25 μg/100 cm^2/day.* The elasticity of the pollution variable could not be computed from the information contained in the study.**

Zerbe (19) estimated a property value equation for Toronto and Hamilton, Ontario. The annual averages of sulfur dioxide and dustfall were the two pollution measures used. Both linear and log-linear specifications were employed; in the log-linear specification, the elasticity of property values with respect to sulfur dioxide ranged from -0.061 to -0.121 for Toronto and -0.081 for Hamilton.+

Crocker (20), in a study of the relationship between home sale price and the annual arithmetic means for sulfur dioxide and total suspended particulates in Chicago, found a consistently significant negative relationship between sale price and particulate matter. The elasticity of home sale price with respect to particulate matter ranged from -0.25 to -0.83 and was generally significant. The coefficient of SO_2 was inconsistently signed and sometimes insignificant. However, when SO_2 was entered separately into the property value equation, it was generally negative and significant.

Anderson and Crocker (25) estimated the relationship between air pollution and median property values (estimated by owner) for three cities: St. Louis, Washington, D.C., and Kansas City. Using separate equations for

* Freeman (13) concluded that Ridker and Henning's results were over-interpreted and could not be used to predict changes in property values when air quality changed because the demand curve for air quality had not been identified. This led to quite a debate in the literature over the proper interpretation of the derivative of the air quality variables. [See Anderson and Crocker (14); Freeman (15); Polinsky and Rubinfeld (16); Small (17); and Harrison and Rubinfeld (18).]

** In this section, the elasticity measures the percentage change in residential property value that can be expected from a 1 percent change in the pollution variable. In a log-linear property value equation, the elasticity is equal to the coefficient of the pollution variable.

+ Information on the studies by Zerbe (19), and Steele (21) is taken from Freeman (22), Waddell (23), and Appel (24).

owner-occupied and renter-occupied housing, they found a significant negative relationship between the annual arithmetic means of air pollution and property values while controlling for median family income, percentage of old units, percent of run-down units, percent of non-white population, distance to the central city, and median number of rooms. The annual arithmetic means of sulfur oxides and suspended particulates were the pollution variables considered in this study. Using a log-linear specification, they found that the elasticity of sulfur oxides ranged from -0.07 to -0.12, while the elasticity of total suspended particulates ranged from -0.06 to -0.17. It is interesting to note that by using plausible interest rates (e.g., 8 to 12 percent), the results for the owner and renter equations were roughly consistent. This indicates that the marginal willingness to pay for air quality improvements estimated for households living in owner-occupied residences may be similar to the marginal willingness to pay of households that rent their residences.

Steele (21) did not find a significant relationship between property values, as measured by mean value per room, and SO_2 and particulates for residences in Charlestown, South Carolina. However, the relationship between property values and pollution was plausibly signed.

Wieand (26) regressed per-acre housing expenditures in St. Louis (a proxy for land values) on property characteristics, neighborhood characteristics, income, and pollution as measured by annual mean sulfation and annual mean particulates. Neither pollution variable was significant.

Deyak and Smith (27), using a log-linear specification, found a significant relationship between median property values of representative SMSAs and total suspended particulates. Other variables included in their best equation were median family income and percent of inferior housing units. The elasticity of particulate matter was quite consistent and ranged from -0.083 to -0.088. In a later study on the owner- and renter-occupied housing market for 85 cities which included measures of local public services and taxes, Smith-Deyak (28) did not find a significant negative relationship between air pollution and property value. Subsequent analysis by Deyak showed that if cities with relatively low levels of air pollution were excluded from the analysis, there was a significant negative relationship between air pollution and property value.

Using the data from Anderson and Crocker's St. Louis study (25), Polinsky and Rubinfeld (29) empirically estimated the equilibrium housing market function developed by Polinsky and Shavell (9) using a Cobb-Douglas form of utility function. Log-linear equations were developed for both owned and rented properties. The annual arithmetic mean of TSP was negative and significantly different from zero at the 0.05 level for both equations, while the annual arithmetic mean of the sulfation variable was negative and significantly different from zero at the 0.10 level for the homeowner equation. In the owner-occupied property value equations, the elasticity of TSP was equal to -0.132 and the elasticity of sulfates was equal to -0.063.

Nelson (8) also found a significant relationship between air pollution and median census tract owner-occupied property values in Washington, D.C. Several different specifications were employed with the semi-log and log-linear forms giving the best results. It was concluded that an increase of 10 $\mu g/m^3$ in the average monthly geometric mean from February to July of total suspended particulates would reduce the mean value of property by $576 to $693. In the most representative equations, the elasticity of TSP ranged from -0.078 to -0.116. The estimated marginal willingness to pay was then used to calculate a bid price function (i.e., an inverse demand curve for air quality). The price elasticity of demand for TSP in this equation ranged from -1.2 to -1.4, indicating that the implicit price of TSP is quite responsive to changes in the level of TSP. The bid price function estimated by Nelson, however, is only a first attempt at estimating the demand curve for air quality. In fact, Palmquist (10) suggests that unless some rather stringent assumptions are met, it is not possible to identify the demand curve for air quality using the data from one city. Consequently, the true bid price function is probably more complicated than the one estimated by Nelson.

In a study of single-family owned residences in the Los Angeles area, Brookshire *et al*. (30) found a significant negative relationship between the sale price of homes and air pollution measures as measured by nitrogen dioxide (NO_2) and total suspended particulates. Actual market transactions for individual homes were used as the unit of observation. Both the linear and nonlinear specifications employed showed a significant relationship between home sale price and pollution. The average sale price differential attributable to a change in the level of pollution from "poor" to "fair" ranged from $5,793 per home to $6,134 per home. Elasticities could not be calculated from the information contained in the study. Brookshire *et al*. also estimated an inverse demand function for air quality, but used NO_2 as the air quality measure.

In a study of Philadelphia property values, Peckham (31) found a negative relationship between 1969 air pollution levels as measured by particulates and sulfates, and 1960 owner-occupied property values. In the log-linear equation, the elasticity of the sulfate variable was -0.096, while the elasticity of the particulate variable was -0.116.

Spore (32) analyzed the effect of air pollution on property values in Pittsburgh. Sulfation and dustfall were the two pollution variables included in the analysis. A significant negative relationship between property values and air pollution was generally exhibited in the log-linear equations that were estimated. The elasticity of dustfall in these equations ranged from -0.092 to -0.149.

The concentration of nitrogen oxides (used as a proxy for air pollution) was found to be negatively related to median property values in Boston by Harrison and Rubinfeld (18). Besides air pollution, the housing characteristics that were included in the equation were: two structural variables, eight neighborhood variables, and two accessibility variables. With all the independent variables at their mean levels, a change in nitrogen oxides (NO_x) of 1 pphm was associated with a change in median housing values of $1,613. When the variable for NO_x was replaced by a variable measuring particulate matter, particulate matter exhibited a negative and significant relationship with property value. Evaluated at the mean levels of the variables, the elasticity of particulate matter was -34.24. No explanation was given for the large magnitude of this number.

In a study of the New York metropolitan area, Appel (24) found a significant negative relationship between the annual geometric mean of total suspended particulates and mean property values. No other pollution variables were included in the study. The hedonic equation that performed best was one in which the TSP variable was entered in exponential form. This form conforms to a priori expectations that the marginal damages of pollution increase as pollution increases. Evaluated at the mean, the elasticity of TSP was equal to -0.039. Other variables included in the best equation were the mean number of rooms, the crime rate, the percent of non-white persons, and minutes of time to the central business district. It is interesting to note that when the property value equation was estimated in log-linear form, the elasticity of the TSP variable was equal to -0.117. This elasticity was not significant, however.

A summary of the studies that have found a significant negative relationship between residential property values and some measure of particulate matter is given in Table 5-2.

LIMITATIONS OF THE HEDONIC TECHNIQUE

Before preceeding with the calculation of benefits, it is important to reiterate the limitations of using the hedonic technique and the effect these limitations have on the ability to predict the benefits of improvements in air quality. The hedonic technique is capable of estimating the implicit price of the characteristics of a good that the consumer is able to perceive accurately. Since most characteristics of a good are tangible and easily perceived, this is not unreasonable. Air quality, per se, is not a tangible characteristic of housing and it is possible that households are unable to accurately perceive the effect of air quality on their residential property. Even if households are cognizant of some of the effects of air quality, it is doubtful that they will be aware of all of its

Table 5-2

REVIEW OF PROPERTY VALUE STUDIES

Study	City; Dependent Variable	Pollutants Measured, Method of Measurement	Form	Elasticities of Pollution Variables (At Means)	Estimated Benefits; Base Year
Ridker & Henning (12)	St. Louis; MPV[a]	Index of sulfation	Linear	Not Available[b]	If sulfation falls by 0.25 $\mu g/100\ cm^2$/day, MPV increases by $186.50 to $245.00; 1960
Zerbe (19)	Toronto and Hamilton, Canada; MPV	Annual average and median of averages for sulfation (lead candle) in both cities. Annual average and median of averages for dustfall in Toronto.	Linear and log-linear	Log-linear equation: Sulfation: Toronto -0.061 to -0.121 Hamilton -0.081	At the mean, a decrease of 1 mg SO_3/100 cm^2/day would increase mean property value by a maximum of $97 in Toronto; 1961
Crocker (20)	Chicago; home value given by sale price	Annual arithmetic mean for sulfation (lead candle) and particulates	Log-linear	Equation with both pollutants: Particulates: -0.2 to -0.5 Sulfation: 0.06[c]	At the mean, a reduction of 10 $\mu g/m^3$ in particulates and 1 ppb of SO_2 would lead to a $350 to $600 increase in the mean value of property; 1964-1967
Peckham (31)	Philadelphia; MPV	One-month average for sulfation and arithmetic mean for particulates	Linear and log-linear	Log-linear equation: Sulfation: -0.096 Particulates: -0.116	At the mean, a decrease in SO_3 of 0.1 mg/100 cm^2/day and a 10 $\mu g/m^3$/day in suspended particulates leads to an increase in the mean property value of $600 to $750; 1960
Anderson & Crocker (14)	Washington, DC, St. Louis and Kansas City; MPV, median gross rent and median contract rent	Annual arithmetic mean for concentrations of SO_x (measured by lead candle) and particulates	Log-linear	Owner-occupied equation: Sulf. / Part. D.C. -0.07 / -0.06[c] K.C. -0.08 / -0.09[d] S.L. -0.10 / -0.12[d]	At the mean, a reduction of 1 mg SO_3/100 cm^2/day and a 10 $\mu g/m^3$/day in suspended particulates would increase mean property value of owner-occupied housing by $300 to $700 in Washington, DC; 1960
Spore (32)	Pittsburgh; MPV	Annual geometric means and maximum monthly values for sulfation (lead candle) and dustfall	Log-linear	Sulfation: 0.03[d] Dustfall: -0.12	A reduction of 0.005 ppm/day in SO_2 and 5 tons/mi^2/month in dustfall increases the value of mean property by $150 to $200; 1970
Polinsky & Rubinfeld (29)	St. Louis; MPV, median gross rent and median contract rent	Same as Anderson & Crocker (14)	Log-linear	Owner-occupied equation: Sulfation: -0.063[c] Particulates: -0.132	A 5% reduction in sulfation & particulate levels in all areas of St. Louis would lead to a predicted change in aggregate property values of $55 million; 1960

(continued)

Table 5-2 (Continued)

Study	City; Dependent Variable	Pollutants Measured, Method of Measurement	Form	Elasticities of Pollution Variables (At Means)	Estimated Benefits; Base Year
Deyak & Smith (27)	SMSA; MPV	Annual arithmetic average of total suspended particulates	Log-linear	Particulates: -0.085	Not reported
Nelson (8)	Washington, DC; MPV	Monthly geometric mean of particulates and arithmetic average of means of oxidant levels	Log-linear	Particulates: -0.078 to -0.116 Oxidants: -0.007 to -0.019	At the mean, a decrease in particulates of 10 $\mu g/m^3$ increases the value of mean property by $576 to $693. At the mean, a decrease in oxidants of 0.001 ppm increases the value of mean property by $141 to $152; 1970
Brookshire *et al.* (30)	South Coast Air Basin in California; sale price of individual houses	Arithmetic average for nitrogen dioxide and particulates	Linear and semi-log exponential	Not Available	At the mean, a decrease of 1 pphm in nitrogen dioxide would result in an increase in the mean sale price of housing of $2,010; 1977-1978
Appel (24)	New York Metropolitan Area; mean property value of single family owner-occupied housing	Geometric mean of suspended particulates	Exponential	Particulates: -0.039	The average benefit (weighted by the number of households exposed to alternative pollution levels) for a 1 $\mu g/m^3$ reduction in suspended particulates is $42.13; 1970
Harrison & Rubinfeld (18)	Boston; MPV	Mean concentrations for nitrogen oxides and particulates calculated by a dispersion model	Exponential semi-log	In separate equations -- Nitrogen oxide: -0.39 Particulates: -34.24	Mean value of property would increase by $1,613 if the oxidant concentration decreased by 0.01 ppm; 1970

[a] MPV is median property value of single-family owner-occupied housing units in a census tract.

[b] The mean values of pollution and property values were not reported; consequently, the elasticities could not be estimated.

[c] Not significantly different from zero at 0.05 level.

[d] Not significantly different from zero at 0.01 level.

effects. Consequently, all of the effects of air quality may not be capitalized into residential property values. Application of the hedonic technique in order to estimate the effects of air pollution may therefore result in an underestimate of the "true benefits" accruing to residential properties. Although there has been some criticism that the hedonic technique is invalid for predicting the benefits of air quality improvement because households are unable to accurately perceive <u>any</u> of the effects of air pollution, the studies in Table 5-2 appear to support the hypothesis that households perceive at least some of the effects of air pollution and these effects are capitalized into property values.

Benefits estimated through hedonic property value equations may only provide estimates of the perceived benefits that occur at the <u>residential property</u>. Some of the benefits from air quality improvements that occur away from home (e.g., at the workplace, recreational areas) may not be capitalized into residential property values. Since a portion of the household's time is spent away from home, it is possible that only a portion of the total perceived benefits accruing to a household may be predicted from the hedonic property value equations. This must be kept in mind when comparing benefits estimated by the hedonic technique to benefits estimated by other methods.

As mentioned in the last subsection, the assumptions that are necessary in order to use the hedonic equation to estimate the marginal willingness to pay for air quality improvements are:

- Individuals must be able to perceive the characteristics and attributes of housing.
- The housing market must be in equilibrium.
- A complete range of houses with alternative characteristics must be available.

It is very unlikely that these conditions will hold in the housing market. In this study, we are mainly concerned with how the violation of these assumptions will affect the estimated air pollution-property value relationship. The violation of the first of these three assumptions has already been addressed in the discussion on the difficulty of applying the hedonic technique to a good possessing a characteristic such as air quality.

In order for the second assumption to be met in the housing market, households must be just willing to hold the existing stock of housing at the prevailing prices. Equilibrium will be achieved only if: 1) all households have complete information on the prices and characteristics of housing, 2) transactions and moving costs are equal to zero, and 3) housing prices adjust instantaneously to changes in demand and supply. According to Freeman (33), divergencies from equilibrium, in most cases, will only result in random errors in marginal willingness-to-pay estimates. Freeman mentions, however, that less than instantaneous adjustment in the housing market to changes in demand or supply may result in biased estimates of the air quality variable. For example, if equilibrium is disrupted due to an air quality change, and transactions and moving costs are non-zero, households will not move unless the benefit is at least as great as the costs involved in moving. If air quality is consistently changing in one direction and households consistently lag in their adjustment to that change, the observed marginal implicit price will diverge from the true marginal willingness to pay. In this case, the marginal implicit price of air quality identified in the hedonic property value equation is a biased estimate of the equilibrium marginal willingness to pay.

Freeman also mentions that future expectations on housing prices may result in biased estimates of the implicit price of air quality. If households perceive that an improvement in air quality will take place in the future and housing prices are affected by that perception, the market has adjusted to the air quality change before the change actually takes place. If a hedonic price equation is specified for the housing market in an area that has already adjusted to a future air quality change, the marginal willingness to pay for air quality would be underestimated. This possibility can be tested by entering the pollution variables in lagged form.

It is quite possible that the third assumption may be violated due to the nature of the housing market. Given the time necessary for the supply of housing to adjust to changes in demand, it is likely that some households will not be able to find housing with all of the characteristics that the household finds desirable. In these households, utility cannot be maximized. Whether this is a problem that will seriously affect the estimates of the marginal implicit price of air quality has not been investigated at the present time. It is doubtful, however, that the existence of an incomplete range of homes in the study area will make the estimated relationship between air pollution and property values totally unreliable.

Segmentation in the housing market can also affect the estimates of the marginal implicit prices of housing attributes. Housing market segmentation exists when the purchasers of housing participate in distinctly separate housing submarkets even though the purchasers are technically participating in the same housing market. The submarkets may exist because of racial discrimination, cultural differences, or geographic immobility. Where housing market segmentation exists, the structure of the prices of housing in each submarket will be different. The specification of a hedonic price function for one housing market when submarkets exist will result in incorrect estimates of the marginal implicit prices of housing attributes. In order for the implicit prices of housing characteristics to be correctly estimated, separate equations for each submarket must be used. Nelson (34) did not find that stratified samples for the Washington, D.C. area affected the hedonic price functions. Further research investigating this problem is needed before anything more conclusive can be said regarding the effect of market segmentation on the hedonic price functions.

BENEFIT ESTIMATION

The studies reviewed in the Literature Review subsection provide estimates of the willingness to pay for air quality improvements. All of these studies have included some form of particulate matter in estimating hedonic property value equations. The standards under consideration in this report are stated in terms of particulate matter with a diameter of 10 μm (PM10) and total suspended particulates (TSP). Since it is assumed that PM10 is equal to approximately 0.55 of TSP (see Section 9), only the studies that specifically include TSP will be considered in estimating the benefits accruing to households as a result of these standards.

Because of the relatively large number of property value studies that have included TSP as an explanatory variable, it was possible to limit further the selected studies to those that have included at least one other pollutant besides TSP. Limiting the selected studies in this way minimizes the possibility that particulate matter is proxying for the effects of the general air pollution phenomenon. Table 5-3 lists the studies that will be used for estimating benefits.

For the purposes of this analysis, it is assumed that the results of these studies are representative of the relationship between particulate matter and property values in the counties examined in this study, and that these results can be used to estimate the benefits of achieving alternative particulate matter standards. It should be noted that there are a number of reasons why a strict comparison of the results of these studies is not possible. These reasons can be explained by referring to Table 5-2. Although the majority of these studies use the median property value of a census tract as the dependent variable in their equations, Crocker (20) uses the sale price of individual homes. Most studies have concentrated on

Table 5-3

STUDIES CONSIDERED IN ESTIMATING THE BENEFITS OF PARTICULATE MATTER REDUCTIONS

Crocker (20)
Peckham (31)
Anderson and Crocker (14)
Polinsky and Rubinfeld (29)
Nelson (8)

only the owner-occupied housing market, while some studies have also estimated equations for the rental market using median gross rent and median contract rent as dependent variables.

The results of the studies in Table 5-3 are based on data collected in different years (e.g., 1960 and 1970 Census data). This is not likely to be a problem in comparing the studies because the demand for air quality probably has not changed significantly over the years in which these studies were done. However, the benefits estimated by the studies using data from different years are obviously not comparable because of the differences in property values due to increases in the price level. For this reason, the comparison of the results of the property value studies will be based on the estimated elasticities of the TSP variables.

As can be seen in Table 5-2, all of the studies examining the relationship between TSP and residential property values have used a nonlinear functional form to estimate this relationship. The choice of a nonlinear specification in these studies can be viewed as being twofold. The hedonic equation need not be linear if costless repackaging of the characteristics of the good is impossible. In the housing market, it is unlikely that costless repackaging of the characteristics of housing will be common. For example, two rooms with four sides are not equal to one room with eight sides. In addition, the hedonic equation may be nonlinear in the air quality variable depending on the assumptions regarding the marginal implicit price of air quality. If the hedonic equation is linear in the air quality variable, its marginal implicit price is constant over the entire range of air quality. Since there is no variation in the implicit price of air quality, it is not possible to identify the demand for air quality. In those hedonic studies where both linear and nonlinear specifications have been tried in order to measure the implicit price of air quality within a specific geographic area (e.g., SMSA), the nonlinear specifications have given more satisfactory results.

All of the studies listed in Table 5-3 have used a log-linear functional form to specify a nonlinear relationship between air pollution and property values. A significant negative relationship between air pollution and property values has been found in all of these studies. Unlike the marginal implicit price of air pollution in a linear specification, the marginal implicit price in these specifications varies depending on the ratio of the property value to the pollution level.* Of more interest, however, is the rate of change of the marginal implicit price schedule. It is positive for the log-linear specification, implying that the marginal implicit price (a negative) is an increasing function of the level of pollution. Since pollution is something to be avoided (i.e., a disamenity), this means that the marginal willingness to pay to avoid pollution becomes less negative as pollution increases; in other words, the marginal willingness to pay to avoid pollution is lower as the level of pollution rises. Intuitively, one would expect that the higher the level of pollution, the greater the marginal willingness to pay for an improvement in air quality.

Since the hedonic technique examines the equilibrium relationship between property values and air pollution, it is not clear whether the positive slope of the marginal implicit price curve results from the fact that people living in relatively clean air environments may tend to have larger incomes, and consequently a higher equilibrium marginal willingness to pay for additional air quality improvements, than poorer people who may tend to live in relatively dirty air environments. Not enough empirical research has been done in this area, however, to justify the hypothesis that the marginal implicit price curve is negatively sloped.

As mentioned in the Methodology subsection, the hedonic price technique yields only the equilibrium willingness to pay for marginal improvements in air quality. The changes in particulate matter considered in this analysis, however, will involve non-marginal changes. In order to accurately estimate the benefits of these changes in air quality, the demand price function of consumers for air quality must be known. This

* The first derivative of the log-linear specification, (Property Value) = a(Pollution)^b, is b(Property Value/Pollution).

function can be calculated using the implicit prices estimated by the hedonic technique, and information on air quality levels, consumer income and characteristics. Nelson (8) is the only researcher to specifically estimate a demand price function for TSP. However, Palmquist (10) has shown that without some rather limiting assumptions, the inverse demand function for TSP cannot be identified based on data from one city. Consequently, the benefits estimated in this section will be based solely on the information yielded by the first stage of the hedonic price technique.

As previously mentioned, the benefits of achieving alternative particulate matter standards will be approximated using the results of the studies listed in Table 5-3. Table 5-4 provides a comparison of the elasticities evaluated at the mean TSP level projected under baseline conditions (i.e., without implementation of particulate matter standards) and the mean 1980 residential property value for those counties that will be used to calculate the benefits of particulate matter reductions. As can be seen in the table, the elasticities range from -0.048 in Nelson's study to 0.5 in Crocker's analysis. As just mentioned, Nelson used measures of the monthly mean of particulates from February to July in order to estimate

Table 5-4

COMPARISON OF TSP ELASTICITIES CALCULATED FROM RESIDENTIAL PROPERTY VALUE STUDIES

Study	Range
Crocker (20)	-0.2 to -0.5
Peckham (31)	-0.116
Anderson and Crocker (14)	-0.06 to -0.12
Polinsky and Rubinfeld (29)	-0.132
Nelson (8)	-0.048 to -0.116

the relationship between residential property values and TSP. Since this averaging period may not represent the annual average of TSP, Nelson's estimates will not be used in calculating the benefits of particulate matter reductions. Except for Crocker, none of the remaining studies being considered have elasticities in excess of −0.20. For the purposes of this study, −0.20 will be used as the maximum elasticity. The minimum elasticity that will be used in the calculation of benefits is based on the Anderson and Crocker study, and is equal to −0.06. Since three studies report elasticities in the range of −0.116 to −0.132, −0.12 will be used as the point elasticity in calculating benefits.

As previously mentioned, the range of elasticities that will be used to calculate the benefits of particulate matter reductions is based on studies that estimate a log-linear property value equation. The marginal implicit price curve for air quality for the log-linear specification is shown in Figure 5-3. MPV'(P) is a plot of the derivative of the housing equation with respect to air pollution (i.e., TSP) and also traces out the equilibrium willingness to pay to avoid air pollution. D(P) is the true demand curve for air pollution. Since air pollution is a "bad", a large negative price implies that the household is willing to pay large amounts to avoid air pollution. Note that the marginal implicit price curve resulting from the log-linear specification implies that the marginal implicit price of air pollution increases (becomes less negative) as pollution increases.

The benefits of an improvement in air quality can be estimated by the area under the demand curve over the range of improvement. For the improvement in air quality from P_0 to P_1 that is shown in Figure 5-3, the benefits are estimated by the area AP_0P_1C. The demand curve for air quality has not been estimated in these studies, however, and it is necessary to rely on information contained in the hedonic price equations to approximate the benefits of an improvement in air quality. The benefits of an improvement in air quality from P_0 to P_1 can be approximated by the area under the marginal implicit price curve, AP_0P_1B. It must be kept in mind that this approximation implies that all households' marginal willingness-

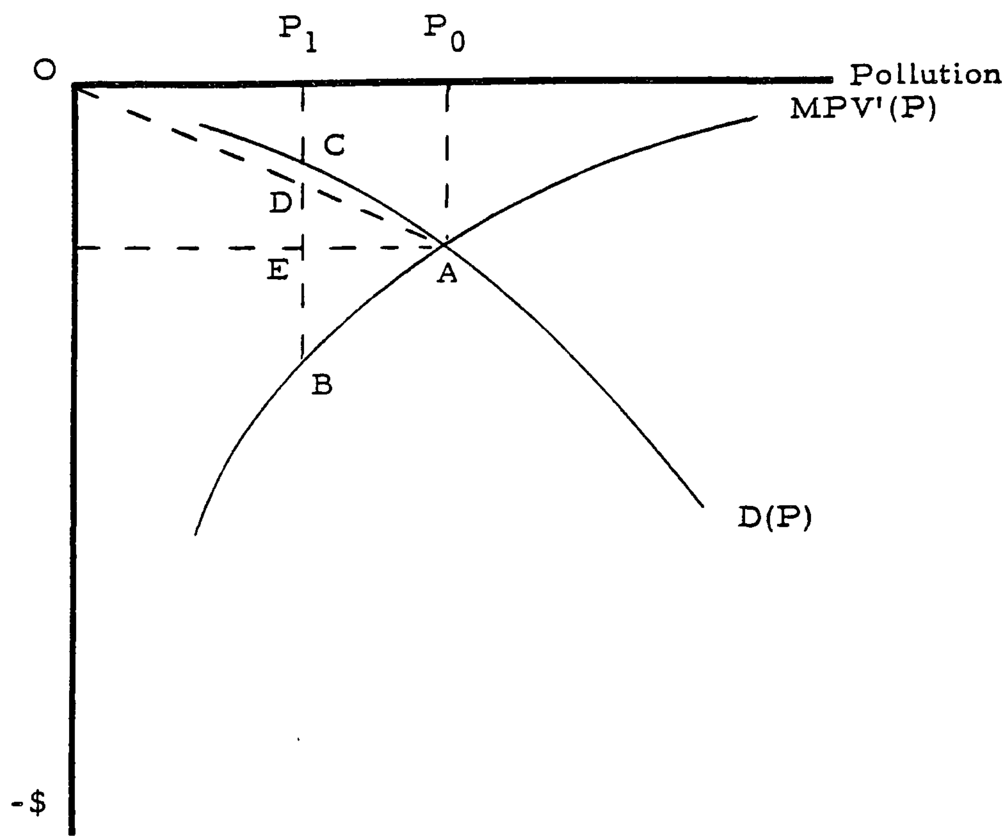

Figure 5-3. Alternative benefit estimates for a given change in air quality.

to-pay functions are identical and increasing in pollution abatement.* Clearly, this is an overestimate of the true benefits of improvement.

Freeman (35) has suggested two alternative ways of approximating the benefits of non-marginal changes in air quality when the demand curve for air quality is not known. By assuming that the household's marginal willingness to pay for air quality is constant over the entire range of air quality, household benefits can be approximated by the area AP_0P_1E. The benefits represented by this area can be estimated by:

$$\text{Benefits} = \frac{\partial \text{Property Value}}{\partial \text{Pollution}} (\Delta \text{Pollution}) \tag{5.15}$$

For the log-linear specification, this is equivalent to:

$$\text{Benefits} = b \, \frac{\text{Property Value}}{\text{Pollution}} (\Delta \text{Pollution}) \tag{5.16}$$

where b = the estimated coefficient of the pollution variable in the hedonic equation.

If the true demand curve for air pollution is D(P), this approximation technique will result in an overestimate if the marginal implicit price function is increasing in pollution abatement. However, this technique clearly will result in a closer approximation of true benefits estimated by the area AP_0P_1B.

The other alternative is consistent with the *a priori* expectation that the marginal willingness to pay for air pollution abatement declines as air quality improves. One point on the household's demand curve for air

* The marginal implicit price function will necessarily be increasing in pollution abatement only for log-linear specifications. The linear specification of the property value equation will result in a constant marginal implicit price. Exponential, semi-log exponential, quadratic, and the Box-Cox transformation may yield marginal implicit price curves that are decreasing in pollution abatement.

quality is known from the hedonic price equation. By assuming that the household's marginal willingness to pay for air pollution abatement declines linearly from that point to a zero marginal willingness to pay when air pollution has been completely abated, benefits can be approximated for a given improvement in air quality. For the reduction in air pollution from P_0 to P_1 shown in Figure 5-3, household benefits can be approximated by the area AP_0P_1D. The benefits represented by this area can be easily calculated as the difference in triangle OP_0A and OP_1D. This area can be approximated by:

$$\text{Benefits} = \frac{1}{2}\left[(P_0A \cdot OP_0) - (P_1D \cdot OP_1)\right] \qquad (5.17)$$

For the log-linear specification, this is equivalent to:

$$\text{Benefits} = \frac{b}{2}\,\text{Property Value}\left[1 - \frac{(\text{Pollution}_1)^2}{(\text{Pollution}_0)^2}\right] \qquad (5.18)$$

where Pollution_0 = initial pollution level

Pollution_1 = pollution level after an air quality change.

Depending on the shape of the actual demand curve for air quality, the approximation of benefits under the assumption of a linearly declining marginal willingness to pay curve can result in either an underestimate or overestimate of true benefits.

Obviously, either of these alternatives will result in closer estimates of the true benefits of a given air quality improvement than the benefits estimated by the area under the marginal implicit price curve of the log-linear hedonic property value specification. The linearly declining marginal willingness-to-pay alternative, however, is consistent with the *a priori* assumption that the household's marginal willingness to pay for air pollution abatement declines as air quality improves. Since it seems reasonable to expect that the marginal willingness to pay for air quality improvements will be decreasing, the benefits of alternative particulate matter standards will be calculated using the linear to the origin technique.

Household benefits in a particular county will be calculated for the single-family owner-occupied household with median property value that is exposed to the average level of pollution within the county. For the purposes of this analysis, the benefits accruing to this household will be taken as representative of the benefits accruing to households residing in rental and multiple-dwelling units. This may lead to an overestimate or underestimate of benefits if the willingness to pay for air quality improvements tends to be different for the households residing in these types of structures.

All of property value studies being considered in this section have estimated the particulate matter exposure of census tracts within a city through the interpolation or dispersion modeling of city data. Since these measures of exposure are more likely to represent the average of the ambient level of particulate matter monitored throughout the city than the worst incidence of pollution throughout the city, county benefits will be calculated using the average of the annual arithmetic means of particulate matter from all of the monitors within a county.

A list of the sources of data used in the calculation of benefits is given in Appendix 5A.

The alternative standards being considered in this analysis are listed in Table 5-5. As the table shows, the standards are stated in terms of both the annual and 24-hour averages. For each county, the averaging time that is most stringent is considered to controlling averaging time. Since the studies being used in the calculation of benefits are stated in terms of annual averages, the 24-hour average is converted to an equivalent annual average if the 24-hour average is the controlling averaging time.

Table 5-5

ALTERNATIVE PARTICULATE MATTER STANDARDS
(in $\mu g/m^3$)

Standard	Measure of Particulate Matter	Annual Mean*	24-Hour Expected Value	Attainment Date
1	PM10	70	250	1989
2	PM10	55	--	1989
3	PM10	55	250	1989
4	PM10	55	150	1989
5	TSP	75	260**	1987
6	TSP	--	150**	1987

* PM10 standards are stated in terms of the annual arithmetic mean while TSP standards are stated in terms of the annual geometric mean.

** Maximum value not to be exceeded more than once a year.

The benefits of achieving alternative particulate matter standards are listed in Tables 5-6 through 5-11. These benefits represent the benefits that would be achieved when all counties included in the analysis are in compliance with the standard for all years under consideration.*

Table 5-6 reports the discounted present value of the benefits resulting from a PM10 standard of 70 $\mu g/m^3$ annual arithmetic mean (AAM) and a 250 $\mu g/m^3$ 24-hour expected value (EV). Under this standard, benefits are estimated to be in the range of $3.4 to $11.4 billion and include a point estimate of $6.9 billion. The South Pacific region is the region with the

* In the language of Section 9, these benefits represent "Type B" scenario benefits.

Table 5-6

ESTIMATED BENEFITS FOR: RESIDENTIAL PROPERTY VALUE STUDIES

Benefits Occurring Between 1989 and 1995
Scenario: Type B PM10 - 70 AAM/250 24-hr.

Federal Administrative Region			Minimum	Point Estimate	Maximum
REGION	I	New England	0.0	0.0	0.0
REGION	II	N.Y.-N.J.	6.5	13.0	21.6
REGION	III	Middle Atlantic	113.3	226.5	377.5
REGION	IV	South Atlantic	135.4	270.8	451.3
REGION	V	E.N. Central	1025.2	2050.3	3417.2
REGION	VI	South Central	337.4	674.8	1124.6
REGION	VII	Midwest	35.3	70.5	117.5
REGION	VIII	Mountain	121.4	242.9	404.8
REGION	IX	South Pacific	1481.7	2963.3	4938.9
REGION	X	North Pacific	171.1	342.2	570.4
Total U.S.			3427.2	6854.3	11423.9

Discounted Present Value in Millions of 1980 Dollars in 1982
Using a 10 Percent Rate of Discount.

Annualized Benefits Between 1989 and 1995 Total U.S.	1371.8	2743.6	4572.7

Table 5-7

ESTIMATED BENEFITS FOR: RESIDENTIAL PROPERTY VALUE STUDIES

Benefits Occurring Between 1989 and 1995
Scenario: Type B PM10 - 55 AAM

Federal Administrative Region			Minimum	Point Estimate	Maximum
REGION	I	New England	59.4	118.8	197.9
REGION	II	N.Y.-N.J.	69.2	138.5	230.8
REGION	III	Middle Atlantic	205.6	411.2	685.3
REGION	IV	South Atlantic	303.4	606.9	1011.4
REGION	V	E.N. Central	1392.2	2784.4	4640.6
REGION	VI	South Central	525.0	1050.0	1750.0
REGION	VII	Midwest	103.5	207.0	345.0
REGION	VIII	Mountain	253.8	507.6	846.1
REGION	IX	South Pacific	2809.9	5619.8	9366.3
REGION	X	North Pacific	236.3	472.6	787.6
Total U.S.			5958.3	11916.6	19861.1

Discounted Present Value in Millions of 1980 Dollars in 1982
Using a 10 Percent Rate of Discount.

Annualized Benefits Between 1989 and 1995 Total U.S.	2385.0	4770.0	7949.9

Table 5-8

ESTIMATED BENEFITS FOR: RESIDENTIAL PROPERTY VALUE STUDIES

.Benefits Occurring Between 1989 and 1995
Scenario: Type B PM10 - 55 AAM/250 24-hr.

Federal Administrative Region			Minimum	Point Estimate	Maximum
REGION	I	New England	59.4	118.8	197.9
REGION	II	N.Y.-N.J.	69.2	138.5	230.8
REGION	III	Middle Atlantic	205.6	411.2	685.3
REGION	IV	South Atlantic	303.4	606.9	1011.4
REGION	V	E.N. Central	1397.1	2794.1	4656.9
REGION	VI	South Central	535.4	1070.8	1784.6
REGION	VII	Midwest	104.3	208.5	347.5
REGION	VIII	Mountain	253.8	507.6	846.1
REGION	IX	South Pacific	2810.0	5620.0	9366.6
REGION	X	North Pacific	259.8	519.7	866.1
Total U.S.			5998.0	11996.0	19993.3

Discounted Present Value in Millions of 1980 Dollars in 1982
Using a 10 Percent Rate of Discount.

	Minimum	Point Estimate	Maximum
Annualized Benefits Between 1989 and 1995 Total U.S.	2400.9	4801.7	8002.9

Table 5-9

ESTIMATED BENEFITS FOR: RESIDENTIAL PROPERTY VALUE STUDIES

Benefits Occurring Between 1989 and 1995
Scenario: Type B PM10 - 55 AAM/150 24-hr.

Federal Administrative Region			Minimum	Point Estimate	Maximum
REGION	I	New England	226.2	452.4	754.0
REGION	II	N.Y.-N.J.	146.2	292.3	487.2
REGION	III	Middle Atlantic	389.3	778.7	1297.8
REGION	IV	South Atlantic	397.4	794.9	1324.8
REGION	V	E.N. Central	1637.5	3274.9	5458.2
REGION	VI	South Central	644.6	1289.3	2148.8
REGION	VII	Midwest	152.2	304.3	507.2
REGION	VIII	Mountain	387.9	775.9	1293.1
REGION	IX	South Pacific	3135.8	6271.6	10452.7
REGION	X	North Pacific	515.0	1030.0	1716.7
Total U.S.			7632.2	15264.4	25440.6

Discounted Present Value in Millions of 1980 Dollars in 1982
Using a 10 Percent Rate of Discount.

Annualized Benefits Between 1989 and 1995 Total U.S.	3055.0	6110.0	10183.3

Table 5-10

ESTIMATED BENEFITS FOR: RESIDENTIAL PROPERTY VALUE STUDIES

Benefits Occurring Between 1987 and 1995
Scenario: Type B TSP - 75 AGM/260 24-hr.

Federal Administrative Region			Minimum	Point Estimate	Maximum
REGION	I	New England	185.1	370.3	617.1
REGION	II	N.Y.-N.J.	156.0	311.9	519.9
REGION	III	Middle Atlantic	569.9	1139.7	1899.5
REGION	IV	South Atlantic	630.7	1261.3	2102.2
REGION	V	E.N. Central	2616.9	5233.8	8723.0
REGION	VI	South Central	891.4	1782.9	2971.4
REGION	VII	Midwest	278.5	557.0	928.4
REGION	VIII	Mountain	493.3	986.6	1644.3
REGION	IX	South Pacific	4757.7	9515.5	15859.1
REGION	X	North Pacific	599.9	1199.9	1999.8
Total U.S.			11179.4	22358.8	37264.7

Discounted Present Value in Millions of 1980 Dollars in 1982 Using a 10 Percent Rate of Discount.

	Minimum	Point Estimate	Maximum
Annualized Benefits Between 1987 and 1995 Total U.S.	3126.3	6252.6	10421.1

Table 5-11

ESTIMATED BENEFITS FOR: RESIDENTIAL PROPERTY VALUE STUDIES

Benefits Occurring Between 1987 and 1995
Scenario: Type B TSP - 150 24-hr.

Federal Administrative Region			Minimum	Point Estimate	Maximum
REGION	I	New England	736.7	1473.5	2455.8
REGION	II	N.Y.-N.J.	357.0	714.0	1190.0
REGION	III	Middle Atlantic	996.5	1993.1	3321.8
REGION	IV	South Atlantic	839.0	1677.9	2796.5
REGION	V	E.N. Central	3260.1	6520.3	10867.2
REGION	VI	South Central	1126.4	2252.7	3754.5
REGION	VII	Midwest	528.8	1057.7	1762.8
REGION	VIII	Mountain	699.6	1399.3	2332.1
REGION	IX	South Pacific	5332.3	10664.6	17774.3
REGION	X	North Pacific	992.8	1985.5	3309.2
Total U.S.			14869.3	29738.5	49564.2

Discounted Present Value in Millions of 1980 Dollars in 1982
Using a 10 Percent Rate of Discount.

Annualized Benefits Between 1987 and 1995 Total U.S.	4158.2	8316.4	13860.6

largest benefits. Approximately 43 percent of the total benefits associated with the point estimate of this standard accrue to this region. Another 30 percent of total benefits accrue to the East North Central region. With the exception of these two regions, none of the remaining regions receive benefits in excess of $1 billion. In fact, the New England region receives no benefits under this standard since all of the region is estimated to be in compliance with this standard.

A more stringent PM10 standard of 55 $\mu g/m^3$ AAM that is reported in Table 5-7 results in benefits estimates ranging from $6.0 to $19.9 billion. This range includes a point estimate of $11.9 billion. Again, the majority of benefits accrue to the South Pacific (47 percent) and East North Central (23 percent) regions. With the exception of the South Central and South Atlantic regions which receive about 9 percent and 5 percent, respectively, of the total benefits, each of the remaining regions receive less than 5 percent of national benefits.

Table 5-8 reports the benefits estimated to accrue under the PM10 standard of 55 $\mu g/m^3$ AAM and 250 $\mu g/m^3$ 24-hour EV. As shown in the table, benefits range from $6.0 to $20.0 billion and include $12.0 billion as a point estimate. The regional ranking of benefits remains relatively unchanged from the benefits reported in Table 5-7.

Benefits under the PM10 standard of 55 $\mu g/m^3$ AAM and 150 $\mu g/m^3$ 24-hour EV reported in Table 5-9 range from $7.6 to $25.4 billion. The point estimate for this range is $15.3 billion. Based on the point estimate, the South Pacific, East North Central, South Central, and North Pacific regions each receive benefits in excess of $1 billion under this standard.

The benefits under a TSP standard of 75 $\mu g/m^3$ AGM and 260 $\mu g/m^3$ 24-hour maximum value not to be exceeded more than once a year are reported in Table 5-10. With a point estimate of $22.4 billion, these benefits range from $11.2 to $37.3 billion. Under this standard, point estimates of benefits in excess of $1 billion accrue to each of the following regions:

South Pacific, East North Central, South Central, South Atlantic, North Pacific, and Middle Atlantic.

The last TSP standard considered in this report reflects a 150 μg/m³ 24-hour maximum value. As indicated by Table 5-11, the point estimate of benefits under this standard is $29.7 billion. The minimum and maximum of the range surrounding this point estimate are $14.9 and $49.6 billion, respectively. Under this standard, the point estimate of benefits for each of the regions except the New York-New Jersey region is greater than $1 billion.

Finally, Table 5-12 shows the benefits that accrue under a 70/250 PM10 primary standard when all counties are not in attainment with the standard throughout the 1989-1995 time horizon.* This can occur because available control options are exhausted prior to standard attainment. This table can be compared to Table 5-6 where all counties were assumed to be in compliance with the same 70/250 PM10 standard. As expected, the benefits estimates in Table 5-6 exceed those shown in Table 5-12.

CONCLUSION

In this analysis, the discounted present value of the benefits associated with reducing particulate matter levels to comply with alternative particulate matter standards has been estimated using the results of past property value differential studies. Table 5-13 provides a summary of these estimates in discounted present value terms. These estimates range from $3.4 to $11.4 billion under the most lenient PM10 standard of 70 μg/m³ AAM and 250 μg/m³ to $7.6 to $25.4 billion under the strictest PM10 standard of 55 μg/m³ AAM and 150 μg/m³ 24-hour EV. The estimated benefits under the TSP standard of 75 μg/m³ AGM and 260 μg/m³ 24-hour maximum range from $11.2 to $37.3 billion while the benefits under the TSP standard of 150 μg/m³ 24-hour maximum range from $14.9 to $49.6 billion. These

* In the language of Section 9, these are "Type A" benefits.

Table 5-12

ESTIMATED BENEFITS FOR: RESIDENTIAL PROPERTY VALUE STUDIES

Benefits Occurring Between 1989 and 1995
Scenario: Type A PM10 - 70 AAM/250 24-hr.

Federal Administrative Region			Minimum	Point Estimate	Maximum
REGION	I	New England	0.0	0.0	0.0
REGION	II	N.Y.-N.J.	6.5	13.0	21.6
REGION	III	Middle Atlantic	109.4	218.7	364.5
REGION	IV	South Atlantic	113.8	227.6	379.3
REGION	V	E.N. Central	738.1	1476.3	2460.4
REGION	VI	South Central	232.8	465.6	776.0
REGION	VII	Midwest	31.5	63.1	105.1
REGION	VIII	Mountain	116.0	231.9	386.5
REGION	IX	South Pacific	859.3	1718.5	2864.2
REGION	X	North Pacific	62.1	124.2	207.1
Total U.S.			2269.5	4538.9	7564.9

Discounted Present Value in Millions of 1980 Dollars in 1982
Using a 10 Percent Rate of Discount.

Annualized Benefits Between 1989 and 1995 Total U.S.	908.4	1816.8	3028.1

Table 5-13

BENEFITS OF ATTAINING ALTERNATIVE PARTICULATE MATTER STANDARDS*
(Billions of 1980 Dollars)

Standard	Minimum	Point Estimate	Maximum
PM10 - 70 $\mu g/m^3$ AAM and 250 $\mu g/m^3$ 24-hour EV	$ 3.4	$ 6.9	$11.4
PM10 - 55 $\mu g/m^3$ AAM	6.0	11.9	19.9
PM10 - 55 $\mu g/m^3$ AAM and 250 $\mu g/m^3$ 24-hour EV	6.0	12.0	20.0
PM10 - 55 $\mu g/m^3$ AAM and 150 $\mu g/m^3$ 24-hour EV	7.6	15.3	25.4
TSP - 75 $\mu g/m^3$ AGM and 260 $\mu g/m^3$ 24-hour MAX	11.2	22.4	37.3
TSP - 150 $\mu g/m^3$ 24-hour MAX	14.9	29.7	49.6

* Benefits are stated in terms of the discounted present value in 1982 and assume a 10 percent discount rate. Benefits for the PM10 standards are accumulated from 1989 to 1995 while the benefits for the TSP standards are accumulated from 1987 to 1995.

estimates are approximations of the benefits of meeting these standards for basically four reasons:

1) The benefits reported in this section represent the benefits associated with perceived differences in air quality. The unperceived benefits associated with air quality improvements are not reflected in this section. Consequently, these benefits are underestimates of the total benefits of reductions in the ambient level of particulate matter.

2) The results of studies on specific cities in the early 1960's and 1970's are used to estimate the benefits of pollution reductions occurring from 1987 to 1995 for the counties included in this analysis. The effect of this assumption is unknown.

3) The assumptions of the hedonic technique are assumed to hold in the property value market. The effect of this assumption is unknown.

4) The benefits of the air quality improvements are approximated without knowledge of the true demand curve for air quality. The effect of this assumption is unknown.

5) The marginal willingness to pay for air quality improvements of households residing in single-family units is assumed to be representative of the marginal willingness to pay of all households. The effect of this assumption is unknown.

6) The average of the air pollution readings in a county is taken as representative of the level of exposure of all households in the county. The effect of this assumption is unknown.

These estimates are useful, however, because they provide some idea of the magnitude of the willingness to pay for improvements in residential air quality associated with implementing alternative particulate matter standards.

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APPENDIX 5A

SOURCES OF DATA

Households

Number of households in a county in 1980.

Source: Bureau of the Census (36).

Property Value

Property value of single-family owner-occupied houses in a county in 1980.

Source: Bureau of the Census (37).

SECTION 6

HEDONIC WAGE STUDIES

SECTION 6

HEDONIC WAGE STUDIES

SUMMARY OF RESULTS

In this section, estimates of individual willingness-to-pay for air quality derived from hedonic wage studies are used to calculate benefits of alternative standards for particulate matter. Hedonic wage studies relate observed wage differentials to various explanatory factors, including individual-specific characteristics (such as education or prior experience), job-specific characteristics (such as risk of injury or death), and site-specific characteristics (such as climate or air quality). The wage differential which is attributable to variations in air quality can be measured and used to approximate willingness-to-pay for air quality.

Estimated coefficients from selected hedonic wage studies are used to calculate a range of benefits resulting under alternative particulate matter standards; a point estimate of benefits is also generated for each standard. These results are summarized in Tables 6-1 and 6-2, which present benefits associated with selected primary and secondary standards, respectively.* These estimates represent the present discounted value in 1982 of the stream of benefits which accrue from the attainment date (1989 for PM10 standards; 1987 for the TSP standards) through 1995, using 10 percent as the social discount rate and expressed in 1980 dollars.

Point benefits estimates range from $19.8 billion for the most lax PM10 primary standard to $58.9 billion under the current TSP primary

* See Section 9 for a more complete description of the particulate matter standards under consideration.

Table 6-1

SUMMARY OF ESTIMATED BENEFITS* FOR HEDONIC WAGE STUDIES -- PRIMARY STANDARDS

Standard**	Minimum	Point	Maximum
PM10 70 AAM/250 24-Hour	9,810	19,815	37,208
PM10 55 AAM/250 24-Hour	16,611	33,554	61,453
PM10 55 AAM/150 24-Hour	20,263	40,929	72,598
TSP 75 AGM/260 24-Hour	29,166	58,914	107,138

Table 6-2

SUMMARY OF ESTIMATED BENEFITS* FOR HEDONIC WAGE STUDIES -- SECONDARY STANDARDS+

Standard**	Minimum	Point	Maximum
PM10 55 AAM	16,534	33,398	61,239
TSP 150 24-Hour	36,376	73,477	126,840

* Discounted present value in millions of 1980 dollars in 1982.

** The PM10 standards will be attained in 1989, while the TSP standards will be attained in 1987. Benefits for all standards are accumulated from the attainment year through 1995.

\+ These estimates include benefits which accrue as current (baseline) particulate matter levels are reduced to a secondary standard.

standard. If the secondary standards are also included, then point benefits estimates will range from $33.4 billion to $73.5 billion.

Under most standards, better than 70 percent of all benefits accrue to the East North Central, South Central, and South Pacific regions. As the particulate matter standard becomes more stringent, there is some redistribution of benefits towards the New England, Middle Atlantic, New York-New Jersey, South Atlantic, Midwest and Mountain regions.

These benefits estimates should be interpreted carefully, since several assumptions are required in order to adapt both the hedonic wage models and the data to the procedures used in calculating these benefits. In particular, the following points should be noted:

- The procedure used in extrapolating benefits from hedonic wage models assumes that the marginal willingness to pay for air quality declines linearly as air pollution is abated from the baseline observation to zero. To the extent that the actual relationship between marginal willingness to pay and particulate matter diverges from this linear approximation, the true benefits of abating ambient particulate matter will diverge from the estimates presented above. The direction of any divergence cannot be predicted.
- The hedonic wage models from which these benefits were estimated did not include any measures of air pollution other than TSP as explanatory varibles. Thus, the estimated coefficient on the TSP measure may also proxy the effects of omitted air pollutants. To the extent that this occurs, the benefits presented above may overstate the true benefits.

These and other caveats are discussed more fully in the conclusion to this section.

INTRODUCTION

In the previous section, differentials in residential property values were used to approximate individual willingness-to-pay for air quality.

This approach may not accurately reflect the benefits which accrue from improvements in air quality for the following reasons:*

- Residential property-value differentials may not reflect the value placed on clean air in non-residential areas (e.g., the work place).

- Property value estimates of the benefits of clean air may be unreliable since air quality may not vary significantly within a city.

As an alternative, wage differentials may reflect willingness-to-pay for air quality, on the premise that, all other things equal, an individual will require more compensation for working in more highly polluted areas. Thus, wage differentials attributable to air pollution can reflect the economic value placed on clean air in the work place.** In addition, since it is assumed that labor is mobile and will relocate in response to disequilibrium differentials, an inter-city estimate of willingness-to-pay for air quality is appropriate. This approach has the advantage of allowing more variation in air pollution levels and thus produces more stable estimates of willingness-to-pay for air quality.

It should be noted that wage differentials will reflect only the perceived health and welfare effects of improved air quality. Any unperceived health effects, for example, which are attributable to declines in ambient air pollution levels will not be accounted for in hedonic wage models. Also, real wage differentials may reflect regional differentials in both nominal wages and prices of local goods (e.g., property values) which are linked to variations in air quality. Real wage differentials may, in this event, also measure at least some of the value placed on improved air quality in residential areas.

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* See Cropper and Arriaga-Salinas (1).

** Wage differentials estimated with a properly-specified model of urban location may also reflect the value placed on clean air in residential areas. See Cropper and Arriaga-Salinas (1).

There are two distinct procedures which can be used to measure willingness-to-pay for air quality from wage differentials:

- A labor supply curve can be estimated which includes air quality as an argument in the individual worker's utility function [Cropper (2); Cropper and Arriaga-Salinas (1)].

- A hedonic-wage model can be specified, relating observed wage levels to various hypothesized determinants of wage behavior, including air quality. [See, for example, Rosen (4), Smith (8)].

In each case, willingness-to-pay for air pollution is derived from the estimated model.

In this chapter, hedonic wage models are used to calculate the benefits which result from the implementation of alternative control strategies designed to meet specified primary and secondary national ambient air quality standards for particulate matter (TSP).* Following a preliminary discussion of the underlying theory of hedonic wage models,** empirical attempts to estimate hedonic wage models are briefly reviewed. This discussion will focus on those models which include air pollution as an explanation of wage differentials. Coefficients from selected studies are then used to calculate the benefits which result from the implementation of various primary standards governing ambient concentrations of particulate matter. These benefits are subject to a number of caveats which are summarized at the conclusion of this section.

* The discussion in this chapter centers on the use of compensating wage differentials to measure the value which an individual places on air quality. This differs from the wage compensation studies discussed in the Appendix to Volume II, which use wage differentials associated with job risk to assess the statistical value of life.

** This discussion is limited to hedonic wage models because the only attempts to assess the effect of air pollution on wages within a labor-supply framework do not use TSP as a measure of air pollution [Cropper (2); Cropper and Arriaga-Salinas (1)]. Thus, the results of these studies cannot be used to generate benefits estimates for changes in the levels of particulates.

HEDONIC WAGE MODELS: THEORETICAL CONSTRUCT

Hedonic wage models are a subset of the hedonic price models discussed in the previous section. The reader is referred to that section for a more complete discussion of the hedonic price technique and its implications. A brief exposition of the hedonic wage model, adapted primarily from the models discussed in Rosen (3,4), Thaler and Rosen (5), and Lucas (6), is offered below.

