THE COST OF REDUCED VISIBILITY DUE TO PARTICULATE AIR POLLUTION FROM MOTOR VEHICLES

Report #13 in the series: *The Annualized Social Cost of Motor-Vehicle Use in the United States, based on 1990-1991 Data*

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13.1 INTRODUCTION

Particles and gases in the atmosphere scatter and absorb light, and thereby reduce visibility (Watson and Chow, 1994; Richards et al., 1990; Ozkaynak et al., 1985). Although natural sources of particles, such as volcanoes, can significantly degrade visibility, it generally is true that "when visibility is poor...most particles are found to be of human origin, from sources such as power plants, vehicle exhaust, biomass burning, suspended dust, and industrial activities" (Watson and Chow, 1994, p.244). Poor visibility diminishes the enjoyment of scenic vistas and makes travel hazardous[1]. Statistical analyses of property values (discussed below) reveal that people are willing to pay extra for houses in areas with good visibility and air quality.

The particles that are most efficient at scattering light are roughly the same size as the wavelength of visible light -- about 0.5 µm (Watson and Chow, 1994; Richards et al., 1990; Ozkaynak et al., 1985). Because most particles emitted by the combustion of diesel fuel, and some particles of re-entrained road dust, are 0.5 µm ± 0.4 µm, emissions related to motor-vehicle use can significantly degrade visibility. In support of this, Trijonis (1984) has estimated that direct emissions from heavy-duty diesel vehicles in California cause 10% to 20% of the light extinction.

In this report, we review some of the literature on the cost of visibility, and then develop our own estimate of the cost. For our own estimate, we select a simple hedonic model, from the meta-analysis of Smith and Huang (1995), of the relationship between the asset value of homes, levels of total suspended particulate matter (TSP), and per-capita income. Because the hedonic price of TSP undoubtedly comprises the price of visibility (as well as the price of other effects of TSP, such as bad health), and because we can relate TSP emissions to visibility, we can use this hedonic model to estimate the visibility cost of TSP emissions. Specifically, we will apply this hedonic meta-model to estimate the visibility cost of all anthropogenic TSP pollution, and of motor-vehicle TSP pollution, in every county in the U. S. in 1990.

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[1] Mensah and Osei-Adjei (1992) estimated that a 10% improvement in visibility reduces non-fatal accidents by 15.6 units per day, and reduces travel time, but actually increases the probability of a fatal accident by 0.023 per day, apparently because people drive faster when they can see better.

13.2 LITERATURE REVIEW

13.2.1 General estimation methods

There are two ways to estimate the cost of impaired outdoor visibility. With *contingent valuation*, researchers survey people and ask them to make explicit, but hypothetical, tradeoffs between visibility and dollars or things with a known dollar value. In *hedonic price analysis*, researchers analyze the value of visibility that is implicit in the prices that people pay for houses in regions that have different average annual levels of visibility. These two methods have complementary strengths and weaknesses.

Contingent valuation. The main strength of contingent valuation (CV) is that it is explicit: the item to be valued (in our case, visibility) is identified and described and "marketed" explicitly. In principle, one can perform a CV study of any nonmarket good. One can value separately items that otherwise are difficult to disentangle: for example, the aesthetic effects and the health effects of polluted air. Because they are hypothetical, CV studies are not limited by the availability of data from real markets. And because they explicitly ask for individual willingness to pay for specific goods or services, in principle they tell the cost-benefit analyst precisely what she needs to know.

However, the obvious and potentially grave weakness of CV is that the valuation is hypothetical, and therefore reliable only insofar as people respond realistically to the hypothetical market. Unfortunately, this difficulty becomes most serious in precisely those situations in which CV in principle is the most useful: the valuation of nonmarket goods and services that people apparently care about but have little experience with. With CV studies, the challenge then is to design a credible scenario and market mechanism, to induce people to behave as realistically as possible.