Hedonic price techniques relate the price of a good to the characteristics which comprise that good. The price of each good thus embodies a series of implicit prices placed on these characteristics. Hedonic wage models belong to this general class of functions; however, in addition to job characteristics, hedonic wage functions also include individual-specific characteristics (e.g., prior experience, education, etc.) as predictors of wage differentials. According to Lucas (6), individual-specific characteristics must be included because of the basic difference between the labor market and the consumer goods market. Unlike the sale of consumer goods, it cannot be assumed that entrepreneurs are indifferent to the identity of the workers to whom they "sell" jobs.

Hedonic wage models thus relate observed wage differentials to three factors:

- Differences in individual-specific characteristics.
- Differences in job-specific characteristics.
- Differences in site-specific characteristics.

The marginal implicit price of air quality can be derived from properly-specified hedonic wage models; this is illustrated below within a simple theoretical construct of the labor market.

In making their labor-supply decisions, workers are assumed to maximize a utility function which contains the wage rate, tastes and preferences,* consumer goods and services, and job characteristics, which can include factors relating specifically to the type of job (e.g., risk of personal injury or death) as well as site-specific characteristics (e.g., air quality, climate, etc.). This utility function for worker α is written as follows:

$$U^{\alpha} = U(w_i^{\alpha}, Z_i, X^{\alpha}, Q_c, P) \qquad (6.1)$$

where U^{α} is utility of worker α.

w_i^{α} is the wage accepted by worker α for the i^{th} job.

Z_i is the vector of characteristics specific to the i^{th} job.

X^{α} is a vector of personal characteristics associated with worker α.

Q_c is a vector of goods and services available for consumption.

P represents a measure of air pollution, an inverse measure of air quality.

If pollution is a disamenity and an increase in air pollution decreases each worker's utility, then, <u>ceteris paribus</u>, a trade-off exists between the acceptance wage (which has a positive effect on utility) and air pollution.** This trade-off is illustrated in Figure 6-1 by a set of indifference curves for two different workers; θ^1 and θ^2. Each curve slopes upward, indicating that, for each worker, higher wages must accompany higher pollution levels in order to maintain a constant level of utility. For each worker, a higher indifference curve is associated with a higher

* These can be represented by a vector of individual-specific characteristics [Lucas (6)].

** It is not necessary to assume here that the worker has detailed knowledge of the technical relationship between air pollution and personal health or property damage. It is assumed that he perceives that his well-being is diminished by the presence of air pollution. Thus, it is the perceived health and welfare effects of air pollution which are considered here. Effects of air pollution which are not perceived by the worker have no impact on this tradeoff between acceptance wage and air pollution.

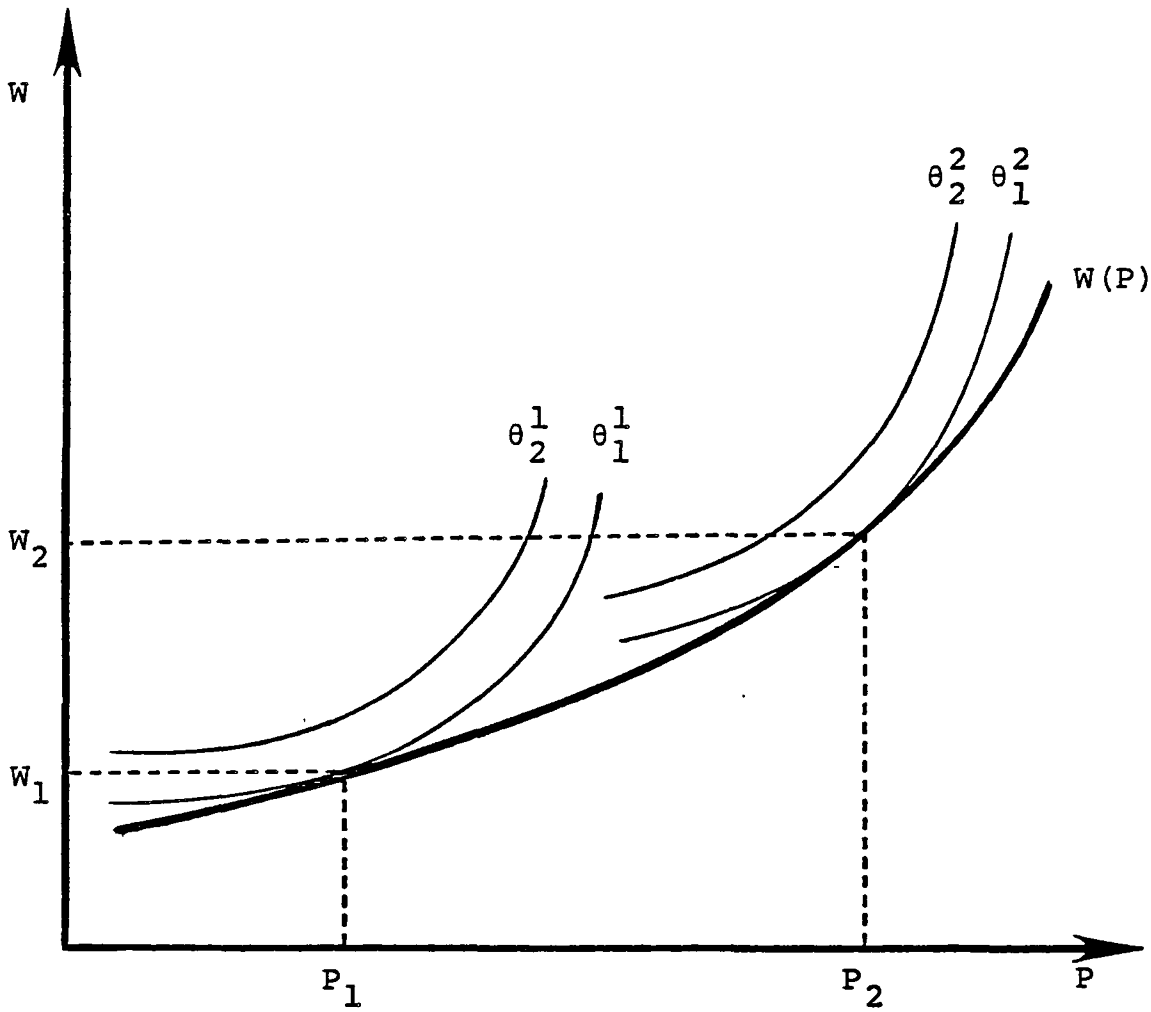

Figure 6-1. Indifference maps and equilibria for two workers

level of utility. The convex shape of each indifference curve reflects a diminishing marginal rate of substitution between wages and pollution. Tastes for clean air may vary among workers; in this example, worker 1 has a higher preference for clean air than worker 2 (i.e., worker 1 requires a larger wage increase than worker 2 to compensate for a given change in air pollution levels).

Each worker is faced with the task of choosing that combination of wage rate and pollution which maximizes his utility function [represented by Equation (6.1)], subject to the opportunities offered by the market. Market-determined equilibrium wage rates associated with varying levels of pollution are represented by W(P). Each worker's utility is maximized where his marginal rate of substitution between pollution and the wage rate (i.e., his marginal willingness-to-pay for air quality)** equals the rate at which the market compensates for higher pollution levels [i.e., the marginal implicit price of clean air, or $\partial W(P)/\partial P$]. Thus, in equilibrium, worker 1 will accept level P_1 of pollution in return for wage rate W_1. Worker 2 will tolerate higher levels of pollution in return for wage rate W_2.

It is also possible that air pollution may affect labor productivity, and this has not been considered in the discussion so far. However, the

* Pollution is a disamenity, and individuals must be paid in order to accept higher levels of air pollution. Thus, ceteris paribus, wages should be higher when air pollution levels are higher. Conversely, when pollution levels decline, (or when air quality improves), wages will also decline. This decline in wages which must accompany an improvement in air quality in order to maintain a constant level of utility indicates the worker's willingness-to-pay for air quality.

productivity effects of air pollution and other site-specific characteristics have received little theoretical discussion to date.*

In order to complete the hedonic wage model, demand factors must be introduced into the wage-determination process. Below, a simple model of labor demand, based on the procedure used by Thaler and Rosen (5) in modeling job safety and labor demand, is used to illustrate the effect of air pollution on the wage offered by the firm. This discussion abstracts from the complications introduced when the influence of air quality on the firm's location decision is considered. Furthermore, for purposes of clarity in exposition, it is assumed that each individual firm can, through some variation in its production process, alter the ambient air quality in its immediate vicinity.

The firm combines a variety of inputs, including labor (L), to produce marketable output (Q). Air pollution (P) may occur as a by-product of this production process. Ignoring all other inputs except labor, the joint production function for this firm is written as follows:

$$F(Q,P,L) = 0 \tag{6.2}$$

The inverse of this production function is specified as:

$$Q = g(P,L) \tag{6.3}$$

It is assumed that this production function exhibits the following properties:

---

* One very recent contribution in this area is presented by Roback (7) who develops a general equilibrium model which includes both the amenity effects and the productivity effects of site-specific characteristics. Her general result indicates that wages will rise as air quality deteriorates if air quality has no impact on labor productivity. However, if air pollution adversely affects labor productivity, then the wage change is ambiguous. Roback notes that the direction and strength of both the amenity and productivity effects of site-specific characteristics can only be determined empirically.

- The marginal product of labor is positive and diminishing.*
- The marginal product of labor varies inversely with the level of pollution.**
- The level of output varies directly with the level of pollution, up to some very large (and technically-determined) level of pollution ($\bar{P}$).+ This implies that, in order to lower pollution levels, the firm must divert some resources away from the production of marketable output. The transformation locus between output Q and air quality (the inverse of the level of pollution) is negative and concave.

The cost of improved air quality is expressed as a function of the level of air pollution, or G(P). These costs are positive and increasing with the level of air quality.++

The firm's profit function is written as follows:

$$\pi = g(P,L) - w(P)L - G(P) \qquad (6.4)$$

where w(P) is the competitive wage which must be paid at alternate air pollution levels.

The firm maximizes profit with respect to labor and pollution; the resulting first-order conditions are written as follows:

$$\frac{\partial Q}{\partial L} = w(P) \qquad (6.5)$$

$$\frac{\partial Q}{\partial P} + \frac{\partial G}{\partial P} = \frac{\partial w(P)}{\partial P} \cdot L \qquad (6.6)$$

---

* $\partial Q/\partial L > 0$, $\partial^2 Q/\partial L^2 < 0$.

** $\partial Q/\partial L \partial P < 0$.

+ $\partial Q/\partial P > 0$ for $0 \leq P < \bar{P}$, $\partial^2 Q/\partial P^2 < 0$.

++ $\partial G/\partial P < 0$, $\partial^2 G/\partial P^2 > 0$.

Equation (6.5) is the familiar result that labor is hired until the marginal product of labor equals the competitive wage rate. Equation (6.6) states that air pollution levels are adjusted so that the marginal cost of air pollution to the firm (i.e., the additional cost of hiring labor to work in a polluted environment) equals the marginal benefits of air pollution (i.e., additional market output and cost savings which accrue because anti-pollution devices are not installed).

An offer function can be specified which indicates the wage paid to the optimal number of workers at alternative pollution levels in order to maintain a constant profit level. This offer function, $\phi(P,\pi)$, is expressed as:

$$\phi = [g(P,L) - G(P) - \pi]/L \quad (6.7)$$

$$\phi = \frac{\partial Q}{\partial L} \quad (6.8)$$

This offer function defines a set of iso-profit curves for each firm. A set of iso-profit curves for two different firms is illustrated in Figure 6-2. These curves are positively-sloped, indicating that the cost savings and increase in revenues from marketable output which occur as air pollution levels increase are matched by the additional wage costs which the firm incurs in order to maintain its optimal labor stock.* These iso-profit curves differ among firms as a result of differences in optimal technologies. W(p), as the market-generated locus of wage rates which correspond to each pollution level, also forms an envelope of these iso-profit curves. At the tangency points between firms' iso-profit curves and W(P), the internal trade-off between wages and air pollution within the

* Mathematically, $\partial\phi/\partial P = (\partial Q/\partial P + \partial G/\partial P)/L > 0$. Thus, the marginal demand price for pollution, or the iso-profit curves in Figure 6-2, is positively sloped. However, the second-order conditions do not produce an unambiguous result. Thus, $\partial^2\phi/\partial P^2 \gtrless 0$ [see Thaler and Rosen (5)]. The iso-profit curves in Figure 6-2 are based on the assumption that $\partial^2\phi/\partial P^2 < 0$.

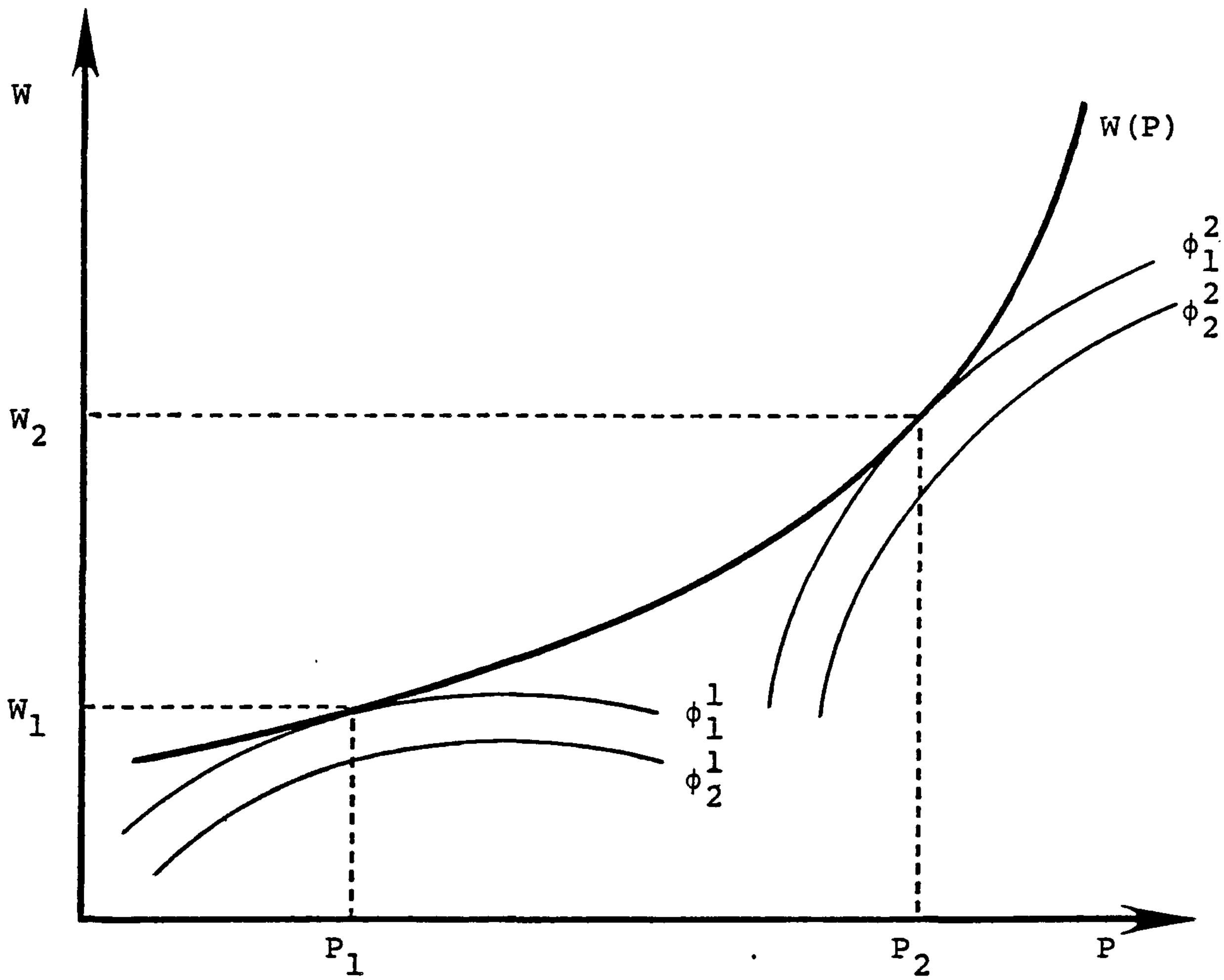

Figure 6-2. Iso-profit lines and equilibria for two firms

firm (i.e., the slope of the iso-profit curve) equals the marginal implicit price of air quality determined by the market.

Equilibrium in the labor market is established where the worker's marginal willingness-to-pay for air quality equals the firm's ability to substitute wage payments for air quality while maintaining an optimal (i.e., profit-maximizing) input stock. W(P) thus defines a series of tangencies between workers' indifference curves and firms' iso-profit curves (see Figure 6-3). Workers with high preferences for clean air (e.g., worker 1) are employed by firms which produce lower levels of air pollution. Workers who do not place as high a value on air quality are employed by firms which produce higher levels of pollution (and are paid higher wages).

Hedonic wage models relate observed equilibrium wage rates, generated by the interaction of labor supply and demand decisions, to the underlying factors which influence these decisions. Thus, estimates of hedonic wage models trace out the market wage locus [i.e., W(P)]. The implicit marginal price of each underlying characteristic is expressed by the derivative of W(P) with respect to that characteristic. The implicit marginal price schedule of air quality, $\partial W(P)/\partial P$, is illustrated in Figure 6-4. If the labor market is in equilibrium, then this implicit price schedule also represents the marginal willingness-to-pay for air quality of different sets of workers exhibiting different preferences for air quality.

Figure 6-4 also indicates the compensated supply price functions for pollution derived from the indifference curves for workers 1 and 2 in Figure 6-3. These supply price functions are defined as $\partial \Theta/\partial P$. They show the increase in wage rate which is required to compensate each worker for an increase in air pollution levels while maintaining a constant level of well-being (or his marginal willingness-to-pay for air quality at each level of pollution). There is only one point on each worker's compensated supply price function which lies in the implicit marginal price schedule; this point corresponds to the equilibrium represented by the tangency between that worker's highest indifference curve and the market wage locus,

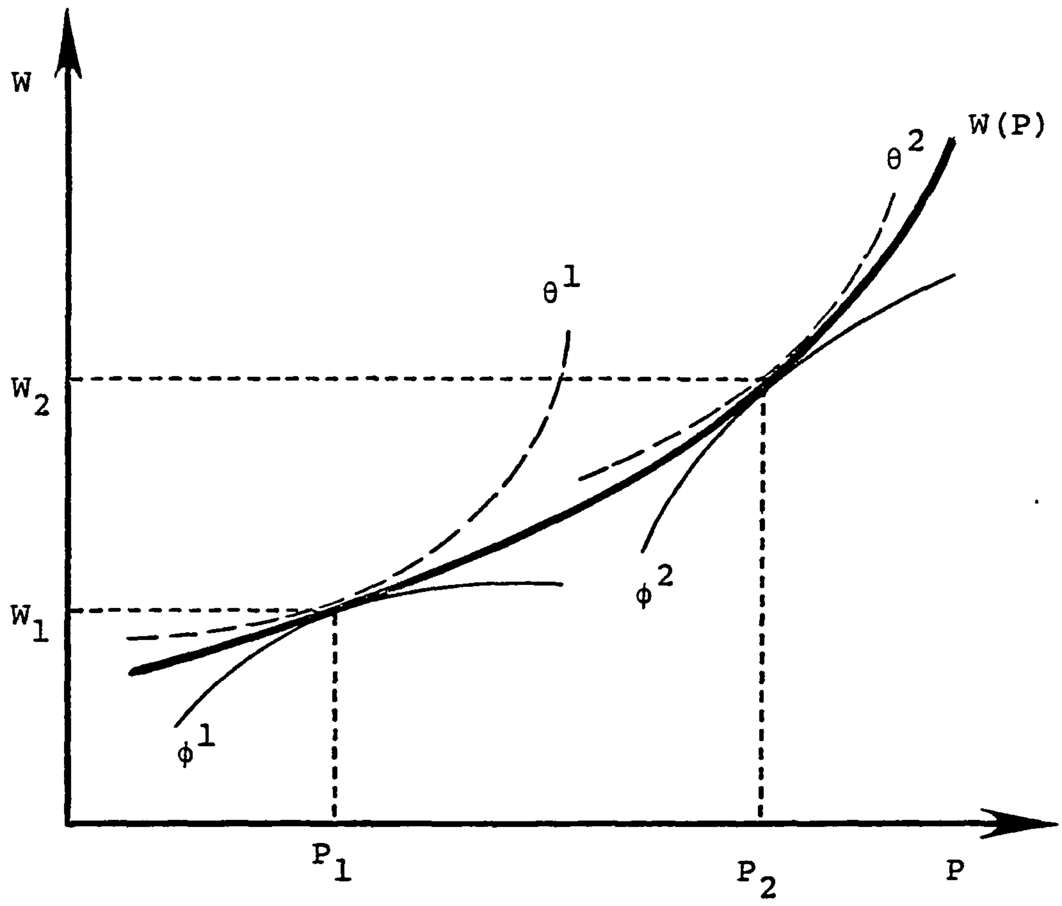

Figure 6-3. Illustration of labor-market equilibrium

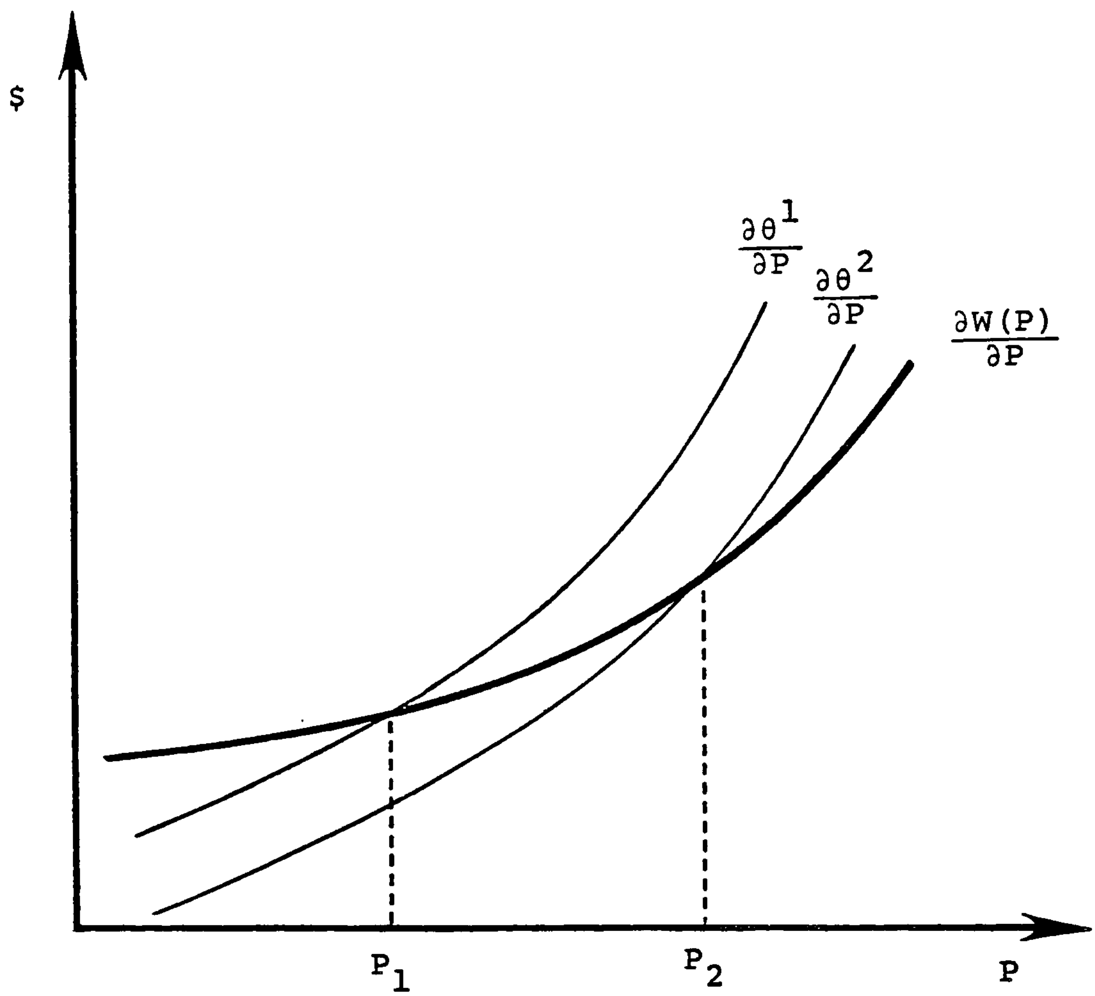

Figure 6-4. Implicit marginal price schedule for air quality and compensated supply functions for two workers

W(P). Thus, the marginal implicit price schedule for air quality indicates the equilibrium marginal willingness-to-pay for air quality at each level of air pollution.

EMPIRICAL ESTIMATES OF HEDONIC WAGE MODELS

Hedonic wage models relate wage differentials to variations in three types of factors:

- Individual-specific characteristics, defined as those characteristics which distinguish job-holders or job-seeking individuals. These characteristics include such factors as education, prior experience, race, sex, veteran status, union-membership, etc. as possible variables in explaining wage differentials.
- Job-specific characteristics, i.e., distinct characteristics exhibited by various types of jobs. Some examples of job-specific characteristics are risk of injury or death, work of a repetitive nature, or work within a supervisory capacity.
- Site-specific characteristics, or characteristics associated with job location. Since job-location decisions may be tied to residential-location decisions,* site-specific characteristics generally reflect the levels of amenities which influence residence choice. Wage differentials may compensate for variations in the levels of such amenities as pollution, climate, crowding, crime, cultural opportunities, etc.

Thus, hedonic wage models are specified in general functional form follows:

$$W = F(Z_1, Z_2, Z_3)$$

where W is the observed wage rate.**

Z_1 is a vector of individual-specific characteristics.

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* That is, an individual first selects an area of residence; this decision constrains his job search to a specific geographic area.

** Smith (8) argues that the real wage rate, and not the nominal wage rate, is the appropriate dependent variable.

Z_2 is a vector of job-specific characteristics.

Z_3 is a vector of site-specific characteristics.

To date, most estimates of hedonic wage models generally include individual-specific characteristics (i.e., Z_1) and either job-specific characteristics (i.e., Z_2) or site-specific characteristics (i.e., Z_3) as explanatory variables [Smith (8)]. Attempts to link wage differentials to job-specific characteristics include studies conducted by Lucas (6), Thaler and Rosen (5), Viscusi (9), Hamermesh (10), and Olson (11). These models have produced conflicting results regarding the effect of job-specific characteristics on wage rates. Brown (12) failed to confirm the hypothesis that these inconsistent estimates result from a misspecified model which omits important job characteristics.

Other investigators have used the hedonic wage model to impute the values attached to urban amenities (i.e., the site-specific characteristics defined above), and thus measure the quality of urban life [see Rosen (4); Meyer and Leone (13); Getz and Huang (14); Izraeli (15); Hoch (16)]. However, there are many site-specific characteristics which might conceiveably affect wage rates, and several distinct methods of quantifying some of these variables.*

A general comparison of hedonic wage model estimates indicates that, while individual-specific characteristics exert a consistent and predictable effect on wages, the impact of both job- and site-specific characteristics is less consistent. Comparisons among these models are difficult, since they vary in their data sources, sample designs, model specification, and measurement of both wage rates and explanatory variables. However, even within models which include all three general characteristics as

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* For example, the climate can be measured by rainfall, number of days of sunshine, high, low, and/or average temperature, humidity, etc. Each measures a somewhat different climatic effect; however, the inclusion of all variables may not be feasible where degrees of freedom are limited. In addition, interrelationships among the different measures may cause collinearity and thus blur the effect of each factor on wages.

explanatory variables, coefficient estimates for site-specific characteristics are sensitive to the choice of the particular site-specific characteristics included in the model [Rosen (4); Smith (8)].

It is not the intent of this review to evaluate all attempts to estimate hedonic-wage models.* Instead, models which include the effect of air pollution (specifically, ambient TSP levels) on wage rates are evaluated for use in the calculation of benefits obtained under alternative particulate matter (PM) standards. The selection of studies utilized in these benefits calculations is based on the criteria discussed in Section 1. The studies used in this section meet the following specific criteria:

- They each use TSP as an explanatory variable. This is an obvious prerequisite for use in benefits calculations.
- They each express the dependent variable as the real wage rate or earnings. A regional cost-of-living deflator will adjust earnings for differences in the prices of local goods (e.g., property values) which may also reflect regional variations in air quality.
- Each model is properly specified in that it includes, either explicitly or implicitly, explanatory variables measuring individual-, job-, and site-specific characteristics.
- Estimated coefficients produced by each model are plausible in terms of the underlying theoretical construct.

Despite an abundance of empirical work relating wage differentials to site-specific characteristics within a hedonic-wage framework, only nine studies have been identified which analyze the effect of ambient levels of particulate matter on wages [Getz and Huang (14), Izraeli (15,18), Meyer and Leone (13), National Academy of Science (19), Mathtech (20), Roback (7), Rosen (4), and Smith (8)]. Of these, only two studies are suitable for use in benefits calculations [i.e., Rosen (4) and Smith (8)].

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* The reader is referred to Smith (17) for a review and critique of hedonic wage models.

In their study of consumer preferences for site amenities, Getz and Huang (14) analyze the relationship between median annual earnings of white males employed full-time and both individual-specific variables and site-specific variables, including air quality. A principal component* of the ambient levels of two pollutants (sulfur dioxide and TSP) is used as an inverse measure of air quality; this relationship is estimated for each of nine urban occupational groups, as well as over all occupations. Getz and Huang obtained mixed results; air pollution generally exerted an insignificant effect on median earnings except for professionals, whose earnings are significantly higher in the presence of higher levels of air pollution. Other explanatory variables used in this analysis include median worker age and the proportion of adults in each SMSA who are high school graduates as human capital variables, and a variety of site-specific characteristics, such as the FBI violent crime index, the number of days of freezing temperatures, the proportion of teachers with graduate degrees, and a principal component measure of the per capita number of hospital beds and physicians. Since the coefficients estimated by Getz and Huang do not differentiate between TSP and sulfur dioxide in measuring the effect of air pollution on earnings, they cannot be used in the current benefits calculations.

Meyer and Leone (13), NAS (19) and Izraeli (15,18) focus on the role which urban amenities (or site-specific characteristics) play in explaining wage or income differentials. Using aggregate data for 39 SMSAs, Meyer and Leone examine the impact of both TSP and sulfur dioxide on several specifications of the dependent variable (i.e., real median family income and the real wage rate for skilled workers, for unskilled workers, and for computer analysts) within a log-linear functional form. In most instances TSP levels exerted an insignificant negative effect on earnings or wages; however, real wages for computer analysts were significantly higher in the presence of higher TSP levels. Sulfur dioxide levels had a mixed but always insignificant effect on the various dependent variables. The

* Principal components analysis is a statistical device which allows the investigator to express two or more collinear explanatory variables as a linear combination.

inclusion of two highly correlated air pollution measures together in the same model (i.e., sulfur dioxide and TSP) may explain the resultant insignificant coefficient estimates for these variables. The NAS study (19) is a slightly expanded version of the models estimated by Meyer and Leone. Additional site amenities, including NO_2, are included, and both linear and log-linear specifications are estimated over various subsets of explanatory variables. Once again, the estimated coefficients for the air quality variables are generally not significant, and are sometimes negative. TSP is particularly problematic in this respect: negative and insignificant coefficients are often observed. The very small coefficient values and the lack of significance exhibited by the air quality variables may be due to collinearity among these variables, or between these variables and other explanatory factors.

The performance of other explanatory variables is mixed. Some consistently exhibit the "wrong" sign, and many are insignificant. Given the relatively high R^2s which characterize some of the specifications, the evidence indicates a severe problem with collinearity among the explanatory variables.

A similar model was estimated by Izraeli (15), using median real wage rates as a dependent variable from 67 SMSAs between 1964 and 1967. Using three air pollution measures (i.e., TSP, sulfur dioxide, and benzene soluble organic matter), Izraeli obtained a positive and significant coefficient for sulfur dioxide; the coefficient in TSP was negative but insignificant. When TSP was used as the only pollution variable, the estimated coefficient was positive but not significantly different from zero. In a recent study, Izraeli (18) estimates a more refined model using a greatly expanded sample which includes 237 SMSAs in the year 1970. Median annual earnings are related to variables measuring the median age and schooling of the population, the number of weeks worked, the racial composition of the population and a series of environmental variables, including air quality, the crime rate, climate, and population size and growth. Air quality is measured by suspended particulate matter; no additional air pollutants are included. Separate equations are estimated for males and females. In each case, TSP exerts a positive but insignificant effect on median earnings.

Given the aggregate nature of the data used in the above-mentioned studies, no job-specific characteristics can be explicitly included as explanatory variables. Similarly, individual-specific characteristics, such as prior experience, education, etc., are difficult to include in their models. However, median schooling is used as an explanatory variable in both Meyer and Leone (13) and NAS (19). Some other explanatory variables, such as the median age or racial composition of the population, may also reflect the education or experience levels of the population. Since these models do not account for the impact of both individual- and job-specific characteristics on wage or earnings differentials, they cannot be regarded as properly-specified hedonic wage models. Thus, benefits calculations should not be based on their results.

The remaining studies [Mathtech (20), Roback (7), Rosen (4), Smith (8)] use micro-data to relate wage rates or earnings reported by surveyed individuals to individual-specific characteristics, job-specific characteristics, and site-specific characteristics. The Mathtech study (20) used observations drawn from the University of Michigan <u>Panel Study of Income Dynamics</u> for the 1971 interview year for 699 counties. The log of the real wage,* is related to three measures of pollution (i.e., TSP, sulfur dioxide, and nitrogen dioxide), entered in both linear and quadratic terms. Since pollution data is available only over 247 counties, two procedures were suggested to replace missing observations:

- The use of the means of the observed values.
- A method adapted from a technique developed by Dagenais (21), which involves regressing each pollution variable in all remaining (non-pollution) explanatory variables and on relevant auxiliary variables. Values for the missing

* Defined as hourly money income from labor received by the head of household deflated by the BLS indicator of comparative living costs for a family of four at the lowest living standard.

pollution variables are predicted using these regression results.

Regression results are reported using a restricted subsample where all missing observations are deleted, as well as for the full sample (i.e., 1,395 observations),* using the two procedures outlined above to replace missing pollution variables. Neither sulfur dioxide nor nitrogen dioxide significantly affect real wages. The coefficient on the linear TSP variable is positive and significant only when the mean values of the pollution variables are used to approximate missing observations; the coefficient on the quadratic TSP term is negative and significant in this instance. Thus, real wages will rise at a declining rate as TSP concentrations increase. However, the estimated elasticity of real wage with respect to the TSP level is -0.16, measured at the mean value of TSP;** this contradicts a priori expectations regarding the relationship between the real wage and TSP levels. These implausible results leads to the rejection of these coefficients as a basis for benefits calculations.[+]

Rosen (4), Roback (7), and Smith (8) each use micro-data from the Current Population Survey (CPS)[++] in their respective analyses. Each includes TSP levels (measured at the annual geometric mean) as an explanatory variable in conjunction with several other individual-specific, job-

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* This sample is restricted to households which received no transfer income and whose head worked 400 hours or more per year.

** This elasticity indicates the percentage change in the real wage rate which will occur for a given percentage change in TSP levels. It thus measures the responsiveness of the real wage to changes in TSP levels. In this instance, a 10 percent increase in TSP levels will lead to a 1.6 percent decline in the real wage.

\+ The hedonic wage model specified in the Mathtech study was also estimated over various portions of the data set based on sex, age, and race. Coefficients estimated for air pollution variables were seldom significantly different from zero in these equations.

++ The Current Population Survey data allows the investigator to link specific individual- and job-specific attributes to each surveyed individual; this provides better control over these explanatory variables than the more aggregated data used in many previous studies.

specific, and site-specific factors, and each produces plausible estimates for the TSP coefficients. Roback's model uses nominal wage rates as the dependent variable, while both Rosen and Smith specify the dependent variable as the real wage rate.

Variations in nominal wages or earnings may be explained in part by regional differences in the cost of living. Cost-of-living differentials may reflect the following:

- Regional differences in the prices of goods which are exchanged between regions due, for example, to transport costs.

- Price differentials for nontraded goods (e.g., housing) which are attributable to variations in environmental conditions across regions.

The effect of these regional variations in cost of living should be accounted for in assessing the relationship between wage rates and air quality. Roback (7) does not account for this factor; thus, this study is excluded from further consideration.

Both Rosen (4) and Smith (8) use an appropriate data base to estimate well-specified hedonic models which meet the following criteria:

- Each includes TSP as an explanatory variable.

- Each specifies real wage or earnings as the dependent variable.

- Each includes, either explicitly or implicitly, explanatory variables measuring individual-, job- and site-specific characteristics.

- Each produces a plausible relationship between TSP and the real wage rate.

Thus, both studies meet the general criteria for use in benefits calculations. A more detailed review of each study is offered below; this discussion is summarized in Table 6-3.

Table 6-3

SUMMARY OF SELECTED HEDONIC WAGE MODELS

Study	Sample	Dependent Variable; Pollutant	Functional Form	Estimated Coefficients; Elasticities of Pollution Variables (At Means)	Estimated Benefits; Base Year
Rosen (4)	Males out of school & reporting earnings in 1969 over 19 major SMSAs. Obtained from 1970 CPS.	Total real earnings (wages & salaries + self-employment income); Annual geometric mean for particulates ($\mu g/m^3$).	Semi-log	Estimated coefficients range from 0.000553 to 0.0015; Elasticities range from 0.0627 to 0.1702.	A reduction in levels by 1 $\mu g/m^3$ leads to a change in mean annual earnings ranging from $4.92 to $13.35; 1970.
Smith (8)	All surveyed individuals residing in 44 major SMSAs who reported earnings in 1977. Obtained from 1978 CPS.	Real wage rate; Annual geometric mean for particulates ($\mu g/m^3$).	Semi-log	Estimated coefficients range from 0.000615 to 0.00112; Elasticities range from 0.0413 to 0.075.	Reducing TSP levels by 1 $\mu g/m^3$ will decrease mean annual earnings by $6.05 to $16.50; 1978.

In his analysis of wage rate differentials and urban amenities, Rosen used data from the 1970 CPS over 19 major SMSAs for males who were out of school and who reported earnings in 1969. He uses a semi-log specification where the dependent variable is the log of real annual earnings* and the explanatory variables are entered in linear form. In addition to TSP levels, air pollution is also measured by sulfur dioxide levels and by the number of inversion days. Individual-specific variables include schooling and previous experience (entered in both linear and quadratic form), as well as dummy variables for race, sex, marital status, veteran status, and head-of-household. Dichotomous variables are also entered for self-employed individuals, government employees, full-time employees, and individuals who worked for 35 hours per week or less, as well as for individuals who were not employed at any time during the year and individuals who were unemployed once during the year. Job-specific characteristics are not explicitly recognized. However, Rosen uses dummy variables to distinguish across one-digit occupational and industry classes; this may provide a crude measure of differences in characteristics common to various jobs across the sample. Finally, measures of site-specific characteristics include climate (i.e., the number of sunny days, the number of rainy days, and the number of days when the temperature exceeded 90^{o}F), crime (measured by the total crime rate), crowding (i.e., population density, population size, and whether the surveyed individual lives in the central business area), and labor market conditions (approximated by the unemployment rate and the rate of population growth). In addition to the air pollution variables cited above, a measure of water pollution is also included.

Rosen estimated his model using all individual- and job-specific characteristics and various combinations of the site-specific attributes discussed above.** Estimated coefficients for individual-specific attributes are generally significant and of the same sign and order of magnitude

* Real annual earnings are defined here as nominal earnings (wages and salaries, plus self-employed income) reported in the CPS divided by a cost-of-living index for either low-, medium-, or high-expenditure families, depending on individual circumstances.

** Regression results reported by Rosen are listed in Appendix 6A.

as those observed in other studies using less restricted samples. Results for the site-specific variables are less robust. Measures of climate, crime, and market conditions generally affect wage rates in the expected fashion; however, the size of the effect varies with the particular set of site-specific attributes included in the model. Significance levels are also inconsistent across specifications; this probably reflects varying degrees of multicollinearity among these variables. TSP had a consistently positive and generally significant impact on real earnings.* Reported significant estimates for the TSP coefficient range from 0.00055 to 0.00150; this translates to elasticity estimates ranging from 0.062 to 0.170.** The measured impact of changes in TSP levels on real earnings is thus very slight: at the mean TSP level, an increase in TSP concentrations by 10 percent will increase real earnings by less than 2 percent.

Smith (8) explicitly examines the effect of both site-specific and job-specific characteristics on real wage in his hedonic wage model, using data obtained from the 1978 CPS to define the dependent variable and several explanatory variables over 44 SMSAs. Like Rosen, Smith uses a semi-log functional form which specifies the log of the real wage rate[+] as a function of several explanatory variables. Individual-specific attributes include years of schooling and years of job experience (both entered in linear and quadratic form), as well as a series of dummy variables reflecting socio-economic characteristics. Job-specific characteristics

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* The number of inversion days also had a positive and significant impact on real wage. The results for sulfur dioxide are less robust; significant negative coefficients appear in several instances.

** For the semi-log functional form, the elasticity of the real wage with respect to TSP at a particular level of TSP is computed as the product of the estimated coefficient on the TSP variable and the level of TSP. Thus, the responsiveness of the real wage to changes in TSP concentrations varies with the level of TSP. Here we calculate elasticities at the mean TSP level observed in the sample.

\+ Defined as the nominal hourly wage divided by the 1977 Bureau of Labor Statistics' cost-of-living index for families at an intermediate living standard. Since this index is only available for 27 SMSAs, Smith uses a procedure suggested by Cebula (22) and Cebula and Smith (23) to estimate this index for the remaining SMSAs.

include injury rates, an index of exposure to carcinogens, an indicator of worker knowledge of job hazards,* and occupational dummy variables. Smith's model also allows for an interaction between experience and the effect of product market uncertainty on the firm's willingness to invest in on-the-job training (OJT). Another set of risk-interaction terms for race, head of household, and union membership are also included in some regressions. In his preliminary analysis, Smith experimented with a large number of site-specific characteristics, including various measures of climate, cultural amenities (i.e., dummy variables indicating presence of symphony or live theatre, the number of major newspapers, art museums, and professional sporting teams), the crime rate, the unemployment rate, and the number of hospitals. Three measures of air pollution, TSP, sulfur dioxide and ozone, were also considered. Here, Smith found that TSP provided the most consistent results. The model was estimated over all individuals in the sample and separately for males and for females; Smith's best results using the most robust set of site-specific attributes are presented in Table 6A-3 in Appendix 6A.

The site-specific attributes which are included in Smith's final analysis are TSP levels, the unemployment rate, the crime rate, and the mean annual percentage of possible sunshine (i.e., the number of hours of actual sunshine/the number of hours between sunrise and sunset). Generally, the estimated coefficients for these and other explanatory variables are statistically significant and their signs conform to both *a priori* expectations and the results of previous studies.**

Real wage rates are significantly higher for higher levels of TSP; coefficient estimates over the entire sample range from 0.00083 to 0.00087.

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* Measured as the relative number of workers in each industry covered by collective bargaining agreements with provisions relating to health and safety conditions.

** Smith notes that his estimated coefficient for the unemployment rate differs in sign from estimates reported by Rosen (4). He suggests that differences in the industrial composition of the two samples may explain this inconsistency.

The elasticity of the real wage rate with respect to TSP; calculated at the mean observed TSP levels, varies from 0.056 to 0.058. Smith's results for men indicate that elasticities range from 0.0726 to 0.0750; this confirms Rosen's finding that TSP levels have an extremely small, albeit statistically significant, impact on real earnings.

Generally, the hedonic wage studies cited above produce consistent coefficient estimates for individual-specific attributes. However, there is less agreement among these models with respect to coefficient estimates for both job-specific and site-specific attributes. Smith (8) suggests that the constraints imposed by data availability result in non-random samples which, in turn, produce diverse coefficient estimates. He tests the sensitivity of his site-specific and job-specific coefficient estimates to sample composition by deleting selected SMSAs and industry classes from the sample and re-estimating his model. He concludes that coefficients estimated for site-specific attributes are quite sensitive to sample composition, while job-specific effects are less sensitive in this regard.

Before proceeding with benefits calculations based on these results derived by Rosen and by Smith, some general remarks concerning certain unresolved empirical issues which arise within hedonic wage models are in order.

Estimates of hedonic wage models may be subject to bias from at least two sources:

- Bias resulting from the omission of important explanatory variables.
- Sample selection bias.

Investigators who attempt to estimate hedonic wage models are faced with the task of choosing among a large number of potential explanatory variables. The omission of important variables from the model introduces a bias of unknown magnitude into the estimates of the model's parameters.

Hedonic wage models may also be biased as a result of sample truncation. Many of the empirical models cited above are estimated over somewhat restricted samples.* Even when arbitrary restrictions are not placed on the data set, the sample is necessarily restricted to those individuals who report wages for the sample period [Smith (8)]. In either case, a sample selection bias is introduced into the estimated coefficients.** Additional assumptions are required in order to use these coefficients to make some inference about the behavior of those individuals not included in the sample.

BENEFITS

Benefits calculations for the alternative primary and secondary particulate matter standards described in Section 9 will be based on coefficient estimates obtained by Rosen (4) and Smith (8) for their respective hedonic wage models. These estimates will be used to calculate individual willingness-to-pay for air quality and benefits will be extrapolated over the labor force.

In order to use the coefficients estimated by Rosen and Smith to obtain an assessment of benefits over the entire labor force, the following assumptions are required:

- The estimated coefficient on the TSP variable in each study accurately captures the effect of changes in TSP levels on real earnings.
- Benefits based on these coefficients reflect the willingness-to-pay for air quality of those individuals in the labor force who are not included in the samples from which these coefficients were estimated.

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* For example, Rosen (4) restricted his sample to males, and the Mathtech study (20) deleted all households which reported transfer income or whose head worked less than 400 hours per year.

** The reader is referred to Heckman (24,25) and Gronau (26) for a discussion of sample selectivity. Wales and Woodland (27) survey various methods of estimating labor supply functions using truncated samples.

Measures of TSP may be correlated with other possible explanatory variables, including other types of air pollution, which are not considered in the model. In this event, the estimated coefficient for the TSP variable may also capture the effect of these omitted variables on real earnings. It is assumed here that correlation between TSP and excluded explanatory variables does not substantially affect the coefficient estimates obtained in the selected studies. This assumption is certainly tenuous, particularly in view of the sensitivity of Rosen's reported results for TSP as different combinations of site-specific characteristics are introduced within his model. There is also strong evidence that TSP concentrations tend to be highly correlated with other air pollutants. Unfortunately, very few hedonic wage models report results for more than one measure of air pollution. Those which include the effect of more than one air pollutant in real wages or earnings are deficient in other respects.* It is possible that the estimated coefficient on TSP as the sole pollutant in this type of model may also proxy the effects of other pollutants in real wages or earnings. However, it is difficult to assess the extent to which this might occur because neither of the studies with well-specified models (Rosen and Smith) report equations containing more than one air pollutant.

The possibility of biased coefficient estimates due to sample selection or truncation must also be considered. Smith attempted to measure the bias introduced by sample truncation by applying adjustment indices developed by Olsen (28) to his OLS estimates.** The resultant adjusted coefficients increased in absolute value by one to two percent, while the standard errors of these coefficients rose by one percent. Smith concluded that sample truncation bias did not pose a serious problem in his analysis.

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* See, for example, Meyer and Leone (13), NAS (19), or Izraeli (15).

** Olsen (28) developed a simple approximation to the maximum likelihood estimators for the truncated regression model. A table of conversion factors is applied to OLS estimators in order to produce these approximate maximum likelihood estimates.

The hedonic-wage models developed by Smith (8) and Rosen (4) were estimated over different samples,* using somewhat different model specifications. Despite this, the results obtained within both models for TSP corroborate each other. The estimated coefficients appear to be quite robust with respect to both the sex and the residence of surveyed individuals;** these results support the use of these coefficients in calculating willingness-to-pay for air quality for every worker in the labor force.+

Both Rosen and Smith use a semi-log specification of the hedonic wage function, expressed as follows:

$$\ln(W) = \alpha + \beta \, TSP + \lambda X \qquad (6.9)$$

where W is the real wage rate (Smith) or real annual earnings (Rosen).

TSP is the annual geometric mean level of total suspended particulates.

X is a vector of other explanatory variables.

α, β and λ are estimated parameters.

Estimates of this model reveal the equilibrium value of air quality. From this, the decline in real wage rate or earnings which will accompany a marginal improvement in air quality; (i.e., the marginal willingness-to-pay

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* Rosen used a sample of males over 19 major SMSAs drawn from the 1970 CPS, while Smith used a sample of all surveyed individuals over 44 SMSAs drawn from the 1978 CPS.

** Smith reports that the difference between coefficients estimated separately for males and for females is not statistically significant. His coefficient estimates for the total sample over 44 SMSAs lie within the range reported by Rosen for 19 SMSAs.

\+ Here, it is also assumed that the coefficients estimated by Smith (8) and Rosen (4) also apply to those individuals in the labor force who were not represented in these studies because they did not report earnings for the sample periods. In essence, it is assumed that these benefits calculations are not affected by sample selection bias. As discussed above, sample selection bias does not appear to influence the coefficient estimates generated by Smith (8).

for air quality) can be estimated. This marginal willingness-to-pay for air quality is calculated as the first derivative of real wages (or earnings) with respect to air pollution. For the semi-log function given in Equation (6.9), the marginal willingness-to-pay for air quality at a given level of real earnings is defined as:

$$\frac{\partial W}{\partial TSP} = \beta \cdot W \qquad (6.10)$$

If the estimated coefficient (β) is positive, then individuals must receive higher wages in order to compensate for deteriorations in air quality. Their marginal willingness-to-pay for air quality, or the decrease in the wage rate which they would accept in order to enjoy improved air quality, is positive and varies in direct proportion with their wage level. Individuals with higher real earnings will relinquish more of their earnings in response to a marginal improvement in air quality as compared to those with lower real earnings. The second derivative of Equation (6.9) is expressed as follows:

$$\frac{\partial W^2}{\partial^2 TSP} = \beta^2 \cdot W > 0 \qquad (6.11)$$

Marginal willingness-to-pay for improved air quality will increase at an increasing rate as air quality deteriorates. The magnitude of this effect will also vary directly with the wage rate.

Table 6-4 lists calculations of individual marginal willingness-to-pay for air quality on an annual basis using coefficients estimated by Smith (8) and Rosen (4).

The implementation of the proposed particulate matter standards will probably result in a non-marginal change in ambient TSP concentrations. In order to calculate the precise effect of these non-marginal improvements in air quality on real wages (and thus on benefits), some knowledge of the supply price function for TSP for each individual is required. This

Table 6-4

ESTIMATED BENEFITS FOR MARGINAL CHANGES IN AIR QUALITY*
BASED ON RESULTS REPORTED BY ROSEN (4) AND SMITH (8)

Study	Change in average annual real earnings**	
	Minimum	Maximum
Rosen (4)	$ 10.44	$ 28.33
Smith (7)+		
Total sample	13.22	13.88
Males	20.17	20.84
Females	7.70	8.44

* A change in TSP levels of 1 $\mu m/g^3$ is assumed.

** Calculated at the average wage or earnings levels reported for each sample and expressed in 1980 dollars.

\+ The reported average nominal wage rates are divided by the cost-of-living index for a 4-person family at an intermediate expenditure level in order to calculate the real wage. The change in the real wage as a result of the change in TSP levels is then multiplied by 2,080 hours in order to approximate annual real earnings.

function is <u>not</u> estimated within the hedonic wage model. However, these benefits can be approximated using a simple technique suggested by Freeman (29).

Figure 6-5 illustrates the equilibrium marginal implicit wage that the sampled individuals will accept in return for working under varying levels of ambient TSP levels. This marginal implicit wage, W' (TSP), is the first derivative with respect to TSP of the hedonic wage model specified above as calculated in Equation 6.10. Each point in W' (TSP) corresponds to a single point in each individual's supply price function for TSP. $S(TSP)_1$ is the hypothesized supply price function of individual 1, indicating that this worker must be paid higher real wages as compensation for higher TSP levels in his work environment.

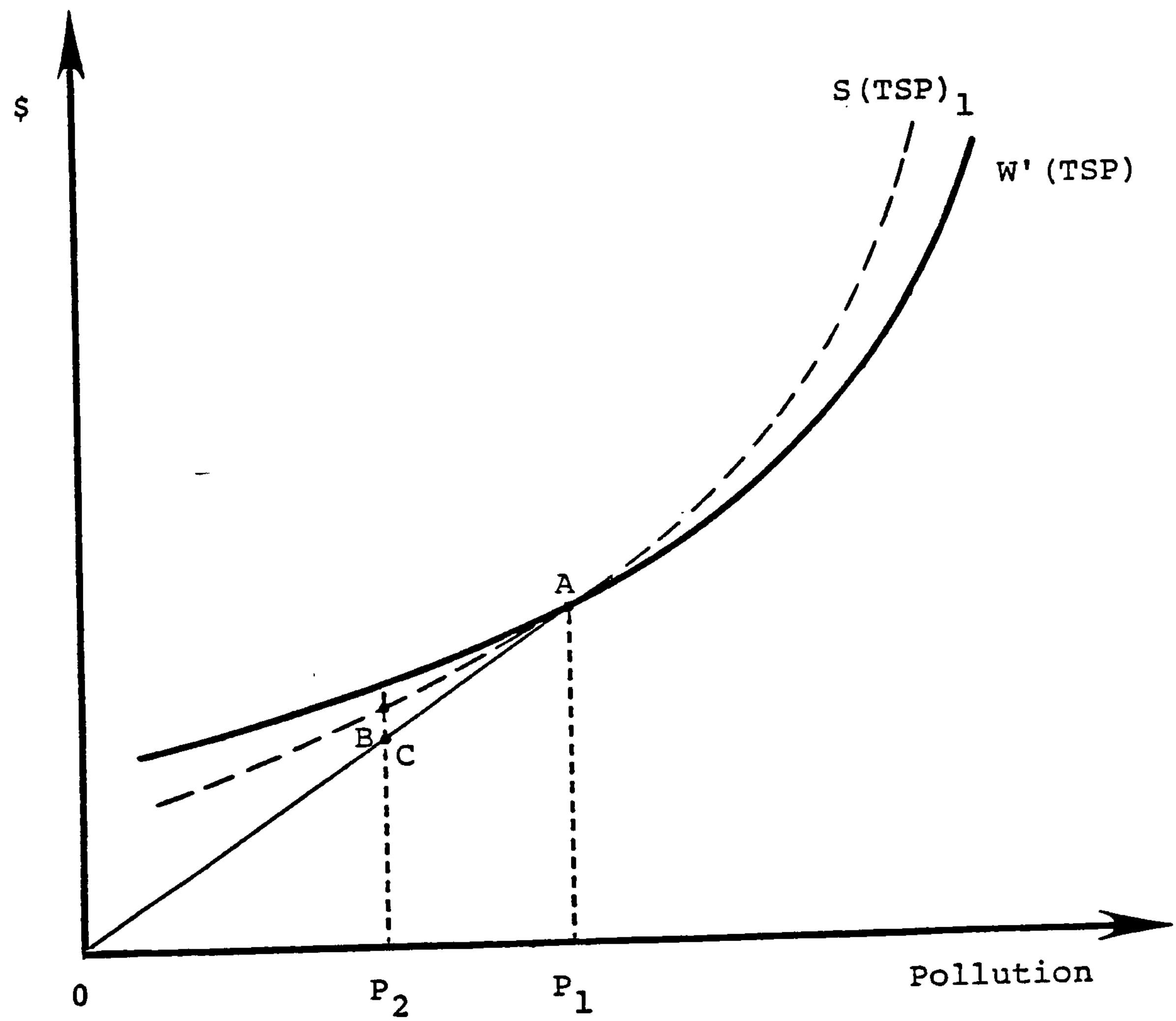

Figure 6-5. Illustration of benefits calculation for non-marginal changes in TSP levels

Benefits calculations for non-marginal changes in TSP levels involve measuring the area under $S(TSP)_1$ between the two pollution levels (i.e., area AP_1P_2B for a decline in TSP levels from P_1 to P_2). Since $S(TSP)_1$ is not directly observable, this area is approximated by assuming that the supply price functions for each individual for TSP decrease linearly from the observation point (i.e., point A) to zero as TSP is continuously abated. Thus, benefits can be calculated as the difference between the areas of two triangles AP_10 and CP_20, or

$$\text{Benefits} = \frac{1}{2}\left[(AP_1 \cdot OP_1) - (CP_2 \cdot OP_2)\right] \tag{6.12}$$

For the semi-log specification of the hedonic wage model, benefits are calculated as follows:

$$\text{Benefits} = \frac{\beta(W)}{2}\left[P_1 - \frac{P_2^2}{P_1}\right] \tag{6.13}$$

where P_1 is the initial TSP level.

P_2 is the TSP level after implementation of the appropriate control strategy.

and all other variables are as defined above.

Clearly, the accuracy of this approach to benefits calculations depends on how closely the linear segment CA approximates the curvilinear segment BA. If segment CA falls below segment BA (as drawn in Figure 6-5), then Equation (6.13) will underestimate the true benefits obtained from the given non-marginal change in TSP concentrations. Conversely, if segment CA lies above segment BA, the result is an overestimate of these benefits. Since segment BA is not observed, the direction and extent of the bias in benefits calculations resulting from this approach is unknown.

The average real wage expressed in 1980 dollars is used to calculate individual willingness-to-pay for air quality; these benefits are multiplied by average annual work hours (i.e., 2,080 hours per year) to approximate average annual benefits per individual at the attainment date. Individual benefits are then multiplied by the projected labor force at the attainment date in order to extrapolate benefits over the population. These benefits are extended over the relevant time horizon under the assumption of continuous growth in the labor force, and then discounted back to 1982.

Both Rosen and Smith use data aggregated to the SMSA level in estimating their models; however, information on ambient TSP concentrations is compiled by county. In this study, benefits from hedonic wage models are calculated at the county level; this facilitates comparisons with the benefits estimates from health effects studies and property value studies presented elsewhere in this report.

The following information is required for benefits calculations from hedonic wage models:

- Real wage rates, expressed in 1980 dollars.*
- Projected changes in ambient TSP concentrations for a given attainment date resulting from the attainment of a specified standard.
- Projections of labor force growth into the future.

Data sources and the procedures used in transforming the raw data into a more suitable form are summarized in Table 6-5.

Benefits estimates are calculated for six alternative particulate matter standards. For each standard, minimum and maximum estimates provide

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* Technically, the real wage at the attainment date should be used. In these benefits calculations, the average real wage in each county in 1978 is used. The average nominal wage rate in 1978 for each county is deflated by the BLS cost-of-living index for intermediate expenditure families in order to approximate this average real wage. The consumer price index is then used to inflate this real wage to 1980 dollars. The real wage is then extrapolated to the attainment date and beyond using income projections provided by the Bureau of Economic Analysis, Department of Commerce (30).

Table 6-5

DATA SOURCES AND TRANSFORMATIONS

Variable	Source	Comments
Nominal wage rate	Payroll and employment information for non-government* and Federal government employees obtained from County Business Patterns 1978 published by the Bureau of Census (31)	The combined Federal government and non-government payroll is divided by the total number of employees reported by each sector in order to estimate average annual earnings per individual. This estimate is divided by 2,080 (i.e., no. of hrs. worked/year) as an approximation to the average hourly wage.
Cost-of living deflator	Index of comparative costs based on an intermediate budget for a 4-person family (Autumn 1977), published by the Bureau of Labor Statistics.	This index is calculated for SMSAs and for non-metropolitan areas within each census region. Generally the SMSA index associated with each county is used to deflate that county's nominal wage rate. When a deflation factor is not available for an SMSA the U.S. metropolitan index is used. The regional non-metropolitan index applies for counties which are not part of an SMSA.
Consumer Price Index	Bureau of Labor Statistics	Consumer price indices are published on a regional basis for the 4 census divisions. These regional price indices are used to convert benefits estimates to 1980 dollars.
Income growth projection	The real wage rate at the attainment date is extrapolated from the real wage rate in 1980 using income growth projections to year 2000. Continuous growth is assumed. Growth rates are calculated from projections of personal income to year 2000 obtained from the U.S. Bureau of Economic Analysis (30)	Income projections are available by state.
TSP concentrations	Provided by EPA	PM10 concentrations are converted to equivalent TSP levels expressed as the annual geometric mean. These TSP readings are then transformed to an annual geometric mean to conform with data used by Rosen (4) and Smith (8). This data in its original form represented the worst incidence of air pollution within each area. Data was transformed in order to derive a measure of average exposure throughout the county. The procedure used in this transformation is discussed in Section 9.
Labor force	Labor force as of attainment date is extrapolated from the labor force in 1978 under the assumption of a continuous growth rate. Labor force by county in 1978 is obtained from unpublished data provided by the Bureau of Labor Statistics. The employment & population projections to 2000 used to calculate the growth factor are provided by the Bureau of Economic Analysis (32,33)	Employment projections are available on an SMSA level and are used to calculate labor force growth for counties within these SMSAs. Population projections at the state level are used to approximate labor force growth in rural counties.

* Excluding self-employed individuals, railroad employees, farm workers, and domestic-service workers, and government employees at the state and local levels.

a likely range of benefits, while a single point estimate indicates the best defensible benefits estimate.* The choice of coefficient for the maximum benefits estimate is based on a review of a series of specifications estimated by Rosen (4). The coefficient was selected from that specification which included a maximum number of explanatory variables, most of which had a statistically significant effect on real earnings. This minimizes, to the extent possible, the impact of omitted explanatory variables on the estimated TSP coefficient.

The point benefits estimate is derived from results reported by Smith (8). In order to incorporate the uncertainty which is associated with this estimate due to the stochastic nature of the estimation procedure, the lower bound of the confidence interval around this point estimate is used to define the lower bound of the reported range of benefits.**

The coefficients on the TSP measure derived by both Smith and Rosen were estimated from air pollution data at the SMSA level. Table 6-6 summarizes the extent of ambient TSP exposure which each model assumed, and the adjustments made to the design values used in the current benefits estimates in order to replicate these conditions.

Table 6-7 reports calculations of individual willingness-to-pay for air quality, based on the coefficients and the air pollution data which are used in benefits estimates. Estimates of willingness to pay for marginal changes in concentrations of particulate matter range from $3.32 per year to $10.98 per year, depending on the sample. These estimates appear to be quite reasonable, and reflect a highly inelastic relationship between real wages and particulate concentrations.

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* The coefficients used in these calculations are given as follows: Minimum estimate 0.000431; Point estimate 0.000871; Maximum estimate 0.000921.

** This procedure is not used to define the maximum benefits estimates because sufficient information is not available to calculate a statistically-meaningful confidence interval around the coefficients estimated by Rosen (4).

Table 6-6

AIR QUALITY DATA: ORIGINAL MODELS AND CURRENT BENEFITS ANALYSIS

Study	Geographic Area	Monitor(s) Used in Original Study	Pollution Measure Used in Benefits Analysis*
Rosen	19 SMSAs	Monitor representing worst incidence within SMSA	Design value monitor in county
Smith	44 SMSAs	Average over all monitors within SMSA	Average over all monitors in county

* See Section 9 for a complete description of the air quality data used in this benefits analysis.

Table 6-7

ESTIMATED BENEFITS FOR MARGINAL CHANGES IN AIR QUALITY*

Standard	Change in Annual Real Earnings**		
	Minimum+	Point+	Maximum
PM10 70 AAM/250 24-hr (93 counties)	$3.32	$6.71	$11.36
PM10 55 AAM (161 counties)	3.52	7.11	11.36
PM10 55 AAM/250 24-hr (163 counties)	3.52	7.12	11.36
PM10 55 AAM/150 24-hr (297 counties)	3.65	7.38	11.21
TSP 75 AGM/260 24-hr (282 counties)	3.62	7.31	11.15
TSP 150 24-hour (499 counties)	3.71	7.49	10.98

* A change in ambient TSP levels of 1 $\mu g/m^3$ (annual geometric mean) at the design value monitor is assumed. This is roughly equivalent to a change in ambient PM10 levels of 0.55 $\mu g/m^3$.

** Calculated at the average real wage over all affected counties for each standard, expressed in 1980 dollars and multiplied by 2,080 hours in order to approximate annual real earnings. Thus, these figures represent a change in average annual earnings. Similar calculations by Smith (8) suggest that the range of estimated benefits could be somewhat wider if these benefits were cumulated over observed individual earnings.

+ The coefficients used here reflect the relation between real wage rates and average exposure to ambient TSP. Thus, for these calculations, a 1 $\mu g/m^3$ change in ambient TSP at the design value monitor is translated into the equivalent change in average exposure using the ratio of the mean average exposure to mean design value exposure for each standard.

Benefits estimates for three alternative PM10 standards and one associated PM10 secondary standard, as well as for the current TSP primary and secondary standards, are presented in Tables 6-8 through 6-13. The standards are arranged in the following order:

- PM10 Primary Standard -- 70 AAM/250 24-hour expected value (Table 6-8).
- PM10 Secondary Standard -- 55 AAM (Table 6-9).
- PM10 Primary Standard -- 55 AAM/250 24-hour expected value (Table 6-10).
- PM10 Primary Standard -- 55 AAM/150 24-hour expected value (Table 6-11).
- TSP Primary Standard -- 75 AGM/260 24-hour second-high (Table 6-12).
- TSP Secondary Standard -- 150 24-hour second-high (Table 6-13).

In each case, a range of benefits, accompanied by a point estimate, is presented by air pollution control region and then aggregated over the entire nation. The stream of benefits is estimated from the attainment date (1989 for PM standards; 1987 for TSP standards) to 1995 and then discounted back to 1982, using a 10 percent social discount rate. The present discounted value of benefits in 1982 is expressed in millions of 1980 dollars.

Table 6-8 presents estimates of the benefits which will accrue when the most lax standard (PM10 70 AAM/250 24-hour expected value) is imposed. Total benefits estimates range from almost $10 billion to about $37 billion, with a point estimate of about $19.8 billion. About one-third of these benefits accrue to the South Pacific air pollution control region. Another one-third will accrue to the East North Central region, while the South Central region will receive about 12 percent of the total benefits. The remaining benefits are divided among the Middle Atlantic region (5 percent), the South Atlantic region (5 percent), the Midwest region (2 percent), the Mountain region (4 percent), and the North Pacific region (5

Table 6-8

ESTIMATED BENEFITS FOR: HEDONIC WAGE STUDIES

Benefits Occurring Between 1989 and 1995
Scenario: Type B PM10 - 70 AAM/250 24-hr.

Federal Administrative Region			Minimum	Point Estimate	Maximum
REGION	I	New England	0.0	0.0	0.0
REGION	II	N.Y.-N.J.	10.0	20.3	40.1
REGION	III	Middle Atlantic	436.3	881.4	1404.7
REGION	IV	South Atlantic	533.6	1077.9	1850.5
REGION	V	E.N. Central	2842.2	5741.1	14659.9
REGION	VI	South Central	1230.8	2486.1	4875.1
REGION	VII	Midwest	150.8	304.6	547.0
REGION	VIII	Mountain	382.8	773.3	1259.8
REGION	IX	South Pacific	3697.8	7469.3	10848.6
REGION	X	North Pacific	525.2	1060.8	1721.8
Total U.S.			9809.6	19814.9	37207.5

Discounted Present Value in Millions of 1980 Dollars in 1982
Using a 10 Percent Rate of Discount.

Annualized Benefits Between 1989 and 1995 Total U.S.	3926.6	7931.4	14893.3

Table 6-9

ESTIMATED BENEFITS FOR: HEDONIC WAGE STUDIES

Benefits Occurring Between 1989 and 1995
Scenario: Type B PM10 - 55 AAM

Federal Administrative Region			Minimum	Point Estimate	Maximum
REGION	I	New England	117.6	237.6	362.3
REGION	II	N.Y.-N.J.	121.9	246.3	541.1
REGION	III	Middle Atlantic	772.5	1560.3	2494.5
REGION	IV	South Atlantic	1183.2	2390.0	3889.2
REGION	V	E.N. Central	3994.1	8067.9	21219.5
REGION	VI	South Central	1918.2	3874.7	7294.4
REGION	VII	Midwest	426.2	860.8	1394.4
REGION	VIII	Mountain	772.5	1560.5	2287.7
REGION	IX	South Pacific	6557.1	13245.1	19474.0
REGION	X	North Pacific	670.7	1354.8	2281.6
Total U.S.			16534.1	33398.0	61238.5

Discounted Present Value in Millions of 1980 Dollars in 1982
Using a 10 Percent Rate of Discount.

	Minimum	Point Estimate	Maximum
Annualized Benefits Between 1989 and 1995 Total U.S.	6618.2	13368.4	24512.4

Table 6-10

ESTIMATED BENEFITS FOR: HEDONIC WAGE STUDIES

Benefits Occurring Between 1989 and 1995
Scenario: Type B PM10 - 55 AAM/250 24-hr.

Federal Administrative Region			Minimum	Point Estimate	Maximum
REGION	I	New England	117.6	237.6	362.3
REGION	II	N.Y.-N.J.	121.9	246.3	541.1
REGION	III	Middle Atlantic	772.5	1560.3	2494.5
REGION	IV	South Atlantic	1183.2	2390.0	3889.2
REGION	V	E.N. Central	4004.2	8088.2	21252.2
REGION	VI	South Central	1940.5	3919.7	7359.9
REGION	VII	Midwest	428.0	864.6	1399.8
REGION	VIII	Mountain	772.5	1560.5	2287.7
REGION	IX	South Pacific	6557.7	13246.1	19475.5
REGION	X	North Pacific	713.0	1440.3	2390.5
Total U.S.			16611.1	33553.6	61452.7

Discounted Present Value in Millions of 1980 Dollars in 1982
Using a 10 Percent Rate of Discount.

	Minimum	Point Estimate	Maximum
Annualized Benefits Between 1989 and 1995 Total U.S.	6649.1	13430.7	24598.1

Table 6-11

ESTIMATED BENEFITS FOR: HEDONIC WAGE STUDIES

Benefits Occurring Between 1989 and 1995
Scenario: Type B PM10 - 55 AAM/150 24-hr.

Federal Administrative Region			Minimum	Point Estimate	Maximum
REGION	I	New England	381.4	770.5	1233.9
REGION	II	N.Y.-N.J.	239.0	482.8	944.6
REGION	III	Middle Atlantic	1121.6	2265.5	3533.7
REGION	IV	South Atlantic	1509.4	3048.9	4825.4
REGION	V	E.N. Central	4545.9	9182.4	22940.6
REGION	VI	South Central	2251.1	4547.0	8350.8
REGION	VII	Midwest	597.4	1206.8	1898.4
REGION	VIII	Mountain	1159.4	2341.9	3244.4
REGION	IX	South Pacific	7239.5	14623.3	21613.7
REGION	X	North Pacific	1217.8	2459.9	4012.6
Total U.S.			20262.5	40929.1	72598.1

Discounted Present Value in Millions of 1980 Dollars in 1982
Using a 10 Percent Rate of Discount.

Annualized Benefits Between 1989 and 1995 Total U.S.	8110.6	16383.0	29059.3

Table 6-12

ESTIMATED BENEFITS FOR: HEDONIC WAGE STUDIES

Benefits Occurring Between 1987 and 1995
Scenario: Type B TSP - 75 AGM/260 24-hr.

Federal Administrative Region			Minimum	Point Estimate	Maximum
REGION	I	New England	369.7	746.7	1145.9
REGION	II	N.Y.-N.J.	303.9	613.8	1190.8
REGION	III	Middle Atlantic	1734.6	3503.7	5471.1
REGION	IV	South Atlantic	2245.3	4535.4	7156.6
REGION	V	E.N. Central	6931.2	14000.7	36390.0
REGION	VI	South Central	2999.6	6058.9	11855.5
REGION	VII	Midwest	1018.1	2056.5	3170.1
REGION	VIII	Mountain	1393.1	2814.0	3947.9
REGION	IX	South Pacific	10816.1	21848.0	32258.7
REGION	X	North Pacific	1354.6	2736.2	4551.2
Total U.S.			29166.1	58913.9	107137.7

Discounted Present Value in Millions of 1980 Dollars in 1982
Using a 10 Percent Rate of Discount.

Annualized Benefits Between 1987 and 1995 Total U.S.	8156.3	16475.3	29961.0

Table 6-13

ESTIMATED BENEFITS FOR: HEDONIC WAGE STUDIES

Benefits Occurring Between 1987 and 1995
Scenario: Type B TSP - 150 24-hr.

Federal Administrative Region			Minimum	Point Estimate	Maximum
REGION	I	New England	1105.3	2232.7	3475.5
REGION	II	N.Y.-N.J.	600.8	1213.5	2158.6
REGION	III	Middle Atlantic	2588.2	5228.0	7933.7
REGION	IV	South Atlantic	2807.4	5670.8	8832.1
REGION	V	E.N. Central	8262.0	16688.8	39904.8
REGION	VI	South Central	3536.0	7142.5	12477.3
REGION	VII	Midwest	1672.8	3379.0	5015.8
REGION	VIII	Mountain	1867.8	3772.9	5198.6
REGION	IX	South Pacific	11858.1	23952.7	35013.4
REGION	X	North Pacific	2077.2	4195.7	6829.8
Total U.S.			36375.5	73476.5	126839.6

Discounted Present Value in Millions of 1980 Dollars in 1982
Using a 10 Percent Rate of Discount.

	Minimum	Point Estimate	Maximum
Annualized Benefits Between 1987 and 1995 Total U.S.	10172.4	20547.7	35470.7

percent). The New York-New Jersey region accounts for a miniscule proportion of total national benefits (0.1 percent). The entire New England region is projected to be in compliance with the standard by 1989; thus, no benefits will accrue to this region as a result of the proposed standard.

The remaining tables indicate the benefits which are associated with increasingly stringent PM10 standards, as well as with the current TSP standard (which is more stringent than the strictest PM10 standard). As more stringent standards are applied, benefits increase accordingly. Point benefits estimates rise from $19.8 billion for the most lax PM primary standard to $73.5 billion under the current TSP secondary standard. The regional distribution of these benefits also varies as stricter standards are imposed. The proportion of benefits received by the East North Central, South Central, and South Pacific regions declines in favor of the remaining areas.

The very large benefits reported in Tables 6-8 through 6-13 are consistent with the small marginal effects observed in Table 6-7. While the responsiveness of each individual's real earnings to changes in the ambient levels of particulate matter is highly inelastic, the effect on real earnings of non-marginal changes in particulate matter concentrations cumulated over the entire labor force is considerable. For example, assume for the moment that a decrease in TSP levels by 1 $\mu g/m^3$ will cause the real wage rate to fall by $0.005 per hour, or by $10.40 per year. A very large decline in ambient levels of particulate matter -- say about 100 $\mu g/m^3$ -- could lead to a decline in real annual earnings of roughly $1,000. If a regional labor force of 10,000 individuals is assumed, then the total benefits at the attainment date alone will amount to some $10 million. This figure will, of course, grow as the labor force expands and as the effects of improved air quality are felt in the future.

The benefits estimates presented in Tables 6-8 through 6-13 are based on the assumption that all affected counties attain the standard in the implementation year and maintain it through 1995. As noted in Section 9, these are referred to as "B" scenarios. An alternative "A" scenario was also considered. In this scenario, the appropriate control strategies used to implement the standards may not bring all counties into attainment. This can occur because available control options are exhausted prior to standard attainment. In order to test the sensitivity of these benefits estimates to the attainment assumption, an alternate set of benefits estimates for the most lax PM10 standard (PM10 70 AAM/250 24-hour expected value) are presented in Table 6-14. The assumption that all counties comply with the standard is relaxed, i.e., residual nonattainment counties are not forced into attainment.

Table 6-14 should be compared with Table 6-8, where all counties are assumed to be in compliance with the same PM10 standard. As expected, the benefits estimates in Table 6-8 exceed those shown in Table 6-14.

Benefits estimates for the remaining particulate matter standards when the assumption of full compliance is relaxed are presented in Section 11.

CONCLUDING REMARKS

In this section, the results reported in two hedonic wage models [Rosen (4) and Smith (8)] are used to estimate the benefits which result from the attainment of three alternative primary standards for ambient levels of particulate matter. Point estimates of these benefits* range from $73.5 billion under the most stringent standard (the current TSP secondary standard) to about $19.8 billion for the most lax PM10 primary standard.

The marginal willingness-to-pay for air quality calculated from the data is quite reasonable, ranging from about $3.30 per year to over $11 per year. The very large benefits reported in Tables 6-8 through 6-13 reflect two factors:

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* Calculated as the discounted present value of a stream of benefits over a 7-year (9-year) horizon from an attainment date of 1989 (1987), expressed in 1980 dollars in 1982.

Table 6-14

ESTIMATED BENEFITS FOR: HEDONIC WAGE STUDIES

Benefits Occurring Between 1989 and 1995
Scenario: Type A PM10 - 70 AAM/250 24-hr.

Federal Administrative Region			Minimum	Point Estimate	Maximum
REGION	I	New England	0.0	0.0	0.0
REGION	II	N.Y.-N.J.	10.0	20.3	40.1
REGION	III	Middle Atlantic	422.0	852.3	1359.5
REGION	IV	South Atlantic	458.2	925.6	1553.4
REGION	V	E.N. Central	2267.8	4580.8	10830.1
REGION	VI	South Central	829.2	1675.0	3278.4
REGION	VII	Midwest	136.4	275.6	485.1
REGION	VIII	Mountain	364.8	736.9	1088.4
REGION	IX	South Pacific	2073.4	4188.1	6064.2
REGION	X	North Pacific	178.6	360.8	600.0
Total U.S.			6740.4	13615.3	25299.1

Discounted Present Value in Millions of 1980 Dollars in 1982
Using a 10 Percent Rate of Discount.

	Minimum	Point Estimate	Maximum
Annualized Benefits Between 1989 and 1995 Total U.S.	2698.0	5449.9	10126.7

- The effect of larger (i.e., non-marginal) improvements in air quality on real annual earnings.
- The extrapolation of individual willingness-to-pay over the entire labor force in the affected areas.

The benefits estimates cited above are derived from the application of the estimated relationship between real earnings and particulate matter levels reported in Smith (8) and Rosen (4) to a set of data obtained from other sources. The assumptions which are required in order to adapt these models and data to the procedure used in the benefits calculations may bias these calculations. Some cautionary remarks relating to possible sources of bias are summarized in Table 6-15.

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Table 6-15

SUMMARY OF BIASES IN BENEFITS CALCULATIONS: HEDONIC WAGE MODELS

Source of Bias	Direction of Bias
Hedonic wage models can only measure perceived health and welfare effects of improved air quality.	Benefits underestimated since unperceived health or welfare effects omitted.
Formula for benefits calculations based on procedure suggested by Freeman (28) that assumes marginal willingness to pay for air quality declines linearly from initial concentration of ambient PM to zero as PM is abated.	Cannot be predicted since the true supply price function for particulate matter is not observed.
TSP may be highly correlated with other site characteristics (including other pollutants) which are omitted from model. Est. coefficient on TSP may also include some of the effect of the omitted variables on real earnings.	Cannot be predicted in the absence of additional information on the omitted site characteristics and their correlation with TSP.
Benefits are extrapolated over entire labor force while the coefficients on TSP were estimated over specific subsamples of the labor force.* It is assumed that unemployed individuals place the same value on improved air quality as employed individuals.	To the extent that unemployed individuals place a lower (higher) value on air quality, benefits are overestimated (underestimated).
Certain occupations not included in calculation of county real wage rate.**	Unknown.

* Rosen (4) used data defined over employed males while Smith (8) estimated his model over all employed individuals (both male and female). There is some evidence that the response of real wage to changes in air quality does not vary by sex (8). However, neither study can measure willingness-to-pay for air quality among the unemployed, although Smith shows that this sample truncation does not seriously bias his coefficient estimates.

** These data exclude self-employed individuals, railroad, farm and domestic-service workers, and state and municipal employees.

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APPENDIX 6A

ESTIMATED RESULTS FROM HEDONIC WAGE MODELS

Coefficient estimates obtained by Rosen (4) and Smith (8) for their respective hedonic wage models are reproduced in this Appendix. Explanatory variables are briefly defined either within the tables presented below or within the text of Chapter 6; the reader is referred to the original studies for more detailed information regarding variable definitions and data sources.

Each study uses a semi-log functional form, regressing the log of the real wage rate or real annual earnings on some linear (or quadratic) function of the given explanatory variables. Table 6A-1 lists Rosen's results for individual- and job-specific characteristics when all site-specific attributes are included in the model. Table 6A-2 presents estimated coefficients for different combinations of a select group of these site-specific variables.*

Results reported by Smith for various specifications and data samples are listed in Table 6A-3.

* Rosen does not report the estimated coefficients obtained for individual- and job-specific variables for these specifications.

Table 6A-1

HEDONIC WAGE MODEL ESTIMATED BY ROSEN (4):
EFFECTS OF INDIVIDUAL-SPECIFIC CHARACTERISTICS

Explanatory Variable	Coefficient	Explanatory Variable	Coefficient
Race (white = 1)	0.150*	Operatives (yes = 1)	-0.263*
Head of Household (yes = 1)	0.160*	Laborer (yes = 1)	-0.270*
Married (yes = 1)	0.085*	Service (yes = 1)	-0.302*
Employed Full Time (yes = 1)	0.597*	Durable Goods (yes = 1)	-0.086*
Work 35 Hours/Week or Less (yes = 1)	-0.142*	Nondurables (yes = 1)	-0.105*
		Transport (yes = 1)	-0.074*
Self-Employed (yes = 1)	0.160*		
		Trade (yes = 1)	-0.165*
Government Employee (yes = 1)	0.125*		
		Other Service (yes = 1)	-0.186*
Never unemployed During the Year (yes = 1)	0.050		
		Public Administration (yes = 1)	-0.039
Unemployed Once During the Year (yes = 1)	-0.068		
		Education	0.048*
Veteran (yes = 1)	0.050*	Experience	0.015*
		$(\text{Experience})^2$	-0.0002*
Sales (yes = 1)	-0.198*		
		Log Weeks Worked	0.835*
Crafts (yes = 1)	-0.157*	R^2	0.337

* Coefficient has a t-statistic $\geq$ 2.

Table 6A-2

HEDONIC WAGE MODELS ESTIMATED BY ROSEN (4):
EFFECTS OF SITE-SPECIFIC CHARACTERISTICS

Explanatory Variables	Selected Regression Results: Estimated Coefficients								
TSP[a]	0.1060*	0.0681*	0.0897*	0.1500*	0.1100*	0.0692*	0.0602*	0.0553*	0.0921*
Inversion Days			0.0102*						
Water Pollution[a]			-0.0868						
Rainy Days[a] (No.)	0.1220*	0.2860*		0.0406	0.2250*	0.2300*	0.2720*	0.2950*	0.1740*
Sunny Days[a] (No.)			-0.9620*						
Temperature 90°F+[a] (Number)			0.2390*					NA	
Crime Rate[b]	0.1070	-0.0521	0.3160*	0.0270	-0.1700	0.1200	0.0614	0.0926	0.0492
Unemployment Rate		0.0457*			0.0539*		0.0149	0.0095	
Population Growth Rate				0.4790*	0.5330*				0.1950*
Population Density[b]						-0.1100*	-0.0998*	-0.1120*	-0.0899*
Population Level[c]						0.0966*	0.0899*	0.0967*	0.1040*
Live in Center City (yes = 1)	-0.0943*	-0.0908*	-0.0823*	-0.0910*	-0.0863*	-0.0960*	-0.0950*	-0.9950*	-0.0864*

[a] Coefficient scaled up by 100.

[b] Coefficient scaled up by 10,000.

* Coefficient has a t-statistic $\geq$ 2.

[c] Coefficient scaled up by 10,000,000.

NA = Not reported.

Table 6A-3

HEDONIC WAGE MODELS ESTIMATED BY SMITH (8)*

Explanatory Variable	Full Sample	Male	Female	Full Sample	Male	Female
Intercept	0.3411 (6.15)	0.6512 (8.98)	0.2021 (2.30)	0.4038 (6.93)	0.6443 (8.24)	0.2328 (2.53)
Education (no. of years)	0.0244 (3.88)	0.0308 (4.06)	0.0283 (2.60)	0.0234 (3.72)	0.0304 (4.02)	0.0254 (2.34)
$(\text{Education})^2$	0.0013 (5.05)	0.0010 (3.30)	0.0009 (2.13)	0.0013 (5.22)	0.0010 (3.30)	0.0011 (2.40)
Experience (age - education - 6)	0.0261 (32.44)	0.0309 (25.67)	0.0181 (15.94)	0.0263 (32.60)	0.0310 (25.78)	0.0182 (16.05)
$(\text{Experience})^{2(a)}$	-0.0455 (-26.62)	-0.0532 (-22.26)	-0.0301 (-11.91)	-0.0458 (-26.76)	-0.0535 (-22.41)	-0.0303 (-12.00)
Race (white = 1)	0.0560 (5.85)	0.1118 (8.66)	-0.0261 (-1.86)	0.0026 (0.13)	0.0734 (2.55)	-0.0329 (-1.10)
Sex (male = 1)	0.1663 (17.59)	-- --	-- --	0.1662 (17.58)	-- --	-- --
Veteran (yes = 1)	0.0749 (7.80)	0.0359 (3.60)	-- --	0.0748 (7.80)	0.0363 (3.65)	-- --
Unemployment Rate	-0.0138 (-5.59)	-0.0208 (-6.47)	-0.0051 (-1.38)	-0.0138 (-5.59)	-0.0206 (-6.40)	-0.0050 (-1.35)

(continued)

Table 6A-3 (Continued)

Explanatory Variable	Full Sample	Male	Female	Full Sample	Male	Female
Professional (yes = 1)	0.3471 (16.67)	0.0871 (2.79)	0.5650 (19.21)	0.3499 (16.80)	0.0903 (2.89)	0.5678 (19.32)
Manager	0.3740 (17.32)	0.1411 (4.45)	0.5228 (16.19)	0.3741 (17.33)	0.1426 (4.50)	0.5184 (16.05)
Sales	0.1491 (6.52)	-0.0019 (-0.05)	0.2010 (6.36)	0.1479 (6.47)	-0.0011 (-0.03)	0.1981 (6.27)
Clerical	0.2001 (10.15)	-0.1009 (-3.06)	0.3924 (15.45)	0.1994 (10.11)	-0.0975 (-2.96)	0.3911 (15.39)
Craftsman	0.2646 (12.26)	0.0171 (0.54)	0.4495 (8.76)	0.2625 (12.14)	0.0184 (0.58)	0.4432 (8.65)
Operative	0.0780 (3.62)	-0.1465 (-4.40)	0.2375 (8.18)	0.0741 (3.44)	-0.1496 (-4.50)	0.2244 (7.69)
Transport Equipment Operator	0.1225 (4.68)	-0.1180 (-3.35)	0.3694 (5.38)	0.1236 (4.72)	-0.1134 (-3.22)	0.3587 (5.22)
Labor (Non-farm)	0.0776 (3.25)	-0.1288 (-3.81)	0.2004 (3.99)	0.0767 (3.21)	-0.1293 (-3.82)	0.1872 (3.72)
Service	-0.0098 (-0.48)	-0.2533 (-7.77)	0.1702 (6.40)	-0.0100 (-0.49)	-0.2488 (-7.64)	0.1683 (6.33)

(continued)

Table 6A-3 (Continued)

Explanatory Variable	Full Sample	Male	Female	Full Sample	Male	Female
Injury Rate (BLS)	0.0114 (12.87)	0.0113 (10.65)	0.0117 (7.66)	0.0037 (1.47)	0.0122 (3.39)	0.0100 (2.36)
Cancer Exposure Index	0.0219 (2.76)	0.0283 (2.77)	0.0089 (0.72)	0.0231 (2.91)	0.0290 (2.84)	0.0100 (0.81)
TSP[(a)] ($\mu g/m^3$)	0.0871 (3.88)	0.1120 (3.85)	0.0675 (1.97)	0.0830 (3.70)	0.1084 (3.73)	0.0615 (1.80)
Household Head	0.1570 (18.08)	0.2318 (16.96)	0.0694 (6.02)	0.1641 (10.90)	0.3035 (11.69)	0.1106 (4.74)
Union	0.1832 (22.32)	0.1730 (17.09)	0.1857 (13.47)	0.1174 (7.01)	0.1035 (4.70)	0.0971 (3.25)
OJT · Experience	-0.0012 (-0.98)	-0.0022 (-1.60)	-0.0010 (-0.40)	-0.0017 (-1.38)	-0.0022 (-1.65)	-0.0021 (-0.82)
Crime Rate[(b)]	0.0943 (4.60)	0.0782 (2.94)	0.1007 (3.24)	0.0954 (4.66)	0.0797 (3.00)	0.1007 (3.25)
Sun (mean annual % of possible sunshine)	-0.0015 (-2.62)	-0.0021 (-2.79)	-0.0002 (-0.25)	-0.0014 (-2.47)	-0.0020 (-2.71)	-0.0001 (-0.13)
Dual Job-Holder	-0.0439 (-2.28)	-0.0408 (-1.71)	-0.0256 (-0.82)	-0.0426 (-2.21)	-0.0400 (-1.67)	-0.0228 (-0.73)

(continued)

Table 6A-3 (Continued)

Explanatory Variable	Full Sample	Male	Female	Full Sample	Male	Female
Workers' Knowledge of Cancer Hazard	4.3032 (6.01)	3.8789 (4.70)	5.7079 (4.22)	4.1518 (5.79)	3.8538 (4.66)	5.52 (4.07)
Injury Rate · Race				0.0070 (3.01)	0.0044 (1.49)	0.0012 (0.30)
Injury Rate · Head of Household				-0.0001 (-0.67)	-0.0084 (-3.24)	-0.0064 (-2.06)
Injury Rate · Union				0.0078 (4.53)	0.0073 (3.55)	0.0133 (3.76)
R^2	0.460	0.462	0.322	0.461	0.464	0.323
S	0.171	0.160	0.173	0.171	0.160	0.173
N	16,199	9,105	7,094	16,199	9,105	7,094

* t-statistics are given in parentheses.

[a] Coefficients are scaled up by 100.

[b] Coefficients are scaled up by 100,000.

SECTION 7

ECONOMIC BENEFITS OF REDUCED SOILING

SECTION 7

ECONOMIC BENEFITS OF REDUCED SOILING

INTRODUCTION

Overview

Soiling is the accumulation of particulate matter on the surface of an exposed material. This accumulation leads to changes in the quality of reflectance or transparency for materials such as painted surfaces and glass so that these materials "look dirty" [Beloin and Haynie (1)]. In addition, textiles can weaken and become faded with exposure to abrasive particles, sunlight, and other pollutants [Criteria Document (2)]. The discoloration of fabrics is also considered to be a soiling effect.

With the implementation of PM control programs, particle deposition will decrease, and households and firms may find that they can maintain desired levels of cleanliness with fewer resources (e.g., labor and materials) than previously required. As a consequence, less time and money would have to be devoted to the variety of cleaning tasks usually undertaken. Appropriate identification of these cost savings provides a measure of the benefits of reduced soiling.

Two major questions are addressed in this section:

- Can a consistent method be identified for calculating the economic benefits of increased cleanliness due to reduced ambient levels of particulate matter (PM)?
- What are the monetary benefits of reduced soiling, given the alternative PM10 (i.e., PM $\leq$ 10 μm) and TSP scenarios described in Section 9?

Much of this section focuses on the first of these questions. Over the past two decades, a number of studies have been completed which attempt to assess the costs associated with PM-related soiling damages. Our objective is to review the basic approaches utilized in these studies and to assess their suitability for the calculation of benefits. No new research is attempted as part of this effort. The evaluation of alternative studies is based on how well the studies conform to certain criteria which reflect desirable traits of a benefits analysis. These criteria include issues such as the methodological soundness of the study, consideration of all relevant variables, and the legitimacy of the empirical analysis.

Most of the studies which examine the benefits of reduced soiling focus on the household sector. While none of the household studies reviewed here completely satisfies all the criteria we identify as being relevant, a class of studies, the behavioral models, are sufficiently well-specified to warrant the calculation of benefits. In our judgment, the necessary analytical tools have been developed to the point where reasonable estimates of benefits from reduced soiling in the household sector can be derived.

While other sectors of the economy have received less emphasis, there have been several attempts to identify benefits from reduced soiling for specific industries in the manufacturing sector and for commercial operations associated with cleaning services. Of these studies, only the industry analysis, which examines the impact of changes in PM on production costs, provides a basis for the calculation of benefits. The results of the non-household sector analyses will also be reviewed in this section.

Scope of Analysis

Evaluation Criteria —

The principal objective of this study is to review the analyses which have attempted to measure the benefits of reduced soiling and to assess the soundness of the estimates. To provide a consistent method for evaluating the alternative studies, several criteria, which are important for the successful completion of any benefits analysis, are identified. These criteria help identify where individual analyses may be particularly weak or strong, and are useful in comparing the plausibility of benefit estimates generated from different studies. Thus, the criteria form a set of conditions by which the range of studies to be considered can be narrowed.

Five general criteria are used to evaluate critically the various studies which examine the benefits from reduced soiling. These criteria include:

- Theoretical basis for the study -- Is the study's technical approach consistent with the requirements for calculation of economic benefits as prescribed in theoretical welfare economics?

- Consideration of relevant variables -- Has the study accounted for all relevant variables (e.g., economic, social, pollution, climate) that may influence cleaning decisions?

- Quality of input data -- Does the study use data consistent with the variables of the theoretical model and are these data accurately measured?

- Legitimacy of the empirical analysis -- Were the empirical techniques used in the study appropriate and properly applied, and were the results correctly interpreted?

- Transferability of models and/or results -- Can the study be used as a basis for estimating benefits of reduced soiling given the implementation of various PM control strategies?

Although these criteria are fairly stringent, they represent the types of conditions that must be satisfied if defensible, quantitative estimates of benefits are to be derived. In the next major subsection, these criteria are used to assess strengths and weaknesses of the various studies.

Coverage of Studies —

An important issue that arises in the development of benefit estimates is the degree of coverage associated with the alternative studies. As mentioned above, the literature concerned with the benefits of reduced soiling has focused primarily on household responses. Clearly, many other sectors of the economy may also be affected. Commercial establishments, industrial plants, and government facilities are all likely to experience less soiling as a result of reduced levels of ambient PM. In this section, benefits are calculated only for the household sector and two industries in the manufacturing sector -- SIC 344 (Fabricated Structural Metal Products) and SIC 354 (Metalworking Machinery). Although a limited number of studies have been designed and undertaken for other sectors of the economy, to date these efforts have not found a statistically significant association between PM and cleaning-related cost data. Consequently, no benefits are calculated for these other sectors. If these other sectors of the economy do derive benefits from reduced soiling, then the estimates of benefits developed in this section should be considered conservative estimates of total benefits from reduced soiling.

Pollutant Measures —

The development of physical and economic damage functions for use in benefits analysis requires that specific assumptions be made about measures of air quality. At least three questions arise in the course of designing a study, estimating damage relationships, and calculating benefits. These questions are:

- What is (are) the most appropriate pollution variable(s) for the model?
- What variable(s) is (are) actually used by the study?
- Will the non-marginal improvements in ambient air quality that are implied by pollution controls change the composition of PM and consequently alter physical effects and/or behavioral responses?

These questions involve issues of both a physical and statistical nature. The issues related to the physical dimension include particle size, deposition rates, and composition. These three attributes of PM help define the soiling potential of the pollutant. The statistical issues include choice of averaging time and definitions of spatial and temporal indices.

The questions posed above are directly addressed in a later subsection. Here, we note that particle size plays a prominent role in the analysis since alternative standards are stated in terms of TSP and PM10. However, with either type of standard, data are available for both particle size divisions.* Consequently, benefit calculations for studies which rely on TSP as a measure of air pollution can be conveniently carried out in the units of the original study, even when the standard is stated in terms of PM10. In this case, the estimates represent the benefits of the TSP reduction that results from PM10 controls.

Summary of Results

Based on the review in this section, national benefits for reduced soiling are estimated for the household sector and a part of the manufacturing sector. Benefit estimates for the household sector are developed from three studies: Cummings et al. (5), Watson and Jaksch (6), and Mathtech (7). Benefit estimates for the manufacturing sector are derived from a single study, Mathtech (8).

Tables 7-1 and 7-2 summarize the benefit estimates of reduced soiling for six alternative ambient air quality standards examined in the report. Table 7-1 reports the benefits associated with three PM10 primary standards and the current TSP primary standard. Table 7-2 shows the benefits associated with two alternative secondary standards. The values in Table 7-2 represent the total benefits of moving from pre-control to post-control

* These data are generated under the assumption that the base year relationship of ambient PM10 to TSP is fixed at 0.55 (4).

Table 7-1

SUMMARY OF ESTIMATED BENEFITS FOR ALTERNATIVE PRIMARY STANDARDS*

Standard	Sector	Benefits		
		Minimum	Point	Maximum
PM10 70/250	Household	0.73	3.14	13.85
	Manufacturing	0.73	1.30	9.45
PM10 55/250	Household	1.30	5.68	25.72
	Manufacturing	1.32	2.41	20.51
PM10 55/150	Household	1.62	7.16	32.76
	Manufacturing	1.48	2.86	26.24
TSP 75/260	Household	2.41	10.74	49.90
	Manufacturing	2.43	4.80	40.75

* Discounted present values in 1982 in billions of 1980 dollars.

Table 7-2

SUMMARY OF ESTIMATED BENEFITS FOR ALTERNATIVE SECONDARY STANDARDS*

Standard	Sector	Benefits		
		Minimum	Point	Maximum
PM10 55	Household	1.29	5.64	25.53
	Manufacturing	1.32	2.41	20.25
TSP 150	Household	3.15	14.21	66.36
	Manufacturing	2.81	5.81	55.13

* Discounted present values in 1982 in billions of 1980 dollars.

concentration levels. To ascertain the incremental benefits of the secondary standards, given that the primary standards are attained, it is necessary to net out the benefits associated with the relevant primary standard. In Table 7-2, the 55 PM10 secondary standard should be compared with the 70/250 PM10 primary standard, while the 150 TSP secondary standard should be compared with the 75/260 TSP primary standard.

The benefit numbers reported here represent total U.S. benefits. The estimates are reported as discounted present values in 1982 in billions of 1980 dollars. The real discount rate is assumed to be equal to 10 percent, and the estimates are developed over a horizon beginning at the start of 1987 (TSP) or 1989 (PM10) and continuing through to the end of 1995. For the estimates reported here, it is assumed that all counties are in attainment with the relevant standard over the entire horizon. In the body of the report, estimates are also derived when not all counties are assumed to be in compliance throughout the time period. This latter scenario is possible if available means of controlling emissions do not allow for a control level sufficient for standard attainment throughout the time period.*

Total benefits from reduced soiling in the household sector and a subset of the manufacturing sector are estimated to range from $1.46 to $23.30 billion for the most lenient primary standard (70/250 PM10), and from $4.84 to $90.65 billion for the most stringent primary standard (TSP 75/260). An important point to note is that even though the primary standards are typically associated only with health effects, substantial welfare benefits are also derived with attainment of the primary standards.

For the two ranges cited above, the resultant point estimate of the benefits associated with moving to a secondary standard, given that the corresponding primary standard is attained, are $3.61 and $4.48 billion for PM10 and TSP, respectively.

* This latter scenario is equivalent to the Scenario A described in Section 9.

Although the numbers reported in Table 7-1 and 7-2 are large in magnitude, on a per-household or per-plant basis, they appear intuitively reasonable. For example, the per-household benefit of a 1 $\mu g/m^3$ reduction in TSP is estimated to range from about \$0.40 to \$11.50 per year. Similar calculations can be developed for the manufacturing sector. The benefit associated with a 1 $\mu g/m^3$ reduction in TSP for SIC 354 is estimated to be approximately \$260 per plant per year. This amounts to about 0.019 percent of the total production cost for an average plant in the industry. For SIC 344, these numbers are \$610 per plant per year, which is about 0.031 percent of the total cost for an average plant in the industry.

The estimates reported in Tables 7-1 and 7-2 are subject to certain qualifications. The major factors that limit the generality of the results reported above include:

- All possible benefit categories (sectors) are not included in the analysis. (Leads to an underestimate of benefits.)
- The benefit estimates are sensitive to a variety of model and extrapolation biases. These are discussed in detail in the report. (Benefits affected in an unknown direction.)
- The air quality data used in the benefits analysis relies primarily on design value monitor readings. This implies that a correction factor is required in some of the studies to better characterize population and facility exposure. (Impacts benefits in an unknown manner.)
- The physical effects and behavioral responses observed for a given composition of PM do not change when pollution controls are applied. (Affects benefits in an unknown direction.)
- Air quality is assumed to improve only in the subset of counties included in the air quality data file. (Leads to an underestimate of benefits.)

These limitations, as well as others that are specific to particular studies, are discussed in the body of the report. While it is difficult to assess whether the various limitations lead to an under- or overestimate of benefits, there has been a conscious effort to adopt a more conservative assumption when warranted. As used here, a conservative assumption is one that leads to benefit estimates that are lower in magnitude relative to estimates associated with a competing assumption. On the basis of our review and critique of studies, our evaluation of biases, and the development of ranges of benefits to reflect uncertainty, we believe the point estimates reported in this section represent conservative estimates of the total benefits from reduced soiling.

MODELS OF BENEFITS FROM REDUCED SOILING

Introduction

The object of an analytically proper analysis of benefits from reduced soiling is to provide an estimate of the income-equivalent change in welfare for a specified improvement in some measure of PM. This subsection describes the general approaches that have been used to estimate this value and assesses the success individual studies have had in obtaining benefits estimates.

As noted in the Criteria Document (2), there are several relationships that must be formalized if an acceptable benefits analysis is to be conducted. These relationships start with the transformation function between emissions and ambient concentrations, and conclude with the specification of the relationship between economic damage and the benefits associated with reduced soiling. In this study, the factors that translate emissions into ambient concentrations are taken as given. Therefore, the driving force of the analysis is the expected change in ambient concentration levels associated with the implementation of alternative air quality standards.

Figure 7-1 shows the linkages between ambient levels of PM and the realization of economic benefits. As ambient levels of PM decrease, it is expected that there will be reductions in observed physical effects (e.g., dirtiness of windows), which ultimately translate into reduced effort required to maintain a given level of cleanliness. In turn, this reduced effort means a cost savings to households and firms. Under certain

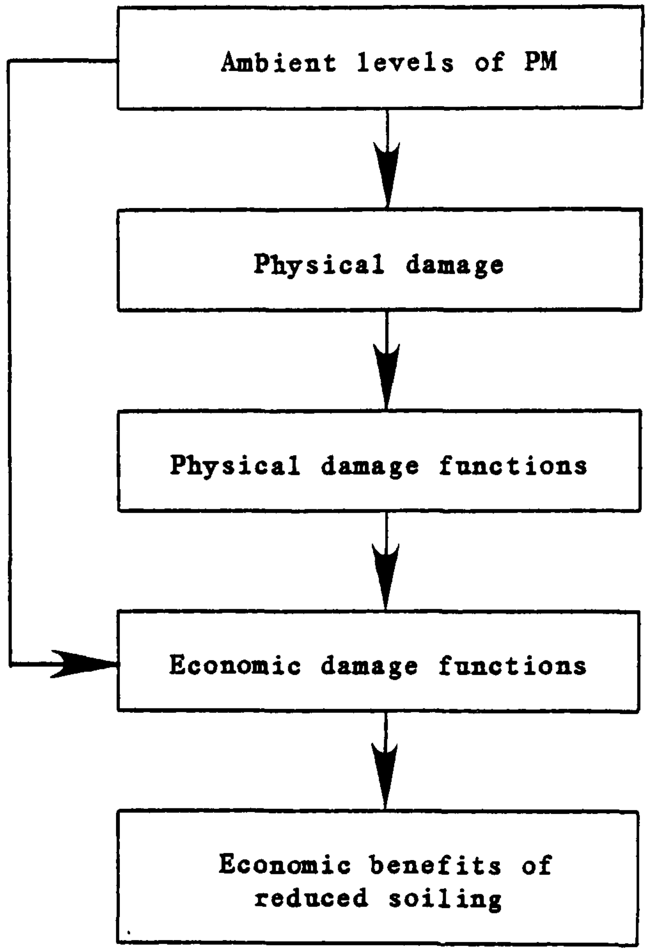

Figure 7-1. Processes leading to economic benefits

conditions, the cost savings can be interpreted as the amount that households or firms are willing to pay to have the improved air quality rather than the air quality that existed prior to the PM reduction. In this case, the cost savings are an estimate of economic benefits.

This subsection examines the data and methods that have been used in completing the steps identified in Figure 7-1. The discussion focuses initially on the air quality measures that are most relevant for an analysis of soiling damage. Following this, we begin our evaluation of the various models which have been developed to measure economic benefits of reduced soiling. In general, there are two distinct classes of models:

the physical damage function models and the behavioral models. Each of these model types is evaluated in terms of the criteria outlined earlier, and individual studies within each class are identified. A detailed review of selected individual studies is also presented to identify those studies best suited for the calculation of benefits.

PM Measures and Soiling

As mentioned earlier, several questions relating to appropriate measures of air quality arise in the course of designing and completing an air quality benefits analysis. The questions reflect concern about both physical and statistical characteristics of pollutants.

With respect to the physical characteristics, the Staff Paper for PM (3) asserts that the soiling of textiles and vertical surfaces is generally associated with fine particle deposition. On the other hand, horizontal surfaces are considered to be more susceptible to deposition of large particles. However, it is also pointed out in Reference (3) that the direct relation between increased soiling potential and increased particle size may be mitigated by lighter color of coarse mode particles, smaller transport distances, and lower penetration rates of larger particles to indoor surfaces. Because of these offsetting factors, no concensus has been reached on the most appropriate particle size division to use in an analysis of horizontal surface soiling.

With respect to the statistical issues, it is a commonly held belief that long-term measures of PM concentrations such as annual means are most representative of soiling damage. However, this appears to be based only on qualitative evidence. The real test of this issue involves an analysis of behavioral responses to long-term as well as episodic PM measures. In fact, one of the studies examined later in this section finds that a measure of the 24-hour second highest reading is statistically the most robust measure in the economic function that is estimated.

The other statistical issues that arise in defining air pollution measures involve definitions of indices. Since air quality varies in time and space, it is necessary to construct a summary index that provides a single-valued representation of air quality in a given area. The procedures used to develop such indices in the present study are described in Section 9.

The above discussion indicates that no concensus has been reached on the most appropriate pollution measure to use in a soiling study. Despite this conclusion, it is the case that physical characteristics of the pollutant will affect the degree of physical impact and the extent of economic response. Although qualitative observations link ambient particle loadings and soiling, attempts to provide quantitative measures of association have not directly addressed the issues of particle size, deposition rates, and composition. In fact, the studies reviewed in this section all use a statistical measure of ambient TSP. At issue then is what biases may be introduced by using TSP in a statistical relationship when other measures of particulate matter may be the factors that are appropriate for the model posited.

This is a classic errors-in-variables problem. To determine what biases may arise in such a situation, it is necessary to know the underlying relationship between TSP and the "true" measure. If, for example, TSP is always exactly two times greater than the true measure, then the coefficient of TSP will be biased in inverse proportion to the factor. In this case, the coefficient will be one-half the value of the coefficient in the true model. However, it is not necessarily the case that benefits will be understated as well. In fact, benefits will be unaffected if the proposed model is linear and all observations exhibit the same proportional relationship. With nonlinear models and/or more complicated relationships between TSP and the true variable, it becomes more difficult to define precisely the extent of bias and the ultimate impact on benefits.

Even if the estimation phase of the analysis is complicated using the appropriate measure of pollution, problems can still arise once air quality is allowed to change. With non-marginal changes in ambient PM, one would expect the composition of PM to differ after the change. If this occurs and behavioral responses are sensitive to the composition, then benefits estiated from a model with observations for the pre-change composition may be misstated. Since the composition of PM is not considered in the studies reviewed here, the implicit assumption is that any changes in pollutant composition will not alter the marginal responses.

Physical Damage Functions

To date, many of the studies that have attempted to identify the benefits of reduced soiling have relied on an analysis plan like that portrayed in Figure 7-1. When each of the five processes shown in the figure is a direct part of the analysis, the methodology for determining benefits is typically classified as the damage function approach. In this approach, the first step involves a determination of exposure for specific materials at places with different levels of ambient particulate concentrations. Exposure to PM is then related to an objective physical measure appropriate to the material under review. For example, with glass, the measure might be the loss of transparency. The relationship between exposure and physical impact provides an estimate of the physical damage function.