Hedonic price analysis. By contrast, the strength of hedonic price analysis is that it is based on real, "revealed" behavior in the market place. In this approach, developed theoretically by Rosen (1974), one estimates a marginal willingness-to-pay function, or demand function, for visibility or air quality, on the basis of an estimated relationship between housing price and housing attributes including visibility or air quality[2]. This approach thus attempts to capture the actual value that people place on

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[2] There are two stages in the hedonic method. First, one regresses observed housing prices against observed housing attributes, including air quality. The resulting functional relationship between air quality and housing prices can be used to estimate the capitalized housing value of small changes in air quality, for households similar to those used in the regression. However, this hedonic function is not valid for large changes in air quality, or for households with significantly different characteristics, if household marginal willingness-to-pay (MWTP) for air quality depends on the level of air quality or the characteristics of households. In this case, one must estimate MWTP for air quality as a function of air quality and household characteristics such as income. To estimate this MWTP (demand) function (the second stage of the analysis), one differentiates the first-stage hedonic function with respect to the air quality attribute, to produce the MWTP for (or price of) air quality for each household, and then regresses the MWTP (price) against air pollution and household characteristics, to obtain the MWTP function. With this, one calculates the value of a large change in air pollution by integrating the MWTP function between the before and after pollution levels.

visibility or air quality as revealed by their willingness to pay more for homes with better visibility or air quality, all else equal.

However, hedonic price analyses have several weaknesses. First, the individual items being valued, such as air quality or visibility, of course are not actually marketed explicitly as separate items, but rather are marketed implicitly, as part of a bundle of many attributes. An analyst can identify an implicit relationship between housing price and air quality or visibility, but because nobody buys and sells air quality or visibility, the analyst cannot be sure that his measure of air quality or visibility is the one that people actually use. More importantly, even if he has the right measure of air quality or visibility, he cannot on the basis of the hedonic analysis alone determine the "components" of the implicit value of air quality -- health, visibility, soiling, etc. -- because air quality and visibility are so highly correlated, in reality and in people's minds. (By contrast, in a CV study, one can isolate these components explicitly.) (We discuss this more below.)

Moreover, analyses of housing values tell us only what people are willing to pay for visibility at home; they do not tell us, necessarily, what they are willing to pay for visibility at work or on vacation. Although it is possible to apply the hedonic price technique to commercial and industrial property and to wages, little work has been done in these areas.

13.3.2 Review of contingent valuation studies of visibility

1). Rowe et al. (1980) attempted to establish the economic value of visibility over long distances in the Four Corners region in New Mexico. This study was the first bidding method in which the scenarios were developed to link physical measures of visibility levels with emission rates. Three alternative scenarios showed decreasing levels of visibility. The first (A) depicted a visual range of about 120 km, which was described as being marginally better than the current "typical" conditions. The second (B) represented a visual range of about 80 km, and the third (C) represented a visual range of about 40 km. The questionnaire attempted to break down the total benefits into separate benefits for visibility, acute health, and chronic health values.

Respondents were given variations on the typical iterative bidding procedure for proposed degradation in air quality from the highest level (A) to the lower levels (B or C). The results were annual bids for residents of $82 (level A to level C) and $57 (level B to level C).

2). Brookshire et al. (1979, 1982) used a contingent market approach to examine benefits from air-pollution control in the South Coast Air Basin of California. Three scenarios were developed. The A scenario depicted "poor" air quality with a visual range of about two miles. The B scenario represented "fair" air quality with a visual range of around 12 miles. The C scenario depicted "good" air quality with a visual range of about 28 miles. In communities with poor air quality, households bid $11 to $22 per month (mean of $14.54/month) to obtain fair air quality. In communities with fair air quality, households bid $5.55 to $28.18 per month to improve local conditions to good, with an overall average bid of $20.21. On average, for all proposed changes, the aesthetic, acute health, and chronic health components constituted about 34 percent, 40 percent and 26 percent, respectively, of the total mean bids.

3). Schulze et al. (1983) report the results of an experimental study designed to measure the economic value of visibility in the National Parks of the Southwestern United States. The purpose of the study was to estimate the visibility benefits of controls on SO_2 emissions from power plants, as part of a cost-benefit analysis of the emissions regulations. To derive their estimate, Schulze et al. (1983) used a study of visibility perception in which participants were shown photographs of vistas in different National Parks. For each vista, there were photographs with five different visibility ranges. Participants then were asked questions about their willingness to pay for the different visibility levels, as depicted by the five photographs.

The survey was designed to elicit the existence or option values of people who wouldn't use the park, as well as the values of people who would. To estimate user values, one-third of the participants were asked about their willingness to pay higher park entrance fees to: (1) improve visibility in the Grand Canyon, (2) prevent a deterioration of visibility from the current average in the Southwest National Parks, and (3) prevent plume blight in the Grand Canyon. The remaining two thirds of the participants, the hypothetical non-users, were asked about their willingness to pay for increased electricity rates, rather than increased park-entrance fees.[3] The survey was conducted in 1980, with over 600 households in Denver, Los Angeles, Chicago , and Albuquerque participating.