The foremost example of estimating physical damage functions for soiling effects is Beloin and Haynie (1). In their study, damage functions are developed from data collected for six types of building materials: painted cedar siding, brick, limestone, concrete block, asphalt shingles, and window glass. Data on PM concentrations and soiling effects were collected over time for a cross-section of five controlled sites around Birmingham, Alabama.

In the best specifications, they found that soiling, as measured by reduced reflectance, could be stated as a function of PM levels and duration of exposure. Physical damage functions for acrylic emulsion paint and white asphalt shingles are provided in Reference (1), and these specifications are reproduced in Table 7-3. Note that the constant term in the left-hand side variable of each regression equation represents an initial reflectance value prior to exposure. Thus, the regressions can be interpreted as showing the expected change in reflectance for a given level of, and exposure to, TSP.

Naturally, in the development of physical damage functions, care must be taken to control for factors other than PM that may contribute to a change in the physical status of the material. In soiling studies, climatological parameters would seem to be especially relevant explanatory factors. However, because the sites in Beloin and Haynie (1) are located near one another, the expectation is that the microclimate is similar from site to site. Nevertheless, Beloin and Haynie monitored temperature,

Table 7-3

REGRESSION RESULTS FROM BELOIN AND HAYNIE

Material	Equation*
Acrylic Emulsion Paint	$\ln(92.5-y) = -0.311 + 0.345 \ln(TSP) + 0.612 \ln(t)$
White Asphalt Shingles	$\ln(41.8-y) = -4.881 + 1.007 \ln(TSP) + 0.595 \ln(t)$

y = Measured percent reflectance.

TSP = Annual geometric mean of total suspended particulates ($\mu g/m^3$).

t = Exposure time in months.

* The R^2 for the equations is 0.896 and 0.608, respectively. The number of observations is 640 and 40, respectively.

Source: Table IV, Beloin and Haynie (1).

rainfall, dew duration, and relative humidity to test for significant differences in these data across sites. Their statistical analysis indicated that the only difference among the variables was a higher level of humidity at one of the sites. In turn, the higher humidity led to an increase in mildew at the site. Despite this finding, none of the recommended specifications in Reference (1) includes a measure of humidity. Consequently, as noted in Reference (1), the increased mildew formation is confounded with soiling by TSP.

Given relationships like those shown in Table 7-3, the next step in the damage function approach links the PM-related physical impacts to a measure of economic damage. Ideally, an assessment of economic damage would be able to account for the alternative preventative or ameliorative actions that may be taken by individuals in response to perceived physical damage. In terms of household soiling, responses would likely take the form of more frequent and/or more intense cleaning. However, preventative measures such as filtered air conditioners may also be employed. As noted in Reference (1), if an accurate assessment of soiling damage is to be developed, it is important to consider how such decisions are made by individuals. Unfortunately, the mechanism of choice is usually not considered directly in the physical damage function studies.

In addition to information on the types of responses that may be observed, an analysis of soiling benefits via the damage function approach must also consider the range of tasks and materials affected as well as the unit value of the added cleaning costs.* Not only are these information requirements burdensome, but the process of developing benefits estimates with the physical damage function models implies some strong underlying assumptions and limitations. For example, Waddell [(10), p. 24] mentions that extrapolation of controlled study results to the real world ignores the possibility of nonconstant marginal products, nonlinearities, and problems of aggregation and substitution. Freeman (11) stresses the lack

* See Geomet (9) for an example of what is required to develop an inventory of materials in a sulfates materials damage study. A similar effort would also be necessary for a PM study.

of consideration of consumer adjustments, and the difficulty in assessing the inventory of exposed area for the multitude of surfaces that may become soiled.

Evaluation of Physical Damage Function Studies —

Many of these limitations can be related to the evaluation criteria listed earlier.

- Theoretical basis -- Physical damage function studies typically do not consider the adjustment opportunities that are available to economic decision-makers. Estimates of cost-savings reflect only changes in expenditures required to return a material to a "clean" state and do not provide accurate estimates of willingness to pay.

- Consideration of relevant variables — Oftentimes physical damage functions are determined from data collected in a controlled laboratory setting. These conditions may not adequately reflect the conditions in the real world. In particular, climatic variables may act synergistically with PM to increase the potential soiling effect.

- Quality of input data — Most data used in these analyses are micro in nature and are well-suited to the analysis of specific materials. However, data must be collected for many very specific tasks and/or materials. Furthermore, estimates of exposed surface areas are usually very rudimentary.

- Legitimacy of the empirical analysis -- The estimation of physical and economic damage functions typically involves simple linear regression techniques. Little *a priori* evidence is available on the most appropriate specification for alternative damage functions. Misspecification of the damage functions can be especially important to a benefits analysis when dealing with non-marginal changes in pollution levels.

- Transferability of models -- Individual physical damage functions can be adapted easily to a variety of alternative settings. The major difficulties that arise are: the definition of damage functions for each affected material; and the estimation of the exposed inventory of each material.

The negative tone of the above evaluation is reinforced by discussions in both the Criteria Document (2) and the Staff Paper (3). The Criteria Document reports damage functions for the Beloin and Haynie (1) study mentioned earlier, and offers an example of how repainting frequencies can be obtained from their model for different PM levels. However, the conclusion reached in the Criteria Document is that:

> The least reliable of the "significant" damage functions are those for soiling from particulate matter. The poorly understood deposition rates and poorly characterized chemical and physical properties make general application of the functions difficult, if not impossible.

The Criteria Document goes on to say:

> The limitations of these and other physical damage functions hinder accurate estimates of total material damage and soiling. Coupled with these limitations is the lack of material exposure estimates. These problems presently preclude complete and accurate estimates of the costs of damage based on a physical damage function approach.

In our judgment, we agree with the assessment that currently available data limit the usefulness of calculating national benefits from reduced soiling when physical damage functions are required.* However, as will be seen in the discussion below, we also believe that recent research based on behavioral models is sufficiently well-defined to warrant the calculation of benefits.

Although the data requirements of the physical damage function approach may preclude its widespread use in estimating national benefits of reduced soiling, the research embodied in the development of specific damage functions is very important. In general, there is no a priori economic reason for believing that a particular air quality variable affects specific economic choices. As a consequence, the behavioral

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* Lodge et al. (12) reach similar conclusions in their review of non-health effects of PM.

approach (described below) for estimating the benefits of reduced soiling must rely on information like that available in physical damage studies to narrow the range of alternative specifications to be considered.

Behavioral Models of Reduced Soiling Benefits

An alternative approach to the physical damage function studies is the analysis of benefits based on behavioral models. Referring back to Figure 7-1, it can be seen that a direct link between "ambient levels of PM" and "economic damage functions" is also indicated. In this case, the steps dealing with physical soiling effects are bypassed. The rationale behind this way of characterizing the benefits process is that damages from soiling may eventually be manifested in economic choices. As soiling damage effects are perceived by households and firms, they respond by purchasing goods that help to maintain a desired level of cleanliness. In deciding how much of their available budget to allocate to cleaning-type goods, they indicate their willingness to pay for units of cleanliness. Thus, willingness to pay for PM reductions may be observed in the economic choices made by households and firms.

Within the class of behavioral models, there are several approaches which can be distinguished. These include:

- Property value studies.
- Surveys of frequency and expenditures for cleaning activities.
- Economic demand and/or supply models.

Property Value Studies —

The hypothesis underlying the property value studies is that structures in areas with relatively better air quality will have higher values than similar structures in relatively dirty areas. In effect, much like a swimming pool or an enclosed garage adds to the value of a home, good air quality is also a positive attribute. Many studies have been completed which employ this approach, yet the Criteria Document (2) and Staff Paper (3) provide only a limited discussion of the technique. The principal concerns identified in these reports are that:

- It is difficult to identify separately the benefits of reduced soiling versus other benefits such as health and aesthetics.
- It is difficult to extrapolate results from a single city (study) to obtain national estimates of benefits.

Because of the first concern, no additional discussion of property value studies is provided in this section. However, further discussion can be found in Section 5.

Surveys of Cleaning Expenditures —

This type of study has been the most popular for measuring reduced soiling benefits.* Among the studies included in this group are: Michelson and Tourin (13), Ridker (14), Narayan and Lancaster (15), Booz, Allen and Hamilton (16), Liu and Yu (17), Brookshire et al. (18), and Cummings et al. (5). In many cases, the survey studies use some variant of a paired cities approach to generate data for their analysis. For example, Michelson and Tourin (13) compare the frequencies of household maintenance and cleaning activities in Steubenville, Ohio (a dirty area) with the frequencies of these activities in Uniontown, Pennsylvania (a clean area). Under the assumption that all other factors that may influence the responses of households to PM levels are similar in the two cities, a relationship between ambient PM and frequency of cleaning activities is estimated. Then, for a given cost per activity, it is possible to predict how changes in PM impact on frequency and ultimately on total expenditures

* As noted in the Criteria Document (2), the physical damage function approach has been the most widely used method in materials damage studies. These studies usually involve metal corrosion or material deterioration. For the soiling effects considered in this section, we believe it is more appropriate to view the survey approaches as part of the behavioral class of models since no quantitative measure of physical effect is typically included in these analyses.

for cleaning tasks. In the Michelson and Tourin study cited above, the analysis indicated that annual per capita costs for cleaning activities were $84 (1967 dollars) higher in Steubenville than in Uniontown. Since the difference in annual mean particulate concentration was approximately 115 $\mu g/m^3$, the value per unit change in ambient PM is estimated to be $0.73 per capita.

The Narayan and Lancaster (15) study also used a paired cities approach. In this study, the costs of maintaining a house were compared for two cities in Australia. This study, as well as Michelson and Tourin (13) are faulted in the Criteria Document (2) for potentially suspect data. In particular, it is noted that attitudes of the respondents to questions directly connected to air pollution may have provided an incentive for the respondents to misstate purposefully their true, historical responses. This type of bias is, of course, possible in any survey situation where historical data are collected and respondents have a desire to influence the study results. A procedure for ameliorating this bias is to collect data on observed activities or to use data collected for reasons not directly related to air pollution. One of the economic studies reviewed below uses this procedure.

Another example of the paired cities approach is Brookshire et al. (18). In this experiment, a more sophisticated survey instrument was designed to test for the presence of various biases. In addition, the questionnaire was better suited to obtain estimates of household willingness to pay than earlier studies which focused only on task frequency and fixed unit costs. Unfortunately, there are several problems with using this "contingent valuation" method in a soiling effects study. The major drawback is that each respondent implicitly makes a choice of what a given change in PM level means in terms of actual soiling effects. In effect, there is the presumption that individuals can translate changes in PM into the effect on average household cleanliness and in turn calculate the added cost if PM levels were to increase. Since different individuals may have different implicit "physical damage functions", it is difficult to isolate the value of a unit change in cleanliness.

In the Brookshire _et al_. (18) study, the difficulty raised above was overcome by assessing how changes in visual range affected individuals' willingness to pay. Studies have shown that scientific measures of visual range and people's perception of visual range correlate well. However, in valuing changes in visual range, it is difficult to relate changes in willingness to pay directly to changes in PM levels alone, since multiple pollutants contribute to visibility impairment. Furthermore, since the "bids" elicited in the survey did not distinguish among types of effects, it is difficult to ascribe a part of total benefits to reduced soiling damages. For this reason, Brookshire _et al_. (18) is not considered further in this section.

In one of the first studies of the economic costs of air pollution, Ridker (14) developed a series of analysis plans to test for the significance of TSP in the cleaning decisions of commercial and industrial firms as well as households. The analyses relied on cross-sectional data collected from both interurban and intraurban areas. In the analysis of interurban data, Ridker looked at economic data from three types of cleaning services. These included receipts from laundry and cleaning establishments, the costs of cleaning office and apartment building interiors, and the performance frequency of contract cleaning firms. In these studies, the hypothesis tested was that cleaning costs per unit time increased with higher levels of suspended particulates.

For each of these studies, the null hypothesis of no difference could not be rejected. This conclusion was based on a scan of scatter diagrams and the calculation of rank correlation coefficients. In order to control for factors that may confound the identification of a soiling effect, Ridker partitioned his data to hold constant such factors as climate, per capita income and interurban price (wage) differentials. Even with these factors held constant, no clear association between cleaning costs and suspended particulates was found.

With the intraurban data, Ridker examined supermarket sales of cleaning supplies and maintenance procedures of firms with branches in different parts of a city. Again, no significant association was evident from the data.

Ridker offers several possible explanations for the lack of association between TSP and cleaning cost data. These include: 1) the levels of air pollution experienced may not be severe enough to lead to an identifiable response; 2) measurement error may be an important factor; 3) the averaging times and statistical aggregation of the pollution data may not be appropriate; and 4) there may be confounding variables that prevent the identification of an independent effect of air pollution. Each of these factors is plausible and could indeed lead to the results reported by Ridker.

Despite the finding of no association between cleaning costs and levels of suspended particulates, Ridker's proposed analysis plans were very innovative and undoubtedly had a significant impact on the design of soiling cost studies for the following decade. This is especially evident with respect to the study of soiling costs for households. In Reference (14), Ridker summarizes a soiling study conducted in Philadelphia, which is similar in design to a study later conducted by Booz, Allen and Hamilton (16). In both instances, a survey instrument was designed to elicit information on cleaning expenditures, frequencies, and time durations for a variety of household cleaning activities. The specific attributes of this type of household study are considered in more detail below.

The remaining three studies in the group of survey studies have an element in common. Both Liu and Yu (17) and Cummings <u>et al</u>. (5) use data collected by Booz, Allen and Hamilton (BAH) (16) to estimate the relationship between frequency and ambient PM levels. While the BAH study is perhaps the best known of the many soiling studies, the data set suffers from many inconsistencies. This becomes especially evident in Cummings <u>et al</u>. (5), where a great deal of effort goes into constructing a sound data base from the original BAH information.

Although the type of data collected by BAH is similar to that collected for the paired city approaches described earlier, the data are not drawn from a sample within paired cities. Rather, the data come from four "pollution zones" in the greater Philadelphia area. Consequently, the analysis of the data must control for demographic characteristics that vary across pollution zones and may influence household response to alternative PM levels.

Given the average frequency and aggregate expenditure per task in each pollution zone, the analysis of soiling damages in References (16), (17), and (5) is carried out much in the same fashion as described for the paired city studies. There are, however, some changes of substance that serve to alter the flavor of the analysis. For example, Liu and Yu (17) use Monte Carlo techniques to generate a larger data sample, while Cummings et al. (5) incorporate the opportunity cost of labor into the analysis. Still, the basic method of calculating soiling damages remains fundamentally the same in all the survey studies. For this reason, we have chosen to review in detail only one of the studies in this group. The study chosen is Cummings et al. (5). In our judgment, this study is a good example of the type of analysis that can be carried out with task frequency and expenditure data and it offers some novel additions which are not present in the other survey studies. In addition, since the Cummings study has only recently been completed, a summary of this work is not currently available in the most recent Criteria Document. Thus, a thorough review of the Cummings analysis provides new information on the status of household soiling benefits models. Following the discussion of the Cummings study, the survey-type studies will be compared against the evaluation criteria set forth earlier.

Cummings et al. (5) -- There are essentially four major divisions in the Cummings report. These can be summarized as:

- Background literature review of previous soiling damage function studies.

- A careful analysis of the Booz, Allen and Hamilton (BAH) data set with corrections made as appropriate.

- An analysis of a modified version of the BAH soiling damage study.

- A contingent valuation study of soiling damage.

The discussion here focuses on the third of these topics. As an aside, we note that the Cummings report asserts that the fourth topic, the contingent valuation method, is an infeasible approach for estimating particulate-related household soiling damages.

The objective of the Cummings soiling study is to determine the economic damages associated with soiling effects. This is accomplished by estimating expressions that predict how out-of-pocket expenditures and labor time are likely to vary as ambient PM changes. As noted earlier, the data for the analysis are drawn from the BAH study (16), although an extensive data-cleaning effort was undertaken to eliminate inconsistencies in the BAH data base.

The BAH survey was completed in 1970, and involved 1,800 households in the greater Philadelphia area. For analysis purposes, the region was divided into four pollution zones representing concentration levels of:

- Less than 75 $\mu g/m^3$.

- 75 to 100 $\mu g/m^3$.

- 101 to 125 $\mu g/m^3$.

- Greater than 125 $\mu g/m^3$.

Although BAH collected data for 27 specific maintenance and cleaning activities, the Cummings study focuses on the 11 particulate-sensitive tasks in the BAH study. Table 7-4 summarizes these activities. Note that plausible cleaning tasks such as dusting and vacuuming are not included since they were not part of the BAH survey. This could lead to an underestimate of total benefits.

Table 7-4

CLEANING ACTIVITIES IN CUMMINGS' ANALYSIS

Inside Activities	
1.	Replace air-conditioner filter
2.	Wash floor surfaces
3.	Wax floor surfaces
4.	Wash windows (inside)
5.	Clean venetian blinds/shades
Outside Activities	
1.	Clean/repair screens
2.	Wash windows (outside)
3.	Clean/repair storm windows
4.	Clean outdoor furniture
5.	Maintain driveways, walks
6.	Clean gutters

Source: Cummings *et al*. (5), Table 8.

For each task, data were collected on the number of households that performed the task (both households where all tasks were performed by the residents as well as households that hired outside help), as well as the mean annual frequency. These data were summarized by pollution zone. In order to estimate damages, the following cost equations were assumed:

- Cleaning costs incurred by those households that hire outside help (HIRE)

$$C_1 = a_1 \cdot N_1 \cdot F_1 \quad (7.1)$$

where a_1 is the unit cost of having the task performed; N_1 is the number of HIRE households; and F_1 is the mean annual frequency for the task in HIRE households.

- Cleaning costs incurred by do-it-yourself households (DIY)

$$C_2 = N_2 \cdot [V \cdot T + a_2 \cdot F_2] \quad (7.2)$$

where N_2 is the number of DIY households performing the task; V is the imputed labor cost per unit of time in DIY households; T is household time spent performing the task; a_2 is the unit out-of-pocket cost of the task in a DIY home; and F_2 is the mean annual frequency for DIY households. The inclusion of a measure for the value of labor is a unique feature that distinguishes the Cummings study from other benefits analyses of reduced soiling.

Total costs are determined as the sum of C_1 and C_2. Note that since data for N_i and F_i are summarized by pollution zone, total cost estimates are derived for each zone. In addition, since F_i and possibly V and T will vary with pollution levels, changes in PM will impact total costs. This provides the way in which soiling damages can be assessed for changes in PM.

Given data for N_i and F_i, the next step in the Cummings analysis is to determine values for a_1, a_2, V, and T. The unit cost parameters a_1 and a_2 are determined from the BAH study. Unfortunately, these costs are provided for only five of the 11 particulate-sensitive tasks included in the Cummings analysis. Consequently, costs must be attributed to the other tasks on the basis of similarity with tasks that do have cost data. This is likely to be an important source of measurement error in the analysis. However, the direction of bias is unknown.

In order to develop quantitative estimates for T and V, a contingent valuation survey was developed for the Cummings study. This questionnaire was used to obtain measures of the opportunity cost of household labor as well as the time spent in cleaning operations. The sample respondents were drawn from each of the four pollution zones in the Philadelphia area, with each zone represented by 30 respondents.

With data identified for T and V by pollution zone, the next step involved relating F, T, and V to PM. Since the various pollution zones include households with diverse incomes, this variable should also be controlled for in the regression analysis. Cummings _et al_. posit the following relationships:

$$F = \alpha_0 + \alpha_1 P + \alpha_2 Y \qquad (7.3)$$

$$T = \beta_0 + \beta_1 P + \beta_2 Y \qquad (7.4)$$

$$V = \lambda_0 + \lambda_1 P + \lambda_2 Y \tag{7.5}$$

where F, T, and V are as defined previously; P is ambient annual average TSP concentrations; and Y is household income. When these regressions were run, approximately half the specifications failed to reject the null hypothesis that all the estimated coefficients were zero. Three of the frequency equations and one time equation had negative signs reported for the pollution coefficient. Thus, estimates of the task-specific F and T functions are only moderately successful. Furthermore, the assumption of linearity and the consideration of only two independent variables may be too restrictive. Alternative specifications may yield very different results.

Because pollution levels have decreased from the time of the original BAH study Cummings et al. were forced to make some adjustments in the data prior to the determination of total costs by pollution zone. Given these adjustments, total costs for 10 of the 11 particulate-sensitive tasks were computed using Equations (7.1) and (7.2).* Table 7-5 summarizes the findings.

Table 7-5

TOTAL PER-HOUSEHOLD SOILING COSTS BY POLLUTION ZONE
(1980 dollars)

	Pollution Zone (μg/m^3)			
	40	81	102	123
HIRE Households	$1,531	$2,887	$2,558	$2,683
DIY Households	763	905	1,067	1,386

Source: Cummings et al. (5), Tables 18 and 19.

* The task of maintaining driveways was not considered.

With the per-household costs identified, economic damage estimates by pollution zone can be derived by multiplying cost/task by the number of households performing the task in a given zone. Note that the term "damage" as used here is really appropriate only in the case where cleaning costs are zero when particulate levels are zero. By labelling all cleaning costs as economic damages, the implicit assumption is that all cleaning occurs only because of pollution. A better way to describe economic damages is the added costs incurred because of increases in ambient PM levels. Thus, it is the valuation of changes in cleaning activities that is most relevant.

The economic damages derived in the Cummings study are on the order of $300 million for each of the pollution zones. Although these numbers are much larger than those found in BAH, this can be traced to the value of time which is included in Cummings analysis.

The data on per-household cleaning costs by pollution zone can be related to the corresponding zone pollution level to identify an economic damage function. Given the Cummings data, a linear specification was estimated as:

$$D = 251.43 + 6.63P \tag{7.6}$$

where D represents damages in dollars per household per year, and P is the annual average level of TSP. The linear damage function implies that marginal damages are $6.63 (1980 dollars) per household per year for each microgram change in TSP levels.* This is the information that would be required to make extrapolations to national benefits estimates. Benefits in county i in a given year would be estimated as:

$$B_i = 6.63 \cdot \Delta P_i \cdot H_i \tag{7.7}$$

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* Recall that the marginal value in the Michelson and Tourin (12) study was estimated to be $0.73 in 1967 dollars, or about $2.50 in 1980 dollars.

where B_i is benefits in the i^{th} county; ΔP is the change in TSP levels in the county, and H is the number of households in the county.*

It should be pointed out that the linear damage function in Equation (7.6) is simplistic and as Cummings et al. note, "must be viewed as little more than of expository value." While it is true that a nonlinear damage function would be expected, we also feel that data problems (e.g., unit cost data), and the several statistically insignificant task frequency regressions add to the difficulty in accepting the damage function in Equation (7.6). While the derived marginal damage estimate is not strong enough to stand alone as an indicator of economic damage, it does seem reasonable to use Equation (7.7) as part of the information base available for developing estimates of reduced soiling benefits. In fact, given the framework of the Cummings study, it may be possible to ascertain whether this estimate should be an upper- or lower-bound to an estimate derived from another study. This may help to define a reasonable range for benefits from reduced soiling.

We have described in some detail the major elements of the Cummings soiling study. In the report, an effort is also made to clarify some confusing issues in the BAH work and they close with several recommendations for the future course of frequency studies. First, they believe that it is more appropriate to define aggregate tasks rather than specific tasks. Second, time spent per unit time in an activity is perhaps a more relevant variable than frequency in the estimation of the relationship between activities and pollution levels. Cummings et al. believe that a mixed approach based on the contingent valuation and soiling frequency techniques would best be able to obtain the data that would incorporate these considerations.

Evaluation of Survey Studies -- Several of the direct survey studies have been discussed briefly, and one study reviewed in some detail. This

* This is also the equation used by SRI (19) to estimate benefits from reduced soiling.

class of studies is now examined to see how well they conform to the evaluation criteria.

- Theoretical basis -- With the exception of Brookshire et al. (18), the survey studies do not collect data sufficient to obtain the appropriate measure of economic benefits. In general, frequency of cleaning data and/or total expenditure data do not allow one to observe the variations in demand or supply that are required for the proper estimation of benefits. Consideration of variation in total expenditures alone will yield underestimates of "true" benefits. See Courant and Porter (20) for additional treatment of this issue.

- Consideration of relevant variables -- Ideally, the paired city approaches are designed so that other potentially significant explanatory variables in the frequency/PM regressions would be constant across study areas. In those studies which use the BAH data, however, factors such as income should be included in the frequency specifications, since this attribute may influence cleaning decisions and will differ across the pollution zones being analyzed.

- Quality of input data -- Based on comments in the Criteria Document (2), this would appear to be of major concern. The principal problem with the paired cities studies is that the frequency data may contain inherent biases. Furthermore, the BAH data set also suffers from inconsistencies in many of the variables. Thus, since these studies typically collect only expenditure data, unit cost (price) information is not directly available from the surveys. As a consequence, there is likely to be measurement error in the cost data collected from outside sources.

- Legitimacy of the empirical analysis -- The frequency functions that are estimated are usually simple linear specifications. As with the physical damage functions, there is little information available on the most appropriate functional form for these economic damage functions. In the Cummings study, it was noted that the null hypothesis that all parameters in an equation were zero could not be rejected in almost half the frequency equations. Despite this statistical problem, cost estimates were still derived for each task. More work is required to give a better theoretical basis to the estimated equations.

- Transferability of models -- As evidenced by Equations (7.6) and (7.7), it is relatively easy to identify the information needed to develop national estimates of benefits. It is perhaps wise to reiterate that the extrapolation relies on a marginal damage estimate developed from data from a single city. As a consequence, an analysis of benefits from the Cummings results must assume that individuals in other areas will react to soiling damage in a fashion similar to that of Philadelphians.

Overall, the evaluation for the survey studies is not much more optimistic than that presented for physical damage function studies. Indeed, the negative comments quoted earlier from the Criteria Document (2) likely were meant for these studies as well. There are, however, some distinct advantages to this approach that should be recognized. First, the approach focuses on people's responses to air pollution rather than an imputed value of expenditures for returning to some hypothetical clean state. Second, the data requirements would seem to be less burdensome. With the survey studies, it is no longer necessary to develop estimates of surface area exposed or to identify damage functions for a variety of objects.

In summary, it does not appear that any one of the survey studies could stand alone and provide a defensible estimate of benefits. However, when used as part of a general information base, marginal damages derived from the survey studies may be valuable components of a more general benefits analysis.

Economic Demand and/or Supply Models —

The final class of behavioral models includes those studies that rely on economic demand or supply functions to estimate benefits. We are aware of three models that can be classified in this manner.

- Watson and Jaksch (16).
- Mathtech's model of household expenditures (7).
- Mathtech's model of cost and production relationships in the manufacturing sector (8).

Since these models differ markedly, it is not possible to provide a blanket description of how benefits estimates are developed. However, the underlying rationale on how economic benefits should be defined is the same in each case. Basically, the value to society of a reduction in ambient PM levels should be measured by the aggregate amount members of society would be willing to pay to be in a preferred state (i.e., cleaner air) as opposed to a less preferred state (i.e., dirtier air). This willingness-to-pay measure includes two components. The first of these is the level of reduced out-of-pocket cost that would accompany lowered PM levels. This is the measure captured by the survey methods described in the previous subsection. The second component allows for the possibility that the cost savings may reduce prices and thus stimulate an increase in the quantity of goods and services demanded. Since the increased quantity demanded is direcly attributable to improved air quality, the willingness-to-pay measure should include this component as part of the benefit estimate as well.

Measures of willingness to pay can be ascertained from knowledge of demand and supply curves. In Figure 7-2, the demand curve is given by D and the supply (marginal cost) curve is designated as MC. If these curves are thought of as the households' demand and supply of cleanliness, then a decrease in PM levels may imply that each unit of cleanliness could be produced at lower unit cost than before. That is, less resources would be required to attain the level of cleanliness that occurred before the air quality improvement. In this case, the supply curve would shift down to MC'. The shaded area ABCO represents the change in economic surplus, or the amount consumers would be willing to pay to have the improved air quality. Thus, it is the correct measure of economic benefits.

The same general principles for measuring benefits are used in each of the three studies reviewed in this subsection. As noted above, however, because the underlying models that produce the relevant demand and supply functions do differ, each of the studies will be evaluated individually.

Watson and Jaksch (6) — The study by Watson and Jaksch (WJ) is somewhat unique in that it could easily be classified as a physical damage function study, a survey study, or an economic demand/supply model study.

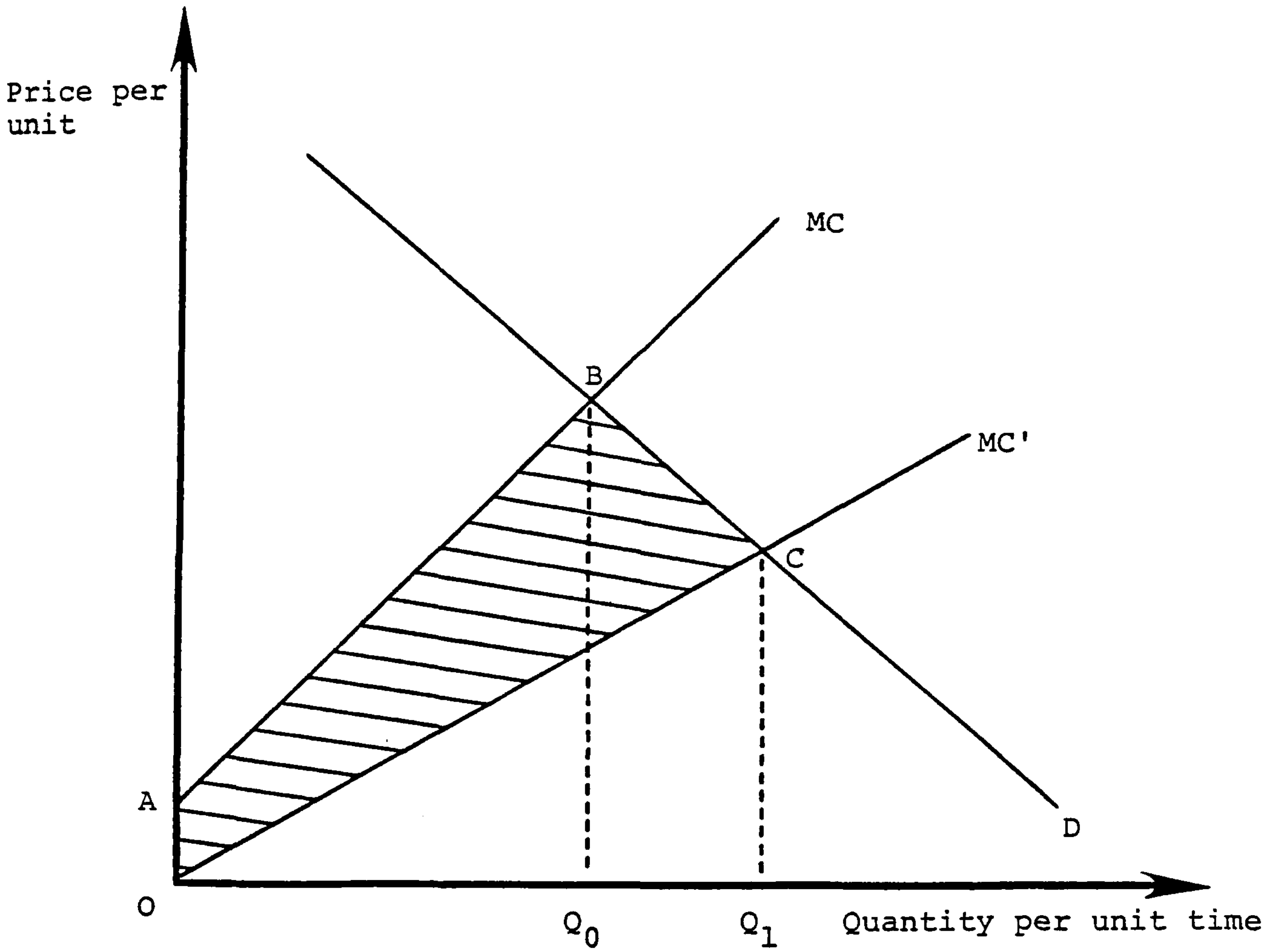

Figure 7-2. Example of economic surplus

Elements of each type of study appear in the WJ analysis. However, since a major distinguishing feature of their analysis is the use of demand and supply curves (rather than cleaning frequency or expenditure), it seems most appropriate to include the study in this subsection.

The data set used in the WJ analysis is taken from the Booz, Allen and Hamilton (16) study discussed earlier. Since the WJ study was completed prior to the Cummings et al. (5) study, WJ did not have the benefit of the data-cleaning effort undertaken by Cummings et al. Thus, some caution is warranted since the BAH data in its original form does contain inconsistencies.

The WJ reliance on the BAH data set did provide for an easy characterization of the demand curve. In the original BAH analysis, it was determined that expenditure remained constant across different levels of PM for a variety of tasks. If alternative levels of PM reflect different states of household cleanliness, then this implies that expenditures remain constant across units of cleanliness. In this case, the demand curve for cleanliness would have constant unitary negative elasticity (i.e., a rectangular hyperbola). This makes specification of the demand function straightforward.

The assumption of unit elasticity is an important part of the WJ analysis. However, several recent commenters have questioned whether this assumption can legitimately be drawn from the BAH data. Cummings et al. note that many of the tasks that were identified as not being sensitive to particulate matter involved materials damage-type impacts. In addition, Cummings et al. point out that activites identified in BAH as having low unit values (and thus providing only small additions to total cost) are actually performed many times over the course of a year so that total annual costs may be high. Rowe (21) also provides an example which shows how increasing pollution coupled with a constant cleaning frequency can imply expenditure increases. In this case, outlays on cleaning are positively related to pollution levels and an inelastic demand curve would be implied.

These comments indicate that the constant elasticity demand curve used by WJ may impose constraints on the model that are not supported by available data. If the demand curve is suspected to be inelastic, then as Rowe (21) points out, it is likely that the WJ benefits estimates are overestimates for improvements in air quality on this point.

Similar problems are possible with the WJ supply (marginal cost) curve. The assumption made in the WJ case 1 (with which we deal exclusively) is that the marginal cost schedule rotates in proportion to the ratio of the final and base pollution levels.

$$MC = a \cdot (P_f/P_b)^{\alpha} \cdot Q \qquad (7.8)$$

where MC is the marginal cost per unit of cleanliness; P_f is the final level of pollution; P_b is the base level of pollution; Q is units of cleanliness; and a and α are parameters to be determined.

Several comments can be made about Equation (7.8). First, WJ argue that the MC curve will be increasing in cleanliness because cleaning costs and the opportunity cost of labor will increase as pollution increases. This would imply that "a" is positive. However, it is not explicitly recognized by WJ that there may be economies of scale related to certain cleaning activities (e.g., buying larger boxes of soap) which could alter the slope of the MC curve. Indeed, even the linear representation of the MC schedule may be at odds with *a priori* expectations. One would instead expect the MC curve to increase at an increasing rate.*

In addition to these observations on the shape of the MC curve, it is also pertinent to examine the impact of pollution changes on MC. As written, Equation (7.8) implies a multiplicative rotation. The factor that determines the degree of shift, α, is derived from several damage function studies. In particular, the painted cedar siding equation from Beloin and

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* WJ recognize this point during their discussion of the MC curve, but treat it as linear for ease of presentation.

Haynie (1) yields estimates of α of 0.56 and 1.0. The study by Esmen (22) was used to obtain an upper-bound estimate for α of 2.0. These factors were used to rotate the MC schedules for each of the eight cleaning and maintenance tasks examined by WJ. These tasks represent a subset of the BAH activities. They include: painting indoor and outdoor walls, washing indoor and outdoor windows, washing indoor walls, wallpapering, painting trim, and cleaning venetian blinds. As with the Cummings study, plausible cleaning activities such as dusting and vacuuming are not considered because they were not included in the BAH survey. As the earlier discussion of physical damage functions noted, the absence of damage functions for a variety of materials makes it difficult to measure benefits. WJ rely on functions developed for only two materials to derive their estimates of α. Thus, the shape and rotation of the MC schedule may also contribute to a bias in the benefits estimates. With so little empirical evidence available for α, it is difficult to assess whether the bias will lead to an overestimate or an underestimate of benefits.

Figure 7-3 shows the WJ demand and supply curves for cleanliness. The shaded area OBF represents the consumers loss from an increase in pollution to P_2 from P_1. Given the assumptions on the demand elasticity, original outlays OAB equal final outlays OEF. The important point to observe is that economic benefits are generated even though no additional outlays are made. Thus, the WJ analysis picks up a component of benefits that could not be observed in the survey methods reviewed earlier.

With specific algebraic expressions for the demand and supply curves, it is possible to solve for the value of economic surplus as a function of the base and final pollution levels, the value of α, and total expenditures, by pollution zone. The derived expression is:

$$-\Delta CW_{ij} = \alpha \ln\left[\frac{P_{2j}}{P_{ij}}\right] \cdot X_{ij} \qquad (7.9)$$

where ΔCW_{ij} is the change in welfare for task i in pollution zone j.

P_{2j} is the final level of pollution in zone j.

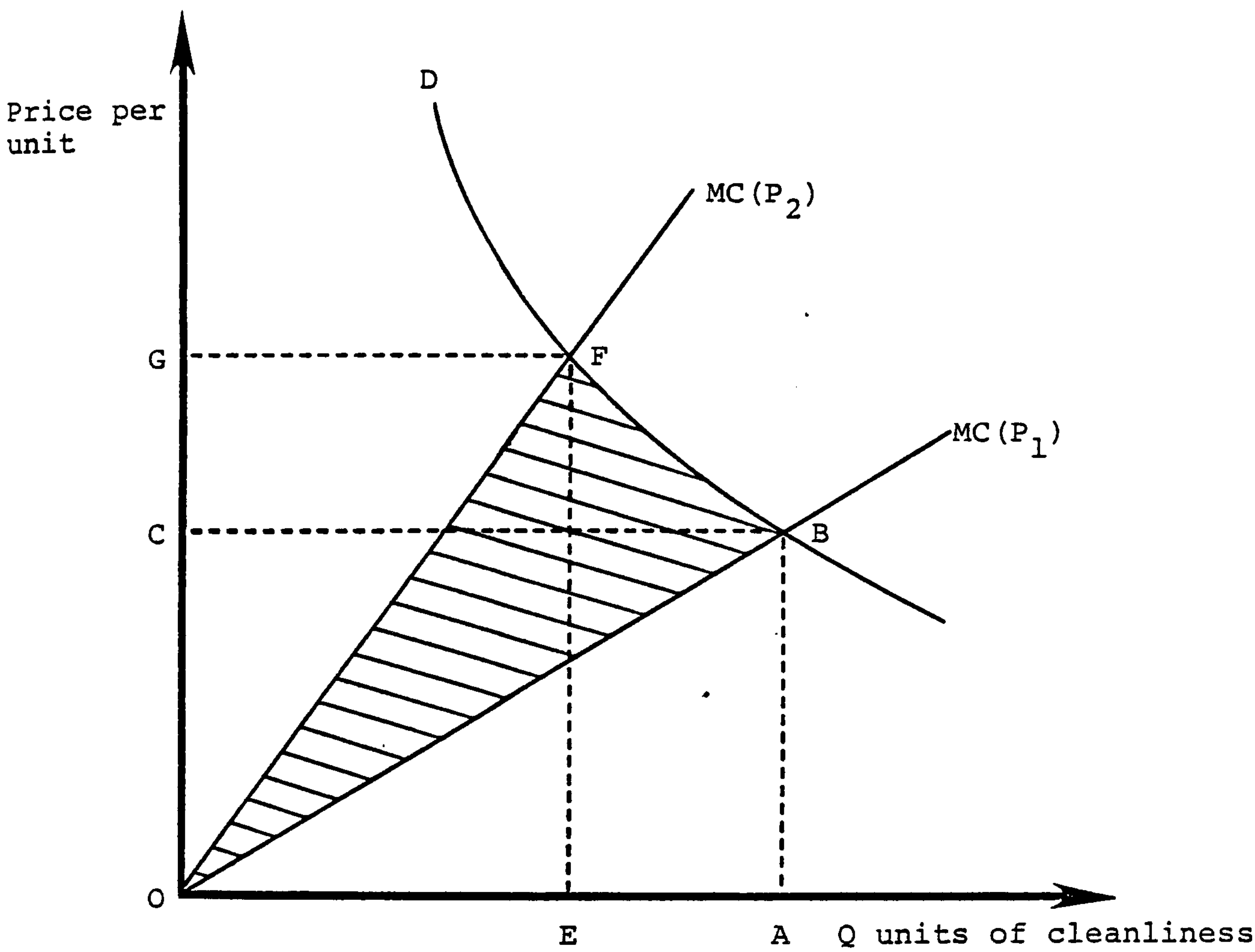

Figure 7-3. Demand and supply curves in the WJ analysis

P_{1j} is the initial level of pollution in zone j.

α is the factor estimated from the damage function studies. It's value is 0.56, 1.0, or 2.0.

X_{ij} is the outlay for task i in zone j.

Equation (7.9) is the equation needed to estimate national benefits. Because of the required extrapolations, we believe that separate calculations by task and pollution zones are not warranted. Thus, in any benefits calculations, pollution values would be county averages and total expenditures by county would be developed by multiplying the implied <u>per-household</u> total cost (expenditures) in Philadelphia times the number of households in each specific county. The necessary data on household expenditures in Philadelphia is developed in WJ.

In terms of the evaluation criteria, the following comments can be made:

- <u>Theoretical basis</u> -- The manner in which economic benefits are calculated is appropriate for the single activity considered in the study. Questions do arise on the validity of the assumptions implicit in the shapes of the demand and supply curves.

- <u>Consideration of relevant variables</u> -- The assumptions underlying the demand curves imply that specific household classes do not have to be identified when estimating benefits. This occurs because of the constant unit elasticity.

- <u>Quality of input data</u> -- With the BAH data set used to estimate benefits, there is some concern on the reliability of the data. As noted earlier, Cummings <u>et al</u>. (5) devote some time to cleaning up inconsistencies in the BAH data. If possible, it would be appropriate to use the corrected BAH data in any calculations performed with Equation (7.9). This may be limited by differences in tasks between the studies.

- <u>Legitimacy of the empirical analysis</u> -- Despite the fact that WJ use demand and supply curves, no new estimation is performed in this study. The crucial aspect is whether the assumptions made by WJ in specifying the demand and supply relations are reasonable. The only numerical calculations involve evaluation of Equation (7.9).

- Transferability of Model -- This can be readily accomplished using Equation (7.9). Data on expenditures are available from WJ. As with Cummings et al., extrapolations to national benefits estimates rely on data collected for only one city.

In general, this evaluation coincides with comments made in the Criteria Document (2) and the Staff Paper (3). Both of these reports are cautious in accepting the estimated benefits of WJ because of the limited number of soiling functions which are available to represent a variety of cleaning tasks. In addition, we reiterate comments made earlier that additional empirical work is required to validate the assumptions underlying the forms of the demand and supply schedules. Though there are areas where improvements are possible, the WJ study is an innovative approach to estimating soiling benefits. While it is difficult to rank WJ in relation to Cummings et al. (5), it seems prudent to view WJ as providing additional information for defining the probable range of soiling benefits.

Mathtech Household Model (7) -- In the WJ analysis, household decisions are examined for only one of the many commodities (services) that influence economic behavior, the production and consumption of cleanliness. In addition to the services provided by cleanliness, individuals also require shelter, nutrition, clothing, and other services to maintain a desired quality of life. In the Mathtech household model (MTH), the interdependency of economic decisions is recognized, and systems of demand equations are estimated. That is, household demands for a variety of services are considered simultaneously. This permits consideration of some of the adjustment opportunities available to individuals as air quality improves.

The basic structure of the MTH model involves a two-stage decision process. Figure 7-4 outlines the major components of this process. The initial decision facing the household is the allocation of a fixed budget among the many market goods that may be purchased. To determine these

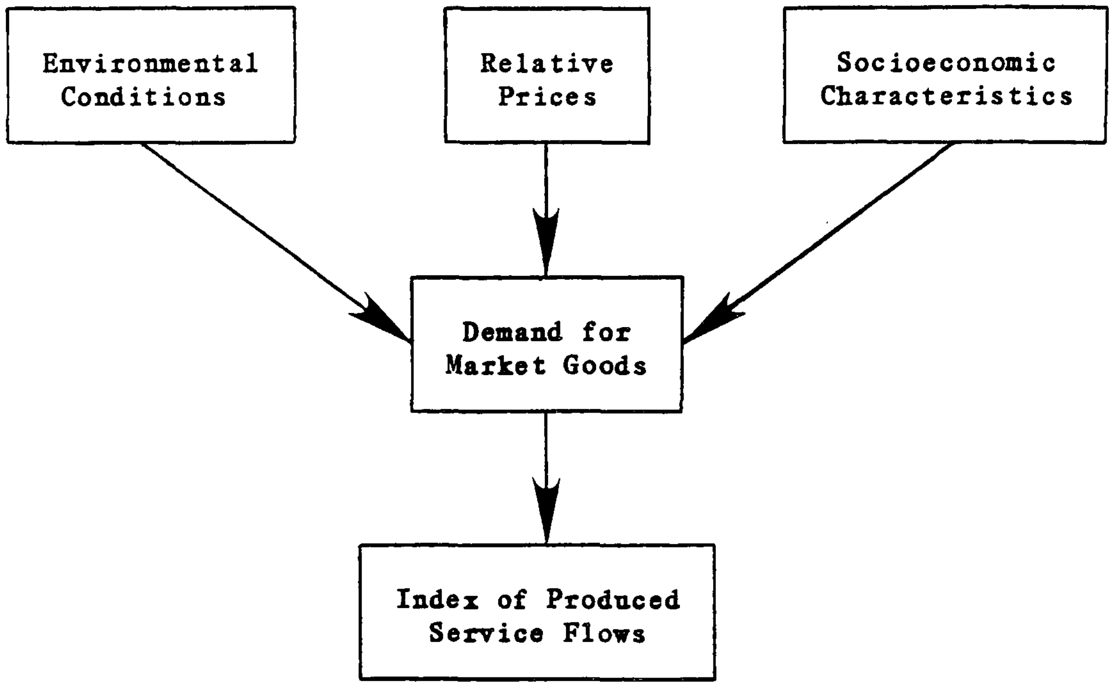

Figure 7-4. Household decision process

"demands", various factors that are beyond the control of the household must be taken into account. In particular, the relative prices of the goods, income, and various demographic factors all help shape the pattern of household demand. Furthermore, environmental variables such as ambient concentrations may also influence the demand for certain goods. For example, the demand for detergents or other cleaning products may be sensitive to the level of PM concentrations.

Once the allocation decision for market goods has been made, conditional on the factors mentioned above, the decision-making role of the household is essentially complete. However, there is a natural extension to the process that is important for benefits analysis. This additional step represents the second stage mentioned above.

The idea behind the extension is that items like detergents are not demanded for their own sake, but rather for the services they provide.

Thus, it may be instructive to view the demand for detergents as a derived demand based on a more fundamental consumer demand for cleanliness. Viewed in this way, the allocation decision made by households with respect to demands for detergents and other cleaning items is consistent with the attainment of a particular level of cleanliness. Furthermore, the role of air pollution is clear. Air pollution increases the cost of cleanliness by increasing the quantity of detergents and other cleaning items required to obtain a unit of cleanliness. Conversely, a reduction in ambient air pollution can lead to a reduction in the unit cost of cleanliness.

In terms of Figure 7-4, this discussion implies that a link must be established between an index of produced services such as cleanliness and market goods. This link is formalized in the MTH model with the adoption of "separability" assumptions that permit the many market goods that may be purchased to be grouped naturally into a series of categories. These categories represent the various "produced" goods described above. The implication of the separability assumption is that the various items that contribute to the production of nutrition (e.g., meats, dairy products, fruits, vegetables, etc.) can be analyzed independently of the market goods which contribute to the production of cleanliness (e.g., laundry products, floor wax, etc.). Thus, the separability assumption narrows the dimensionality of the system estimation effort. Furthermore, the assumption plays an important part in the definition of quantitative indices for the unobserved produced services.

The model described above is structured to deal directly with household adjustments to air quality changes. The focus is on the value households place on certain activities rather than specific pollution-induced damage. A physical damage function between pollution and objects that may be damaged is not included in the analysis. Instead, pollution enters the model as a proxy for damage. It is not imperative that the type or extent of physical damage be identified explicitly. The knowledge that is required is the value household decision makers attach to activities or services that may be sensitive to air quality changes.

A factor that can limit the usefulness of this approach is that price and quantity data are not available for the various produced services. Thus, it is not possible to estimate directly demand relations for these non-market services. Fortunately, the assumptions that permit the grouping of market goods are also instrumental in establishing consistent price and quantity indices for the produced services. As would be expected, these indices, for any particular service, depend on the relative prices (demands) for the market goods in the service category. This is an important observation, since it implies that the aggregate indices may be indirectly affected by levels of air quality through the demand equations of the market goods.

Thus, with information on price and quantity indices for the produced services, it is possible to estimate a system of demand equations for these services. Furthermore, since air quality indirectly affects the indices, it is possible to ascertain the impact of changes in air quality on the service indices. This permits the identification of economic benefits associated with the postulated air quality change.

The data used to estimate the MTH model are drawn primarily from the 1972-73 Consumer Expenditure Survey (23). Expenditure data for over 100 current consumption items are available for 24 large Standard Metropolitan Statistical Areas (SMSA). Price data for items defined in Reference (23) are taken primarily from Reference (24). The SMSAs included in the MTH analysis are shown in Table 7-6, while the goods eventually included in the analysis are shown in Table 7-7. Note that the 20 basic goods are grouped into seven commodity aggregates. This is in accord with the structure of the decision process outlined above.

The goods included in the MTH analysis account for approximately 40 percent of total annual consumption expenditures. Two categories of commodity demand that may be affected by changes in PM levels are omitted from the analysis. Data and conceptual problems did not permit the analysis of recreational (leisure) services nor services generated by property. Since labor-leisure tradeoffs and location adjustments are two

Table 7-6

SMSAs INCLUDED IN MTH ANALYSIS

REGION I: NORTHEAST	REGION III: SOUTH
1. Boston	1. Atlanta
2. Buffalo	2. Baltimore
3. New York City	3. Dallas
4. Philadelphia	4. Houston
5. Pittsburgh	5. Washington, D.C.
REGION II: NORTH CENTRAL	**REGION IV: WEST**
1. Chicago	1. Denver
2. Cincinnati	2. Honolulu
3. Cleveland	3. Los Angeles
4. Detroit	4. San Diego
5. Kansas City	5. San Francisco
6. Milwaukee	6. Seattle
7. Minneapolis	
8. St. Louis	

Source: Mathtech (7), Table 4-1.

Table 7-7

GOODS INCLUDED IN THE MTH ANALYSIS

- Food
  - Cereal and Bakery Products
  - Meat
  - Dairy Products
  - Fruits and Vegetables
  - Miscellaneous Foods
- Shelter
  - Home Repair
  - Utilities
- Home Operations
  - Laundry and Cleaning Products
  - Other Household Products
- Home Furnishings and Equipment
  - Textiles
  - Furniture
  - Major and Minor Appliances
  - Housewares
- Clothing
  - Clothing
  - Dry Cleaning
- Transportation
  - Gas and Fuel
  - Other Vehicle Operations
- Health and Personal Care
  - Personal Care
  - Non-Prescription Drugs
  - Non-Insured Medical Treatment

Source: Mathtech (7), Table 4-11.

plausible means of responding to perceived changes in PM levels, failure to recognize these adjustment possibilities could lead to an underestimate of the households' true willingness to pay. In addition, lack of data precluded the use of activity-specific measures of time in the analysis. This can also lead to an underestimate of benefits.

The estimating forms for the demand specifications in the first stage of the decision process are derived from a Stone-Geary utility function. This function has the mathematical properties required for the two-stage decision process to be valid. The demand system associated with this form of the utility function is known as the Linear Expenditure System.*

In the first stage estimation, the demands for two goods are found to be sensitive to PM levels. As expected, the demand for laundry and cleaning products is directly related to PM concentrations. Also, the demand for utilities (gas and electricity) exhibits a statistically significant direct relation with PM. A possible explanation for the latter finding is that electricity is used in conjunction with other goods to mitigate the effects of ambient PM. These two equations are shown in Table 7-8. Recall from the discussion above that these equations represent only a part of the decision process of the household.

The measure of PM included in the soiling studies reviewed previously was an annual arithmetic or geometric mean measure of TSP. In the MTH study, the measure of PM that is found to be most robust in the various specifications is a 24-hour averaging time, second-high TSP value for the year. The index of TSP for the SMSA is formed by taking the maximum of second-high concentrations across all sites in the SMSA.

An important feature of the MTH analysis is the variety of checks undertaken to test the plausibility and sensitivity of the results. These checks include: consideration of an alternative functional form (the

* A discussion of the properties of the Stone-Geary utility function and the LES system can be found in Stone (25).

Table 7-8

DEMAND EQUATIONS WITH TSP

$$Y31 = (1 - A1) \cdot (C0 + C1 \cdot TX2HI) \cdot (LAUCPI/MOPS) + A1 - A1 \cdot (D0 + D1 \cdot REGION) \cdot (OHSEPI/MOPS)$$

Coefficient	Value	St. Er.
A1	0.42462	0.04504
C0	-21.09430	12.46690
C1	0.01865	0.00647
D0	-32.13680	16.82930
D1	-10.13580	4.97639

$$Y21 = (1 - A1) \cdot (C0 + C1 \cdot SX2HI) \cdot (RPRPI/MSHELTER) + A1 - A1 \cdot ((D0 + D1 \cdot TX2HI) \cdot (UTILPI/MSHELTER))$$

Coefficient	Value	St. Er.
A1	0.23301	0.01562
C0	-32.23830	15.55350
C1	0.02393	0.00977
D0	-149.34600	47.04200
D1	0.12010	0.05375

Definition of Acronyms

Y31 = Expenditure share of home operations budget on laundry and cleaning.
TX2HI = 24-hour averaging time, maximum second-high concentration of TSP.
LAUCPI = Price index for laundry and cleaning goods.
MOPS = Total expenditure on home operations.
REGION = Dummy variable for region of country.
OHSEPI = Price index for other household service goods.
Y21 = Expenditure share of shelter budget on home repairs.
SX2HI = 24-hour averaging time, maximum second-high concentration of SO_2.
RPRPI = Price index for home repairs.
MSHELTER = Total expenditure on shelter.
UTILPI = Price index for utilities.

Source: Tables 4-16 and 4-17 of MTH (7).

homogeneous translog); looking at different ways to enter pollution variables in the demand specifications; comparisons of price elasticities with elasticities from other studies; and reasonableness checks for implied TSP impacts. These tests add support to the plausibility of the basic results in MTH, and lend additional credence to benefit numbers generated from the household model.

Benefits estimates are derived in the MTH study by comparing expenditure functions before and after the PM change.* This procedure differs slightly from the method described earlier, where benefits were defined in terms of the area to the left of the ordinary demand curve and between the marginal cost curves (see Figure 7-2). In the MTH analysis, the comparison of expenditure functions is equivalent to measuring benefits in terms of the area to the left of the <u>compensated</u> (i.e., utility constant) demand curve and between the marginal cost curves. For air quality improvements, this latter way of measuring benefits will lead to a lower estimate than that obtained via the former method.

The calculation of benefits through a comparison of expenditure functions can also be identified with the compensating variation measure of benefits. In particular:

$$CV = E(P^1,\bar{U}) - E(P^2,\bar{U}) \qquad (7.10)$$

where CV is compensating variation; E(•) is the expenditure function; P^1 is a vector of price indices in an initial situation; P^2 is the vector of price indices after a change in the indices due to an air quality improvement; and $\bar{U}$ represents a constant level of the utility index. The CV measure is interpreted as the amount a consumer would be willing to pay (or would have to be paid) in order to be indifferent between an original situation and a new situation with lower (higher) prices. It is thus a proper measure of economic benefits.

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* For a discussion of expenditure functions, see Diamond and McFadden (26).

In terms of the evaluation criteria, the following comments can be made:

- Theoretical basis -- Estimates of economic benefits are derived in a manner that is consistent with tenents of welfare economics.

- Consideration of relevant variables -- The focus of MTH on the optimizing behavior of consumers allows one to take advantage of *a priori* restrictions available in conventional models of consumer behavior. This helps narrow the scope of relevant economic variables. However, it may be the case that socioeconomic factors or other environmental measures may also contribute to the explanation of variation in quantity demanded. Because of the complexity of the system estimation procedures, only four exogenous factors are analyzed in the various demand specifications.

- Quality of input data -- The model derived in MTH requires observations on individual household behavior. Available data are limited to average, SMSA-level observations for 24 cities in two years. Air pollution data are also averaged over the entire SMSA. It is not clear what biases may be introduced by reliance on the aggregate data. A positive aspect of the economic input data is that it was collected for purposes other than an air quality benefits analysis, and so would not be subject to the inherent biases suspected in the survey studies.

- Legitimacy of the empirical analysis -- The MTH study uses advanced econometric techniques which are appropriate to the model being analyzed. The choice of functional forms for the demand relations is dictated by the choice of a particular utility function. The Stone-Geary function chosen for this study has been used often in economic analysis, is fairly easy to work with, and has properties that are required for the two-stage decision problem to be valid. In addition, a variety of plausibility checks were undertaken, including the specification of an alternative functional form.

- Transferability of models -- Benefits are calculated in the MTH model by comparing expenditure functions before and after pollution-induced price changes. Although the expression used to evaluate benefits is complex, benefits can be derived in a fairly straightforward manner for the scenarios to be reviewed in this report. The extrapolation to national benefits requires assumptions be made on regional prices and expenditures. These variables are assigned values based on the data observed for the 24 SMSAs used in the MTH analysis.

Despite the recent completion of MTH, the Criteria Document (2) contains a brief commentary on the overall Mathtech effort. The Document notes that the Mathtech models allow consideration of substitution possibilities and appear to be well based from a theoretical and empirical perspective. In addition to the concerns raised above with respect to the quality of the input data, it is noted in the Criteria Document that additional analysis would be beneficial in helping to explain more fully some of the behavioral adjustments implied by the models. The Staff Paper (3) does not specifically address the theoretical or empirical methods employed by Mathtech. However, additional detailed comments are available from an EPA-sponsored public meeting held in July 1981 to assess the overall Mathtech study.* At this meeting, a panel of leading environmental economists was asked to review and comment on each of the sector analyses. With respect to the household model, the general conclusion was that this was an excellent piece of research. Theoretical and econometric methods were properly carried out, and sufficient care was given to assessing the limitations imposed by required assumptions. The major area of concern was with the input data. The aggregate nature of the data and the limited number of sample points made for less than an optimal data set.

Despite the data limitations, the general consensus of the review panel members was that the MTH model would generate the most defensible estimates of benefits from among currently available studies. Because of assumptions made in the analysis, it was recognized that benefits numbers generated from the MTH model would be conservative estimates of willingness to pay.

This evaluation leads us to believe that reduced soiling benefits generated from the MTH model should be weighted most heavily in a comparison of benefits across studies. Benefit estimates derived from survey studies like Cummings et al. (5) and the demand/supply model of Watson and Jaksch (6) can serve as plausibility checks to the MTH numbers, and help define a probable range of benefits from reduced soiling for households.

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* See Volume VI of Mathtech (27) for a summary of the public meeting.

Mathtech Manufacturing Model (8) -- The economic models discussed earlier all focus on the household sector. Clearly, other sectors in the economy can also be affected by soiling damage. Commercial establishments, industrial plants, and government facilities may all experience decreases in costs associated with soiling damage as PM levels are reduced. The Mathtech manufacturing analysis (MTM) examines the benefits associated with reduced PM levels for six manufacturing industries at the 3-digit level of the Standard Industrial Classification.*

The MTM analysis uses economic techniques to derive a general model of production costs for manufacturing firms. The hypothesis of the analysis is that soiling or contamination effects within manufacturing plants add to the total cost of production. The costs of production may increase because of 1) increased expenditures for cleaning, maintenance, and repairs; 2) substitution to costlier materials which are more resistant to damage; or 3) reduced performance from affected equipment or structures.

Comparisons of production costs among similar types of manufacturing firms located in regions with different levels of PM permit the estimation of PM effects. Naturally, in making such comparisons, it is important to control for other factors which may cause production costs to vary among regions. These factors may include variations in: wage rates, capital costs and/or capital investment in-place, taxes, prices for materials and services, etc. Many of these factors are controlled for by including them in the analysis of production cost variations.

Also taken into account in the analysis are variations in climatological conditions which may influence costs directly (e.g., through variations in heating and cooling costs), and which may also influence the extent to which ambient PM causes physical and economic damage. The climatological factors considered include ambient temperature and precipitation. Since SO_2 levels may act in concert with PM to cause damage, ambient measures of SO_2 are also controlled for in the analysis.

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* The MTM study also looks at SO_2 effects in the manufacturing sector. These are not discussed here.

The approach described above results in an estimate of the total costs of production for a firm as a function of input prices, the level of output, and other exogenous factors. An evaluation of costs before and after implementation of a PM control strategy provides an estimate of benefits.

The formulation of the model in terms of production costs has several advantages relative to the more standard physical damage function approach.*

- Data used are for production costs actually incurred by firms as opposed to estimates of what typical maintenance and repair costs might be.
- The model recognizes that firms can make choices in their response to pollution damage. For example, the model allows for the possibility that firms may substitute to costlier but more damage-resistant materials rather than incur air pollution damages.
- Effects for which damage functions have yet to be developed can still be measured.
- Subtle effects such as efficiency losses are captured.

Data employed in the estimation of the total cost functions are taken from the 1972 Census of Manufactures (28). Because of confidentiality restrictions, the Census Bureau does not report data on individual plants. For this reason, the MTM analysis focuses on county data for the 3-digit SIC level. An assessment of where PM damage might be expected to be greatest, coupled with data availability constraints, limits the MTM analysis to six industries. Estimation of the cost relationships indicates that PM, specifically 24-hour average second-high TSP values, is an important explanatory variable in two industries, SIC 344 (Fabricated Structural Metal Products) and SIC 354 (Metalworking Machinery). Our

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* Most of the physical damage function studies that are based on industry-related impacts deal only with corrosion. Models of soiling referenced in the Criteria Document (2) and Staff Paper (3) are all household studies.

evaluation of reduced soiling benefits is limited to these two 3-digit SIC classifications and the 2-digit SICs (34 and 35) of which they are a part. Since these industries contribute only a small fraction to the value of product in the manufacturing sector, estimates of benefits are conservative estimates of total benefits in the sector.*

An important component of the MTM analysis is a series of validation checks which are performed to assess the plausibility of the model results. These checks include an evaluation of various estimated economic parameters, tests for sensitivity of results to different methods for including pollution variables in the models, reasonableness checks for implied pollution effects, and tests for spurious correlations due to omission of own pollution control costs. These tests add support to the plausibility of the basic results and thus lend credence to benefit numbers generated from the models.

As noted earlier, the Criteria Document (2) briefly reviews the overall Mathtech effort, with the general conclusion being favorable with some qualifications. In addition, the July 1981 Public Meeting also considered a draft version of the MTM study. The general conclusion at the Public Meeting was that the MTM analysis is a careful and sophisticated piece of research. The assumptions underlying both the model structure and the empirical analysis are made explicit and plausibility checks are conducted at many points in the study.**

There were three major areas of concern. First, general comments made at the meeting by representatives of the American Iron and Steel Institute (AISI) were that the relationship observed between air pollution and manufacturing costs should not be construed as indicative of causation but only correlation. The representatives cited several factors which they felt

* Even within a particular SIC category, data were not complete. For example, in SIC 344, 57 counties were included in the analysis. Plants in these counties represented 38 percent of the industry output.

** See Reference (27) for a summary of comments made at the Public Meeting.

were "true" causes of higher production costs: age of plant, wage rate, tax rates, and age of labor force. It was asserted by the AISI representatives that these factors need to be included in the cost functions so that included air pollution variables do not reflect the impact of these variables on production cost. Mathtech authors acknowledged that omitted variables can lead to statistical bias in the pollution coefficient, but felt that the manufacturing sector analysis adequately controlled for most of the other factors influencing production cost so that the relationship observed between air pollution and production cost in the study <u>suggested</u> a cause-and-effect relationship. In addition to the results of their analysis, the Mathtech representatives noted that physical evidence from other studies, and supporting anecdotal evidence collected as part of their study, were both consistent with the kinds of air pollution effects observed in their analysis. This adds further credence to the results obtained in the MTM study.

The second major area of concern involved the quality of the data. Members of the review panel and the AISI representative commented on the small number of observations available in the analysis, and the possibility of measurement error associated with the aggregate data and proxy variables.

Finally, panel members were concerned with the magnitude of the benefits estimated for SIC 344. The implied effect of a 1 $\mu g/m^3$ increase in TSP is estimated to be a $90 to $340 increase in total production costs for a firm. This is only 0.01 to 0.03 percent of average total costs. However, this one industry accounted for a large fraction of the total benefits estimated in the overall Mathtech study.

At the suggestion of the review panel, additional investigation of SIC 344 was undertaken. One check involved informal interviews with managers of some plants in SIC 344. The purpose of the interviews was twofold. The first was to look for evidence of damage and/or behavioral adjustments due to PM deposition. The second objective was to determine whether plant managers perceived ambient PM deposition as affecting either their production processes or their production costs.

Most of the managers who were interviewed reported no impacts on either production processes or costs. However, air pollution effects may not be readily perceptible because of the predicted small changes in cost. For example, it was suggested that the effects of temperature and moisture may be larger than those of PM, and yet it was found that managers did not respond differently in cities with quite different levels of temperature and humidity. In addition, there was evidence at some plants of prior adjustments made to prevent metal corrosion and contamination. These included the use of coatings on exposed metal surfaces, indoor storage of metal inventories, and surface cleaning before painting or welding. However, these activities might be undertaken for a variety of reasons so that they could not be attributed exclusively or primarily to ambient PM. The overall results of the interviews were thus inconclusive.

As a second check, additional sensitivity analyses were performed for SIC 344. In one test, an outlying observation was eliminated from the sample. When the equations were re-estimated, the implied effect of a change in TSP increased by about 30 percent, but the estimated coefficients for TSP were not as statistically significant.* The implication of this is that the expressions for SIC 344 are sensitive to sample composition. Thus, some caution is warranted in interpreting benefits estimates generated from the MTM cost equations.

Because of the finding for SIC 344, a similar outlier analysis was conducted for the other industry, SIC 354. In this case, elimination of one outlying data point resulted in a decrease in the predicted effect of TSP on production costs, and a decline in statistical significance for the estimated TSP coefficients. However, examination of the data for the

* The re-estimated coefficients were significantly different from zero at the 10.6 percent level, while the coefficients with the outlier were significant at the 1 percent level.

outlying observation suggested that it was valid information, and thus the original version of the model was retained.

In terms of the evaluation criteria, the following observations can be made concerning the Mathtech manufacturing sector analysis:

- Theoretical basis -- Economic benefits are estimated as differences in total production cost evaluated at two levels of ambient PM. As a consequence, the model yields estimates consistent with the theoretical definition of benefits. Furthermore, the structure of the model takes into account behavioral adjustments on the part of affected firms.

- Consideration of relevant variables -- A variety of economic and non-economic variables are controlled for in the cost relationships. However, data limitations prevented controlling for some possibly relevant factors such as local property taxes. Omission of these variables might bias the coefficients of the air pollution variables if these excluded variables tend to be correlated with air pollution.

- Quality of input data -- Confidentiality restrictions preclude the use of disaggregate plant data. Consequently, data for 3-digit SICs at the county level are used. Even with this level of aggregation, lack of appropriate data limit the number of industries which can be analyzed. Of the six industries for which data are collected, only one has more than 50 observations. In terms of specific variables, proxies are created for several of the desired variables, including the input price data series. This may introduce measurement error into the analysis.

- Legitimacy of Empirical Approach -- The MTM analysis uses econometric techniques that are appropriate for the model. The functional form chosen for the cost function analysis is the transcendental logarithmic function (translog). This is a very general function which imposes fewer maintained assumptions than other forms (e.g., Cobb-Douglas).

- Transferability of Model -- As with the MTH model, the expression used to evaluate benefits is complex. Much of the data needed to evaluate benefits for this study's scenarios must come from the MTM data base.

Summary of Models

In this subsection, models which describe the impact of reduced soiling on household and manufacturing plant decisions have been reviewed. To provide a point of reference for judging alternative studies, a set of five evaluation criteria were identified. These criteria help define the desired structure of any defensible benefits analysis model.

Another way in which studies can be evaluated is in terms of the biases implicit in the development and application of the models.* In the discussion of each of the four studies that have been reviewed in detail, the implications of specific assumptions have been noted. Some of the major biases associated with the models are summarized in Table 7-9. Because each model contains biases that will impact benefits in an unknown direction, it is not possible to determine conclusively whether any particular study will provide an over- or underestimate of "true" benefits. Consequently, an important element in reporting benefits should be a range of estimates reflecting, in part, this degree of uncertainty. It should be noted that the types of biases listed in Table 7-9 refer only to biases inherent in the models. There are also biases possible when the models are used to provide estimates of national benefits. These biases are discussed in the next subsection.

In the household sector, three studies were evaluated. Because of differences in study design and model bias it is difficult to make meaningful comparisons across studies. For example, the Cummings model accounts for changes in out-of-pocket expenditures and the opportunity cost of labor time in cleaning, the Watson and Jaksch model yields benefits estimates of a pure utility type; and the Mathtech household model captures only the benefits related to out-of-pocket expenditures. At first glance, it might be expected that estimates derived from the Cummings study should provide an upper-bound plausibility check for the Mathtech household estimates. However, this need not be true because of the different biases

* In fact, many of the criteria reflect concern with the question of bias.

Table 7-9

BIASES IN MODELS OF SOILING STUDIES

Model	Description of Bias	Expected Impact on Benefits
Cummings *et al.*	1. Not all plausible cleaning tasks considered.	Underestimate of benefits
	2. Remaining measurement error in BAH data (e.g., unit cost data).	Unknown
	3. Consideration of differentiated cleaning tasks.	Overestimate of benefits (possible jointness)
	4. The use of a measure of the opportunity cost of leisure may be inappropriate since other activities that are equally undesirable may be substituted for cleaning when air quality improves.	Overestimate of benefits
	5. Adjustments to task frequency data of BAH.	Overestimate of benefits
	6. Use of linear specifications for frequency, labor and damage equations.	Unknown
	7. Exclusion of possible relevant explanatory factors in various specifications.	Unknown
	8. Calculation of benefits not based on variations in demand and supply curves.	Underestimate of benefits

(continued)

Table 7-9 (Continued)

Model	Description of Bias	Expected Impact on Benefits
Watson & Jaksch	1. Uncorrected BAH data employed in analysis.	Unknown
	2. Not all plausible cleaning tasks considered.	Underestimate of benefits
	3. Consideration of differentiated cleaning tasks.	Overestimate of benefits (due to jointness)
	4. Assumption of constant unit elastic demand.	Possible overestimate of benefits
	5. Assumption of linear, upward sloping marginal cost curve with multiplicative shift.	Unknown
	6. Not all adjustment opportunities explicitly recognized.	Underestimate of benefits
	7. No adjustment for reallocation of labor time.	Underestimate of benefits
	8. Estimates of α derived from limited number of studies. Quality of estimates questionable.	Unknown
	9. Benefits calculated with consumer surplus measure.	Small overestimate of benefits

(continued)

Table 7-9 (Continued)

Model	Description of Bias	Expected Impact on Benefits
MTH	1. Problems associated with input data (e.g., aggregate data for SMSAs, measurement error, small number of observations).	Unknown
	2. Limited consideration of possible relevant explanatory variables.	Unknown
	3. No consideration of location adjustment opportunities.	Underestimate of benefits
	4. No consideration of labor-leisure tradeoff possibilities.	Underestimate of benefits
	5. No adjustments for reallocation of labor time.	Underestimate of benefits
	6. Model does not capture benefits of a pure utility type.	Underestimate of benefits
	7. Stone-Geary utility function assumed.	Unknown
	8. Separability assumptions imposed on groups of market goods.	Unknown

(continued)

Table 7-9 (Continued)

Model	Description of Bias	Expected Impact on Benefits
MTM	1. Not all manufacturing sectors treated due to data limitations.	Underestimate of benefits
	2. Use of aggregate data.	Unknown
	3. Approximate data on the prices and quantities of inputs and outputs.	Unknown
	4. Exclusion of potentially relevant variables.	Unknown
	5. Translog cost function assumed.	Unknown
	6. No adjustments permitted for plant relocation.	Underestimate of benefits

associated with each model. As a consequence, each of the three studies must be viewed as contributing individually to the overall stock of knowledge available for estimating benefits from reduced soiling.

Based on the reviews in this subsection, it is possible to make subjective judgments on the relative merits of each of the studies. Because of the model design and the manner in which benefits are calculated, we believe the MTH study should be weighted most heavily, with the other two studies providing additional information on the probable range of soiling benefits. Furthermore, it is our belief that the estimates derived from the MTH model will likely be conservative estimates of the benefits from reduced soiling in the household sector. We are less sanguine about the relationship to "true" benefits for the other two household soiling studies.

In the manufacturing sector, only one study is available for benefits estimation. Based on the evaluation in this section, we believe that it is appropriate to view benefits numbers generated from the MTM model as upper bounds for the "true" benefit numbers in SIC 344 and SIC 354. Note, however, in the context of the entire manufacturing sector, these estimates will likely be conservative estimates of the total benefits from reduced soiling in the sector.

The above observation is also pertinent with respect to other sectors of the economy. In particular, benefits from reduced soiling are not reported for the commercial, government, and institutional sectors. To our knowledge, no studies have been completed which permit the calculation of benefits in these sectors. Consequently, a large part of total benefits from reduced soiling may be uncounted.

BENEFITS CALCULATIONS

Introduction

In this subsection, benefits of reduced soiling are calculated for the household and manufacturing sectors. Benefits in the household sector are estimated using three studies: Cummings *et al.* (5), Watson and Jaksch (6), and the Mathtech household model (7). Benefits estimates in the manufacturing sector are developed entirely from the Mathtech manufacturing model (8).

Benefits estimates are calculated on a county-by-county basis. The counties included in the benefits analysis are determined as part of a research effort conducted by another EPA contractor. This other work examines the costs of implementing alternative PM control strategies in response to various air quality standards. Any county that is expected to experience a reduction in ambient levels of PM because of the PM control programs is included in the benefits analysis.

Although the benefits calculations are performed with county-specific data, for presentation purposes, benefit estimates are reported by EPA Administrative Region. The standard ten-region breakdown is employed. Reporting estimates in this fashion provides an indication of the distribution of benefits.

Table 7-10 summarizes the scenarios to be evaluated in this subsection. As in the other sections of this report, the benefits from reduced soiling associated with the standards shown in the table are presented as discounted present values in 1982, in 1980 dollars. Estimates of annualized benefits are also provided. A discount rate of 10 percent and a time stream of benefits of 7 years (PM10 standards) or 9 years (TSP standards) are also used. A complete description of such issues as non-attainment status for counties, maintenance of ambient levels after control strategy implementation, and the impact of emissions growth on air quality is contained in Section 9.

Table 7-10

AIR QUALITY SCENARIOS

Standard	Pollutant	Level	Averaging Time	Implementation Date
Primary	PM10	70	Annual arithmetic mean	1989
		250	24-hour expected value	1989
Primary	PM10	55	Annual arithmetic mean	1989
		250	24-hour expected value	1989
Primary	PM10	55	Annual arithmetic mean	1989
		150	24-hour expected value	1989
Secondary	PM10	55	Annual arithmetic mean	1989
Primary	TSP	75	Annual geometric mean	1987
		260	24-hour second high	1987
Secondary	TSP	150	24-hour second high	1987

<u>**Household Sector**</u>

Cummings <u>et al</u>. —

In Cummings <u>et al</u>. (5), the damage function is reported as:

$$D = 251.43 + 6.63P \tag{7.11}$$

where D is annual expenditures per household in 1980 dollars and P is the annual arithmetic mean level of TSP. As reported in our review of the Cummings study, this damage estimate represents both out-of-pocket expenses and a measure of the opportunity cost of labor in cleaning activities.

As part of our review of this study, an attempt was made to replicate the results of Cummings. Data were presented in sufficient detail in the

Cummings report to permit reconstruction of the required variables. One reason this exercise was undertaken was that Cummings et al. do not report the standard error for the pollution coefficient. In order to obtain a range of benefit estimates, our plan was to perturb the pollution coefficient by plus and minus two-standard deviations. If one is willing to accept the simple regression form used by Cummings, this perturbation yields an estimate of the 95 percent confidence interval for benefits from reduced soiling.

The data required for replicating the Cummings et al. equation can be developed from their Tables 7 and 20. The following steps were carried out:

- Per-household estimates of cost were identified by task and pollution zone for the households that hired help as well as households that performed the tasks themselves. Our estimates for this step coincided with those reported in Cummings.

- A weighted average, based on the distribution of the two types of households, was calculated. This gave an average per household expenditure for all houses that performed the tasks. This weighted average was again estimated by task and pollution zone.

- In order to identify the average expenditures for all households in a pollution zone, the weighted average estimates were multiplied by a factor representing the proportion of households in the zone that performed the task. In several cases, the Cummings data was such that greater than 100 percent of households performed a task. In these instances, an upper bound of 100 percent was imposed.

- Damages were aggregated across tasks by pollution zone to obtain an estimate of total expenditures per household.

Using this procedure, the following damage equation was estimated:

$$D = \underset{(143.67)}{131.28} + \underset{(1.56)}{8.85} \cdot P \qquad (7.12)$$

Standard errors are given in parentheses. This expression differs from the one estimated in Cummings *et al*. Unfortunately, except for the 100 percent constraint imposed in Step 3, it is not possible to identify other causes for the observed differences. With the exception of the first step described above, no additional tables or descriptions that appear in Cummings are useful for making comparisons.

Equation (7.12) is used in this subsection to calculate benefits. The point estimate of marginal damages is 8.85, with a two-standard deviation range of about 5.72 to 11.98. These numbers represent the dollar value (1980 dollars) of a 1 $\mu g/m^3$ change in annual average TSP levels. This two-standard deviation range is used to identify a confidence interval for the benefits estimates reported below. Note the marginal damage estimate reported in Cummings (6.63) falls within this range. On the other hand, this range does not include the marginal damage estimate derived from the Michelson and Tourin (13) study. Their value (adjusted to 1980 dollars) is $2.50. This discrepancy is to be expected, however, since the Cummings study includes an estimate of the opportunity cost of labor in cleaning activities in their damage relation.

The measure of pollution used in the Cummings study is the annual geometric mean of TSP. More precisely, the midpoint of the range of TSP in each of the four pollution zones of Philadelphia is associated with the cost data for that zone. Thus, the units of the TSP coefficient in Equation (7.12) reflect a dollar value per unit of <u>average</u> TSP annual geometric mean concentrations. That is, the <u>index</u> of pollution for the analysis is an average value. Since the air quality data generated for use in this study rely on design value monitors that likely reflect the highest values in a given county, it is appropriate to adjust the air quality data to provide a representation of population exposure in the county that is more consistent with the structure of Equation (7.12). This adjustment procedure is discussed in detail in Section 9.

Tables 7-11 through 7-16 present the benefits estimates for each of the scenarios listed in Table 7-10. These benefits represent the benefits

Table 7-11

ESTIMATED BENEFITS FOR: CUMMINGS SOILING STUDY

Benefits Occurring Between 1989 and 1995
Scenario: Type B PM10 - 70 AAM/250 24-hr.

Federal Administrative Region			Minimum	Point Estimate	Maximum
REGION	I	New England	0.0	0.0	0.0
REGION	II	N.Y.-N.J.	8.2	12.7	17.2
REGION	III	Middle Atlantic	289.9	447.8	605.7
REGION	IV	South Atlantic	341.0	526.6	712.3
REGION	V	E.N. Central	1768.1	2730.9	3693.7
REGION	VI	South Central	699.0	1079.7	1460.3
REGION	VII	Midwest	100.6	155.4	210.2
REGION	VIII	Mountain	235.2	363.2	491.3
REGION	IX	South Pacific	2263.5	3496.0	4728.5
REGION	X	North Pacific	329.1	508.3	687.5
Total U.S.			6034.7	9320.7	12606.6

Discounted Present Value in Millions of 1980 Dollars in 1982
Using a 10 Percent Rate of Discount.

Annualized Benefits Between 1989 and 1995 Total U.S.	2415.6	3730.9	5046.1

Table 7-12

ESTIMATED BENEFITS FOR: CUMMINGS SOILING STUDY

Benefits Occurring Between 1989 and 1995
Scenario: Type B PM10 - 55 AAM/250 24-hr.

Federal Administrative Region			Minimum	Point Estimate	Maximum
REGION	I	New England	83.2	128.5	173.9
REGION	II	N.Y.-N.J.	107.5	166.0	224.5
REGION	III	Middle Atlantic	565.0	872.7	1180.3
REGION	IV	South Atlantic	797.6	1231.9	1666.2
REGION	V	E.N. Central	2613.7	4036.9	5460.1
REGION	VI	South Central	1140.8	1761.9	2383.1
REGION	VII	Midwest	270.8	418.2	565.6
REGION	VIII	Mountain	501.5	774.5	1047.6
REGION	IX	South Pacific	4384.0	6771.1	9158.2
REGION	X	North Pacific	471.7	728.5	985.3
Total U.S.			10935.7	16890.2	22844.8

Discounted Present Value in Millions of 1980 Dollars in 1982
Using a 10 Percent Rate of Discount.

	Minimum	Point Estimate	Maximum
Annualized Benefits Between 1989 and 1995 Total U.S.	4377.3	6760.8	9144.2

Table 7-13

ESTIMATED BENEFITS FOR: CUMMINGS SOILING STUDY

Benefits Occurring Between 1989 and 1995
Scenario: Type B PM10 - 55 AAM/150 24-hr.

Federal Administrative Region			Minimum	Point Estimate	Maximum
REGION	I	New England	282.2	435.8	589.5
REGION	II	N.Y.-N.J.	202.9	313.4	423.9
REGION	III	Middle Atlantic	814.9	1258.6	1702.3
REGION	IV	South Atlantic	1047.5	1617.9	2188.3
REGION	V	E.N. Central	2998.5	4631.2	6263.8
REGION	VI	South Central	1365.1	2108.3	2851.6
REGION	VII	Midwest	389.0	600.8	812.6
REGION	VIII	Mountain	754.8	1165.8	1576.8
REGION	IX	South Pacific	4954.9	7652.9	10350.8
REGION	X	North Pacific	838.6	1295.3	1751.9
Total U.S.			13648.4	21080.1	28511.7

Discounted Present Value in Millions of 1980 Dollars in 1982
Using a 10 Percent Rate of Discount.

Annualized Benefits Between 1989 and 1995 Total U.S.	5463.2	8437.9	11412.6

Table 7-14

ESTIMATED BENEFITS FOR: CUMMINGS SOILING STUDY

Benefits Occurring Between 1989 and 1995
Scenario: Type B PM10 - 55 AAM

Federal Administrative Region			Minimum	Point Estimate	Maximum
REGION	I	New England	83.2	128.5	173.9
REGION	II	N.Y.-N.J.	107.5	166.0	224.5
REGION	III	Middle Atlantic	565.0	872.7	1180.3
REGION	IV	South Atlantic	797.6	1231.9	1666.2
REGION	V	E.N. Central	2601.5	4018.1	5434.6
REGION	VI	South Central	1116.3	1724.2	2332.0
REGION	VII	Midwest	269.4	416.1	562.7
REGION	VIII	Mountain	501.5	774.5	1047.6
REGION	IX	South Pacific	4383.7	6770.7	9157.6
REGION	X	North Pacific	439.2	678.3	917.5
Total U.S.			10864.9	16780.9	22696.9

Discounted Present Value in Millions of 1980 Dollars in 1982
Using a 10 Percent Rate of Discount.

Annualized Benefits Between 1989 and 1995 Total U.S.	4349.0	6717.0	9085.1

Table 7-15

ESTIMATED BENEFITS FOR: CUMMINGS SOILING STUDY

Benefits Occurring Between 1987 and 1995
Scenario: Type B TSP - 75 AAM/260 24-hr.

Federal Administrative Region			Minimum	Point Estimate	Maximum
REGION	I	New England	287.0	443.3	599.6
REGION	II	N.Y.-N.J.	261.3	403.6	545.9
REGION	III	Middle Atlantic	1322.8	2043.0	2763.3
REGION	IV	South Atlantic	1598.6	2469.0	3339.4
REGION	V	E.N. Central	4835.1	7467.8	10100.5
REGION	VI	South Central	1919.3	2964.4	4009.4
REGION	VII	Midwest	671.6	1037.3	1402.9
REGION	VIII	Mountain	932.4	1440.2	1947.9
REGION	IX	South Pacific	8023.7	12392.6	16761.5
REGION	X	North Pacific	917.2	1416.6	1916.1
Total U.S.			20769.0	32077.7	43386.4

Discounted Present Value in Millions of 1980 Dollars in 1982
Using a 10 Percent Rate of Discount.

	Minimum	Point Estimate	Maximum
Annualized Benefits Between 1987 and 1995 Total U.S.	5808.0	8970.5	12133.0

Table 7-16

ESTIMATED BENEFITS FOR: CUMMINGS SOILING STUDY

Benefits Occurring Between 1987 and 1995
Scenario: Type B TSP - 150 24-hr.

Federal Administrative Region			Minimum	Point Estimate	Maximum
REGION	I	New England	853.5	1318.2	1783.0
REGION	II	N.Y.-N.J.	522.7	807.3	1091.9
REGION	III	Middle Atlantic	2007.8	3101.0	4194.2
REGION	IV	South Atlantic	2086.1	3222.1	4358.0
REGION	V	E.N. Central	5858.1	9047.8	12237.5
REGION	VI	South Central	2304.4	3559.2	4814.0
REGION	VII	Midwest	1178.4	1820.0	2461.6
REGION	VIII	Mountain	1333.8	2060.0	2786.3
REGION	IX	South Pacific	9149.9	14132.0	19114.1
REGION	X	North Pacific	1540.9	2379.9	3218.9
Total U.S.			26835.5	41447.5	56059.4

Discounted Present Value in Millions of 1980 Dollars in 1982
Using a 10 Percent Rate of Discount.

	Minimum	Point Estimate	Maximum
Annualized Benefits Between 1987 and 1995 Total U.S.	7504.5	11590.8	15677.0

that would be achieved when all counties included in the analysis are in compliance with the standard for all years under consideration.* The first three tables present estimates for alternative PM10 primary standards. The order of presentation for the tables is from most lenient to most stringent. The minimum and maximum estimates are obtained by perturbing the coefficient in Equation (7.12) by minus and plus two standard deviations, respectively. From the tables, it can be seen that almost two-thirds of total U.S. benefits will accrue in the East North Central and South Pacific regions.

Table 7-14 presents estimates for a PM10 secondary standard of 55 $\mu g/m^3$. The table reports the total benefits associated with attainment and maintenance of this standard. To identify the incremental benefits of the secondary standard conditional on a primary standard being attained, it is necessary to net out the benefits of the primary standard. For example, if the 55 $\mu g/m^3$ secondary standard is associated with the 70/250 $\mu g/m^3$ primary standard, then the incremental benefits (discounted present value) of the secondary standard would be $7.5 billion for the total U.S. point estimate (i.e., 16.8 - 9.3). Although reduced soiling is a welfare benefit, it is important to note that positive welfare benefits will be generated in the attainment of the primary standard. This occurs even though the primary standard is based only on health considerations.

Tables 7-15 and 7-16 present benefits estimates for the current TSP primary and secondary standards. As before, to identify the incremental benefits of the secondary standard, it is necessary to net out the benefits generated through attainment of the primary standard.

Finally, Table 7-17 shows the benefits that accrue under a 70/250 PM10 primary standard when all counties are not in attainment with the standard throughout the 1989-1995 time horizon. This can occur because available means of controlling emissions are exhausted prior to standard attainment

* In the language of Section 9, these benefits represent "B" scenario benefits.

Table 7-17

ESTIMATED BENEFITS FOR: CUMMINGS SOILING STUDY

Benefits Occurring Between 1989 and 1995
Scenario: Type A PM10 - 70 AAM/250 24-hr.

Federal Administrative Region			Minimum	Point Estimate	Maximum
REGION	I	New England	0.0	0.0	0.0
REGION	II	N.Y.-N.J.	8.2	12.7	17.2
REGION	III	Middle Atlantic	279.3	431.4	583.5
REGION	IV	South Atlantic	274.9	424.5	574.2
REGION	V	E.N. Central	1267.2	1957.2	2647.1
REGION	VI	South Central	442.7	683.7	924.7
REGION	VII	Midwest	89.9	138.8	187.7
REGION	VIII	Mountain	220.9	341.2	461.5
REGION	IX	South Pacific	1221.3	1886.3	2551.3
REGION	X	North Pacific	103.7	160.2	216.7
Total U.S.			3908.0	6036.0	8163.9

Discounted Present Value in Millions of 1980 Dollars in 1982
Using a 10 Percent Rate of Discount.

	Minimum	Point Estimate	Maximum
Annualized Benefits Between 1989 and 1995 Total U.S.	1564.3	2416.1	3267.8

and/or because of emissions growth. This table can be compared to Table 7-11 where all counties were assumed to be in compliance with the same 70/250 PM10 standard. As expected, the benefits estimates in Table 7-11 exceed those shown in Table 7-17.

Watson and Jaksch —

In the Watson and Jaksch study, benefits estimates are calculated by task and pollution zone. The expression used to calculate benefits is:

$$-\Delta CW_{ij} = \alpha \ln\left[\frac{P_{2j}}{P_{ij}}\right] \cdot X_{ij} \qquad (7.13)$$

where ΔCW_{ij} is the change in welfare in task i for pollution zone j.

P_{2j} is the final level of pollution in zone j.

P_{1j} is the initial level of pollution in zone j.

α is a factor estimated from damage function studies.

X_{ij} is the outlay for task i in zone j.

For purposes of extrapolation, it does not seem warranted to estimate benefits at such a disaggregate level as task and zone. Consequently, the benefits derived below are calculated on a county basis only and for the aggregate of tasks. In essence, the subscript i can be deleted in Equation (7.13), and the j index refers to a county instead of a pollution zone.

There are five bits of information needed to determine benefits. The two levels of TSP or PM are provided to us through the cost of control study. These data are representative of the highest value monitors. As with the Cummings study, average TSP indices are used in WJ. Consequently, the design value data from the cost analysis must be adjusted to provide a more consistent match-up with the WJ model.

The third data element that is required is an estimate of α. This factor is taken from WJ, and three values are available: 0.56, 1.0, and

2.0. These three estimates provide the variation needed to obtain a probable range of benefits for the Watson and Jaksch study. The fourth data element required is an estimate of per household expenditures. Earlier in this review, it was mentioned that because of data difficulties with the Booz, Allen and Hamilton data base, it would be advantageous if the Cummings "cleaned" data could be used. Unfortunately, upon closer examination this did not appear to be feasible. The principal constraint is that only three of the eight cleaning/maintenance tasks examined in Watson and Jaksch correspond to those tasks included in Cummings.

Using data provided in Watson and Jaksch, a per-household expenditure estimate of $155.20 was calculated. This figure is a weighted average across pollution zones for all eight cleaning/maintenance tasks. Since this value is in 1971 dollars, it was adjusted to 1980 dollars by the U.S. average Consumer Price Index for home materials repair. In 1980 dollars, the annual per household expenditures are estimated to be $333.68.

The final variable needed to calculate benefits is the number of households per county. This variable and the necessary growth rates are taken from Reference (29) and Reference (30), respectively.

The final form for estimating benefits from the Watson and Jaksch study is:

$$-\Delta CW_j = \alpha \ln\left[\frac{P_{2j}}{P_{ij}}\right] \cdot X_j \cdot N_j \qquad (7.14)$$

where X_j is the per-household outlays in county j.

N_j is the number of households in county j.

The other variables are as defined previously, except that j indexes a county rather than a pollution zone.

Tables 7-18 through 7-23 present the benefits estimates derived from the Watson and Jaksch model for the scenarios described in Table 7-10. As

Table 7-18

ESTIMATED BENEFITS FOR: WATSON AND JAKSCH SOILING STUDY

Benefits Occurring Between 1989 and 1995
Scenario: Type B PM10 - 70 AAM/250 24-hr.

Federal Administrative Region			Minimum	Point Estimate	Maximum
REGION	I	New England	0.0	0.0	0.0
REGION	II	N.Y.-N.J.	5.6	10.0	20.0
REGION	III	Middle Atlantic	107.5	191.9	383.9
REGION	IV	South Atlantic	146.3	261.2	522.5
REGION	V	E.N. Central	905.2	1616.5	3233.0
REGION	VI	South Central	321.3	573.7	1147.4
REGION	VII	Midwest	42.6	76.1	152.1
REGION	VIII	Mountain	106.5	190.1	380.2
REGION	IX	South Pacific	750.8	1340.7	2681.3
REGION	X	North Pacific	151.7	270.9	541.8
Total U.S.			2537.4	4531.1	9062.2

Discounted Present Value in Millions of 1980 Dollars in 1982
Using a 10 Percent Rate of Discount

Annualized Benefits Between 1989 and 1995 Total U.S.	1015.7	1813.7	3627.4

Table 7-19

ESTIMATED BENEFITS FOR: WATSON AND JAKSCH SOILING STUDY

Benefits Occurring Between 1989 and 1995
Scenario: Type B PM10 - 55 AAM/250 24-hr.

Federal Administrative Region			Minimum	Point Estimate	Maximum
REGION	I	New England	38.8	69.4	138.7
REGION	II	N.Y.-N.J.	69.5	124.1	248.3
REGION	III	Middle Atlantic	242.5	433.0	866.0
REGION	IV	South Atlantic	386.0	689.3	1378.7
REGION	V	E.N. Central	1373.1	2452.0	4904.0
REGION	VI	South Central	570.3	1018.4	2036.7
REGION	VII	Midwest	126.8	226.5	453.0
REGION	VIII	Mountain	219.1	391.2	782.4
REGION	IX	South Pacific	1683.7	3006.5	6013.1
REGION	X	North Pacific	232.3	414.8	829.6
Total U.S.			4942.1	8825.2	17650.5

Discounted Present Value in Millions of 1980 Dollars in 1982
Using a 10 Percent Rate of Discount

Annualized Benefits Between 1989 and 1995 Total U.S.	1978.2	3532.5	7065.1

Table 7-20

ESTIMATED BENEFITS FOR: WATSON AND JAKSCH SOILING STUDY

Benefits Occurring Between 1989 and 1995
Scenario: Type B PM10 - 55 AAM/150 24-hr.

Federal Administrative Region			Minimum	Point Estimate	Maximum
REGION	I	New England	193.9	346.3	692.5
REGION	II	N.Y.-N.J.	131.1	234.1	468.2
REGION	III	Middle Atlantic	391.2	698.6	1397.1
REGION	IV	South Atlantic	531.8	949.7	1899.3
REGION	V	E.N. Central	1579.5	2820.5	5640.9
REGION	VI	South Central	711.3	1270.2	2540.4
REGION	VII	Midwest	193.1	344.8	689.5
REGION	VIII	Mountain	339.7	606.6	1213.2
REGION	IX	South Pacific	1992.2	3557.5	7115.0
REGION	X	North Pacific	476.1	850.2	1700.5
Total U.S.			6539.9	11678.3	23356.7

Discounted Present Value in Millions of 1980 Dollars in 1982
Using a 10 Percent Rate of Discount

Annualized Benefits Between 1989 and 1995 Total U.S.	2617.8	4674.6	9349.1

Table 7-21

ESTIMATED BENEFITS FOR: WATSON AND JAKSCH SOILING STUDY

Benefits Occurring Between 1989 and 1995
Scenario: Type B PM10 - 55 AAM

Federal Administrative Region			Minimum	Point Estimate	Maximum
REGION	I	New England	38.8	69.4	138.7
REGION	II	N.Y.-N.J.	69.5	124.1	248.3
REGION	III	Middle Atlantic	242.5	433.0	866.0
REGION	IV	South Atlantic	386.0	689.3	1378.7
REGION	V	E.N. Central	1366.4	2440.0	4879.9
REGION	VI	South Central	555.4	991.9	1983.7
REGION	VII	Midwest	126.2	225.4	450.7
REGION	VIII	Mountain	219.1	391.2	782.4
REGION	IX	South Pacific	1683.5	3006.3	6012.6
REGION	X	North Pacific	214.6	383.2	766.4
Total U.S.			4902.1	8753.7	17507.4

Discounted Present Value in Millions of 1980 Dollars in 1982
Using a 10 Percent Rate of Discount

Annualized Benefits Between 1989 and 1995 Total U.S.	1962.2	3503.9	7007.8

Table 7-22

ESTIMATED BENEFITS FOR: WATSON AND JAKSCH SOILING STUDY

Benefits Occurring Between 1987 and 1995
Scenario: Type B TSP - 75 AGM/260 24-hr.

Federal Administrative Region			Minimum	Point Estimate	Maximum
REGION	I	New England	151.9	271.3	542.5
REGION	II	N.Y.-N.J.	163.2	291.4	582.7
REGION	III	Middle Atlantic	622.7	1112.0	2223.9
REGION	IV	South Atlantic	827.0	1476.8	2953.5
REGION	V	E.N. Central	2586.0	4617.9	9235.8
REGION	VI	South Central	1015.3	1813.0	3626.1
REGION	VII	Midwest	336.5	601.0	1201.9
REGION	VIII	Mountain	413.2	737.9	1475.7
REGION	IX	South Pacific	3380.7	6036.9	12073.8
REGION	X	North Pacific	483.1	862.7	1725.5
Total U.S.			9979.6	17820.8	35641.6

Discounted Present Value in Millions of 1980 Dollars in 1982
Using a 10 Percent Rate of Discount

Annualized Benefits Between 1987 and 1995 Total U.S.	2790.8	4983.6	9967.2

Table 7-23

ESTIMATED BENEFITS FOR: WATSON AND JAKSCH SOILING STUDY

Benefits Occurring Between 1987 and 1995
Scenario: Type B TSP - 150 24-hr.

Federal Administrative Region			Minimum	Point Estimate	Maximum
REGION	I	New England	598.0	1067.9	2135.8
REGION	II	N.Y.-N.J.	335.0	598.2	1196.4
REGION	III	Middle Atlantic	1045.2	1866.4	3732.8
REGION	IV	South Atlantic	1150.2	2054.0	4107.9
REGION	V	E.N. Central	3172.4	5665.0	11330.0
REGION	VI	South Central	1242.4	2218.6	4437.2
REGION	VII	Midwest	670.3	1197.0	2394.0
REGION	VIII	Mountain	657.4	1174.0	2347.9
REGION	IX	South Pacific	4143.3	7398.8	14797.6
REGION	X	North Pacific	938.3	1675.5	3351.0
Total U.S.			13952.6	24915.3	49830.6

Discounted Present Value in Millions of 1980 Dollars in 1982
Using a 10 Percent Rate of Discount

Annualized Benefits Between 1987 and 1995 Total U.S.	3901.8	6967.6	13935.1

before, these benefits represent the benefits associated with complete attainment and maintenance of the standards in all counties. The ordering of the tables is also the same. In particular, the first three tables represent alternative PM10 primary standards, Table 7-21 shows the benefits for the PM10 secondary standard, and Tables 7-22 and 7-23 present benefit estimates for the current TSP primary and secondary standards, respectively. Finally, Table 7-24 shows the benefits that accrue with the 70/250 PM10 scenario when some of the counties remain in nonattainment due to emissions growth.

A comparison of the benefits derived from the Cummings and Watson and Jaksch models reveals that the Watson and Jaksch estimates are lower. However, because of model differences, it is not possible to compare the studies in a definitive manner. Recall that the Cummings study accounts for benefits derived from reduced out-of-pocket expenditures as well as the value of reduced labor time in cleaning activities, while the Watson and Jaksch model identifies adjustments in the demand for cleanliness. These adjustments reflect actions based on "utility" considerations as well as changes in the cost of cleanliness.

Mathtech Household Model (MTH) —

The basic analysis in MTH is limited to 24 SMSAs, with these SMSAs accounting for approximately 30 percent of the total U.S. population in 1976. Since the demand systems estimated in MTH use SMSA-specific price, income, and demographic data, extrapolation to other counties of the U.S. requires assumptions on these data. For example, since price data are not available for many parts of the country, proxies must be created. The proxies take the form of regional averages based on the data available in the basic study.

The specific assumptions made in performing the extrapolation include:

- Certain data are assigned to counties based on the region in which the county is located. In particular, the following steps are taken:

Table 7-24

ESTIMATED BENEFITS FOR: WATSON AND JAKSCH SOILING STUDY

Benefits Occurring Between 1989 and 1995
Scenario: Type A PM10 - 70 AAM/250 24-hr.

Federal Administrative Region			Minimum	Point Estimate	Maximum
REGION	I	New England	0.0	0.0	0.0
REGION	II	N.Y.-N.J.	5.6	10.0	20.0
REGION	III	Middle Atlantic	103.1	184.1	368.2
REGION	IV	South Atlantic	111.0	198.2	396.4
REGION	V	E.N. Central	599.8	1071.0	2142.1
REGION	VI	South Central	192.0	342.9	685.8
REGION	VII	Midwest	36.6	65.3	130.7
REGION	VIII	Mountain	95.9	171.3	342.6
REGION	IX	South Pacific	387.0	691.0	1382.0
REGION	X	North Pacific	41.0	73.2	146.3
Total U.S.			1571.9	2807.0	5614.1

Discounted Present Value in Millions of 1980 Dollars in 1982
Using a 10 Percent Rate of Discount

	Minimum	Point Estimate	Maximum
Annualized Benefits Between 1989 and 1995 Total U.S.	629.2	1123.6	2247.2

- The country is divided into two major areas: Northeast plus North Central and South plus West.
- Averages by region are computed from the 24 SMSA data for the following items:
  a) 30-year average temperature
  b) family size
  c) average annual percent change in the all-item Consumer Price Index
  d) average percent of total consumption expenditures in the SMSA data
  e) disaggregate and aggregate price sets developed in the basic analysis of MTH.

- Certain data are assigned to counties based on county- or state-level data. These data include:
  - Air quality data
  - Baseline county population numbers are taken from Reference (29). Conversions to household data are made by dividing by the regional family size values.
  - County population projections are taken from Reference (30).
  - State income projections for 1985 and 1990 (current 1972 dollars) are obtained from Reference (31).

- Certain data on assumptions are relevant for all counties. These include:
  - The parameters of the demand models in MTH.
  - The air quality scenario.
  - The parameters of the benefits calculations (i.e., discounted present value in 1982, in 1980 dollars; 10 percent discount rate; 7- or 9-year steam of benefits.

Given these assumptions, benefit estimates are developed for each county that experiences a reduction in PM concentrations. Note that the extrapolation from the original 24 SMSAs in the MTH study is only geographic. Recall that the goods included in the basic MTH analysis account for only about 40 percent of current consumption expenditures. With available information, it is not possible to extend the scope of the MTH study beyond this subset of goods.

Tables 7-25 through 7-30 present the benefit estimates of the MTH model for the scenarios described in Table 7-10. Since the measure of TSP used in the MTH analysis is the maximum of all site 24-hour average second-high readings in a county, it is not necessary to adjust the design value data to characterize population exposure.

The ranges of benefits reported in the tables reflect two plausible sources of uncertainty in the MTH benefits equations. First, since the estimators for TSP are random variables with known standard error, values of the coefficient plus or minus two standard deviations from the estimated coefficient provide a range that reflects the stochastic nature of the estimator. Note that this procedure does not yield a 95 percent confidence interval for the MTH model. Because of the across-equation constraints implied by the estimated demand systems, a true confidence interval would have to account for covariances among the variables in the system. The procedure described above does not do this. Analytical problems associated with developing the statistically-preferred measure prevented its use for this review. Nevertheless, the less rigorous approach does provide an indication of the uncertainty associated with the pollution estimator.

The second way uncertainty in the MTH model is reflected in the benefits calculations is through variations in prices. In the original MTH study, price data were available for only 24 SMSAs. An extrapolation to other counties in the country was made by defining two average price sets for the United States. One price set is constructed from the prices of those MTH SMSAs that are in the West and South; the other price set is the average of prices of SMSAs in the Northeast and North Central parts of the country. Taken together, these average prices were used to derive the point estimates of benefits in Tables 7-25 through 7-30.

The minimum and maximum price set estimates are developed by using price data from the MTH SMSAs that yield the lowest and highest marginal valuations per unit change in PM levels. The low price set is associated with Atlanta; the high price set is associated with New York City.

Table 7-25

ESTIMATED BENEFITS FOR: MATHTECH HOUSEHOLD EXPENDITURE STUDY

Benefits Occurring Between 1989 and 1995
Scenario: Type B PM10 - 70 AAM/250 24-hr.

Federal Administrative Region			Minimum	Point Estimate	Maximum
REGION	I	New England	0.0	0.0	0.0
REGION	II	N.Y.-N.J.	0.2	1.7	3.2
REGION	III	Middle Atlantic	4.7	35.4	67.4
REGION	IV	South Atlantic	5.7	40.3	76.7
REGION	V	E.N. Central	35.8	271.0	513.7
REGION	VI	South Central	10.0	72.0	136.5
REGION	VII	Midwest	1.4	10.2	19.4
REGION	VIII	Mountain	3.5	25.1	47.5
REGION	IX	South Pacific	31.5	231.0	440.9
REGION	X	North Pacific	6.6	48.0	91.2
Total U.S.			99.4	734.9	1396.5

Discounted Present Value in Millions of 1980 Dollars in 1982
Using a 10 Percent Rate of Discount.

Annualized Benefits Between 1989 and 1995 Total U.S.	39.8	294.2	559.0

Table 7-26

ESTIMATED BENEFITS FOR: MATHTECH HOUSEHOLD EXPENDITURE STUDY

Benefits Occurring Between 1989 and 1995
Scenario: Type B PM10 - 55 AAM/250 24-hr.

Federal Administrative Region			Minimum	Point Estimate	Maximum
REGION	I	New England	1.1	8.4	15.9
REGION	II	N.Y.-N.J.	2.1	16.1	30.5
REGION	III	Middle Atlantic	8.7	65.5	124.0
REGION	IV	South Atlantic	12.6	89.1	168.4
REGION	V	E.N. Central	56.1	423.3	800.0
REGION	VI	South Central	15.8	113.1	213.4
REGION	VII	Midwest	3.7	27.7	52.3
REGION	VIII	Mountain	7.0	50.4	95.3
REGION	IX	South Pacific	60.4	440.3	835.4
REGION	X	North Pacific	9.2	66.5	126.0
Total U.S.			176.7	1300.3	2461.1

Discounted Present Value in Millions of 1980 Dollars in 1982
Using a 10 Percent Rate of Discount.

	Minimum	Point Estimate	Maximum
Annualized Benefits Between 1989 and 1995 Total U.S.	70.7	520.5	985.1

Table 7-27

ESTIMATED BENEFITS FOR: MATHTECH HOUSEHOLD EXPENDITURE STUDY

Benefits Occurring Between 1989 and 1995
Scenario: Type B PM10 - 55 AAM/150 24-hr.

Federal Administrative Region			Minimum	Point Estimate	Maximum
REGION	I	New England	4.7	35.0	65.8
REGION	II	N.Y.-N.J.	4.1	30.5	57.6
REGION	III	Middle Atlantic	13.0	97.0	183.4
REGION	IV	South Atlantic	15.9	112.5	212.3
REGION	V	E.N. Central	63.3	477.8	902.8
REGION	VI	South Central	19.5	140.0	263.9
REGION	VII	Midwest	5.3	39.6	74.8
REGION	VIII	Mountain	10.0	71.6	135.1
REGION	IX	South Pacific	68.9	501.9	951.1
REGION	X	North Pacific	16.1	116.1	219.1
Total U.S.			220.7	1621.9	3065.9

Discounted Present Value in Millions of 1980 Dollars in 1982
Using a 10 Percent Rate of Discount.

Annualized Benefits Between 1989 and 1995 Total U.S.	88.3	649.2	1227.2

Table 7-28

ESTIMATED BENEFITS FOR: MATHTECH HOUSEHOLD EXPENDITURE STUDY

Benefits Occurring Between 1989 and 1995
Scenario: Type B PM10 - 55 AAM

Federal Administrative Region			Minimum	Point Estimate	Maximum
REGION	I	New England	1.1	8.4	15.9
REGION	II	N.Y.-N.J.	2.1	16.1	30.5
REGION	III	Middle Atlantic	8.7	65.5	124.0
REGION	IV	South Atlantic	12.6	89.1	168.4
REGION	V	E.N. Central	55.8	421.4	796.4
REGION	VI	South Central	15.5	111.1	209.8
REGION	VII	Midwest	3.7	27.5	52.0
REGION	VIII	Mountain	7.0	50.4	95.3
REGION	IX	South Pacific	60.4	440.3	835.3
REGION	X	North Pacific	8.3	59.8	113.3
Total U.S.			175.2	1289.5	2440.8

Discounted Present Value in Millions of 1980 Dollars in 1982
Using a 10 Percent Rate of Discount.