The study found that it was worth about $3.5 billion to control SO_2 emissions from power plants in order to preserve visibility in the Grand Canyon, and $6.2 billion to preserve visibility in all National Parks in the Southwest (1980 dollars). Non-user benefits were about two-thirds of the total.

4). Crocker and Shogren (1991) used contingent valuation to estimate the policy-relevant components of economic valuation of visibility at a wilderness location and an urban location in Oregon. The participants were given a questionnaire with computer-generated haze levels superimposed on a photograph of a vista from a wilderness site in the Central Oregon Cascades. The simulated haze represented visual ranges of 53, 88, 121, and 309 km. The participants were asked how much extra they would pay to enter the wilderness under each of the visibility conditions. They also were asked about their willingness to pay (WTP) even if they could not visit the site ever (i.e., WTP for "existence" value), and their WTP to obtain the visibility benefits at different times. Crocker and Shogren (1991) found that: i) existence value was about 10% of total WTP; ii) the implicit subjective discount rates were relatively high -- about 10% to 40%/year), and iii) it was not clear if WTP for visibility at a specific site represented the WTP for that site only, or rather represented WTP for visibility throughout a much larger region.

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[3] Much of the visibility degradation in the Southwest parks is due to SO_2 emissions from coal-fired electricity plants.

5). Recently, Loehman et al (1994) compared two different willingness-to-pay (WTP) measures: WTP to avoid a loss of air quality, and WTP to obtain gains in air quality. They obtained their data from a contingent valuation survey in the San Francisco Bay Area during the spring of 1980. These data were then used to estimate bid functions for the two WTP measures for both visibility and health. They found that WTP to avoid losses in visibility and health exceeded WTP to obtain gains, especially for large changes, and that the average person was willing to pay more to avoid a health loss than a visibility loss.

13.2.3 Review of hedonic price analyses

1). Brookshire et al. (1979, 1982)[4] analyzed residential property values in the South Coast Air Basin of Southern California in order to relate WTP with NO_2 or TSP levels and community average household incomes. They used 1977-1978 data on housing price and characteristics, 1975 average daily maximum levels of NO_2 and TSP, and community-level income data (household income was not available).

WTP was found to be positively correlated with pollution and income levels. They estimated that each household valued a 25% to 30% reduction in air pollution at $528 ($NO_2$ equation) to $588 (TSP equation) per year. Note, though, that this is the value of reducing pollution, which probably comprises more than the value of improving visibility.

2). Trijonis et al. (1985) analyzed the relationship between housing values and horizontal visibility (expressed in terms of light extinction) in Los Angeles and San Francisco, from 1973-1974 and 1978-1979. The second-stage equation in their hedonic analysis is the demand curve for visibility: WTP for a home as a function of light extinction (which is inversely related to visual range) and community average household incomes. The equation indicates that a 10% improvement in visual range was worth $99/year/household.

The Trijonis et al. (1985) model, which is shown in the Appendix to this report, is appealing because it relates a specific visibility variable -- light extinction -- with WTP. However, for several reasons, we decided not to use their equation as the basis of our national analysis.

First, it is a stretch to extrapolate to the entire U.S. an equation estimated for Los Angeles and San Francisco.

Second, in order to estimate the visibility benefit of eliminating motor-vehicle emissions, one must know the relationship between emissions and the visual-range variable. Although this is not especially difficult to estimate, it is an additional complication.

Third, there is no reason to believe that the "visibility" variable really is any different from an "air-quality" variable. As noted above, visibility levels are closely

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[4] As reviewed above, Brookshire et al. (1979, 1982) also conducted a contingent valuation survey to estimate the value of air quality. The 1982 article compares the two approaches.

correlated with -- and indeed are known to be physically related to -- levels of some kinds of air pollutants, primarily particulate matter. This raises the possibility that *in peoples' minds* "visual range" is a proxy for air pollution. We -- and perhaps most people -- know that the pollutants that cause haze and reduce visibility also damage people, other animals, plants, and materials. Thus, the analytical problem is that we cannot be sure that the value of "visibility" implicit in the hedonic price analyses really is the value of visibility *only,* and not the value of at least some of the other bad effects of pollution as well. We cannot be sure because we believe not only that most people know that the pollution that impairs visibility also has other undesirable effects, but that most people in fact measure pollution by visibility[5].