	Minimum	Point Estimate	Maximum
Annualized Benefits Between 1989 and 1995 Total U.S.	70.1	516.2	977.0

Table 7-29

ESTIMATED BENEFITS FOR: MATHTECH HOUSEHOLD EXPENDITURE STUDY

Benefits Occurring Between 1987 and 1995
Scenario: Type B TSP - 75 AAM/260 24-hr.

Federal Administrative Region			Minimum	Point Estimate	Maximum
REGION	I	New England	3.4	25.8	48.8
REGION	II	N.Y.-N.J.	4.5	33.7	63.7
REGION	III	Middle Atlantic	19.9	148.2	280.0
REGION	IV	South Atlantic	23.0	161.4	304.1
REGION	V	E.N. Central	103.3	777.6	1467.6
REGION	VI	South Central	28.1	200.2	377.0
REGION	VII	Midwest	8.9	66.9	126.4
REGION	VIII	Mountain	12.1	86.5	163.2
REGION	IX	South Pacific	108.9	788.1	1489.9
REGION	X	North Pacific	17.3	124.6	235.8
Total U.S.			329.4	2413.1	4556.4

Discounted Present Value in Millions of 1980 Dollars in 1982
Using a 10 Percent Rate of Discount.

Annualized Benefits Between 1987 and 1995 Total U.S.	92.1	674.8	1274.2

Table 7-30

ESTIMATED BENEFITS FOR: MATHTECH HOUSEHOLD EXPENDITURE STUDY

Benefits Occurring Between 1987 and 1995
Scenario: Type B TSP - 150 24-hr.

Federal Administrative Region			Minimum	Point Estimate	Maximum
REGION	I	New England	13.7	102.7	193.3
REGION	II	N.Y.-N.J.	9.3	69.8	131.7
REGION	III	Middle Atlantic	30.3	224.7	423.9
REGION	IV	South Atlantic	31.2	218.2	410.1
REGION	V	E.N. Central	120.6	907.0	1711.4
REGION	VI	South Central	34.8	247.6	466.0
REGION	VII	Midwest	16.0	119.9	226.0
REGION	VIII	Mountain	17.4	123.3	232.0
REGION	IX	South Pacific	129.7	937.1	1767.6
REGION	X	North Pacific	28.4	204.0	384.3
Total U.S.			431.1	3154.4	5946.4

Discounted Present Value in Millions of 1980 Dollars in 1982
Using a 10 Percent Rate of Discount.

	Minimum	Point Estimate	Maximum
Annualized Benefits Between 1987 and 1995 Total U.S.	120.6	882.1	1662.9

With the two adjustments for uncertainty, there are a variety of ways to define the overall range of benefits. We have chosen the option that yields the widest range. That is, the low estimate reflects the low price set in combination with a pollution coefficient that is two standard deviations below the estimated coefficient; the point estimate reflects the average (two-region) price set in combination with the estimated coefficient; and the high estimate reflects an evaluation of benefits for the high price set and an estimator two standard deviations above the estimated coefficient.

The benefit calculations shown in Tables 7-25 through 7-30 are carried out with SO_2 levels assumed constant at the current primary standard level (260 $\mu g/m^3$). In the MTH analysis, SO_2 is part of an interdependent system of equations so that its value, even if unchanging, can influence allocation decisions. Consequently, some measure of SO_2 must be included in the extrapolation procedure. Because SO_2 data are not available for many of the counties included in the PM10 scenarios, the SO_2 concentrations are fixed at 260 $\mu g/m^3$ for all counties. To test the sensitivity of the benefits calculations to this assumption, estimates were derived for other SO_2 levels. The estimates for the alternative SO_2 levels were quite close. For example, with all counties presumed to be at 100 $\mu g/m^3$, the estimate of total benefits corresponding to the point estimate in Table 7-25 is $733.8 million. This represents a difference of only $1.1 million.

Finally, Table 7-31 shows the benefits associated with the 70/250 PM10 standard when some counties remain in nonattainment after the contol strategy. As before, the benefits for this option are about 65 percent of the benefits when all counties are brought into attainment.

Synthesis of Household Sector Benefits —

Tables 7-11 through 7-31 of this section report the benefits accruing to the household sector from reduced soiling. For each study and each scenario, a range of benefit estimates is presented. This range reflects,

Table 7-31

ESTIMATED BENEFITS FOR: MATHTECH HOUSEHOLD EXPENDITURE STUDY

Benefits Occurring Between 1989 and 1995
Scenario: Type A PM10 - 70 AAM/250 24-hr.

Federal Administrative Region			Minimum	Point Estimate	Maximum
REGION	I	New England	0.0	0.0	0.0
REGION	II	N.Y.-N.J.	0.2	1.7	3.2
REGION	III	Middle Atlantic	4.5	34.2	65.0
REGION	IV	South Atlantic	4.4	31.1	59.3
REGION	V	E.N. Central	25.0	189.7	360.2
REGION	VI	South Central	6.1	44.1	83.8
REGION	VII	Midwest	1.2	9.1	17.3
REGION	VIII	Mountain	3.0	21.4	40.5
REGION	IX	South Pacific	15.9	116.8	223.6
REGION	X	North Pacific	2.1	15.4	29.7
Total U.S.			62.5	463.5	882.7

Discounted Present Value in Millions of 1980 Dollars in 1982
Using a 10 Percent Rate of Discount.

	Minimum	Point Estimate	Maximum
Annualized Benefits Between 1989 and 1995 Total U.S.	25.0	185.5	353.3

in part, the degree of uncertainty in the different studies due to model biases and/or methodological design.

The level of benefits estimates in the various tables may also be affected by biases that occur in the extrapolation to national benefits estimates. Examples of these types of biases are shown in Table 7-32. As can be seen from the table, most of the identified biases are common to each of the studies. Furthermore, because the direction of bias is not known in all cases, it is not possible to determine the impact of extrapolation on the soundness of the estimates. Thus, even if no model biases were present, there would still be uncertainty as to whether a particular benefit value was an over- or underestimate of the "true" level of benefits.

Although it is difficult to make objective judgments on the soundness of the various benefit estimates, consideration of the evaluation criteria, the model and extrapolation biases, and the impact of uncertainty can all help to provide a basis for making subjective judgments on the relative merits of each of the studies.

Because of model design and the manner in which benefits are calculated, we believe the MTH study should be weighted most heavily in the compilation of household benefits of reduced soiling. Since the estimates from this study fall at the low end of the range, and there is reason to believe that the MTH benefits are conservative estimates, a reasonable lower-bound estimate of overall benefits for each scenario is the point estimate of the MTH study.

The process of choosing an upper-bound estimate is more speculative. The option chosen involves adding the point estimates from the Watson and Jaksch (6) and Cummings (5) studies. The rationale for this choice is based on the types of benefits identified in the two studies. In particular, Cummings' model is designed to reflect both changes in out-of-pocket expenditures as well as the opportunity cost of labor time spent in cleaning activities, while the Watson and Jaksch model captures behavioral

Table 7-32

EXTRAPOLATION BIASES IN THE HOUSEHOLD SECTOR MODELS

Model	Description of Bias	Expected Impact on Benefits
Cummings *et al.*	1. The damage function is calculated from data for Philadelphia only.	Unknown
	2. The damage function is based on a TSP range that is less than that in U.S. counties included in extrapolation.	Unknown
	3. Air quality improvements are experienced only in the counties included in air quality data file.	Underestimate of benefits
	4. Population exposure calculated from improvements observed only at design value monitor.	Probable overestimate of benefits
Watson & Jaksch	1. Demand and supply curves are based only on data from Philadelphia.	Unknown
	2. Per-household expenditures are assumed constant across all counties (equal to per-household expenditures in Philadelphia).	Unknown
	3. The data underlying the unit elastic demand curve are drawn from a limited range of TSP values.	Unknown

(continued)

Table 7-32 (Continued)

Model	Description of Bias	Expected Impact on Benefits
Watson & Jaksch (continued)	4. Air quality improvements are experienced only in the counties included in the air quality data file.	Underestimate of benefits
	5. Population exposure calculated from improvements observed only at design value monitor.	Probable overestimate of benefits
Mathtech	1. TSP elasticities for all counties are generated from a model that includes only 24 SMSAs.	Unknown
	2. Price data are assigned to counties based on regional averages.	Unknown
	3. The household model is estimated for a range of TSP concentrations that is more narrow than the range implied in the extrapolation.	Unknown
	4. Air quality improvements are experienced only in the counties included in the air quality data file.	Underestimate of benefits
	5. Population exposure calculated from improvements observed only at design value monitor.	Probable overestimate of benefits

adjustments based on utility and cost considerations. Since the sum of benefits across these two studies likely contains double-counting, we believe that the sum should be viewed as an upper-bound estimate. The extent to which thesum is an upper-bound also depends on the accuracy of the underlying studies. Unfortunately, since many of the biases that are present in the two studies affect benefits in an unknown direction, with an unknown magnitude, it is not possible to determine whether the studies lead to over- or underestimates of benefits. However, because of the potential for double-counting, it is our judgment that the sum of benefits from these two studies provides a reasonable upper-bound estimate of the benefits from reduced soiling.

The point estimate of benefits is calculated as the geometric mean of the lower- and upper-bound estimates. If equal weight were given to each of the studies, then the logical choice for the point estimate would be taken from the Watson and Jaksch results, since the results of this study fall between Cummings and MTH. However, we believe more weight should be given to the MTH results. Thus, we have chosen to use the geometric mean, which gives less weight to higher values (relative to the arithmetic mean).

Table 7-33 summarizes the range of benefits estimated for the household sector for each of the scenarios. For each scenario, the upper-bound estimate is about 20 times larger than the lower-bound estimate. This wide range in benefits estimates reflects, in large part, the uncertainty that is currently present in the modeling and estimation of household soiling models.

Manufacturing Sector

Mathtech Manufacturing Model (8) —

The basic analysis of the MTM study was limited to the analysis of six 3-digit SIC industries comprising about 8.3 percent of the value added in the manufacturing sector. The analysis was restricted to this subset of industries because of data limitations. From this group of six industries,

Table 7-33

SUMMARY OF BENEFITS FROM REDUCED SOILING IN THE HOUSEHOLD SECTOR*

Standard	Benefit		
	Minimum	Point	Maximum
PM10 70/250	0.73	3.14	13.85
PM10 55/250	1.30	5.68	25.72
PM10 55/150	1.62	7.16	32.76
PM10 55	1.29	5.64	25.53
TSP 75/260	2.41	10.74	49.90
TSP 150	3.15	14.21	66.36

* Discounted present values in 1982 in billions of 1980 dollars.

PM was found to be an important explanatory variable in the cost relationships for two of the industries. Thus, the coverage in the basic analysis of MTM is small.

Extrapolation of the MTM results to more complete estimates of national benefits can be done in several ways. First, the geographic coverage of the two PM-sensitive industries could be extended to other areas of the country. However, since the original MTM data collection effort included all the county-level economic data which were available, no additional county coverage could be obtained.

The alternative possibility is to extrapolate the results for the two PM-sensitive industries to other closely related manufacturing industries. For example, instead of conducting the analysis at the 3-digit level, one might take the view that all 3-digit industries in a given 2-digit group can be treated similarly. That is, results for SIC 354 could be treated as representative of effects for all 3-digit SICs in the 2-digit SIC 35. If this approach is taken, extrapolated benefits could be obtained for two 2-digit SICs: SIC 34 and SIC 35.

The extrapolation to other industries raises at least two questions. First, can the effects identified in a subindustry (e.g., SIC 344) be viewed as representative of the effects in the broader industry group? Second, if so, how should the extrapolation be carried out? The first question cannot be answered definitively without actually conducting a specific analysis of other subindustries in each group. Clearly, there are similarities among the various 3-digit industries within a 2-digit group. The similarities can include the use of common raw materials, similar processing techniques, and most importantly, the production of related end products. However, the industries can also be different in important ways, and it is the latter fact which guided the selection of an extrapolation procedure.

One possible extrapolation procedure would be to apply the estimated models from the MTM basic analysis to data for the corresponding 2-digit industries. Data and conceptual problems prevented this alternative from being applied. Consequently, a less formal extrapolation procedure was adopted. The procedure involves answering the following question: If the benefits of improved air quality at the 2-digit level were the same as at the 3-digit level in terms of the percentage savings in production cost for a given change in air quality, how large would benefits be? Note that this approach does not necessarily require that the underlying production technologies be the same — only that air quality benefits, on a percentage basis, be the same.

In order to calculate the extrapolated benefits using the approach described above, data are collected on the value of shipments for both 2-digit and 3-digit industries on a county basis. With estimates of benefits available for the 3-digit industries, a normalizing factor is estimated for each county which reflects the dollar benefits, per dollar of value shipped, per unit change in air quality. In order to establish a probable range for the factor, the minimum, maximum and average across all counties (in the analysis) are calculated. Given county-specific air quality data and value of shipments at the 2-digit level, the three derived normalizing factors can be used to calculate a range of benefits for the 2-digit industries. Note that with the use of the more aggregate 2-digit industry data, data are available for more counties than in the analysis of 3-digit industries. Hence, extrapolation to the industry level means that more counties can be considered in the 2-digit analysis.

Benefits estimates for the two 3-digit SICs are given in Tables 7-34 through 7-45. The first six tables correspond to SIC 344 and represent benefits for the six scenarios shown in Table 7-10. As in the household sector, these numbers represent the case where all counties are brought into attainment throughout the analysis period. Furthermore, because county average second-high 24-hour average TSP data were used in the MTM study, a correction factor to reflect facility exposure relative to the design value monitor readings has been utilized.*

In the tables for the 3-digit SICs, note that only point estimates are given. The nonlinear (in TSP) system used to estimate the cost functions for the various industries make it difficult to compute statistically correct confidence intervals.

Tables 7-40 through 7-45 present the benefit estimates for SIC 354. In this group of tables, the more lenient standards report no benefits for several of the EPA regions. This does not necessarily imply that no TSP benefits will occur in these areas. The zero entries occur because the necessary economic data were not available for counties in these areas. Consequently, no benefits could be calculated.

Tables 7-46 through 7-57 show the benefit estimates for the two 2-digit SICs. As before, six tables are shown for each SIC, corresponding to

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* See Section 9 for a description of the process used to estimate this correction factor.

Table 7-34

ESTIMATED BENEFITS FOR: MATHTECH MANUFACTURING EXPENDITURE STUDY
SIC 344

Benefits Occurring Between 1989 and 1995
Scenario: Type B PM10 - 70 AAM/250 24-hr.

Federal Administrative Region		Minimum	Point Estimate	Maximum
REGION I	New England	0.0	0.0	0.0
REGION II	N.Y.-N.J.	0.0	0.0	0.0
REGION III	Middle Atlantic	0.0	99.1	0.0
REGION IV	South Atlantic	0.0	67.9	0.0
REGION V	E.N. Central	0.0	403.7	0.0
REGION VI	South Central	0.0	140.2	0.0
REGION VII	Midwest	0.0	0.0	0.0
REGION VIII	Mountain	0.0	12.3	0.0
REGION IX	South Pacific	0.0	51.3	0.0
REGION X	North Pacific	0.0	32.9	0.0
Total U.S.		0.0	807.4	0.0

Discounted Present Value in Millions of 1980 Dollars in 1982
Using a 10 Percent Rate of Discount.

Annualized Benefits Between 1989 and 1995 Total U.S.	0.0	323.2	0.0

Table 7-35

ESTIMATED BENEFITS FOR: MATHTECH MANUFACTURING EXPENDITURE STUDY
SIC 344

Benefits Occurring Between 1989 and 1995
Scenario: Type B PM10 - 55 AAM/250 24-hr.

Federal Administrative Region			Minimum	Point Estimate	Maximum
REGION	I	New England	0.0	7.7	0.0
REGION	II	N.Y.-N.J.	0.0	14.7	0.0
REGION	III	Middle Atlantic	0.0	221.5	0.0
REGION	IV	South Atlantic	0.0	225.5	0.0
REGION	V	E.N. Central	0.0	756.9	0.0
REGION	VI	South Central	0.0	269.2	0.0
REGION	VII	Midwest	0.0	39.6	0.0
REGION	VIII	Mountain	0.0	47.1	0.0
REGION	IX	South Pacific	0.0	83.9	0.0
REGION	X	North Pacific	0.0	37.1	0.0
Total U.S.			0.0	1703.1	0.0

Discounted Present Value in Millions of 1980 Dollars in 1982
Using a 10 Percent Rate of Discount.

Annualized Benefits Between 1989 and 1995 Total U.S.	0.0	681.7	0.0

Table 7-36

ESTIMATED BENEFITS FOR: MATHTECH MANUFACTURING EXPENDITURE STUDY
SIC 344

Benefits Occurring Between 1989 and 1995
Scenario: Type B PM10 - 55 AAM/150 24-hr.

Federal Administrative Region			Minimum	Point Estimate	Maximum
REGION	I	New England	0.0	134.1	0.0
REGION	II	N.Y.-N.J.	0.0	45.7	0.0
REGION	III	Middle Atlantic	0.0	299.1	0.0
REGION	IV	South Atlantic	0.0	294.9	0.0
REGION	V	E.N. Central	0.0	789.9	0.0
REGION	VI	South Central	0.0	309.7	0.0
REGION	VII	Midwest	0.0	66.9	0.0
REGION	VIII	Mountain	0.0	76.6	0.0
REGION	IX	South Pacific	0.0	105.5	0.0
REGION	X	North Pacific	0.0	97.2	0.0
Total U.S.			0.0	2219.5	0.0

Discounted Present Value in Millions of 1980 Dollars in 1982
Using a 10 Percent Rate of Discount.

	Minimum	Point Estimate	Maximum
Annualized Benefits Between 1989 and 1995 Total U.S.	0.0	888.4	0.0

Table 7-37

ESTIMATED BENEFITS FOR: MATHTECH MANUFACTURING EXPENDITURE STUDY
SIC 344

Benefits Occurring Between 1989 and 1995
Scenario: Type B PM10 - 55 AAM

Federal Administrative Region			Minimum	Point Estimate	Maximum
REGION	I	New England	0.0	7.7	0.0
REGION	II	N.Y.-N.J.	0.0	14.7	0.0
REGION	III	Middle Atlantic	0.0	221.5	0.0
REGION	IV	South Atlantic	0.0	225.5	0.0
REGION	V	E.N. Central	0.0	756.9	0.0
REGION	VI	South Central	0.0	266.4	0.0
REGION	VII	Midwest	0.0	39.6	0.0
REGION	VIII	Mountain	0.0	47.1	0.0
REGION	IX	South Pacific	0.0	83.9	0.0
REGION	X	North Pacific	0.0	37.1	0.0
Total U.S.			0.0	1700.3	0.0

Discounted Present Value in Millions of 1980 Dollars in 1982
Using a 10 Percent Rate of Discount.

	Minimum	Point Estimate	Maximum
Annualized Benefits Between 1989 and 1995 Total U.S.	0.0	680.6	0.0

Table 7-38

ESTIMATED BENEFITS FOR: MATHTECH MANUFACTURING EXPENDITURE STUDY
SIC 344

Benefits Occurring Between 1987 and 1995
Scenario: Type B TSP - 75 AAM/260 24-hr.

Federal Administrative Region		Minimum	Point Estimate	Maximum
REGION I	New England	0.0	27.3	0.0
REGION II	N.Y.-N.J.	0.0	36.1	0.0
REGION III	Middle Atlantic	0.0	427.4	0.0
REGION IV	South Atlantic	0.0	413.5	0.0
REGION V	E.N. Central	0.0	1482.2	0.0
REGION VI	South Central	0.0	521.0	0.0
REGION VII	Midwest	0.0	129.0	0.0
REGION VIII	Mountain	0.0	73.0	0.0
REGION IX	South Pacific	0.0	164.6	0.0
REGION X	North Pacific	0.0	67.6	0.0
Total U.S.		0.0	3341.6	0.0

Discounted Present Value in Millions of 1980 Dollars in 1982
Using a 10 Percent Rate of Discount.

Annualized Benefits Between 1987 and 1995 Total U.S.	0.0	934.5	0.0

Table 7-39

ESTIMATED BENEFITS FOR: MATHTECH MANUFACTURING EXPENDITURE STUDY
SIC 344

Benefits Occurring Between 1987 and 1995
Scenario: Type B TSP - 150 24-hr.

Federal Administrative Region			Minimum	Point Estimate	Maximum
REGION	I	New England	0.0	225.2	0.0
REGION	II	N.Y.-N.J.	0.0	102.1	0.0
REGION	III	Middle Atlantic	0.0	623.4	0.0
REGION	IV	South Atlantic	0.0	599.5	0.0
REGION	V	E.N. Central	0.0	1527.6	0.0
REGION	VI	South Central	0.0	502.7	0.0
REGION	VII	Midwest	0.0	271.0	0.0
REGION	VIII	Mountain	0.0	125.5	0.0
REGION	IX	South Pacific	0.0	116.7	0.0
REGION	X	North Pacific	0.0	149.6	0.0
Total U.S.			0.0	4243.2	0.0

Discounted Present Value in Millions of 1980 Dollars in 1982
Using a 10 Percent Rate of Discount.

Annualized Benefits Between 1987 and 1995 Total U.S.	0.0	1186.6	0.0

Table 7-40

ESTIMATED BENEFITS FOR: MATHTECH MANUFACTURING EXPENDITURE STUDY
SIC 354

Benefits Occurring Between 1989 and 1995
Scenario: Type B PM10 - 70 AAM/250 24-hr.

Federal Administrative Region			Minimum	Point Estimate	Maximum
REGION	I	New England	0.0	0.0	0.0
REGION	II	N.Y.-N.J.	0.0	2.4	0.0
REGION	III	Middle Atlantic	0.0	34.8	0.0
REGION	IV	South Atlantic	0.0	1.2	0.0
REGION	V	E.N. Central	0.0	680.4	0.0
REGION	VI	South Central	0.0	10.2	0.0
REGION	VII	Midwest	0.0	0.0	0.0
REGION	VIII	Mountain	0.0	0.0	0.0
REGION	IX	South Pacific	0.0	1.0	0.0
REGION	X	North Pacific	0.0	0.0	0.0
Total U.S.			0.0	730.0	0.0

Discounted Present Value in Millions of 1980 Dollars in 1982
Using a 10 Percent Rate of Discount.

	Minimum	Point Estimate	Maximum
Annualized Benefits Between 1989 and 1995 Total U.S.	0.0	292.2	0.0

Table 7-41

ESTIMATED BENEFITS FOR: MATHTECH MANUFACTURING EXPENDITURE STUDY
SIC 354

Benefits Occurring Between 1989 and 1995
Scenario: Type B PM10 - 55 AAM/250 24-hr.

Federal Administrative Region			Minimum	Point Estimate	Maximum
REGION	I	New England	0.0	7.1	0.0
REGION	II	N.Y.-N.J.	0.0	25.4	0.0
REGION	III	Middle Atlantic	0.0	62.1	0.0
REGION	IV	South Atlantic	0.0	2.7	0.0
REGION	V	E.N. Central	0.0	1199.3	0.0
REGION	VI	South Central	0.0	20.4	0.0
REGION	VII	Midwest	0.0	2.4	0.0
REGION	VIII	Mountain	0.0	0.0	0.0
REGION	IX	South Pacific	0.0	1.8	0.0
REGION	X	North Pacific	0.0	0.0	0.0
Total U.S.			0.0	1321.3	0.0

Discounted Present Value in Millions of 1980 Dollars in 1982
Using a 10 Percent Rate of Discount.

Annualized Benefits Between 1989 and 1995 Total U.S.	0.0	528.9	0.0

Table 7-42

ESTIMATED BENEFITS FOR: MATHTECH MANUFACTURING EXPENDITURE STUDY
SIC 354

Benefits Occurring Between 1989 and 1995
Scenario: Type B PM10 - 55 AAM/150 24-hr.

Federal Administrative Region			Minimum	Point Estimate	Maximum
REGION	I	New England	0.0	94.3	0.0
REGION	II	N.Y.-N.J.	0.0	61.2	0.0
REGION	III	Middle Atlantic	0.0	70.6	0.0
REGION	IV	South Atlantic	0.0	4.8	0.0
REGION	V	E.N. Central	0.0	1219.0	0.0
REGION	VI	South Central	0.0	23.4	0.0
REGION	VII	Midwest	0.0	5.4	0.0
REGION	VIII	Mountain	0.0	0.0	0.0
REGION	IX	South Pacific	0.0	1.9	0.0
REGION	X	North Pacific	0.0	0.0	0.0
Total U.S.			0.0	1480.5	0.0

Discounted Present Value in Millions of 1980 Dollars in 1982
Using a 10 Percent Rate of Discount.

	Minimum	Point Estimate	Maximum
Annualized Benefits Between 1989 and 1995 Total U.S.	0.0	592.6	0.0

Table 7-43

ESTIMATED BENEFITS FOR: MATHTECH MANUFACTURING EXPENDITURE STUDY
SIC 354

Benefits Occurring Between 1989 and 1995
Scenario: Type B PM10 - 55 AAM

Federal Administrative Region	Minimum	Point Estimate	Maximum
REGION I New England	0.0	7.1	0.0
REGION II N.Y.-N.J.	0.0	25.4	0.0
REGION III Middle Atlantic	0.0	62.1	0.0
REGION IV South Atlantic	0.0	2.7	0.0
REGION V E.N. Central	0.0	1199.3	0.0
REGION VI South Central	0.0	20.4	0.0
REGION VII Midwest	0.0	2.4	0.0
REGION VIII Mountain	0.0	0.0	0.0
REGION IX South Pacific	0.0	1.8	0.0
REGION X North Pacific	0.0	0.0	0.0
Total U.S.	0.0	1321.3	0.0

Discounted Present Value in Millions of 1980 Dollars in 1982
Using a 10 Percent Rate of Discount.

Annualized Benefits Between 1989 and 1995 Total U.S.	0.0	528.9	0.0

Table 7-44

ESTIMATED BENEFITS FOR: MATHTECH MANUFACTURING EXPENDITURE STUDY
SIC 354

Benefits Occurring Between 1987 and 1995
Scenario: Type B TSP - 75 AAM/260 24-hr.

Federal Administrative Region			Minimum	Point Estimate	Maximum
REGION	I	New England	0.0	20.8	0.0
REGION	II	N.Y.-N.J.	0.0	47.4	0.0
REGION	III	Middle Atlantic	0.0	122.1	0.0
REGION	IV	South Atlantic	0.0	6.9	0.0
REGION	V	E.N. Central	0.0	2164.3	0.0
REGION	VI	South Central	0.0	41.0	0.0
REGION	VII	Midwest	0.0	20.5	0.0
REGION	VIII	Mountain	0.0	0.0	0.0
REGION	IX	South Pacific	0.0	4.3	0.0
REGION	X	North Pacific	0.0	0.0	0.0
Total U.S.			0.0	2427.2	0.0

Discounted Present Value in Millions of 1980 Dollars in 1982
Using a 10 Percent Rate of Discount.

Annualized Benefits Between 1987 and 1995 Total U.S.	0.0	678.8	0.0

Table 7-45

ESTIMATED BENEFITS FOR: MATHTECH MANUFACTURING EXPENDITURE STUDY
SIC 354

Benefits Occurring Between 1987 and 1995
Scenario: Type B TSP - 150 24-hr.

Federal Administrative Region			Minimum	Point Estimate	Maximum
REGION	I	New England	0.0	192.2	0.0
REGION	II	N.Y.-N.J.	0.0	107.7	0.0
REGION	III	Middle Atlantic	0.0	157.7	0.0
REGION	IV	South Atlantic	0.0	10.0	0.0
REGION	V	E.N. Central	0.0	2229.8	0.0
REGION	VI	South Central	0.0	40.2	0.0
REGION	VII	Midwest	0.0	65.1	0.0
REGION	VIII	Mountain	0.0	0.0	0.0
REGION	IX	South Pacific	0.0	5.4	0.0
REGION	X	North Pacific	0.0	0.0	0.0
Total U.S.			0.0	2808.1	0.0

Discounted Present Value in Millions of 1980 Dollars in 1982
Using a 10 Percent Rate of Discount.

Annualized Benefits Between 1987 and 1995 Total U.S.	0.0	785.3	0.0

Table 7-46

ESTIMATED BENEFITS FOR: MATHTECH MANUFACTURING EXPENDITURE STUDY
SIC 34

Benefits Occurring Between 1989 and 1995
Scenario: Type B PM10 - 70 AAM/250 24-hr.

Federal Administrative Region			Minimum	Point Estimate	Maximum
REGION	I	New England	0.0	0.0	0.0
REGION	II	N.Y.-N.J.	0.0	0.0	0.0
REGION	III	Middle Atlantic	136.9	251.4	368.8
REGION	IV	South Atlantic	97.5	179.0	262.6
REGION	V	E.N. Central	1082.0	1986.0	2912.9
REGION	VI	South Central	166.8	306.0	448.8
REGION	VII	Midwest	13.4	24.6	36.0
REGION	VIII	Mountain	20.6	37.9	55.6
REGION	IX	South Pacific	332.2	609.9	894.8
REGION	X	North Pacific	65.2	119.7	175.6
Total U.S.			1914.6	3514.5	5155.1

Discounted Present Value in Millions of 1980 Dollars in 1982
Using a 10 Percent Rate of Discount.

	Minimum	Point Estimate	Maximum
Annualized Benefits Between 1989 and 1995 Total U.S.	766.4	1406.8	2063.5

Table 7-47

ESTIMATED BENEFITS FOR: MATHTECH MANUFACTURING EXPENDITURE STUDY
SIC 34

Benefits Occurring Between 1989 and 1995
Scenario: Type B PM10 - 55 AAM/250 24-hr.

Federal Administrative Region			Minimum	Point Estimate	Maximum
REGION	I	New England	47.5	88.7	139.4
REGION	II	N.Y.-N.J.	50.7	94.7	148.8
REGION	III	Middle Atlantic	263.4	491.9	772.6
REGION	IV	South Atlantic	257.8	481.5	756.4
REGION	V	E.N. Central	1910.7	3568.1	5604.5
REGION	VI	South Central	309.6	578.0	907.7
REGION	VII	Midwest	78.0	145.6	228.7
REGION	VIII	Mountain	67.4	125.9	197.7
REGION	IX	South Pacific	750.1	1401.0	2201.1
REGION	X	North Pacific	88.1	164.5	258.5
Total U.S.			3823.3	7139.9	11215.4

Discounted Present Value in Millions of 1980 Dollars in 1982
Using a 10 Percent Rate of Discount.

Annualized Benefits Between 1989 and 1995 Total U.S.	1530.4	2858.0	4489.3

Table 7-48

ESTIMATED BENEFITS FOR: MATHTECH MANUFACTURING EXPENDITURE STUDY
SIC 34

Benefits Occurring Between 1989 and 1995
Scenario: Type B PM10 - 55 AAM/150 24-hr.

Federal Administrative Region			Minimum	Point Estimate	Maximum
REGION	I	New England	223.0	391.2	713.1
REGION	II	N.Y.-N.J.	120.4	211.2	384.9
REGION	III	Middle Atlantic	385.6	676.4	1232.8
REGION	IV	South Atlantic	359.1	630.0	1148.2
REGION	V	E.N. Central	2519.6	4420.3	8056.5
REGION	VI	South Central	405.7	711.5	1296.9
REGION	VII	Midwest	152.3	267.2	487.0
REGION	VIII	Mountain	142.2	249.4	454.6
REGION	IX	South Pacific	1014.3	1780.2	3244.6
REGION	X	North Pacific	185.7	326.0	594.1
Total U.S.			5507.9	9663.3	17612.7

Discounted Present Value in Millions of 1980 Dollars in 1982
Using a 10 Percent Rate of Discount.

	Minimum	Point Estimate	Maximum
Annualized Benefits Between 1989 and 1995 Total U.S.	2204.7	3868.0	7050.0

Table 7-49

ESTIMATED BENEFITS FOR: MATHTECH MANUFACTURING EXPENDITURE STUDY
SIC 34

Benefits Occurring Between 1989 and 1995
Scenario: Type B PM10 - 55 AAM

Federal Administrative Region			Minimum	Point Estimate	Maximum
REGION	I	New England	47.5	88.3	139.4
REGION	II	N.Y.-N.J.	50.7	94.3	148.8
REGION	III	Middle Atlantic	263.4	489.8	772.6
REGION	IV	South Atlantic	257.8	479.5	756.4
REGION	V	E.N. Central	1910.7	3553.1	5604.5
REGION	VI	South Central	308.1	572.7	903.3
REGION	VII	Midwest	78.0	145.0	228.7
REGION	VIII	Mountain	67.4	125.3	197.7
REGION	IX	South Pacific	750.1	1395.1	2201.1
REGION	X	North Pacific	88.1	163.8	258.5
Total U.S.			3821.7	7107.1	11211.0

Discounted Present Value in Millions of 1980 Dollars in 1982
Using a 10 Percent Rate of Discount.

Annualized Benefits Between 1989 and 1995 Total U.S.	1529.8	2844.8	4487.5

Table 7-50

ESTIMATED BENEFITS FOR: MATHTECH MANUFACTURING EXPENDITURE STUDY
SIC 34

Benefits Occurring Between 1987 and 1995
Scenario: Type B TSP - 75 AAM/260 24-hr.

Federal Administrative Region			Minimum	Point Estimate	Maximum
REGION	I	New England	144.8	267.5	385.0
REGION	II	N.Y.-N.J.	121.1	223.7	322.0
REGION	III	Middle Atlantic	566.5	1046.2	1505.3
REGION	IV	South Atlantic	466.3	861.2	1239.3
REGION	V	E.N. Central	3748.6	6923.0	9961.4
REGION	VI	South Central	585.2	1080.5	1554.5
REGION	VII	Midwest	246.4	455.0	654.7
REGION	VIII	Mountain	152.6	281.9	405.7
REGION	IX	South Pacific	1542.9	2850.8	4103.2
REGION	X	North Pacific	149.6	276.4	397.9
Total U.S.			7724.0	14266.3	20528.9

Discounted Present Value in Millions of 1980 Dollars in 1982
Using a 10 Percent Rate of Discount.

	Minimum	Point Estimate	Maximum
Annualized Benefits Between 1987 and 1995 Total U.S.	2160.0	3989.6	5740.9

Table 7-51

ESTIMATED BENEFITS FOR: MATHTECH MANUFACTURING EXPENDITURE STUDY
SIC 34

Benefits Occurring Between 1987 and 1995
Scenario: Type B TSP - 150 24-hr.

Federal Administrative Region			Minimum	Point Estimate	Maximum
REGION	I	New England	551.1	1008.2	1663.5
REGION	II	N.Y.-N.J.	267.3	489.1	807.0
REGION	III	Middle Atlantic	858.4	1570.5	2591.1
REGION	IV	South Atlantic	660.4	1208.8	1994.5
REGION	V	E.N. Central	4775.9	8738.0	14417.1
REGION	VI	South Central	634.8	1161.0	1915.6
REGION	VII	Midwest	457.8	837.7	1382.2
REGION	VIII	Mountain	246.6	451.2	744.5
REGION	IX	South Pacific	1987.5	3638.9	6003.8
REGION	X	North Pacific	296.6	543.1	896.0
Total U.S.			10736.3	19646.6	32415.4

Discounted Present Value in Millions of 1980 Dollars in 1982
Using a 10 Percent Rate of Discount.

Annualized Benefits Between 1987 and 1995 Total U.S.	3002.4	5494.2	9065.0

Table 7-52

ESTIMATED BENEFITS FOR: MATHTECH MANUFACTURING EXPENDITURE STUDY
SIC 35

Benefits Occurring Between 1989 and 1995
Scenario: Type B PM10 - 70 AAM/250 24-hr.

Federal Administrative Region			Minimum	Point Estimate	Maximum
REGION	I	New England	0.0	0.0	0.0
REGION	II	N.Y.-N.J.	10.3	28.4	45.1
REGION	III	Middle Atlantic	119.5	327.6	521.3
REGION	IV	South Atlantic	67.4	184.8	294.0
REGION	V	E.N. Central	1148.7	3148.3	5008.4
REGION	VI	South Central	261.0	715.2	1137.8
REGION	VII	Midwest	0.0	0.0	0.0
REGION	VIII	Mountain	26.4	72.5	115.3
REGION	IX	South Pacific	460.8	1263.4	2009.9
REGION	X	North Pacific	71.7	196.7	313.0
Total U.S.			2165.8	5936.9	9444.8

Discounted Present Value in Millions of 1980 Dollars in 1982
Using a 10 Percent Rate of Discount.

Annualized Benefits Between 1989 and 1995 Total U.S.	866.9	2376.4	3780.5

Table 7-53

ESTIMATED BENEFITS FOR: MATHTECH MANUFACTURING EXPENDITURE STUDY
SIC 35

Benefits Occurring Between 1989 and 1995
Scenario: Type B PM10 - 55 AAM/250 24-hr.

Federal Administrative Region			Minimum	Point Estimate	Maximum
REGION	I	New England	26.5	73.9	116.5
REGION	II	N.Y.-N.J.	152.2	423.9	668.7
REGION	III	Middle Atlantic	262.3	730.2	1151.9
REGION	IV	South Atlantic	170.4	474.8	749.0
REGION	V	E.N. Central	2381.9	6631.7	10461.5
REGION	VI	South Central	502.9	1399.8	2208.2
REGION	VII	Midwest	10.6	29.6	46.7
REGION	VIII	Mountain	146.2	407.1	642.2
REGION	IX	South Pacific	1054.5	2937.4	4633.6
REGION	X	North Pacific	94.2	262.6	414.2
Total U.S.			4801.7	13370.9	21092.5

Discounted Present Value in Millions of 1980 Dollars in 1982
Using a 10 Percent Rate of Discount.

Annualized Benefits Between 1989 and 1995 Total U.S.	1922.0	5352.1	8442.8

Table 7-54

ESTIMATED BENEFITS FOR: MATHTECH MANUFACTURING EXPENDITURE STUDY
SIC 35

Benefits Occurring Between 1989 and 1995
Scenario: Type B PM10 - 55 AAM/150 24-hr.

Federal Administrative Region			Minimum	Point Estimate	Maximum
REGION	I	New England	202.6	562.6	875.0
REGION	II	N.Y.-N.J.	246.6	685.1	1065.5
REGION	III	Middle Atlantic	341.2	947.9	1474.2
REGION	IV	South Atlantic	213.6	593.8	923.5
REGION	V	E.N. Central	2704.5	7514.9	11686.4
REGION	VI	South Central	594.6	1651.9	2568.9
REGION	VII	Midwest	43.7	121.5	188.9
REGION	VIII	Mountain	214.2	595.2	925.6
REGION	IX	South Pacific	1213.1	3372.8	5244.9
REGION	X	North Pacific	192.3	535.0	831.9
Total U.S.			5966.4	16580.8	25784.8

Discounted Present Value in Millions of 1980 Dollars in 1982
Using a 10 Percent Rate of Discount.

	Minimum	Point Estimate	Maximum
Annualized Benefits Between 1989 and 1995 Total U.S.	2388.2	6636.9	10321.1

Table 7-55

ESTIMATED BENEFITS FOR: MATHTECH MANUFACTURING EXPENDITURE STUDY
SIC 35

Benefits Occurring Between 1989 and 1995
Scenario: Type B PM10 - 55 AAM

Federal Administrative Region			Minimum	Point Estimate	Maximum
REGION	I	New England	26.5	73.9	116.5
REGION	II	N.Y.-N.J.	152.2	423.9	668.7
REGION	III	Middle Atlantic	262.3	730.2	1151.9
REGION	IV	South Atlantic	170.4	474.8	749.0
REGION	V	E.N. Central	2322.5	6466.2	10200.4
REGION	VI	South Central	480.9	1338.4	2111.4
REGION	VII	Midwest	10.6	29.6	46.7
REGION	VIII	Mountain	146.2	407.1	642.2
REGION	IX	South Pacific	1054.5	2937.4	4633.6
REGION	X	North Pacific	94.2	262.6	414.2
Total U.S.			4720.3	13144.1	20734.6

Discounted Present Value in Millions of 1980 Dollars in 1982
Using a 10 Percent Rate of Discount.

Annualized Benefits Between 1989 and 1995 Total U.S.	1889.4	5261.3	8299.6

Table 7-56

ESTIMATED BENEFITS FOR: MATHTECH MANUFACTURING EXPENDITURE STUDY
SIC 35

Benefits Occurring Between 1987 and 1995
Scenario: Type B TSP - 75 AAM/260 24-hr.

Federal Administrative Region			Minimum	Point Estimate	Maximum
REGION	I	New England	119.0	278.9	472.0
REGION	II	N.Y.-N.J.	361.0	846.3	1432.2
REGION	III	Middle Atlantic	684.8	1604.4	2715.2
REGION	IV	South Atlantic	374.8	879.3	1488.1
REGION	V	E.N. Central	5781.8	13544.3	22921.8
REGION	VI	South Central	1009.6	2363.6	4000.0
REGION	VII	Midwest	99.1	232.6	393.6
REGION	VIII	Mountain	272.5	638.6	1080.8
REGION	IX	South Pacific	2415.9	5667.0	9590.4
REGION	X	North Pacific	181.0	424.8	718.9
Total U.S.			11299.5	26479.7	44813.0

Discounted Present Value in Millions of 1980 Dollars in 1982
Using a 10 Percent Rate of Discount.

	Minimum	Point Estimate	Maximum
Annualized Benefits Between 1987 and 1995 Total U.S.	3159.9	7405.1	12531.9

Table 7-57

ESTIMATED BENEFITS FOR: MATHTECH MANUFACTURING EXPENDITURE STUDY
SIC 35

Benefits Occurring Between 1987 and 1995
Scenario: Type B TSP - 150 24-hr.

Federal Administrative Region			Minimum	Point Estimate	Maximum
REGION	I	New England	797.9	1811.8	2949.0
REGION	II	N.Y.-N.J.	627.0	1424.7	2318.8
REGION	III	Middle Atlantic	1022.9	2323.9	3782.5
REGION	IV	South Atlantic	497.6	1132.4	1843.0
REGION	V	E.N. Central	7297.1	16577.0	26981.5
REGION	VI	South Central	1143.1	2596.2	4225.8
REGION	VII	Midwest	332.6	756.0	1230.4
REGION	VIII	Mountain	463.1	1051.8	1711.9
REGION	IX	South Pacific	3049.6	6936.7	11289.7
REGION	X	North Pacific	384.7	875.4	1424.7
Total U.S.			15615.5	35485.9	57757.4

Discounted Present Value in Millions of 1980 Dollars in 1982
Using a 10 Percent Rate of Discount.

Annualized Benefits Between 1987 and 1995 Total U.S.	4366.9	9923.6	16151.8

the six scenarios described in Table 7-10. These tables are also based on complete attainment of the various standards, and the correction factor for facility exposure has been incorporated in the estimates. In this group of tables, minimum and maximum estimates are presented in addition to the point estimates. As described above, these bounding values are calculated from the minimum and maximum values of the normalizing factor.

Finally, for comparative purposes, Tables 7-58 through 7-61 show the benefits that would accrue for the two 2-digit SICs and the two 3-digit SICs when not all counties are assumed to be in attainment throughout the analysis period. The estimates in these tables are given only for the 70/250 PM10 standard.

At the conclusion of the section describing the benefits models, a table of model biases was presented. Of the six biases listed for the MTM study, four were identified as having an "unknown" impact on the benefit estimates. As a consequence, it is not possible to determine conclusively whether the estimates shown above represent over- or underestimates of some "true" level of benefits <u>for the SICs</u> examined in MTM. If production costs of other industries are also affected by changes in TSP, then the estimates of this section represent conservative estimates of benefits for the total manufacturing sector.

In addition to the model biases, there are several biases that arise in the course of estimating national benefits. One of these biases, the concern with a limited number of SICs, was mentioned above. Other biases of this type include:

- A limited number of counties are included in the extrapolation since confidentiality restrictions do not allow identification of needed economic data in all cases.
- It is assumed that air quality improvements are experienced only in the counties included in the air quality data file.
- The procedure for benefits calculation assumes a perfectly inelastic demand for plant output.

Table 7-58

ESTIMATED BENEFITS FOR: MATHTECH MANUFACTURING EXPENDITURE STUDY
SIC 344

Benefits Occurring Between 1989 and 1995
Scenario: Type A PM10 - 70 AAM/250 24-hr.

Federal Administrative Region		Minimum	Point Estimate	Maximum
REGION I	New England	0.0	0.0	0.0
REGION II	N.Y.-N.J.	0.0	0.0	0.0
REGION III	Middle Atlantic	0.0	95.2	0.0
REGION IV	South Atlantic	0.0	65.2	0.0
REGION V	E.N. Central	0.0	255.9	0.0
REGION VI	South Central	0.0	79.6	0.0
REGION VII	Midwest	0.0	0.0	0.0
REGION VIII	Mountain	0.0	12.3	0.0
REGION IX	South Pacific	0.0	31.3	0.0
REGION X	North Pacific	0.0	5.1	0.0
Total U.S.		0.0	544.6	0.0

Discounted Present Value in Millions of 1980 Dollars in 1982
Using a 10 Percent Rate of Discount.

Annualized Benefits Between 1989 and 1995 Total U.S.	0.0	218.0	0.0

Table 7-59

ESTIMATED BENEFITS FOR: MATHTECH MANUFACTURING EXPENDITURE STUDY
SIC 354

Benefits Occurring Between 1989 and 1995
Scenario: Type A PM10 - 70 AAM/250 24-hr.

Federal Administrative Region			Minimum	Point Estimate	Maximum
REGION	I	New England	0.0	0.0	0.0
REGION	II	N.Y.-N.J.	0.0	2.4	0.0
REGION	III	Middle Atlantic	0.0	33.5	0.0
REGION	IV	South Atlantic	0.0	1.2	0.0
REGION	V	E.N. Central	0.0	459.1	0.0
REGION	VI	South Central	0.0	5.8	0.0
REGION	VII	Midwest	0.0	0.0	0.0
REGION	VIII	Mountain	0.0	0.0	0.0
REGION	IX	South Pacific	0.0	0.6	0.0
REGION	X	North Pacific	0.0	0.0	0.0
Total U.S.			0.0	502.7	0.0

Discounted Present Value in Millions of 1980 Dollars in 1982
Using a 10 Percent Rate of Discount.

Annualized Benefits Between 1989 and 1995 Total U.S.	0.0	201.2	0.0

Table 7-60

ESTIMATED BENEFITS FOR: MATHTECH MANUFACTURING EXPENDITURE STUDY
SIC 34

Benefits Occurring Between 1989 and 1995
Scenario: Type A PM10 - 70 AAM/250 24-hr.

Federal Administrative Region			Minimum	Point Estimate	Maximum
REGION	I	New England	0.0	0.0	0.0
REGION	II	N.Y.-N.J.	0.0	0.0	0.0
REGION	III	Middle Atlantic	132.9	231.8	357.9
REGION	IV	South Atlantic	93.3	162.9	251.4
REGION	V	E.N. Central	784.7	1368.8	2112.6
REGION	VI	South Central	104.4	182.1	281.0
REGION	VII	Midwest	12.1	21.2	32.7
REGION	VIII	Mountain	20.5	35.7	55.1
REGION	IX	South Pacific	160.9	280.8	433.5
REGION	X	North Pacific	15.7	27.5	42.4
Total U.S.			1324.6	2310.7	3566.6

Discounted Present Value in Millions of 1980 Dollars in 1982
Using a 10 Percent Rate of Discount.

Annualized Benefits Between 1989 and 1995 Total U.S.	530.2	924.9	1427.6

Table 7-61

ESTIMATED BENEFITS FOR: MATHTECH MANUFACTURING EXPENDITURE STUDY
SIC 35

Benefits Occurring Between 1989 and 1995
Scenario: Type A PM10 - 70 AAM/250 24-hr.

Federal Administrative Region			Minimum	Point Estimate	Maximum
REGION	I	New England	0.0	0.0	0.0
REGION	II	N.Y.-N.J.	9.6	27.0	43.7
REGION	III	Middle Atlantic	107.3	301.6	488.7
REGION	IV	South Atlantic	56.9	160.1	259.4
REGION	V	E.N. Central	756.2	2124.7	3442.6
REGION	VI	South Central	143.3	402.5	652.1
REGION	VII	Midwest	0.0	0.0	0.0
REGION	VIII	Mountain	24.3	68.3	110.7
REGION	IX	South Pacific	239.5	673.0	1090.5
REGION	X	North Pacific	18.6	52.2	84.6
Total U.S.			1355.7	3809.3	6172.2

Discounted Present Value in Millions of 1980 Dollars in 1982
Using a 10 Percent Rate of Discount.

	Minimum	Point Estimate	Maximum
Annualized Benefits Between 1989 and 1995 Total U.S.	542.7	1524.8	2470.6

Each of these biases is expected to contribute to an underestimate of benefits. There may also be a bias introduced by the assumption that the dollar benefit per microgram reduction is the same for all industries in a 2-digit SIC grouping. Although the minimum and maximum estimates were developed to reflect the uncertainty surrounding the assumption, it is not possible to determine whether the assumption is expeccted to lead to a positive or negative effect on benefits.

Synthesis of Manufacturing Sector Benefits —

A total benefit estimate for industries in the two 2-digit industry groups was developed as follows:

- A lower-bound estimate was calculated as the point estimate for SIC 354.
- An upper-bound estimate was calculated as the sum of the point estimates for the two 2-digit industries.
- A point estimate was calculated as the geometric mean of the upper- and lower-bound estimates.

The choice of the lower-bound estimate was influenced by the fact that TSP was not a significant explanatory factor at the 10 percent level for all specifications in SIC 344. Thus, a very conservative estimate of a lower-bound value would include benefits derived only from SIC 354. Given that these estimates are developed directly from the data and equations in the basic MTM analysis, they are the most defensible of the various benefit numbers presented for the manufacturing sector.

Several options were possible for selecting an upper-bound estimate. The choice of the sum of the two 2-digit SIC point estimates reflects our judgment that the various biases in the MTM model and in the extrapolation procedures will likely lead to an overestimate of benefits at the 2-digit level. As was the case with the household sector, the choice of an upper-bound estimate is more speculative relative to the choice of the lower-bound estimate.

Finally, the point estimate is determined as the geometric mean of the upper- and lower-bound estimates. The geometric mean appears to be a more relevant statistical index than the arithmetic mean since it weights lower values relatively greater. This would conform to our belief that more confidence can be ascribed to the estimates presented as lower-bound values in the various scenarios relative to those identified as upper-bound values.

Table 7-62 summarizes the estimated benefits of reduced soiling for the manufacturing sector. As was pointed out in the review of the MTM study, these estimates should be interpreted with caution. Although the analytical model and empirical technique are carefully applied in the MTM analysis, the results were found to be sensitive to influential observations in the data.

Table 7-62

SUMMARY OF BENEFITS FROM REDUCED SOILING IN THE MANUFACTURING SECTOR*

Standard	Benefit		
	Minimum	Point	Maximum
PM10 70/250	0.73	1.30	9.45
PM10 55/250	1.32	2.41	20.51
PM10 55/150	1.48	2.86	26.24
PM10 55	1.32	2.41	20.25
TSP 75/260	2.43	4.80	40.75
TSP 150	2.81	5.81	55.13

* Discounted present values in 1982 in billions of 1980 dollars.

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SECTION 8

BENEFITS OF NATIONAL VISIBILITY STANDARDS

SECTION 8

BENEFITS OF NATIONAL VISIBILITY STANDARDS

INTRODUCTION

Existing assessments of the benefits of air pollution control have to a large extent focused on the health, soiling, materials damage, and vegetation damage effects of air pollution. However, an increasing body of economic research suggests that the aesthetic effects of air pollution are also important. Visibility, defined as the ability to see distant vistas unobscured, is affected by naturally occurring dust and humidity as well as by air pollution. Based on psychological studies of perception and studies of the value of clean air, visibility appears to be the dominant aesthetic impact of air pollution. Thus, an appropriate research task is the estimation of the value of preserving or improving atmospheric visibility as a result of air pollution control programs. An assessment of the national benefits of visibility protection has not been accomplished to this point. This section attempts to make a very preliminary estimate of such benefits, acknowledging that, at this point, critical research still needs to be completed before such an estimate can be considered to be rigorous. However, the estimates provided here do suggest the order of magnitude of benefits to be derived from a program of national visibility protection.

Benefits are calculated for four alternative visibility standards defined by a minimum annual allowable average visual range of 13 miles, 20 miles, 30 miles, and a 20 percent improvement over existing levels. In making these benefit calculations we assume, for example, for the 13-mile standard that all areas in the country which now have an average annual visibility below 13 miles are brought up to an average annual visual range of 13 miles. Obviously, however, reductions in emissions necessary to bring the worst areas up to a visual range of 13 miles will, as a side effect, improve visibility in nearby areas already meeting the standard. We do not calculate the benefits of these secondary improvements in visibility, although ideally they should be included.

The focus on alternative visual range standards rather than concentrations of PM was required because no rigorous transformation has been defined between visual range and levels of TSP or PM10. Scientific studies of the optical properties of PM indicate that fine particles (FP) are the most dominant size cut influencing light scatter. Consequently, an FP standard may be most appropriate for identifying the benefits associated with changes in visual range. Since the scenarios examined in this report relate to PM10 and TSP only, the benefits reported in this section cannot be added in a consistent fashion with the benefit numbers reported in the other sections. This section is most properly viewed then only as a synthesis of available information of the benefits of alternative national visibility standards.

For calculating national visibility benefits we utilize three additive categories of value: 1) residential, 2) recreation, and 3) existence. In a separate subsection, we discuss in qualitative terms some of the work that has looked at visibility impairment and effects on air and highway safety. Residential benefits are defined as those which are derived from visibility in and around consumers' homes and local communities. Thus, this category includes, for example, benefits of unobscured views from and around homes, unpolluted clear blue skies, and the benefits to recreation undertaken near peoples' homes. These are the benefits presumably captured by the urban surveys of visibility benefits.* Note that these surveys have typically asked households for their willingness-to-pay for clean air and then asked respondents to split their bid into component parts, including as one component visibility. Also, these studies have compared their results with property value studies and, in general, have found survey results to be consistent with the effects of air pollution on property

* See, for example, Brookshire, d'Arge, Schulze and Thayer (1).

values. However, such studies have been completed only for cities on the West Coast (Los Angeles and San Francisco). Although visual ranges are of the same order of magnitude as for eastern cities (less than 20 miles), extrapolating these results to the East is not a desirable procedure. Fortunately, results for East Coast cities will be available within one year from a study underway at the University of Chicago under the overall management of George Tolley. Preliminary pre-test results from Chicago do, however, show roughly the same value of visibility per mile as the West Coast studies done by the University of Wyoming group.*

The second category of benefits, recreation value, is defined as the benefits of visibility improvement to recreation undertaken away from a household's home community. For example, a visit to the Grand Canyon provides enjoyment from being able to see far down the canyon from an overlook. To avoid overlap with residential benefits, we assume that half of the average of 60 days of recreation undertaken by families per year takes place away from the home community. Again, the only available studies of the value of visibility to recreation have been undertaken in the western United States. The extrapolation to eastern recreation is quite weak because visual ranges in the western recreation areas studied have been greater than 50 miles, while in eastern recreation areas they are generally less than 50 miles. But, such an extrapolation is necessary to obtain an order of magnitude estimate of the benefits of visibility standards. Again, the need for new research is clear. The University of Chicago study mentioned above should provide some preliminary evidence in this area for the East Coast.

The final category of benefits, which is examined quantitatively, is existence value. Existence value is defined as the benefit derived from just knowing that the environment is preserved. Note that this value is not associated with use of the environment and probably applies to "natural wonders". Thus, a household in New York may be willing to pay to know that visibility at the Grand Canyon is preserved even if they never intend to

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* Op. cit. Brookshire et al. (1).

visit. Only one study of the existence value of visibility protection has been completed, and that study focused on the Grand Canyon.* Thus, to provide even a rough order of magnitude of the benefits of visibility standards, a weak extrapolation must again be made. We have chosen to include six particularly well-known national parks for which we extrapolate existence values for visibility based on the Grand Canyon results. The results from the Grand Canyon study indicated that the existence value component of visibility benefits is quite large. Consequently, this category may be especially important in forming decisions on where future research may be most valuable.

Prior to reporting aggregate national benefit estimates, we describe in qualitative terms research on safety aspects of reduced visual range. In the discussion, it is suggested that cost of delays is probably a more appropriate measure of better visibility benefits than lives saved. Unfortunately, no usable study has yet to be completed which permits a quantitative evaluation of these safety aspects.

The final part of this section reports on the overall benefits calculations, giving annual benefits and discounted present values for different attainment paths for alternative visibility standards. We have also calculated low, medium, and high estimates for benefits based on differing assumptions. Table 8-1 presents 1980 annual benefits if the alternative visibility standards could have been attained in that year using our medium estimates, except for existence values, where we only include six parks (our low estimate). Of these estimates, as we have indicated above, the residential benefits are the most defensible. We would argue that an appropriate interpretation of Table 8-1 is as follows: "the benefits of a 20-mile visibility standard may be of the order of magnitude of $7 billion (residential benefits) and could easily be as high as $15 billion (total benefits).

* See Schulze, Brookshire et al. (2).

Table 8-1

1980 ANNUAL NATIONAL BENEFITS OF ALTERNATIVE VISIBILITY STANDARDS
(Millions of 1980 Dollars)

Standard	Residential Benefits	Recreation Benefits	Existence Value Benefits	Total
13 miles	1,581	247	2,172	4,000
20 miles	6,986	1,595	7,194	15,775
30 miles	16,887	4,535	14,430	35,852
20% Improvement over current visibility	7,608	12,296	10,172	30,076

ESTIMATING THE BENEFITS OF URBAN VISIBILITY IMPROVEMENTS

Introduction

During the past 15 years, more than a score of econometric and survey studies have been conducted to estimate the economic value of air quality. These studies have usually adopted one of two approaches. First are studies which use published data on housing values to infer a "price" for air quality; and second are those studies which ask individuals to estimate directly their willingness- to-pay for air quality improvements. With the exception of one study, the resulting valuations are for all aspects of air pollution reduction, inclusive of perceived human health effects, vegetation impacts, corrosion, impacts on animals, aesthetic considerations such as visibility, and other humanly conceived effects.

It is the purpose of this subsection to review briefly the results obtained in several of the property value and willingness-to-pay approaches for assessing the benefits of improved visibility in urban-suburban locations. In Section 5, property value studies were reviewed and benefits evaluated for the alternative air quality scenarios being examined in this report. The discussion of property value studies in this section focuses on the attainment of visual range standards and is used primarily as a cross-check on the plausibility of the residential visibility benefit estimates derived from willingness-to-pay studies. For this reason, the discussion of alternative property value studies is limited in this section. There is, however, extended discussion of the various biases that may be part of the direct willingness-to-pay studies.

In the property value studies, the common procedure is to link differences in property values to various measures of air pollution concentration. Since measures of various pollutants are often recorded in different averaging times or units, the various property value studies cannot be easily compared. In addition, further complications arise in that benefits are to be estimated for visual range standards. In order to assess the relative monetary magnitude of the property value estimates, a set of "standardization" equations are developed here to relate various air pollution concentrations to visual range. These "standardization" equations are likely to contain substantial errors for any one site or pollutant condition and therefore should be viewed with caution and qualifications when comparing the various property value studies.

In the review of study results, willingness-to-pay studies are also compared as to their "implied" willingness-to-pay for visibility <u>and</u> other aspects of air pollution. These studies are more directly comparable since in only one case was there a need to use the "standardization" equation (3).

Given the estimated marginal willingness-to-pay for the two approaches, we next examine briefly the relationship of the magnitudes of benefits from the two types of studies. We would expect that the property value estimates should exceed those derived from the willingness-to-pay studies.

Following the cross-check of approaches, prediction equations are developed for estimating the relationship between visibility and willingness-to-pay for clean air. These equations are based exclusively on results obtained in a willingness-to-pay study of Los Angeles air pollution (1). However, the prediction equations constructed from the Los Angeles study are shown to be close to estimates derived from other studies of San Francisco, Chicago, Boston, and Denver.

<u>**Property Value Studies**</u>

Using differences in property values between polluted and less polluted locations has become a rather common approach to assess the implied damages of air pollution. In addition, a large literature has evolved on how the results of these studies should be interpreted and the assumptions necessary to make them valid in estimating the marginal benefits of improved air quality across an urban area (4).* However, no one has made a comparison of the magnitude of estimates derived from the various studies for alternative visibility standards. The major problem in doing so is the difference in air pollution data inclusive of type of air pollution, measurement methods applied, averaging time, and type of device used to measure concentration. In this study, a set of "standardization" equations is developed with reference only to urban visibility. The calculations are included in Appendix 8A. By assuming a precise relationship between equivalents of sulfation and particulates, one can be converted to the other in terms of impact on visibility [see Trijonis (5)]. Next, using data for Los Angeles, a relationship is obtained between nitrogen oxides and particulates holding visibility constant such that an equivalent effect on visibility can be estimated either from concentrations of particulates or nitrogen oxides. Finally, using isopleth maps for Los Angeles, a relationship is obtained between the change in nitrogen oxide concentrations and changes in visibility. Let S, P, and NO_2 represent concentrations of

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* See Section 5 for a detailed description of the theory underlying the property value studies.

sulfation, particulate matter, and nitrogen dioxide, respectively, and let V represent visual range. Then, by calculation:

$$S = \alpha P$$

$$\Delta NO_2 = \beta \Delta P$$

$$\Delta V = \gamma \Delta NO_2$$

where α is estimated from several sources, with β and γ estimated directly from Los Angeles data sources (see Appendix 8A). Depending on particle size and the presence of other pollutants, the β estimated from Los Angeles data may over- or underestimate the relationship for other urban areas of the U.S. It is likely that the estimate for γ is larger for Los Angeles than other areas because of the above average maximum distance of potential visibility. Thus, the same concentration of NO_2 in Los Angeles is likely to have a greater than average impact on visibility. Given the rather tenuous nature of these calculations, most of the property value studies can be compared in visibility units of dollars per mile. For example, a property value study reporting a "hedonic price" of the change in housing value per unit change in sulfation, $\Delta HV/\Delta S$, can be converted to $\Delta HV/\Delta V$ by simply noting that:

$$\Delta V = \gamma \frac{\beta}{\alpha} \Delta S$$

or

$$\frac{\Delta HV}{\Delta V} = \left(\frac{\Delta HV}{\Delta S}\right) \cdot \left(\frac{\alpha}{\beta\gamma}\right)$$

Table 8-2 records the implied or direct willingness-to-pay per mile of visibility for selected property value studies. The last two studies included in Table 8-2 are especially important, since willingness-to-pay (contingent valuation) studies were conducted simultaneously. The remaining nine property value studies represent a sample of the many

Table 8-2

ANNUALIZED PROPERTY VALUE CHANGES PER MILE OF VISIBILITY BY STUDY AND AREA*

Study	Area, Base Year	in Property Value (Δ$/Δpoll.)	Δ in Miles of Visibility	$ Per Mile Per Yr. (1981)
Ridker-Henning (6)	St. Louis, 1960	186.50-245.00/0.25 mg/100 cm^2 (sulfation)	11.49 mi	5.66
Anderson-Crocker (7)	St. Louis, 1960	300.00-700.00/10 $\mu g/m^3$+0.1 mg/100 cm^2 (part. + sulfation)	9.19 mi	16.38
Crocker (8)	Chicago, 1964-1967	350.00-600.00/10 $\mu g/m^3$ + 1 ppb SO_2 (part. + SO_2)	9.19 mi	14.57
Harrison-Rubinfeld (9)	Boston, 1970	800.00/1 ppm NO_x	4.74 mi ($\bar{V}$ = 14.22 mi)	38.84
Smith (10)	Wash., D.C. 1971	430.00-500.00/10 $\mu g/m^3$ (part.)	4.60 mi	22.30
Nelson (11)	Wash., D.C. 1970	576.00-693.00/10 $\mu g/m^3$ part. 141.00-152.00/0.01 ppm oxident	4.66 mi	38.56
Zerbe (12)	Toronto, 1961	200.00-450.00/0.25 mg/100 cm^2 (sulfation)	11.49 mi	8.43
	Hamilton, 1961	580.00-882.00/0.25 mg/100 cm^2 (sulfation)	11.49 mi	18.97
Peckham (13)	Philadelphia, 1960	298.00/0.25 mg/100 cm^2 (sulfation)	11.49 mi	7.81
Brookshire, *et al.* (1)	Los Angeles, 1979	4468.00-6134.00/30% ΔNO_2	Fair → Good 14 mi Poor → Fair 10 mi	39.27 75.47
SRI (14)	San Francisco, 1981	14.73 → 95.42/30% ΔPSI Index 0.68 → 31.55/30% ΔOzone	Fair → Good 2.4 mi	6.14 → 39.76 0.28 → 13.15

* References.

available studies of this type. Note that all nine appeared in the discussion in Section 5.

In each of the property value studies, property value differentials are related to ambient concentrations of various air pollutants. Using the procedure documented in Appendix 8A, these ambient concentrations are converted to NO_2 equivalents and then to changes in visibility utilizing observed relationships for the Los Angeles Air Basin. While this conversion procedure is not likely to be highly accurate, it does allow a comparison between studies on a per mile or average basis. Given the qualifications underlying the conversion procedure, the range of implied willingness-to-pay over the various studies is quite small. The mean for the sample of property value studies is $23.04, with a standard deviation of $19.94, and a range of $.28 to $40.00 per household/mile. What is interesting about the property value studies is that with one exception they all cluster in the $5.00 to $40.00 per household/mile range on an annual basis. This suggests that a rough order of magnitude inference can be made; namely, it is unlikely that households value air pollution, in all of its "perceived" dimensions, at more than $100.00 per mile or less than $1.00 per mile.

Direct Willingness-to-Pay Studies

Table 8-3 records the estimated annual willingness-to-pay per household for miles of visibility when families were asked directly their willingness-to-pay. Since these studies most often use pictures to portray visual range as part of the survey process, no "standardization" equations are required. These studies encompass a fairly broad typing of urban areas ranging from Los Angeles and Chicago down to a small energy impacted community in New Mexico. The estimates ranged from $1.54 per household/mile to $40.25. However, the Bresnock study (3), which provides the lower bound estimate, utilized carbon monoxide as the relevant measure of pollution. There appears to be some question as to whether carbon monoxide is a good proxy for visual range so that the estimated willingness-to-pay may not adequately reflect visibility changes. Also, the range in changes

Table 8-3

ANNUAL WILLINGNESS TO PAY PER MILE OF VISIBILITY BY STUDY AND AREA

Study	Area, Base Year	WTP Per Year	Δ in Miles of Visibility	$ Per Mile Per Year (1981)
Bresnock (3)	Denver, 1977	5.70 for 18 pptm CO (low) 186.24 for 239 pptm CO (high)	5.12 (low) 67.96 (high)	1.54 (low) 3.79 (high)
Brookshire, *et al*. (1)	Los Angeles, 1979	312.00	Fair → Good 14 mi Poor → Fair 10 mi	Fair → Good 28.64 Poor → Fair 40.25
SRI (14)	San Francisco, 1981	70.56	2.4 mi	29.40
EPRI/Blank, *et al*. (15)	Farmington, 1978	ES- 91.08 CS-856.97	50 mi	ES- 2.35 CS-22.11
Tolley-Randall (16)	Chicago, 1981	$200*	9 mi ($\bar{V}$ = 9)	22.22

* This is a preliminary estimate based on a pre-test and given in a telephone conversation with one of the principle investigators.

in visibility are perhaps too non-standardized across the various studies to allow direct comparison between studies. However, the range of estimates is within that postulated earlier as reasonable from the property value studies. The mean is $18.57 with a standard deviation of $14.57.

According to theory, the property value estimate should exceed the willingness-to-pay estimate because the property value differences are represented along a rent gradient, while individual willingness-to-pay is represented by a movement along an indifference curve.* Thus, individuals are willing to pay less than the current market price because they have already taken into consideration their individual "perceived" effects of air pollution. Comparing the means of the property value studies of $23.04, and $18.57 for the willingness-to-pay studies, at least the results conform to expectations from theory. However, this is a very weak test since we are comparing means of estimates derived from different times and locations.

Biases in Direct Willingness-to-Pay Studies

Economists have argued that valuing public goods such as visibility through a direct demand revealing process such as willingness-to-pay would yield biased results. The principal theoretical support for this contention is the possibility of strategic bias. However, as survey techniques to elicit contingent behavior or bids have come into use -- in part because development of energy resources in formerly pristine environments allows no other techniques to be used -- other types of bias have come to be regarded as just as important. These include information bias, instrument bias, hypothetical bias and traditional problems of sampling, interviewer, and nonrespondent bias.

Beginning with Samuelson's seminal work on public goods, it has been supposed that direct revelation of consumer preferences for such goods -- and, of course, environmental quality is a public good -- would be

* See D. S. Brookshire, M. A. Thayer, W. D. Schulze, and R. C. d'Arge (17).

impossible (18). In particular, the free-rider problem would give individuals incentives to misstate their preferences. For example, if residents in Farmington, New Mexico were asked how much they were willing to pay to clean up the air near a power plant, and if they suspected that control costs would be borne by consumers and owners elsewhere, these local residents would have an incentive to overstate their willingness-to-pay. Alternatively, if residents suspected that they would be individually taxed an amount equal to their own willingness-to-pay, then a clear incentive would exist to understate their own true value, hoping that others would bid more.

Each approach for asking willingness-to-pay will potentially generate its own bias. Thus, if recreators are told that the average of their bids to prevent construction of a nearby power plant would be used to set an entrance fee, those individuals who suspected their bid to be greater than the average bid would have an incentive to overstate their willingness-to-pay. They, in fact, would have an incentive to raise the average bid as close as possible to their own true bid. In other words, individuals would have incentives to misstate their own preferences in an attempt to impose their true preferences on others. It would require a substantial amount of information to actually behave in this manner. Of course, if the respondents to such a survey do not believe the survey would have any impact on policy or outcomes, then no incentives for bias exist. The hypothetical nature of such surveys may then, in actuality, aid in eliciting bids which are not strategically biased. Alternatively, since payment is not required, a tendency to exaggerate willingness-to-pay for a preferred outcome might also exist.

Empirical evidence thus far does not support the existence of strategic bias among consumers. Bohm (19), in an experimental approach utilizing actual payments for public television, failed to find strategic bias significantly affecting the outcome. Scherr and Babb (20) utilized three different mechanisms for valuing public commodities and found little evidence supporting the existence of strategic bias. Smith (21), in laboratory experiments, also failed to find strategic bias as a significant problem. Studies at the University of Wyoming have not encountered problems with strategic bias.

Since contingent behavior or valuation is hypothetical, it is clear that answers obtained through surveys are not based on information similar to that which would apply if consumers based answers on real experiences. One is an ex ante response while the other is an ex post statement. Typically, consumers do reevaluate decisions on the basis of experience and gained knowledge. Thus, an individual or household might respond to a hypothetical decrease in environmental quality at one location with a low bid, thinking that other nearby sites would make good substitutes. However, in a real situation the individual might have found that other sites involved more travel costs and were less satisfactory than imagined. The information presented to the respondent in a survey situation relating to substitution possibilities and alternative costs may alter the stated willingness-to-pay. The respondent must be made aware of proposed alternatives in terms of quality or quantity. Other variants of information bias might include giving the respondent information as to how other respondents behaved, whether in the aggregate their bid was sufficient to achieve (or not achieve) the stated goal (e.g., prevention of visibility deterioration) or alternative sequencing of questions.

Related to information bias is instrument bias, whereby characteristics of the mechanism for obtaining willingness-to-pay possibly influence the outcome. Two characteristics of the survey bidding approach are vehicles for payment and a starting point for initiation of the bidding process. Studies have recognized that the mechanism used to collect the bid or pay compensation may influence its magnitude (22). That is, if the recreator pays a higher park entrance fee rather than another type of tax, his bid for an environmental attribute may differ. From economic theory, the bid should differ, if the price of the commodity represented by the bidding vehicle changes, provided the recreator's substitution possibilities associated with alternative payment mechanisms are different. When a payment vehicle allows the individual to substitute over a wider range of current commodities purchased, then the bid or compensation should be related to adjustments in disposable income or wealth, where the individual has the greatest latitude for potential substitution. Practically, however, a believable payment mechanism related to income adjustment, in general, cannot be applied. For example, surveys are often taken at recreation sites away from the individual's locale or state. In this case, a wage tax may not be viewed as realistically payable by the recreator. Thus, there is a tradeoff between accuracy associated with a less than ideal method of payment and the believability of the vehicle for payment or compensation. The reduction in substitution possibilities for a more believable payment mechanism is likely to reduce the contingent expenditure or increase the compensation estimate.

A second type of instrument bias is starting point bias. The contingent valuation approach commences with questions on payment (and/or compensation) for hypothetical changes in environmental attributes. Contingent bidding surveys to date have asked the recreator (or any type of interviewee) a question with a "yes" or "no" answer rather than a question requiring explicit calculations. It is presumed that the recreator can more accurately respond to the yes/no question framework, although to our knowledge this proposition has not been formally tested for individuals responding to contingent valuation questions. Given the proposition that yes/no responses are desirable, often a starting bid or minimal level of compensation has been suggested. The potential bias arises in suggesting a starting point from at least two possible sources. First, the bid itself may suggest to the individual the approximate range of "appropriate bids". Thus, the individual may respond differently depending on the magnitude of the starting bid. Second, if the individual values time highly, he may become "bored" or irritated with going through a lengthy bidding process. In consequence, if the suggested starting bid is substantially different from his actual willingness-to-pay, the bidding process may yield inaccurate or only roughly approximate results. The effect of these two types of starting point biases may substantially influence the accuracy of contingent valuation and therefore the usefulness of this approach for assessment of environmental preferences.

The discussion on information bias suggested that the contingent valuation approach will give answers dependent upon the information or "state of the world" described. The contingent valuation approach requires postulating a change in visibility such that it is believable to the individual and accurately depicts a potential change. The change must be fully understandable to him; i.e., he must be able to understand most, if not all, of its ramifications. The individual also must believe that the change might occur and that his contingent valuation or behavioral changes will affect both the possibility and magnitude of change in visibility. If these conditions are not fulfilled, the hypothetical nature of contingent valuation approaches will make their application utterly useless. A test of hypothetical bias would require that the perturbation proposed would occur and then the respondents' actual reaction would be evaluated in terms of the previous hypothetical statements of willingness-to-pay. This, however, makes it extremely difficult to measure the extent of hypothetical bias within a contingent experiment since it depends not only on the structure of the experiment, but also on the "uncontrolled" factors of the future.

Any survey approach, including the contingent valuation approach, is subject to sampling bias, nonrespondent bias, and interviewer bias. Any of these certainly can subject the results of an experiment to question even if all previously mentioned biases are nonexistent. In a study by Rowe, d'Arge and Brookshire (23), it was found that from 40 to 50 percent of the forecasted differences between "true" bids and reported bids was due to various types of biases. That is, some types of bias can potentially lead to a 50 percent error in reported bids. Given these qualifications, it is interesting to note that estimated willingness-to-pay per mile tends to cluster around $10.00 to $25.00 per household.

We do not attempt to evaluate the extent of the various biases described above for the five direct willingness-to-pay studies identified in Table 8-2. While some of the studies did test for the presence of alternative biases, it is difficult to reach general conclusions on the likely magnitude of particular biases for contingent valuation studies since so much depends on questionnaire design. Detailed discussions of the biases and the manner in which they are dealt with in questionnaire design can be found in Brookshire et al. (1) and Rowe et al. (23).

Before we present the estimates of visibility benefits for urban areas, we want to highlight some of the major assumptions which accompany the development of a benefits number from the contingent valuation studies. These include the following:

- Willingness-to-pay estimates derived primarily for West Coast cities are appropriate for the rest of the nation. (Probably leads to upward bias.)

- That the depictions through photographs in western conditions are appropriate for other regions of the country. (Depends on locale, but probably contributes an upward bias because of greater vistas in the West.)

- That one-half of the total willingness-to-pay was due to aesthetic considerations of poor air quality throughout the nation. (Bias is probably upward since health considerations may be most important in many eastern urban areas.)

- That average willingness-to-pay does not differ markedly from marginal willingness-to-pay. (Empirical estimates suggest average is above marginal, so bias is likely to be upward for visibility improvements.)

- That the techniques used to obtain empirical estimates are unbiased. (Bias, if present, is unknown quantitatively but likely to be upward since there were no budgetary restrictions imposed in discovering willingness-to-pay.)

In summary, there are many assumptions underlying the extrapolation of some experimental estimates to nationwide benefits assessments. Many of the biases can be at least partially evaluated as to direction, and in most instances tend to be upward.

Prediction Relationships for Urban Areas

In order to develop national estimates of visibility values in urban-suburban areas, estimated prediction equations were developed relating willingness-to-pay for improved visibility to income and visibility improvements. The general forms of the equations were:

$$B = \eta Y^{\alpha} V^{\beta} \tag{8.1}$$

$$B' = \eta Y^{\alpha} (\Delta V)^{\beta} \tag{8.2}$$

where B = willingness-to-pay (in 1981 dollars) per family per year for visibility of V rather than no visibility.

B' = willingness-to-pay (in 1981 dollars) per family per year for an air quality improvement that leads to a visibility change of V.

Y = yearly family or household income in 1981 dollars.

V = miles of visibility in an urban setting.

ΔV = improvement in visibility in miles, urban and suburban.

η = a constant term.

α, β = elasticities of income and visibility associated with willingness-to-pay for improved visibility.

Two methods were developed to estimate the coefficients η, α, and β. Both involved starting with results from the Los Angeles experiment (1). In Method I, β was estimated by using an econometric estimate of $\Delta B/\Delta NO_2$ from Brookshire et al., and converted to $\Delta B/\Delta V$ using the results in Appendix 8A, and then recomputed in elasticity form using the means of the Los Angeles data. The coefficient α was obtained from econometric estimates found in Brookshire et al. Finally, using the means for Los Angeles of B, V, and Y, the coefficient η was computed. The complete equation using Method I is then:

$$B = 0.497Y^{0.566}V^{0.399} \tag{8.3}$$

While this equation tended to predict well around the means for Los Angeles, it tended to not predict well for large changes in visibility for Los Angeles or other cities examined. The Boston study (9) contained an equation where $B = 0.279Y^{1.00}V^{0.87}$ (although property value differences were used), while the Denver study (3) had an implied form of $B = 0.204Y^{0.604}V^{0.0032}$ (although because of the rather arbitrary conversion of CO into NO_2 the β elasticity for Denver should be suspect).

Method II involved using the average of the natural logarithms of the means of the household bid and changes in visibility for the Los Angeles experiment to estimate β, the elasticity for visibility. Thus, β equals ln 312/ln 13 = 2.239. Then this value along with α = 0.566 was substituted into Equation (8.2), again using the means for Los Angeles to estimate the constant term, η. The resulting equation was:

$$B' = 0.0039Y^{0.566}(\Delta V)^{2.239} \tag{8.4}$$

This equation tended to predict more accurately the value of changes in visibility across various studies. Using Method II, β was calculated to be 2.239 for Los Angeles, 4.864 for San Francisco (14), 2.411 for Chicago (16), and 2.854 for Boston where property value differences were used (9). Thus, the Los Angeles elasticity is the lowest using Method II for the studies where willingness-to-pay and visibility measures could be inferred from reported results, and also lower when compared with the Harrison and Rubenfeld property value study for Boston.

For estimation purposes, both Equations (8.3) and (8.4) are utilized. The fundamental difference between them is that Method I utilizes the differences of the logarithms to predict, while Method II uses the logarithm of the difference (or change in visibility), both with different weights because of the magnitude of the constant term. As proposed visibility improvements become larger, Method I would tend to predict less than Method II, while for very small changes the reverse would be true. Method I is calibrated to the Los Angeles data set, but tends to underpredict for Boston, overpredict for Denver, and be reasonably close for San Francisco. Alternatively, Method II consistently underpredicts, for small visibility improvements, for San Francisco, Chicago, and Boston.

Table 8-4 records national estimates using the equations resulting from Methods I and II. Note that Method I yields higher estimates for small predicted visibility improvements, yet lower ones when the visibility change becomes larger, as was postulated. Furthermore, both methods tend toward identical predictions around the 20 percent visibility improvement.

For prediction purposes, Method II is probably most accurate for intermediate predictions of visibility improvement across all cities, while Method I would be more accurate for extreme changes and where the base visibility was very high or very low.

It is also a useful exercise to check how the benefit estimates derived from Equations (8.1) and (8.2) compare with some gross estimates of visibility developed simply from the information given in Table 8-3. It appears reasonable to presume that, in the aggregate within an urban context, where visibility is typically in the range of seven to 25 miles, the value that residents place on improved visibility ranges from $5.00 to $40.00 annually per mile for an average household. A "best estimate" value would be about $19.00. Given that there are approximately 76 million U.S. urban-suburban households and that the average improvement of visibility of 20 percent means a mileage increase of seven to ten miles, then urban residential benefits for a 20 percent improvement would be from $133.00 to $190.00 per household each year (in 1981 dollars). Nationally, this translates into an estimate of from $10.0 billion to $14.4 billion per year. Thus, in terms of averages across studies, it is clear that benefits to households in urban areas are likely to be in the billions per year for a 20 percent improvement in visibility per year. Note, however, that this is willingness-to-pay for <u>all</u> effects inclusive of health effects as <u>represented</u> by visibility. In the Los Angeles study, only about one-half of willingness-to-pay can be attributed to aesthetics. Therefore, on a national basis the <u>aesthetic</u> benefit of improved visibility of 20 percent would range from $5.0 to $7.2 billion per year based on the aggregate estimates just given. Note also that the ranges for a 20 percent improvement (medium estimates) are entirely included in the range cited earlier for the total effects case of gross national averages.

Table 8-4

LOW, MEDIUM AND HIGH ESTIMATED RESIDENTIAL BENEFITS PER YEAR IN 1980 MILLIONS OF DOLLARS FOR VISIBILITY POLICIES OF 13, 20, 30 MILES AND A NATIONWIDE 20% IMPROVEMENT*

Policy	Low		Medium		High	
	Eq. 1**	Eq. 2+	Eq. 1	Eq. 2	Eq. 1	Eq. 2
13 Miles	260	39.8	1,581	126	1,893	364
20 Miles	4,230	2,618	6,986	4,010	7,908	6,094
30 Miles	13,242	24,028	16,887	30,637	18,534	38,887
20%	6,743	6,335	7,608	14,391	8,555	27,657

* Let:

B_i = Benefits per year for region i.

Y_i = Average annual household income for region i.

V_i^1 = Initial visibility in region i.

V_i^2 = New visibility imposed by the policy alternatives in region i.

H_i = Number of households in region i.

ΔV_i = $V_i^2 - V_i^1$.

B = Benefits per year = $\sum_{i=1}^{9} B_i$ where the regions are defined by Map 1.

Then Low, Medium and High estimates were calculated by assuming a different V_i^1 (B_i = 0 for unaffected regions).

** Calculated using:

$$B_i = (0.497Y_i^{0.566}(V_i^2)^{0.399} - 0.497Y_i^{0.566}(V_i^1)^{0.399}) \times H_i.$$

\+ Calculated using:

$$B_i = (0.0039Y_i^{0.566}(\Delta V_i)^{2,239}) \times H_i.$$

Note: These numbers must be reduced by at least 50 percent to calculate the aesthetic benefits of improved visibility.

It is important to note that the values obtained here are for all perceived effects of air pollution by those who reside in urban areas. It was impossible to separate out the aesthetic value of visibility from perceived human health and other effects of reduced visibility. However, one study (1) demonstrated that from 22 to 55 percent of the total perceived effect due to visibility changes is associated with aesthetic value. This proportion would likely be lower in urban areas with low visibility and higher in suburban areas with little or no perceived health effect. In consequence, any national estimate of the aesthetic benefit must take this into account. For example, the benefits estimates recorded in Table 8-4 for a 20 percent improvement in visibility nationwide, for just aesthetics, must be adjusted downward to 22 to 55 percent of their values. Using Equation (8.1), a 20 percent improvement would yield national benefits estimates of from $1.47 billion to $4.7 billion annually. This is the approximate range observed for the aggregate estimates discussed earlier, after the correction had been introduced.

Conclusions

The purpose of this brief analysis was to develop approximate yet plausible estimates of the aesthetic value of improved urban-suburban visibility for the U.S. accomplished by using the results of recent direct willingness-to-pay studies. The results were also cross-checked using estimates derived from property value studies. From the studies analyzed, it is clear that urban-suburban visibility values are positive and are likely to be in the billion dollar plus category. Given the substantial uncertainties as to precise willingness-to-pay, regional variations in tastes and preferences, and topography that are not taken into account, little more can be reasonably proposed.

RECREATION BENEFITS

In this subsection, the five existing original empirical studies devoted to establishing measures of the value of atmospheric visibility to outdoor recreators and tourists are critically reviewed and synthesized.

The results of this review are used to arrive at magnitudes for the constant b and the exponents β_1 and β_2 in the multiplicative expression:

$$\ln(TWP) = \ln(b) + \beta_1 \ln(Y) + \beta_2 \ln(V) \quad , \qquad (8.5)$$

where TWP is the total willingness-to-pay for a single outdoor recreation activity day of the representative U.S. household, Y is that household's annual income in thousands of dollars, and V is atmospheric visual range in miles. The absence of any site-specific attributes in this expression implies that visibility is to be valued independently of its location. Only three of the five studies have thus far appeared in the refereed literature. To generate their data, all five studies employ the contingent valuation techniques variously reviewed, evaluated, and defended in Brookshire and Crocker (24) and Schulze et al (25).

Review of Studies

Randall et al. (22) —

This 1974 study was the first to apply the contingent valuation technique to the problem of assessing the economic benefits of atmospheric visibility. The study focused on the 1972 environmental damages that a 2,080 MW coal-fired power plant in Fruitland, New Mexico, and its associated raw material and transmission facilities, imposed on residents of and visitors to the Four Corners region of the Southwest. More than 700 people were asked to value the "high," "intermediate," and "low" environmental damages represented by three sets of photographs. The three photographs in each set depicted power plant stack emission conditions, mine spoil bank conditions, and transmission line conditions.

The format and reporting of Randall et al. severely limits its relevance to a discussion of the value of atmospheric visibility to outdoor recreators. Although the authors assert (p. 141) that respondents considered reduced visibility to be "... far and away the most serious" of the three forms of damage, they provide no information supporting this

this conclusion. Moreover, if the conclusion refers to the stack emissions pictures, the reader cannot know how respondents separated the visual impact of the power plant and its stacks from the visibility impact of its emissions. Further limiting the usefulness of the study for determining the separable value of visibility is the authors' failure to relate stack emissions to ambient pollution concentrations; the responsibility to form this relation was left to the interviewee who did not have to report where his imagination led him. Having established a measure of the compensating surplus values the interviewees attached to various representations of environmental damages, the authors, when they reported these values, chose to group residents and nonresidents, thus making it impossible to distinguish the residential portion of the reported total valuation from its outdoor recreator component. Finally, because respondents were asked to express their willingness-to-pay for environmental damage reductions in terms of electricity bills and/or sales taxes rather than income, the reported values are, by the Le Chatelier principle [Silberberg (26), Chapter 9], likely to be biased downward somewhat. Limiting the individual to varying only his consumption of electricity, or the subset of marketed goods subject to sales taxes, reduces the alternative ways he has available to maximize his gains from the visibility improvement.

Whatever the interpretive difficulties Randall _et al_. pose, they do provide for our purposes some useful insights. In particular, they convey information on the signs of β_1 and β_2 in Equation (8.5).

When those Randall _et al_. resident respondents who did not live on an Indian reservation were requested to express their willingness to pay increased sales taxes for reductions in environmental damages, they were willing to pay $35 annually for a reduction from high to intermediate damages, and $50 annually for a reduction from intermediate to low damages.* Given that the visual range and color contrast intervals are equal across the three damage levels, this result implies that the incremental benefits of environmental quality improvement are positive and increasing, which means that β_2 will be positive.

Only when reporting income elasticities (p. 146) do Randall et al. provide separate results for their sample of 526 nonreservation area residents and 150 recreators and tourists from outside the area. For the nonreservation residents, they estimated an income elasticity of 0.65 with a standard error of 0.10 for a move from high to intermediate damages, and an income elasticity of 0.65 with a standard error of 0.08 for a move from intermediate to low damages. The 150 recreators and tourists, who were asked to bid in terms of user access fees, had an estimated income elasticity of 0.09 with a standard error of 0.15 for a move from high to intermediate damages, and an income elasticity of 0.16 with a standard error of 0.11 for a move from intermediate to low damages. These results indicate the possible range in β_1, for subgroups of the survey population.

Brookshire et al. (27) —

As its authors note, this study was inspired by Randall et al. (22). Starting from a pair of photographs representing an undisturbed Lake Powell environment, 83 outdoor recreators and tourists in the region were asked, in 1974, to state their willingness to pay daily access fees to prevent the construction of a 2,400 MW coal-fired power plant having no visible emissions from 700-foot stacks, and their willingness to pay daily access fees to prevent the same power plant with readily perceived emissions and

* On p. 147. Randall et al. state: "Mean individual household willingness to pay for abatement, ..., was about $50 annually to achieve situation B (intermediate damages) and $85 annually to achieve situation C (low damages)." This statement is inconsistent with their detailed presentation of results. The $35 and $50 figures we use are consistent with their detailed presentation.

visibility impacts from being built.* Equivalent surplus measures of value were thus obtained.

Some of the features limiting the usefulness of Randall _et al_. (22) are also found in Brookshire _et al_. Again, although the high damage representation depicted both stack emissions and resulting visibility impairment, no information is provided about the degree of impairment. In addition, because respondents had to express their bids in terms of access fees and were thereby constrained to adjust their access to Lake Powell rather than their consumption of some other good, bids are likely to be biased upward.** This bias could be accentuated by the requirement that respondents state their bids in terms of _per day_ access fees: degraded visibility may result either in a reduced willingness-to-pay for a visit, reduced visit length, and/or reduced visits. If, contrary to what they would have preferred to do, some respondents presumed that they were not supposed to consider the latter two adjustment possibilities, their stated utility losses from the environmental degradation would be exaggerated. Since respondents remained uninformed about what they were to assume with respect to visit lengths and frequencies, an element of noncomparability is present across respondents' valuations.

Brookshire _et al_. (p. 338) only present willingness-to-pay magnitudes for two cases: 1) a movement from a depiction of an undisturbed environment to one with a power plant having no visible emissions; and 2) a movement from the same undisturbed environment to a representation of a power plant with readily perceived visibility impacts. Given additivity across the cases, the difference in willingness-to-pay between these two cases is the willingness-to-pay to stop a movement from the no-visible-emission power plant to the visibility-impacted power plant case. The difference would then approximate the stated value the 83 recreators and

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* The published form of Brookshire _et al_. only contains line drawings of the photographs that were used.

** Although one cannot tell from the published version, the same bias is probably present in the user access fee results of Randall _et al_. (22).

tourists attached to visibility degradation independently of the visual impact of the power plant. Upon taking the difference, a weighted mean bid of $1.33 per day results.* This figure is less than half the weighted mean bid for stopping a movement from the undisturbed environment case to the no-visible-emission power plant case.** Brookshire et al. therefore imply, contrary to the finding in Randall et al. [(22), p. 141], that the visual impact of the power plant contributed more to recreator losses than did the reduction in atmospheric visibility. However, if respondents associated the no-visible-emission impact case with unavoidably small reductions in visibility, and if respondents were indifferent to the presence of the power plant, then the weighted mean daily bid to stop movement from the undisturbed environment case to the "small" reduction in visibility case was $1.81. Thus, as in Randall et al. (22), the results in Brookshire et al. are consistent with β_2 being positive. As in Randall et al. (22), no inferences can be made from Brookshire et al. about the magnitude of β_2 since a quantitative measure of the visibility change is not provided the reader.

Although they do not explicitly provide income elasticity measures for changes in environmental quality, at least two of the Brookshire et al. findings are consistent with a small magnitude for β_1. First, they test for differences due to an income effect between compensating and equivalent surplus measures of value. No statistically significant differences were found. Second, they varied the income distributions across the four group classes of their respondents, including residents. The variations had "little impact" (p. 344) on an aggregate bid consisting of the product of visitor days and bids summed across the four respondent groups.

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* Treating remote campers, developed campers, and motel visitors separately, the weights are the product of each group's sample size and mean visitor days relative to the sum of these products for the same three groups.

** The standard deviations of the mean bids for each group-case combination are always less than 30 percent and generally less than 20 percent of the corresponding daily mean bid. The tails of the distributions of the bids across cases thus have very little overlap.

Rowe et al. (23) —

This study is the immediate successor to the previous two studies. Its method (a contingent valuation technique) of acquiring data on the 1976 value of atmospheric visibility and its geographical focus (the Four Corners region) was the same as its ancestors. In its particulars, however, Rowe et al. displays considerable evolutionary progress. The three sets of two photographs employed to generate data for obtaining equivalent surplus measures of atmospheric visibility contained no prominent man-made features. A fourth set of photographs was employed to obtain an equivalent surplus bid on the value of the visual impact of the same power plant used in Randall et al. (22). At the three times the visibility photos were taken, visual range in the region was estimated by air traffic controllers at the Farmington, New Mexico airport to be approximately 75, 50, and 25 miles.

The study samples consisted of 26 outdoor recreationists at a large, man-made reservoir near Farmington, and 93 Farmington residents who were interviewed in their homes. One cannot tell from the published report whether the former group was allowed to adjust visitation rates and daily access fees simultaneously. The authors separately report (p. 10) the mean equivalent surplus bids for the two groups. Outdoor recreationists were willing to pay daily user access fees of $3.00 (12.00 cents per mile) with a standard deviation of $0.77 to maintain the visibility represented by the 75-mile photographs rather than that represented by the 50-mile photographs. They were willing to pay $2.53 (10.12 cents per mile) per day with a standard deviation of $0.65 to maintain the 50-mile rather than the 25-mile visibility. Thus, although the bid distributions across the photograph sets do overlap to a substantial degree, improved visibility, just as is probably true in Randall et al. (22) and Brookshire et al. (27), causes a progressively greater willingness-to-pay for further improvements. The equivalent surplus bids of Farmington residents in Rowe et al. displayed the same pattern. Thus, if the outdoor recreationist and the resident samples in Rowe et al. are considered as separate studies, four out of four reviewed studies present evidence that β_2 is positive.

Not all the evidence reported in Rowe et al. is so comforting to the interpretations earlier given to Randall et al. (22) and Brookshire et al. (27). Outdoor recreation respondents were only willing to pay $4.06 per day with a standard deviation of $1.05 to maintain 75-mile rather than 25-mile visibility. This mean bid is only 73 percent of the sum of the two bids over the 75-to 50-mile and the 50- to 25-mile intervals. These results clearly raise doubts about the validity of the bid additivity assumption earlier made for the Brookshire et al. (27) study.

Rowe et al. provide empirical evidence supporting Randall's et al. (22) contention that the impact of emissions on visibility plays a far greater role in respondents' bids than does the visual impact of the power plant and its stacks. The equivalent surplus bid of outdoor recreationists for maintaining 75-mile visibility rather than having 25-mile visibility and a power plant in the middle-distance was only $4.56, a figure only $0.50 greater than the offer of the same respondents for 75-mile rather than 25-mile visibility. Similar results were obtained for Farmington residents.

Rowe et al. do not report income elasticities for outdoor recreationists. As calculated for a one-step move from 75-mile to 25-mile visibility, the elasticities they report for Farmington residents range from 0.25 to 0.36. Thus, as do the two previously reviewed studies, Rowe et al. find that stated willingnesses-to-pay for improvements in atmospheric visibility are quite unresponsive to increases in respondent incomes; i.e., β_1 is again estimated to be positive but small. The authors do not present the income ranges to which these elasticities are meant to apply. It is quite conceivable that the low reported elasticity is due more to the small income range that the respondents represented.

Rae (28) —

Though not yet published, Rae adds some new dimensions to the use of contingent valuation techniques to estimate the economic value of atmospheric visibility. This 1980 study was also placed in the Four Corners region, specifically Mesa Verde National Park in southwest Colorado. Visibility impairment due to plume blight was distinguished during the data generation exercise from that due to regional haze. For the first time, telephotometer measurements made at the same times as the photographs allowed the 54 respondents' statements to be related to objective measures of visual range and color contrast. No prominent man-made features confounded respondent interpretations of the depicted natural landscapes. If differences in the natural landscapes are neglected, the valuations obtained from the two sets of regional haze pictures can be compared with the values established with the three Rowe et al. (23) picture sets that did not include a power plant. The estimated visibility valuations corresponding to the two sets of plume pictures used in Rae are perhaps crudely comparable to the visibility conditions represented by the power plant pictures in Randall et al. (22), Brookshire et al. (27), and Rowe et al. (23).

The three contingent valuation studies reviewed earlier say nothing about the atmospheric visibilities and other attributes at alternative outdoor recreational sites: the respondents were allowed to form their own premises about the attributes of these other sites and to keep these formulations to themselves. Thus the range of implicitly considered substitution possibilities for the depicted sites in these three studies could vary widely from one respondent to another.* By the Le Chatelier principle, the wider the range of adjustment possibilities, the less the value the individual respondent will attach to impaired visibility at the depicted site. Rae (pp. 3.12-3.14) placed each of his 54 respondents on nearly the same footing by explicitly limiting the available substitutes to nine, including Arches, Bryce Canyon, and Petrified Forest National Parks, San Juan National Forest, Glen Canyon National Recreation Area, Canyon De Chelly National Monument, Salt Lake City, Las Vegas, Nevada, and the individual

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* Since the range of substitution possibilities the respondent weighs in his answer is likely to be that which he considers in his actual behavior, this variation across respondents can be considered an analytical advantage of the direct asking approach used in Randall et al. (22), Brookshire et al. (27), Rowe et al. (23), and Schulze et al. (25).

respondent's most frequently visited site. The simultaneous influences upon the value of atmospheric visibility at Mesa Verde of the combinations of respondent-perceived attributes at each of these sites were captured by means of a multinomial logit model (29). Included among the stated attributes of Mesa Verde was a daily access fee which formed the basis for estimating compensating surplus measures of improvements at Mesa Verde in atmospheric visibility. Unfortunately, the author did not make clear whether this fee was to be an increment to or a substitute for existing access fees. Brookshire et al. (27) suffers from the same confusion.

In contrast to the direct inquiries into marginal willingness-to-pay that the earlier reviewed studies employed, the multinomial logit approach in Rae infers these willingnesses-to-pay from respondents' stated changes in choice behavior, including visitation rate changes. Rae postulated that each of his 54 utility-maximizing respondents possessed a utility function $U(s,x) + w(s,x)$, where s is a vector of respondent attributes, x is a vector of site attributes, v is a nonstochastic function reflecting "representative tastes", and w is a function that varies randomly in the sample. Assuming that the choice set of interest is $B = (x_1, x_2, \ldots, x_n)$, and that the w values are independently and randomly distributed over B, the probability that a respondent will choose any x can be shown to be (29):

$$\rho(x|s,B) = \frac{e^{v(s,x)}}{\sum_{y \varepsilon B} e^{v(s,y)}}$$

The choice probabilities are invariant to increasing monotonic transformations of $U(\cdot)$ [McFadden (29)]. Given a parametric specification of the utility indicator v, the expression for ρ is used to obtain parameter estimates and is ultimately a basis to predict respondent behavior, given the set of respondent-stated individual and recreational site attributes.

Because only two sets of slides depicting regional haze conditions were presented to the respondents, the results of Rae, by themselves, can provide no insight about the magnitude of β_2. However, because the "clear" conditions represented a visual range of 160 miles, the interval of visual ranges for which valuations have been estimated in the Four Corners region is considerably extended by this study. Rae's 54 respondents in the summer of 1980 were willing to pay $8.45 (8.88 cents per mile) in daily access fees for an improvement in visual range from 75 miles to 160 miles.

Rae's results are in agreement with Randall's et al. (22) and Rowe's et al. (23) finding that power plants and their associated plumes impose lesser insults than does general visibility impairment. An improvement from a severe plume condition (color contrast = -0.04) to a clear condition (color contrast = -0.24) was worth $4.00 in daily access fees to Rae's representative respondent.

In his preferred specification from his Table 4-2, Rae shows that respondents with an annual income of $10,000 were willing to pay a daily access fee of $4.55 for an improvement in visual range from 75 miles to 160 miles; respondents with annual incomes of $25,000 were willing to pay $8.45 for this improvement; and respondents with annual incomes of $40,000 were willing to pay $10.74. For each income category, the standard deviation of the bid estimate was about 30 percent of the bid. The average 1980 income of the respondents was $25,000. Using the lower income and bid in each interval as the base, these results imply that over the $10,000-$25,000 annual income interval, the income elasticity of demand for the visibility improvement is 0.58, while over the $25,000-$40,000 interval it is 0.45. However, when the upper end of each interval is used as the base, these elasticities increase to 0.77 and 0.55, respectively.

Schulze et al. (2) —

This study is the latest entry in the rapidly evolving literature on the economic value that outdoor recreators attach to altered atmospheric visibility. Although it too employs a direct asking technique to obtain compensating and equivalent surplus measures, it adds some significant new dimensions to earlier treatments. Teleradiometer measurements of the apparent green contrast in the five sets of five photographs that are used to represent various levels of Grand Canyon and a regional visibility for outdoor recreators are provided. The photographs used for outdoor recreators represent visual ranges from 78 to 235 miles where no man-made features are present. Separate willingness-to-pay for visibility in the Grand Canyon alone and in the entire Southwest, and for hazes and for plumes, are obtained. Rather than limiting the sample to an arbitrary group of self-selected current users of the Grand Canyon, a stratified random sample of respondents was interviewed in the summer of 1980 at their homes in Albuquerque (61 people), Los Angeles (60 people), and Denver (45 people).* Respondents were explicitly told that their bids were to be interpreted as an increment to a $2.00 daily access fee, thus avoiding the possibility that the bid might be regarded as a substitute for existing daily access fees, but unfortunately retaining the possible Brookshire et al. (27) and Rowe et al. (23) confusions between daily access fee adjustments and visitation rate adjustments. Visibility improvements in the "Grand Canyon only" were tied solely to access fee increases in that Park. Regional visibility changes were said to involve identical daily access fee alterations for all regional National Parks.

All compensating surplus bids for the "Grand Canyon only" referred to the willingness-to-pay in excess of a $2.00 daily access fee for increased visual ranges rather than having a 78-mile visual range. Thus, if one is to obtain the incremental bids across ranges, one must assume additivity of the bids. Making use of this assumption, Table 8-5 presents the mean incremental bids in cents per mile for each of the three cities. The visual ranges were calculated from the Schulze et al. photographs by Dr. Eric Walther of the Visibility Research Center at the University of Nevada-Las Vegas. Each visual range in the table is an unweighted mean of the "Grand Canyon haze only" visual ranges in the three photographs in each of the five sets.

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* Another 334 people in these cities were interviewed about their willingness-to-pay to preserve Grand Canyon and regional visibility independently of their desire to visit the area.

Table 8-5

MEAN INCREMENTAL WILLINGNESS-TO-PAY IN 1980 CENTS PER MILE*

	Albuquerque	Denver	Los Angeles
78 to 87 miles	16.22	16.33	22.78
87 to 140 miles	1.38	1.96	2.79
140 to 189 miles	1.84	2.57	2.61
189 to 235 miles	5.00	5.52	8.65

* Calculated from Schulze et al. [(2), p. 66].

With the exceptions of the move from the 87-140 mile interval to the 140-189 mile interval for Los Angeles respondents, and the moves from the 78-87 mile interval to the 87-140 mile interval for respondents in all three cities, the reported incremental willingnesses-to-pay of Table 8-5 display the positive and increasing incremental valuations for improved visibility that appear with varying degrees of believability in the previously reviewed studies. The relatively high incremental bids reported for the 78-87 mile interval are nevertheless quite disconcerting. They have no obvious and secure explanation. However, in distinct contrast to the four other contingent valuation studies reviewed here, the standard deviations of the bids in Schulze et al. are consistently about as large as the mean bids. The use of the 78-mile visual range as the initial range in the bidding sequence might be another clue to the extraordinarily high 78-87 mile bid. If, for purposes of the interview, respondents chose to interpret the 78-mile visibility as complete darkness, then the mean incremental willingness-to-pay over the 0-87 mile visual range interval would be 1.68 cents, 1.71 cents, and 2.36 cents per mile for Albuquerque, Denver, and Los Angeles, respectively. In the absence of a definitive answer, we choose to treat the incremental values attached to the 78-87 mile interval as an aberration: the evidence for β_2 being positive from the four earlier studies and the last three rows of Table 8-5 dominates.

Schulze et al. also provide equivalent surplus statements of 1980 willingness-to-pay in excess of $2.00 daily access fee to prevent plume blight in what would otherwise be ($\simeq$ 150-200 miles) visual range Grand Canyon scene. The plume appears as a horizontal brown band lying just over some distant mountains. The sky in the photographs is otherwise mostly blue with some patchy cirrus clouds. No man-made objects such as stacks or power lines interfere. Albuquerque respondents were willing to pay an average of $3.18 with a standard deviation of $3.26 to prevent the plume; Denver respondents were willing to pay $4.80 with a standard deviation of $6.98. Since these willingness-to-pay magnitudes are similar to the same respondents' expressed offers to move from haze-impaired 78- to 189-mile visual ranges, support is offered for the findings of Brookshire et al. (27) on the relative contributions to total bids of stacks and plumes versus atmospheric hazes. However, Randall et al. (22) and Rowe et al. (23) are still in place: they contradict Brookshire et al. (27) and Schulze et al. (2). No dominating evidence exists; the question of the relative values of the visual impacts of power plants and stacks and the visibility impairments of atmospheric hazes remains unsolved.

By adding photographs of vistas in Mesa Verde and Zion National Parks to the already depicted Grand Canyon haze-impacted vistas, and asking the respondent to consider the set of five photos as representative of visibility in the entire Southwest, Schulze et al. obtain an equivalent surplus measure of the value of regional atmospheric visibility. The same 166 Albuquerque, Denver, and Los Angeles respondents were asked their willingness-to-pay to prevent a decline in regional visual ranges from a five-photograph unweighted average visual range of 135 miles to a similar unweighted average of 102 miles. The highest and lowest visual ranges in the 135-mile set were 170 miles and 99 miles, respectively. In the 102-mile set, the highest range was 129 miles and the lowest was 82 miles.

All bids for regional visibility were to be expressed by respondents as an addition to a daily $2.00 access fee being charged at all regional National Parks. Albuquerque respondents were willing to pay $3.16 (standard deviation = $3.55) or 9.58 cents a mile to keep regional visual ranges at the 135-mile average; Denver respondents were willing to pay $4.93 (standard deviation = $14.83) or 14.94 cents a mile; and Los Angeles respondents were willing to pay $4.77 (standard deviation = $7.60) or 14.45 cents a mile [Schulze et al. (2), p. 68]. These per-mile of regional visual range equivalent surplus valuations are five to seven times larger than the "Grand Canyon only" 87- to 140-mile visual range valuations of Table 8-5. This is to be expected since all regional site substitutes for the Grand Canyon are also supposed to have had their visual ranges similarly impaired. Most importantly perhaps, the comparison between the regional calculations and those of Table 8-5 provides one piece of empirical evidence of the caution that must be exercised when studying the value of atmospheric visibility, when extrapolating valuations from one or more independent site-specific studies to a regional or national valuation. Extrapolations of this sort will seriously underestimate the value of atmospheric visibility.

Measures of β_1, the income elasticity of demand for visibility, are also given in Schulze et al. [(2), p. 78], provided that the expressions were estimated in multiplicative form.* When this interpretation is attached to the expressions in their Table 18, the income elasticity demand for the "Grand Canyon only" visibility impairments was only 0.05; for the regional impairments it was 0.10. These elasticities, if indeed they are such, are much lower than those reported in the earlier reviewed studies. Given the uncertainty about their actual meaning, we choose to disregard them.

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* Schulze et al. [(2), pp. 77-78] fail to indicate the functional form in which the bid expressions in their Table 18 were estimated. It seems unlikely that the expressions were linear in the original variables since $\hat{b}$ (Mean income/Mean bid at 140 miles) = 0.05 (28,590/$2.77) = 516.

A Synthesis —

In the preceding pages, we have reviewed the only five original studies of which we are aware that attempt to estimate the value to outdoor recreationists and tourists of atmospheric visibility. Though all focus on one or more areas in the Southwest and all employ a contingent valuation technique to generate data, they can hardly be regarded as perfect replicates. Differing sorts of confounding problems are present in each study: some include man-made objects in the photographs presented to respondents, while others do not; some refer only to qualitative visibility measures, while others provide actual measures of the visual ranges and color contrasts the photographs represent; and residents and outdoor recreators are considered separately in most but not all studies. Some studies obtain compensating surplus measures of value, while others choose the equivalent measure. If income effects are large, substantial discrepancies in valuations of the same visual range interval would be expected; however, the empirical findings in at least four and perhaps five of the studies imply that income effects are small and perhaps even trivial.

Several fairly obvious faults are common to most and occasionally all of the studies. Most serious perhaps are several sources of bias in the estimated magnitudes of willingnesses-to-pay. The sign of the bias will differ according to whether the respondent is confronted with having to minimize his losses or maximize his gains. In no study are respondents asked to state their valuations in terms of an income equivalent: access fees, sales taxes, and electricity bills are instead the bidding currencies. Adjustment possibilities are thus unrealistically low; the expected utility losses from visibility impairments will therefore be exaggerated and the utility gains from visibility improvements will be biased downward. Similar biases could arise in all five studies if respondents, contrary to their preferred adjustment mode, assumed the number of outdoor recreational activity days to be invariant.

A third source of bias arises because only local visual ranges are perturbed in all but the two most recent studies. If the physical reality in the Southwest is that local visibility impairment due to hazes implies regional impairment, respondents were then given unrealistically high sets of adjustment possibilities in all studies but Rae (28) and Schulze _et al_. (2). These excessively large sets meant that valuations of visibility impairments were biased downward, with improvements being biased upward. If throughout most of North America visibility impacts tend to be regional in scope, the Southwest regional willingness-to-pay in Rae (8.88 cents a mile for an improvement from 75 to 160 miles) and Schulze _et al_. (a weighted three-city mean of 12.90 cents a mile to avoid an impairment from 135 to 102 miles) would seem most apt for extrapolation to other regions. Because the Schulze _et al_. study involves potential, past, and current outdoor recreators in the region, whereas Rae samples only currently active recreators, the 12.90 cents per mile valuation of the former study could include an option value element. In fact, the 4.02 cents per mile difference between the two studies is 45 percent of the 8.88 cents per mile valuation of Rae. The sole existing empirical study of the magnitudes of option values in outdoor recreational activities of which we are aware is Greenley _et al_. (30). In a contingent valuation study of water quality in the Platte River Basin of Colorado, they found that option values increased the current recreation use values of water quality by 40 percent. Thus, if a single per-mile value for atmospheric visual range is to be used, we opt for the Schulze _et al_. figure of 12.90 cents per mile in 1980 dollars.

Other potential sources of confusion are present, though their exact impacts upon valuations are not readily identified. With the sole exception of Schulze _et al_., those studies that state values in terms of daily access fees fail to indicate to the respondent and/or to the reader whether the stated fee is to be regarded as an increment to or as a substitute for existing fees. Everyone treats incremental valuations as being strictly additive across visual range intervals even though there is weak empirical evidence from Rowe _et al_. that this may be untrue. Again, with the sole exception of Schulze _et al_., the sample respondents have been self-selected current users. This may account for the wide disparity in the standard deviations of the valuations that Schulze _et al_. report and the standard deviations reported by the other studies.

In spite of some confoundings, biases, and confusions, the five studies hold several patterns in common. Most obviously, the income elasticity of demand by outdoor recreators and tourists for atmospheric visibility, though certainly positive, is quite low. It appears to lie somewhere between 0.1 and 0.5, with the weight of evidence leaning more toward 0.1. A reasonable compromise for β_1 is thus perhaps 0.2.

Only because of a couple of aberrations in Schulze et al. and a few rather strained but nevertheless supportive inferences that must be drawn from some other studies, the empirical evidence that incremental willingnesses-to-pay increase with respect to improving visibility is only slightly less convincing. Though highly inconvenient for much of air pollution policymaking (31), this empirical finding is hardly surprising. It is well known that visual range and color contrast in a relatively clean atmosphere is affected much more dramatically by a given addition of fine particles than is already dirty air. The empirical finding that incremental valuations increase with improved visibility simply shows that any tendency toward decreasing incremental utility of visibility improvements is insufficient to cancel out the contributions that increasing incremental physical effects make to outdoor recreator and tourist valuations.

Assuming that the responsiveness of willingness-to-pay for local visibility improvements is similar to that for regional improvements, several of the reviewed studies provide enough information to yield rough estimates of the magnitude of β_2. Defining β_2 as

$$\beta_2 = \frac{\Delta(\text{Willingness-to-pay})}{\Delta(\text{Visual range})} \cdot \frac{\text{Visual range}}{\text{Willingness-to-pay}} ,$$

Table 8-6 gives estimates for this parameter, the visibility valuation elasticity, as calculated from those studies that allow it. Clearly, the willingness-to-pay for a given increase in visual range increases as visual range increases. Once visual range has reached 150 miles or so, β_2 almost certainly exceeds unity. There is no credible empirical evidence whatsoever from either the economics or the physical science literature on atmos-

Table 8-6

VISUAL RANGE VALUATION ELASTICITIES (β_2)

	Using Lower Bound of Mileage Interval as Base	Using Upper Bound of Mileage Interval as Base
From Rowe <u>et</u> <u>al</u>. (23)		
75 to 50 miles	0.38	0.48
From Rowe <u>et</u> <u>al</u>. (23), and Rae (28)*		
75 to 160 miles	0.73	0.81
From Schulze <u>et</u> <u>al</u>. [(2). p. 66]		
Albuquerque		
87 to 140 miles	0.82	0.87
140 to 189 miles	1.17	1.12
189 to 235 miles	2.96	2.45
Denver		
87 to 140 miles	1.15	1.08
140 to 189 miles	1.43	1.27
189 to 235 miles	2.67	2.00
Los Angeles		
87 to 140 miles	1.18	1.53
140 to 189 miles	1.03	0.96
189 to 235 miles	3.46	2.25

* Rowe <u>et</u> <u>al</u>. (23) values were converted to 1980 dollars. The Rowe <u>et</u> <u>al</u>. figure of $4.38 was used as the value for the 75-mile visual range, and the Rae (28) figure of $8.45 was used as the value for the 160-mile visual range.

pheric visibility that contradicts the pattern displayed in Table 8-6. In regions with fairly high background visibility levels, small percentage increases in ambient pollution concentrations will cause even larger percentage losses in the economic value attached to atmospheric visibility. If background visual ranges are extremely lengthy, the percentage losses in economic value can exceed the percentage increases in ambient pollution by factors of 2 to 3. Even, where background visual ranges are relatively low, reductions in visual range will generate economic losses, though the percentage loss is unlikely to be more than half the percentage reduction in visual range.

The visibility valuation elasticities of Table 8-6 do not extend down to 13-, 20-, and 30-mile median summer visual ranges. Nevertheless, given the behavior of these elasticities display, it is not a fearsome task to extend them. Two points can be made. First, there probably is not much variation in the positive magnitude of β_2 over the 13-30 mile interval. Such variation as there is, is likely exceeded by the noise factors inherent in any economic benefits analysis. Second, the positive magnitude of β_2 over the 13-30 mile interval is small. A magnitude of 0.2 is as reasonable as any. Thus, we propose using the following expression to estimate the value per outdoor activity day that the representative U.S. household attaches to improvements in visual range over the 13-30 mile interval:

$$\ln(TWP) = 0.2 \ln(Y) + 0.2 \ln(V) \qquad (8.6)$$

where TWP is the household's total willingness-to-pay for a single outdoor recreation activity day, Y is annual household income in thousands of dollars, and V is visual range in miles. To obtain household annual willingness-to-pay, any answer obtained to the above expression should be multiplied by 30, on the assumption that the collection of adults in the representative U.S. household, whether it has complete darkness or 235-mile visual range, will annually engage in 30 days of outdoor recreational activity at sites well removed from its immediate home environs. As earlier noted, there is nothing whatsoever in the literature giving the slightest hint of the response of household outdoor activity days to variations in visual range.

A nationwide increase of 20 percent in median summer visual ranges would result in 10- or 11-mile visual ranges throughout most of the Ohio Valley and Southeast and 100-mile ranges in the Four Corners area. The rest of the nation would fall between these extremes. On the basis of Table 8-6, we take the following expression to be a reasonable representation for a 20 percent increase in visual range over that part of the country currently experiencing median summer visual ranges in excess of 30 miles.

$$\ln(TWP) = 0.2 \ln(Y) + 0.8 \ln(V) \qquad (8.7)$$

As before, the values obtained from the above expression should be multiplied by 30 in order to obtain annual household willingness-to-pay. It should be noted that the 0.8 value attached to ln(V) is the upper bound of the values from Table 8-6 that one might reasonably attach to a nationwide average (based on land area) visual range of, say, 50 miles.

Table 8-7 summarizes the low, medium, and high estimated annual recreational benefits for the four alternative visibility policies. For the policy involving a nationwide 20 percent improvement in visual range, Equation (8.6) is used when the initial level of atmospheric visibility is less than 45 miles, while Equation (8.7) is used when the initial visual range is greater than or equal to 45 miles.

THE EXISTENCE VALUE OF PROTECTING VISIBILITY

The notion of existence value was first developed by John Krutilla (32). Krutilla argued that consumers may value preservation of a pristine natural environment even if they do not expect to use that particular environment. The classic example is preservation of the large species of whales. Even though an individual may, for example, never see a blue whale in person, knowledge that the species survives is of real value and, as an

Table 8-7

LOW, MEDIUM AND HIGH ESTIMATED RECREATIONAL BENEFITS PER YEAR IN 1980 MILLIONS OF DOLLARS FOR VISIBILITY POLICIES OF 13, 20, 30 MILES AND A NATIONWIDE 20% IMPROVEMENT*

Policy	Low	Medium	High
13 Miles	59	247	455
20 Miles	1,048	1,595	2,201
30 Miles	3,566	4,535	5,606
20%	7,392	12,296	17,448

* In the following equation let:

B_i = Benefits per household per outdoor recreational activity day in region i.

Y_i = Household income in region i.

V_i^1 = Initial visibility in region i (see Table 8-4).

V_i^2 = New visibility imposed by the policy alternatives in region i.

Then Low, Medium and High estimates were calculated by assuming a different V_i^1.

Estimates calculated using:

$$B_i = (Y_i^{0.2}(V_i^2)^{0.02} - Y_i^{0.2}(V_i^1)^{0.2}) \text{ for } V_i^1 < 45 \text{ miles,}$$

and

$$B_i = (Y_i^{0.2}(V_i^2)^{0.8} - Y_i^{0.2}(V_i^1)^{0.8}) \text{ for } V_i^1 \geq 45 \text{ miles.}$$

To obtain <u>annual</u> benefits per household, B_i was multiplied by 30, presuming therefore that the representative U.S. household participates in 30 outdoor recreational days annually. This result was then multiplied by the number of households per region and then summed over regions to obtain total national benefits.

economic measure, an individual may be willing to pay to preserve the species. Existence value can include two components. The first is derived from knowledge that the environment is preserved in the present. The second is derived from knowledge that the environment will be preserved in the future for the benefit of future generations. The latter of these two types of existence values has been termed bequest value.

On a purely subjective basis, existence values in the present are probably associated with natural wonders of the environment which are widely known even by people who cannot visit them. Thus, a resident of New York State may well know of the Grand Canyon and of Yellowstone, yet never intend to visit either park, but still be willing to pay to preserve these natural wonders, desiring simply to know that they remain pristine.

The bequest type of existence value may apply to far more ordinary environments. Thus, parents may wish to know that a particular stretch of river will remain in a natural state after their own death for use by their own children or future generations. Hence, existence value may be a more common phenomenon than is generally supposed.

Unfortunately, to our knowledge, only two studies to date have attempted to estimate existence value. The first of these studies values water quality and is only indirectly relevant to the problem of estimating the existence value of visibility (30). The second study attempts to value preservation of air quality in the Grand Canyon and surrounding parks and is directly relevant for estimating the national benefit of visibility protection (2). We review these two studies in the following subsection.

<u>Studies of Existence Value</u>

The Greenley, Walsh and Young study (to be referred to henceforth as the G.W.Y. study) investigated the benefits of preventing irreversible water quality degradation due to mining activity in the South Platte River Basin of Colorado. G.W.Y. specifically included questions in their survey to estimate existence and bequest values for nonusers. Two hundred and two households in Denver and Fort Collins, Colorado were interviewed using either a sales tax or a residential water-sewer fee as the vehicle for collecting the hypothetical payment to preserve the river. The recreation derived user values (including option value) averaged $79 annually to preserve the river for the 80 percent of the sample that used or expected to use the river. This same group was willing to pay an additional $67 annually for existence and bequest values of preservation. The 20 percent of the sample who were nonusers were willing to pay, on average, $42 annually for preserving the South Platte, a pure measure of existence and bequest value. This latter group provides a better measure of pure existence value, since individuals who do not use and do not plan to use a particular environment can only have existence value for that environment. If we accept $42 per year as the existence value for all of the sample, including users, then existence values are about 53 percent of user values, a significant increase in the total preservation value. Perhaps the most surprising aspect of the G.W.Y. study is that positive existence values were obtained at all. The South Platte is not a wonder of the world, nor, for that matter, recognized on a national basis as an area for environmental concern. Thus, the ratio of existence value to user value (including option value) of 0.53 may provide a lower bound estimate of existence value for preservation of environmental quality for more well-known natural environments.

In contrast to the G.W.Y. study of the South Platte, the study by Schulze, Brookshire, Walther, and Kelley (to be referred to as the S.B.W.K. study) of the value of visibility in the Grand Canyon region deals with an internationally recognized natural wonder.

The S.B.W.K. study can be summarized as follows. During the summer of 1980, over 600 people in Denver, Los Angeles, Albuquerque and Chicago were shown sets of photographs depicting both clear visibility conditions and regional haze conditions. Each set consisted of five photographs ranging from poor to excellent visibility. The middle picture in each case approximated average visibility during the summer (the season of peak visitation). The vistas were three different views from the Grand Canyon, one view from Mesa Verde, and one view from Zion. The 8 x 10 inch textured prints were placed on display boards, each vista a separate row, and each row arranged with five photographs from left to right in ascending order of visual air quality (i.e., photograph A = "poor" visibility and photograph E = "excellent" visibility).

The survey participants were asked either 1) how much they would be willing to pay for visibility as shown in the five sets of photographs from worst to best on the day of a visit to the Grand Canyon (an estimate of user value), or 2) how much they would be willing to pay in higher electric utility bills to preserve the current average condition -- middle picture -- rather than allow visibility to deteriorate, on the average, to the next worst condition as represented in the photographs of the Grand Canyon or of the region (an estimate of total preservation value). They were also asked about their willingness-to-pay in the form of higher monthly electric power bills to prevent a plume from being seen in a pristine area. To represent plume blight, two photographs were taken from Grand Canyon National Park. Both photographs are essentially identical except one has a plume, a narrow gray band, crossing the entire vista in the sky. The source was not industrial or municipal pollution, but a controlled burn in the area around the Grand Canyon. However, the effect was comparable to what a large uncontrolled industrial source might produce.

The bidding game was designed to reveal the household's willingness-to-pay for preserving visibility in specific locations as represented in the photographs. For the interviewees asked the preservation value questions in the survey, the bids include both existence value and user value.

The survey had few refusals, partly because of the nature of the interviews. Typically, interviews were conducted in the late afternoon or early evening hours in residential neighborhoods. Due to the large size of the display boards, most interviews were conducted on the front lawn of the respondent's home. Often, both husband and wife participated jointly in answering the questions. This was viewed by S.B.W.K. as appropriate since the principal question was "how much would you be willing to pay in higher monthly electric utility bills to preserve visibility at the Grand Canyon or in the entire Grand Canyon region?" Household members would often engage in existence discussion before giving a dollar amount. Individual bids ranged from an average of $3.72 per month in Denver to $9.00 per month in Chicago for preserving visibility at the Grand Canyon. These average bids were increased from $2.89 to $7.10 per month per household in the four cities if visibility preservation was to be extended to the Grand Canyon region as a whole. Prevention of a visible plume in the Grand Canyon was worth on the average between $2.84 and $4.32 per month for the four cities surveyed.

The validity of these survey results depends on the perception by individuals of visibility conditions as represented by photographs. The S.B.W.K. study argued that a linear relationship has been shown to exist between perceived visibility as quantified by individuals and with scientific measures of the apparent contrast in the vista by a multiwavelength teleradiometer. This close linear relationship between perception of an actual vista and the apparent contrast of the vista also extends to perception of visibility conditions represented by slides or 8 x 10 inch color photographs as was shown in the research presented in Chapter 4 of the report by S.B.W.K.

The benefit estimates derived from the interview results were extrapolated from the sample population to the country as a whole by applying statistical techniques to the results of the survey. The bids offered by interviewees to preserve visibility were statistically related to income as well as other demographic characteristics. Using an estimated linear relationship of bids to population characteristics, the study estimated the value of benefits to residents for the entire nation. This was done by substituting the average value for these characteristics for each state into the relationship and calculating the average value of the bid of a person in that state. This value was then multiplied by the number of households in the state to get a total bid or benefit.

The estimates of aggregate national benefits for preserving visibility from the S.B.W.K. study are given in Table 8-8. The estimates shown in Table 8-8 include both user and existence values. To estimate the existence value component alone, we must net out the user value component. Fortunately, the S.B.W.K. study does provide individual estimates of user values for the Grand Canyon which are tied to entrance fees per carload. Household bids per visit to maintain visibility at level C (the current summer average) rather than have a worse condition, B, on the day of a visit, averaged $1.08 (from Figure 15, p. 66 of the S.B.W.K. report) for the three cities (Albuquerque, Los Angeles and Denver) where the Grand Canyon user value question was asked. Noting that the Grand Canyon had 2,131,700 individual visits in 1979, or about 761,300 household entrances (we assume one household is equivalent to one carload), a total annual user value bid would be $1.08 x 761,300, or $822,204. Thus, maintaining visibility at current average levels (C in the study) as opposed to allowing a deterioration to level B, a decrease in visibility as represented in the photographs of 31.6 miles, is worth less than $1 million to users. This contrasts with a total preservation value estimated at $3,370 million per year for preventing the downward change in visibility. User value is, at least given the results of the S.B.W.K. study, a negligible component of

Table 8-8

NATIONAL EXISTENCE VALUE BENEFITS FROM S.B.W.K. STUDY

Yearly Benefits From	Total ($ million)
Preserving visibility at the Grand Canyon (maintaining C vs. B)	3,370
Preserving visibility in the Grand Canyon region (maintaining C vs. B)	5,760
Preventing plume blight at the Grand Canyon	2,040

the benefits of preserving visibility at the Grand Canyon. Clearly, the Grand Canyon must be an exceptional case in that virtually all of the measured benefits of visibility preservation are derived from existence value. This is in direct contrast to the G.W.Y. study of the South Platte which found existence values to be only a fraction of user value. However, these results are consistent with a priori expectations in that the relative size of existence values would logically be related to the fame of a particular environmental asset. In crude terms, willingness-to-pay for existence value depends on knowledge of the state of an environmental asset independent of the use of that asset. It is unlikely that most residents of the United States would be aware of the state of water quality in the South Platte, while it is highly likely that many individuals across the nation would be aware of a decline in air quality at the Grand Canyon.

In summary, the two available studies of environmental existence values provide a clear indication that existence values may be important. However, it should be recognized that this is a new area for benefits research, and extrapolations based on the one study done for visibility in the Grand Canyon can only be highly tentative at best.

Tentative Estimates of Existence Values for Visibility

In assessing existence values for visibility we assume that such values apply only to nationally recognized recreation areas. Table 8-9 presents a list of all National Parks and in addition those national recreation areas which have at least one million visits per year. The table also gives visits for 1979 and approximate summer visibility in miles.* Also included in the table is an indication as to whether or not visibility is classed as important to the recreation area.**

* These data are taken from the National Park Statistical Abstract (33).

** The visibility "importance" ranking and data are taken from Protecting Visibility: An EPA Report (34).

Table 8-9

RECREATION AREAS USED IN EXISTENCE VALUE ANALYSIS

	Name of Area	Classification	State	1979 Individual Visits in 1000's	Summer Visibility in Miles	Visibility Classed as Important
1	Acadia	NP	ME	2,787.4	38	Yes
2	Amistad	NRA	TX	1,261.8	29	No
3	Assateague Island	NS	MD-VA	1,674.9	10	No
4	Blue Ridge Parkway		VA-NC	11,700.2	12	No
5	Boston	NHP	MA	1,777.4	15	No
6	C & O Canal	NHP	MD-DC-WV	2,832.6	10	No
7	Cabrillo	NM	CA	1,196.4	15	No
8	Cape Cod	NS	MA	3,922.0	15	No
9	Cape Hatteras	NS	NC	1,516.9	9	No
10	Chickasaw	NRA	OK	1,434.5	17	No
11	Colonial	NHP	VA	7,172.1	8	No
12	Delaware Water Gap	NRA	PA-NJ	2,002.5	14	No
13	Fred Spot	NMP	VA	1,010.7	12	No
14	Gateway	NRA	NY-NJ	8,773.1	10	No
15	Geo. Washington Memorial Pkway.		VA-MD	4,678.0	12	No
16	Glacier	NP	MT	1,446.1	48	No
17	Glen Canyon	NRA	AZ-UT	1,656.0	72	No
18	Golden Gate	NRA	CA	11,321.1	14	No
19	Grand Canyon	NP	AZ	2,131.7	75	Yes
20	Grand Teton	NP	WY	2,446.2	70	Yes
21	Great Smoky Mountains		NC-TN	8,019.8	10	Yes
22	Gulf Islands	NS	FL-MS	2,965.0	8	No
23	Hawaii Volcanoes	NP	HI	1,632.6		Yes
24	Hotsprings	NP	AR	1,118.8	15	No
25	Independence	NHP	PA	2,002.3	9	No
26	Indiana Dunes	NL 51	IN	1,606.2	10	No
27	Jefferson Memorial		DC	2,328.1	12	No
28	Jefferson NEM	NHS	MO	1,859.4	15	No
29	JFK Center for the Performing Arts		DC	4,130.6	12	No
30	J.D. Rockefeller, Jr. Parkway		WY	1,356.0	75	No
31	Lake Mead	NRA	AZ-NV	6,155.1	70	No
32	Lake Meredith	NRA	TX	1,849.4	34	No
33	Lincoln Memorial		DC	3,352.3	12	No
34	Mammoth Cave	NP	KY	1,384.9	9	Yes
35	Mount Rainier	NP	WA	1,516.7	25	Yes
36	Mount Rushmore National Memorial		SD	1,245.4	55	No
37	Muir Woods	NM	CA	1,227.2	14	No

(continued)

Table 8-9 (Continued)

	Name of Area	Classification	State	1979 Individual Visits in 1000's	Summer Visibility in Miles	Visibility Classed as Important
38	Natchez Trace Parkway		MS-TN-AL	9,475.3	9	No
39	National Capital Parks		DC-MD	2,811.0	12	No
40	Olympic	NP	WA	2,078.8	25	Yes
41	Ozark	NSR	MO	1,453.0	10	No
42	Point Reyes	NS	CA	1,489.1	14	Yes
43	Rocky Mountain	NP	CO	2,568.5	70	Yes
44	San Juan	NHS	PR	1,458.8		No
45	Shenandoah	NP/4	VA	1,521.5	10	Yes
46	Statue of Liberty	NM	NY-NJ	1,661.4	10	No
47	Valley Forge	NHPl	PA	3,107.4	11	No
48	Washington Monument		DC	1,304.8	12	No
49	Whiskeytown	NRA	CA	1,162.4	56	No
50	White House		DC	1,312.0	12	No
51	Yellowstone	NP	WY-MT-ID	1,892.9	75	Yes
52	Yosemite	NP	CA	2,350.8	44	Yes
53	Zion	NP	UT	1,040.5	72	No
54	Arches	NP	UT	269.8	73	Yes
55	Badlands	NP8/	SD	858.0	55	Yes
56	Big Bend	NP	TX	282.9	29	Yes
57	Bryce Canyon	NP	UT	558.1	72	Yes
58	Canyonlands	NP	UT	74.5	73	Yes
59	Capitol Reef	NP	UT	288.9	73	Yes
60	Carlsbad Caverns	NP	NM	721.6	61	Yes
61	Crater Lake	NP	OR	410.7	44	Yes
62	Everglades	NP	FL	718.1	15	Yes
63	Guadalupe Mountain	NP	TX	110.5	45	Yes
64	Haleakala	NP	HI	674.0		
65	Isle Royale	NP	MI	14.8	19	Yes
66	Kings Canyon	NP	CA	804.2	80	Yes
67	Lassen Volcanic	NP	CA	380.0	44	Yes
68	Mesa Verde	NP	CO	473.7	74	Yes
69	Mount McKinley	NP	AK	251.1	15	Yes
70	North Cascades	NP	WA	743.0	33	Yes
71	Petrified Forest	NP	AZ	671.6	75	Yes
72	Red Wood	NP	CA	413.9	14	Yes
73	Sequioa	NP	CA	799.6	14	Yes
74	Theodore Roosevelt	NP	ND	591.6	45	Yes
75	Virgin Islands	NP	VI	549.7		Yes
76	Voyageurs	NP	MN	195.3	20	Yes
77	Wind Cave	NP	SD	457.4	55	Yes

The method used to approximate national existence values for visibility can be described as follows. First, the monthly household existence value bid in dollars for visibility at the Grand Canyon from the S.B.W.K. study can be approximated as:

$$\text{Monthly bid} = 2.69\ Y^{0.22}$$

where Y is annual household income in thousands of dollars. This bid is for preserving visibility conditions C as opposed to B or an increment in visibility of 31.6 miles.* Thus, an estimate of an <u>annual</u> household bid <u>per mile</u> of increased visibility at the Grand Canyon is:

$$\text{Annual bid per mile} = \frac{2.69 \times 12}{31.6} Y^{0.22} = 1.02\ Y^{0.22}$$

Since we have argued that existence values are likely to be dependent on the fame of a particular environment or perhaps cultural asset, we use as an index of knowledge by consumers of a recreation area the ratio of visits to each site in Table 8-9 to visits to the Grand Canyon to weight the value of the visibility presented in the formula above. Hence, we effectively assume that if a site has one-tenth the visitation of the Grand Canyon, existence values for visibility at that site are worth one-tenth of the value per mile of the Grand Canyon. While crude, we feel that some adjustment of this sort is essential to approximate even an order of magnitude for existence values.

These assumptions imply that each household in the U.S. will have an existence value for visibility improvement equal to

$$\sum_{i=1}^{n} \Delta V_i \frac{R_i}{R_{GC}} 1.02\ Y^{0.22}$$

* Conversion from apparent contrast of the photographs used in S.B.W.K. to visibility in miles obtained from Eric Walther by personal communication.

or the sum over n sites of the changes in visibility at each site i (ΔV_i) times the ratio of recreation visits at site i to the recreation visits at the Grand Canyon (R_i/R_{GC}) times the annual value per mile of increased visibility at the Grand Canyon.

Table 8-10 presents results for this calculation aggregated across households with varying income levels across the United States. The calculation is made first for all recreation areas listed in Table 8-9. Note that this calculation includes presumed benefits for urban parks and areas where visibility has not been deemed an important value as indicated in Table 8-9. However, one must question the evaluation that visibility would not be important at the Statue of Liberty, the Washington Monument, or Lake Powell. In any case, this provides an upper bound estimate for the benefits of policies where a 13-, 20-, or 30-mile national visibility standard is imposed or where visibility is improved everywhere by 20 percent. Probably a more realistic assessment of existence value benefits is presented in the second column of Table 8-10 where only those areas where visibility is deemed an important factor are included in the calculation. Finally, it may be true that existence values are only important for the most famous of national parks, for which national pride or value to future generations become the dominant values. Using only Acadia, the Grand Canyon, the Grand Tetons, the Great Smoky Mountains, Yellowstone and Shenandoah gives column three of Table 8-10. Note that the possible range of benefits exceeds one order of magnitude from the high to the low estimates shown in Table 8-10. On the basis of one study of the existence value of visibility, such a wide range is an honest reflection of our current knowledge. At this point, we would recommend use of our lower bound estimate as the most appropriate assumption of existence value benefits.

NONAESTHETIC BENEFITS OF VISIBILITY IMPROVEMENT

To this point, the discussion has focused primarily on the aesthetic benefits associated with visibility improvements. In this section, we briefly review several areas where benefits of a nonaesthetic type may be

Table 8-10

ESTIMATED EXISTENCE VALUE BENEFITS PER YEAR IN 1980 MILLIONS OF DOLLARS
PER VISIBILITY POLICIES OF 13, 20 AND 30 MILES AND
A NATIONWIDE 20% IMPROVEMENT

Policy	All Recreation Areas	All Recreation Areas Where Visibility is a Factor	Only the Most Famous Parks*
13 Miles	21,418	4,717	2,172
20 Miles	81,131	13,227	7,194
30 Miles	173,330	27,419	14,430
20%	56,653	23,656	10,172

* Only Acadia, Great Smokies, Shenandoah, Yellowstone, Grand Teton and Grand Canyon are included in this calculation.

generated because of better visibility. Specifically, we consider various safety aspects of improved visibility. Unfortunately, no empirical studies of the nonaesthetic benefits of visibility are available. Conceptually, however, estimation of such benefits is likely to be straightforward. Clearly good visibility is a requirement for the safe operation of vehicles on roads, waterways, or in the air. Additionally, good visibility may be necessary for productive activities such as surveying or possibly laser transmission of messages.

Focusing on safety issues, it is clear that the operation of vehicles may be hindered by bad visibility. Econometric techniques can be applied to estimate the effect of visibility conditions on takeoffs and landings of aircraft, road traffic, and water traffic. If it can be shown that the level of these activities is significantly affected by visibility (and probably in a very nonlinear way), it is a simple matter to estimate the lost economic value associated with a decrease in these activiites from a reduction in visibility from air pollution. It is important to note that although reductions in transportation activities result from safety considerations, a direct calculation based on lives saved from better visibility is probably inappropriate. This results from the obvious behavioral response to delay travel rather than lose lives. Obviously, the cost of delay is far less than the value of lives possibly lost in a transportation accident. The cost of delays induced by poor visibility is thus an appropriate measure of the benefits of better visibility. Finally, it is readily apparent that only when visibility is reduced in the extreme are significant costs likely to be imposed. Thus, the possible role of air pollution in increasing the frequency and intensity of fogs is likely to be the most important component for benefits assessment.

Some empirical estimates along these lines should be available shortly. The University of Chicago group under the direction of George Tolley (with Alan Randall and Glen Blomquist, both of the University of Kentucky, playing important roles in the research) is attempting to econometrically relate takeoffs and landings of aircraft to visibility conditions.* Their model includes safety as well as aesthetic impacts in that the desire to fly may be increased under good visibility conditions since the flight may be more pleasurable. This latter aspect may be of specific importance for private aviators.

NATIONAL BENEFIT ESTIMATE FOR ACHIEVING A 13-, 20-, 30-MILE AND A NATIONWIDE 20 PERCENT STANDARD

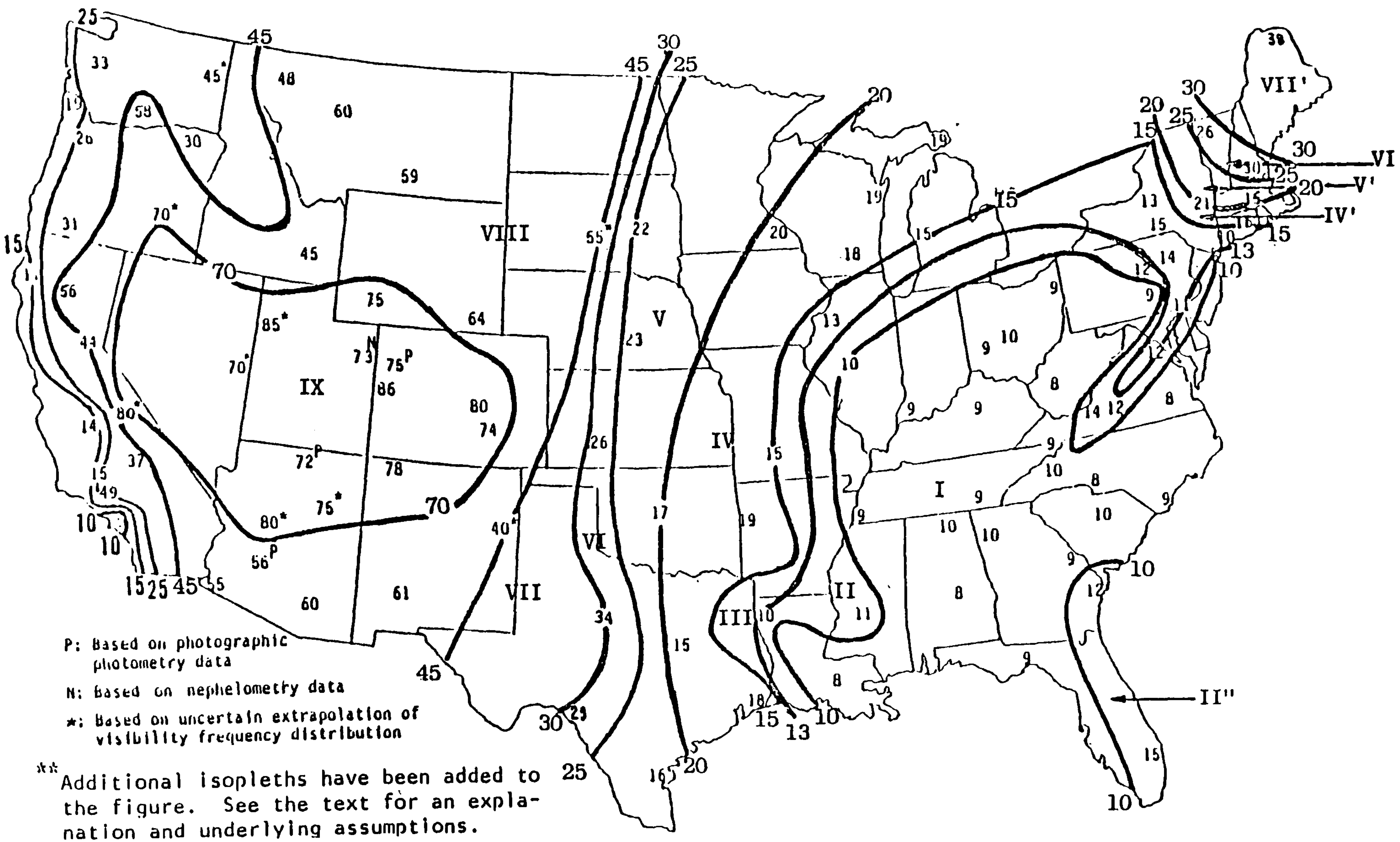
This section discusses the procedures and data utilized in the calculation of national benefits for alternative visibility standards. Problems that required attention were identifying the areas affected by each proposed standard, specifying a mechanism to set upper and lower bounds to the benefit estimate, defining the appropriate unit of analysis for data collection, choosing discount rates and time horizons, and choosing attainment goals. The subsections that follow discuss each of these issues in turn and present the benefit estimates for each proposed standard.

Visual Range Regions Utilized in the Benefit Calculation

In calculating the willingness-to-pay for the proposed 13-, 20-, and 30-mile standards, as well as nationwide improvement of 20 percent in visual range, the U.S. was divided into visibility regions. Figure 8-1 presents the median summer visual range in miles, designated by isopleths for the years 1974-76. The isopleths divide the nation into visual range regions of 10 miles and less, 10-15 miles, 15-25 miles, 25-45 miles, 45-70 miles, and 70 miles or greater. These visual range regions form the basis of the results to be presented later in this section. Also presented on the map in Figure 8-1 are the visual range levels at a multiple number of sites in the U.S. This information was utilized in delineating the regions that represent an improvement from the existing level of visibility to a proposed standard.

Consider first the delineation of the regions affected by a proposed nationwide standard of 13 miles. Inspection of Figure 8-1 reveals that

* These comments are based on a telephone conversation with Alan Randall.



**Additional isopleths have been added to the figure. See the text for an explanation and underlying assumptions.

Source: U.S. Environmental Protection Agency (34).

Figure 8-1. Median Summer Visual Range (Miles) and Isopleths for Suburban/Non-Urban Areas, 1974-76 (35)** many areas of the country already enjoy visibility levels in excess of 13 miles. For instance, all of the West, excluding coastal California, and much of New York and New England have current visibility ranges of 15 miles or greater. Thus the task for the 13-mile national standard was to identify the counties that had current visual range levels below 13 miles.

In identifying the counties and then the number of households in each county, a new set of isopleths was drawn. Consider the area marked Region I in Figure 8-1, which includes major portions of the Southeast. In this region visual range, as indicated by the various data points on the map, is at best 10 miles. Thus for Region I, all of the counties were identified as an area that would experience an improvement in visual range as a result of setting a nationwide minimum standard of 13 miles.

Examining the states of Illinois, Missouri, Arkansas, and Louisiana, one can see that the current distribution of visual ranges is from 10 to 13 miles. Thus for the 13-mile proposed standard a new region was designated — Region II in Figure 8-1 — which identifies areas which would experience improvement from 10 miles to 13 miles. Again, the counties were identified in Region II. Looking at Florida and parts of Georgia and South Carolina, Region II again represents an area which would improve from 10 to 13 miles in visual range. While not drawn on Figure 8-1, similar "10- to 13-mile" visual range regions were designated for the Southern California region, especially in the South Coast Air Basin area. Again, these counties are in areas that would experience an improvement in visibility under a national 13-mile standard. In this process the counties that would experience an improvement in visual range were identified nationwide and utilized in the calculation of the dollar benefits of a national visibility standard of 13 miles. Care was taken to identify major cities in designating a county as an improved area. If a major city within a county fell across the new isopleths, the county was arbitrarily placed into the lower visual range category.

The process for identifying the counties that would experience an improvement under a proposed 20-mile standard was identical to that followed for the 13-mile standard. However, the counties identified for the 13-mile standard are already isolated and one only has to assume the improvement in visual range from the initial level to 20 miles rather than from the initial level to 13 miles. Looking just west of Region II, a Region III was identified whereby the assumed initial level of visual range was the "13-mile isopleth" chosen in identifying affected counties for the 13-mile standard. Thus, Region III in Figure 8-1 represents those counties that would experience an improvement from 13 to 20 miles under a 20-mile standard. Revion IV represents the counties that would experience a visual range improvement from 15 miles to 20 miles. New England and California also have areas where the same procedure was followed in identifying counties that would be affected by a 20-mile nationwide visual range standard. In New England, the corresponding regions are denoted by a " ' ". In the West, the initial isopleths were too narrow to illustrate the boundaries.

In identifying the counties affected by a 30-mile standard, Regions I, II and II" were assumed to improve to 30 miles from their initial levels. Region III was assumed to have a visual range increase of 13 to 30 miles, while Region IV's improvement was from 15 to 30 miles. Region V went from 20 to 30 miles. As before, however, a new region was identified for counties that had a visual range of at least 25 miles and resulted in a new isopleth representing the 30-mile standard -- designated as Region VI. Again, new isopleths as represented by Region VI were identified for the West Coast and New England regions (denoted by " ' ").

For the regions identified thus far for the 13-, 20- and 30-mile proposed national visual range standards, they were in each case evaluated for the visibility change that would accompany a 20 percent nationwide improvement in visibility. That is, Region I was assumed to undergo a change of 10 to 13 miles; Region II, 10 to 13 miles; Region II, 13 to 15 miles, etc. This potentially introduces biases, but given the available visual range data base it would have been inappropriate to attempt a further refinement. In addition to assuming that the already designated regions realized a 20 percent improvement, the procedures for identifying affected counties not previously identified was continued. Thus a Region VII, just to the west of Region VI was identified as counties receiving a 20 percent improvement from an initial base visual range of 30 miles. Again, the appropriate areas in the West Coast and in New England were identified. Finally, Region VIII was assumed to represent a 20 percent improvement from a base of 45 miles, while counties in Region IX experience 20 percent improvements from a base of 70 miles.

In designating visual range regions for the calculation of benefits of alternative standards, an implicit assumption is made for each region. That is, within a region the visual range is homogeneously improved throughout the whole region according to the initial base visual range level. Consider Region IV, where the base isopleth visual range level is 15 miles and counties falling into this region are assumed under the 20-mile national standard not to exceed this level of visual range. In calculating the benefits, the incremental visual range improvement for the region as a whole would be assumed to be 5 miles. Clearly some counties in the region have initial values of visual range greater than 15 miles. Thus under a 20-mile national standard these counties would experience less than a 5-mile visual range improvement. Consequently, if a base visual range for the region as a whole of 15 miles were utilized in the calculation of benefits for a 20-mile standard, the resulting dollar benefits would be viewed as biased upwards. Again, this is due to the non-homogeneous nature of the visual range in the region.

The initial value problem illustrates the need to place upper and lower bounds on the visual range benefit estimates. Table 8-11 presents a range of initial visual range values for the nine regions. These were the values utilized in the benefit calculations. Since Region I is the only area with visual range values below the surrounding isopleths, a "low value" or base value of 8 miles was chosen. For Region II through Region IX the low value corresponds to the lowest visual range in the region and thus is the lower bound isopleth. Again, the use of the "low value" will represent an upper bound of the visual range benefit estimates for each proposed standard in each region. The values chosen as "high" for each

Table 8-11

LOW, MEDIUM AND HIGH VISIBILITY VISUAL RANGE VALUES BY REGION

Region	Low Initial Value Assumed for Regions Visual Range-Yields Upper Bound Benefit Estimate	Medium Initial Value Assumed for Regions Visual Range-Yield Intermediate Benefit Estimate	High Initial Value Assumed for Regions Visual Range-Yield Lower Bound Benefit Estimate
I	8	9	10
II	10	11.5	13
III	13	14	15
IV	15	17.5	20
V	20	22.5	25
VI	25	27.5	30
VII	30	37.5	45
VIII	45	57.5	70
IX	70	80	89

region in Table 8-11 represent the highest level of assumed initial overall visual range in the region. This represents a lower bound to the benefit estimate. The medium values represent an approximate average of visual range values for the region. The results of utilizing the bounds discussed above is to enable the calculation of a range rather than a point estimate for each proposed standard.

Procedures for Data Collection

The estimation of a national household benefit value for improving visibility to 13, 20, and 30 miles and for a 20 percent nationwide improvement required data on average household income and the number of households. Because the three mile-specific policies were not required for all areas of the U.S., nine basic visibility regions were defined (discussed previously) and data were collected by region. Unavoidably, the regional boundaries did not correspond to state boundaries. Therefore, the appropriate unit for observation was determined to be counties (and independent cities where appropriate). This also caused a problem, in that the visibility boundary did not always correspond to a county boundary. The placement of questionable counties was determined by the location of the major cities, thus ensuring that the majority of the households would be placed in the appropriate region. In the rare instances where the visibility boundary actually bisected a major city, the city (and corresponding county) was placed in the lower visibility region.

The counties of each region were identified by U.S. Bureau of the Census Maps (36). Unfortunately, the number of households and average income per household was unavailable at the county level. This required that county data be collected on the number of people and the income per capita (37). This information was aggregated by state (note: a single state could contain several regions, thus requiring several aggregates). These aggregates were then transformed into the desired information by using the state's ratio of individuals per household (38). From these, a regional average was calculated for each of the nine regions.

All the data collected was for 1974. In order to get approximations for 1980, the U.S. percentage change in households and household income was applied to each of the regional averages (39). Hopefully, the described procedures were able to preserve interstate population and income patterns; however, intrastate changes were unavoidably lost.

National Benefits for a 13-, 20-, 30-Mile and 20 Percent Improvement Standard

The previous sections have discussed the delineation of counties into visual range regions. This section will present the results by proposed standard for three benefit categories — residential, recreation and existence values. The underlying assumptions and benefit expressions utilized in the calculation of benefits have been discussed in earlier sections.

Table 8-12 presents the residential annual household benefits for the four standards for the lower to higher bound benefit estimate. Following the discussion in the earlier subsection, two functional forms were utilized. (See footnotes in the table.)

For achieving the 13-mile standard the range of annual residential benefits is from $20 to $947 million. The implementation of a nationwide standard of 20 miles yields a yearly range of $2,309 to $3,954 million, depending upon the calculation procedure. For the 30-mile proposed standard, the range of yearly values is $6,621 to $19,443 million. If the goal of a 20 percent nationwide improvement is sought, the annual household benefit range is $3,168 to $13,289 million.

Table 8-13 presents the range of estimates for household recreation benefits for the alternative standards. Note that different functional forms were utilized for regions above and below an initial visual range level of 45 miles (see footnote in the table). The lower bound benefit estimate for the 13-mile standard is $59 million and $967 million for the 20 percent improvement goal.

Table 8-12

LOW, MEDIUM AND HIGH ESTIMATED RESIDENTIAL AESTHETIC BENEFITS PER YEAR IN 1980 MILLIONS OF DOLLARS FOR VISIBILITY POLICIES OF 13, 20, 30 MILES AND A NATIONWIDE 20% IMPROVEMENT*

Policy	Low		Medium		High	
	Eq. 1**	Eq. 2+	Eq. 1	Eq. 2	Eq. 1	Eq. 2
13 Miles	130	20	791	63	947	182
20 Miles	2,115	1,309	3,493	2,005	3,954	3,047
30 Miles	6,621	12,014	8,444	15,319	9,267	19,443
20%	3,372	3,168	3,804	7,196	4,278	13,829

* Table 8-4 did not represent an "aesthetics only" set of residential values. In this section, the residential values from Table 8-4 have been reduced by 50 percent and thus only represent aesthetic residential values. In the following notes, let:

B_i = Benefits per year for region i.

Y_i = Average annual household income for region i.

V_i^1 = Initial visibility in region i (see Table 8-4).

V_i^2 = New visibility imposed by the policy alternatives in region i.

H_i = Number of households in region i.

$\Delta V_i = V_i^2 - V_i^1$.

BY = Benefits per year = $\sum_{i=1}^{9} B_i$ where the regions are defined by Map 1.

Then Low, Medium and High estimates were calculated by assuming a different V_i^1 ($B_i = 0$ for unaffected regions).

** Calculated using:

$$B_i = [(0.497Y_i^{0.566}(V_i^2)^{0.399} - 0.497Y_i^{0.566}(V_i^1)^{0.399}) \times H_i]/2$$

\+ Calculated using:

$$B_i = [(0.0039Y_i^{0.566}(\Delta V_i)^{2.239}) \times H_i]/2$$

Table 8-13

LOW, MEDIUM AND HIGH ESTIMATED RECREATIONAL BENEFITS PER YEAR IN 1980 MILLIONS OF DOLLARS FOR VISIBILITY POLICIES OF 13, 20, 30 MILES AND A NATIONWIDE 20% IMPROVEMENT*

Policy	Low	Medium	High
13 Miles	59	247	455
20 Miles	1,048	1,595	2,201
30 Miles	3,566	4,535	5,606
20%	7,392	12,296	17,448

* In the following equation let:

B_i = Benefits per household per outdoor recreational activity day in region i.

Y_i = Household income in region i.

V_i^1 = Initial visibility in region i (see Table 8-4).

V_i^2 = New visibility imposed by the policy alternatives in region i.

Then Low, Medium and High estimates were calculated by assuming a different V_i^1.

Estimates calculated using:

$$B_i = (Y_i^{0.2}(V_i^2)^{0.02} - Y_i^{0.2}(V_i^1)^{0.2}) \text{ for } V_i^1 < 45 \text{ miles,}$$

and

$$B_i = (Y_i^{0.2}(Y_i^2)^{0.8} - Y_i^{0.2}(V_i^1)^{0.8}) \text{ for } V_i^1 \geq 45 \text{ miles.}$$

To obtain <u>annual</u> benefits per household, B_i was multiplied by 30, presuming therefore that the representative U.S. household participates in 30 outdoor recreational days annually. This result was then multiplied by the number of households per region and then summed over regions to obtain total national benefits.

Tables 8-14 and 8-15 present the existence value benefits. The results in Table 8-14 are, as discussed earlier, dependent upon an existence value index. The process of calculating the index is shown in the footnote in Table 8-15. Utilizing the existence value index, the category "Selected National Parks" represents, for each standard, the lower bound existence value benefit estimate. For instance, a 20 percent nationwide improvement existence value benefit is $10,172 million.

A complete range of benefit values for residential, recreation and existence value is presented in Table 8-16. Utilizing the values low, medium and high for the initial assumed visual range levels by region by standard and the alternative functional forms, a "low-low" to a "high-high" annual estimate can be constructed. For the 13-mile standard, the lower bound annual estimate is $2,251 million and the upper bound is $3,574 million. These values in Table 8-16 thus represent the extreme bounds on the annual visibility estimates.

In addition to the benefit numbers reported in Tables 8-12 through 8-16, a variety of other calculations were made to reflect different discounting time horizons, discount rates, and attainment periods. Estimates are available for discounted present values as well as annualized numbers. Additionally, a variety of alternative aggregation procedures are also utilized. Tables reflecting these combinations of assumptions are available from the authors upon request.

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Table 8-14

ESTIMATED EXISTENCE VALUE BENEFITS PER YEAR IN 1980 MILLIONS OF DOLLARS PER VISIBILITY POLICIES OF 13, 20, 30 MILES AND A NATIONWIDE 20% IMPROVEMENT*

Policy	Selected National Parks**
13 Miles	2,172
20 Miles	7,194
30 Miles	14,430
20%	10,172

* Let:

B = Benefits.

A = Total existence value index.

H = Number of households in the U.S.

Y = Household income in thousands.

Then the above were calculated as:

$$B = 1.0215AH^{0.22}H$$ where A varies according to Table 8-15.

** Arcadia, Great Smokies, Shenandoah, Yellowstone, Grand Canyon, and Grand Teton.

Table 8-15

TOTAL EXISTENCE VALUE INDEX*
(1980 Millions of Dollars)

Policy	Selected National Parks**
13 Miles	13.42
20 Miles	44.75
30 Miles	89.51
20%	63.27

* $$A = \sum_{i}^{n} \Delta V_i \left(\frac{S_i}{2131.7}\right) D_i.$$

A = Total existence value index.

ΔV_i = Change in visibility at site i compared to standard visibility.

S_i = Visits to site i in thousands.

ΔV_i = 0 if (standard visibility - V_i) < 0.

2131.7 = Visits to the Grand Canyon in thousands.

D_i = Dummy variable, depending upon importance of visibility:

D_i = 0 Visibility is not a factor
D_i = 1 Visibility is a factor.

** D_i = 1 for Arcadia, Great Smokies, Shenandoah, Yellowstone, Grand Canyon and Grand Teton.

Table 8-16

RANGES FOR THE LOW, MEDIUM AND HIGH TOTAL BENEFITS PER YEAR IN 1980 MILLIONS OF DOLLARS FOR VISIBILITY POLICIES OF 13, 20, 30 MILES AND A 20% NATIONWIDE IMPROVEMENT*

Policy	Low		Medium		High	
	Low	High	Low	High	Low	High
13 Miles	2,251	2,361	2,482	3,210	2,809	3,574
20 Miles	10,357	9,551	10,794	12,282	12,442	13,349
30 Miles	24,617	30,010	27,409	34,284	29,403	39,479
20%	20,732	20,936	26,272	29,664	31,898	41,449

* Calculated from Tables 8-4, 8-7, and 8-10. The Low, Medium, and High categories were obtained by assuming different initial visibility levels. The Low and High subcategories indicate the range of the estimates within each of the primary categories.

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APPENDIX 8A

HOW VISIBILITY CHANGES WERE CALCULATED FOR THE PROPERTY VALUE STUDIES

The dollar per mile per year figures were calculated in the following manner:

a. The figure for Δ in property value was capitalized with an interest rate of 10 percent and a life span of 30 years, which gives a per-year bid for the given level of pollution change.

b. The figures for visibility were calculated by the following equations:

i) $1\ mg/100\ cm^2 = 10\ \mu g/cm^2$ (1). (8A)

Assume $10\ \mu g/m^3$ part $= 0.1\ mg/100\ cm^2$ sulfation (2) since $0.1\ mg/100\ cm^2 = 1\ \mu g/cm^2$

$10\ \mu g/m^3$ part $= 1\ \mu g/cm^2$ sulfation (8B)

ii) Given a Δ in sulfation of $0.25\ mg/100\ cm^2$, we can convert it to $2.5\ mg/cm^2$ by Equation (8A).

iii) $$\frac{1\ \mu g/cm^2}{10\ \mu g/m^3} = \frac{2.5\ mg/cm^2}{x \mu g/m^3}$$ by Equation (8B).

$x = 25\ mg/cm^2$.

$2.5\ \mu g/cm^2$ of sulfation is equivalent to $0.25\ \mu g/m^3$ of particulates.

iv) To convert particulates (TSP), the following conversion was used (3):

$\Delta NO_2 = \Delta$ part x 0.097

$\Delta NO_2 = -(25\ \mu g/m^3)(0.097)$

$\Delta NO_2 = -2.43\ \mu g/m^3$.

v) Finally, to convert to visibility (3):

$$\frac{\Delta NO_2}{-0.211} = \Delta V \qquad \frac{-2.43}{-0.211} = 11.49 \text{ miles}$$

c. To calculate the WTP per mile per year:

The yearly WTP was divided by Δ in miles and then adjusted to 1981 dollars.

d. To convert the oxidant measure of pollution to $NO_2 \rightarrow V$ (3):

$$\Delta NO_2/\Delta oxidant = 1.41 \Rightarrow \frac{1.41(\Delta oxidant)}{-0.211} = \Delta V$$

since $\Delta NO_2 = -0.211\ \Delta V$.

To convert $CO_2 \rightarrow NO_2 \rightarrow V$ (3,4):

$$0.006 \cdot \Delta CO_2 \cdot 10 = NO_2 \Rightarrow \frac{0.06 \cdot \Delta CO_2}{-0.211} = \Delta V$$

To convert $SO_2 \rightarrow part \rightarrow V$:

$$10\ \mu g/m^3 = 1\ ppb\ SO_2\ (5) \Rightarrow 10\ \mu g/m^3 + 1\ ppb\ SO_2$$

$$= 20\ \mu g/m^3$$

$$\Delta NO_2/\Delta part = 0.097$$

$$\frac{0.097\ \Delta part}{-0.211} = V$$

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