Finally, in Los Angeles, which contributed the majority of the observations in the combined regression, the light-extinction coefficient might have the wrong sign. Because light-extinction is a "bad," in the economic sense of the word, intuition tells us that the sign of the coefficient for light-extinction should be positive -- that people should be willing to pay more per unit of extinction as extinction increases (i.e., as visibility, the "good", decreases). However, all of the functional forms tested by Trijonis et al. (1985) yielded a negative coefficient, which seems to suggest non-convex preferences, and increasing marginal utility for the visibility good. Although Trijonis et al. (1985) acknowledge that these results are peculiar, they cite an unpublished paper that claims that this is a "mute issue because the non-linearity of the hedonic equation prevents a priori prediction of the sign of the pollution variable. Thus, although the negative sign seems to suggest non-convex preferences, there is really insufficient evidence to make such a conclusion" (page 90).

For these reasons, we have not used the Trijonis et al. (1985) equation for our official model and estimates. (We note, though, that with the model that we do use, discussed next, we in essence still face the third problem above.) However, we do present their model, and discuss its use, in the Appendix to this report.

3). Smith and Huang (1995) performed a meta-analysis of prior hedonic price analyses of the marginal willingness-to-pay (MWTP) to reduce particulate matter levels. They reviewed over 50 studies developed between 1967 and 1988, 37 of which had some empirical estimates involving hedonic price functions with some measure of air pollution. From the 167 hedonic models in these studies, Smith and Huang (1995) were able to reconstruct 86 estimates of the MWTP for reducing total suspended particulates (TSP). They then estimated the relationship between MWTP in each study, expressed as the change in the asset value of a house per $\mu g / m^3$ of TSP pollution, and several independent variables, including: the level of pollution in each city in the year closest to the date of the sample, real per-capita income in each city in the year closest to the date for the housing prices, the vacancy rate for the year closest to the date of the housing

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[5] For example, in the WTP survey by the Brookshire et al. (1979, 1982), air quality was represented by visual range.

sales, and qualitative variables describing the characteristics of each study, such as the number of variables used to describe neighborhood quality.

Smith and Huang (1995) used to two different estimators in their meta-analysis: minimum absolute deviation (MAD) and ordinary least squares (OLS). For each of the two estimators, they specified a simple model, in which TSP levels and per-capita income are the only independent variables, and a more comprehensive model, which includes the vacancy rate, characteristics of the original studies, and other variables as well as pollution and income.

Smith and Huang (1995) found that "the interquartile range for these estimated marginal values, measured as a change in asset (i.e. house) prices lies between zero and $98.52 (in 1982-84 dollars) for a one-unit reduction in total suspended particulates (in micrograms per cubic meter). The mean MWTP is nearly five times the median ($109.90 versus $22.40), suggesting that outliers are important influences to any summary statistics for the estimates."[6]

For several reasons, we will use Smith and Huang (1995)'s simple MAD model to estimate the cost of visibility in the United States. First, the meta-analysis, being a synthesis of many different studies from many different regions, is as good a basis as any for estimating national damages[7]. Certainly, as Smith and Huang note, it is better to use a model that relates MWTP to pollution and income in each city than to pick a single "best-guess" MWTP for every city. Second, our application of their model gives reasonable results. Third, we have data on income and TSP levels in every county in the U.S. Fourth, we can establish a simple relationship between TSP and visibility, and in essence weight TSP emissions according to their effect on visibility. This will allow us to estimate the *visibility* cost of TSP emissions from a particular source, such as motor -vehicles. (Different components of TSP have different effects on visibility, and hence any particular source of particulate emissions might contribute more or less to visibility degradation than do all particulate sources on average.)[8] Fifth, it will be interesting to compare the results of this hedonic-price analysis with the damage-function estimates of the health cost of air pollution.

Of course, we still must determine the portion of the estimated WTP that can be attributed to visibility per se, apart from any simultaneously perceived, or "coproduced," health benefits. We discuss this problem more below.

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[6] MAD tends to be less sensitive to outlying observations, but does not explicitly adjust for heteroscedasticity. OLS with adjusted estimates for coefficient variance takes heteroscedasticity into account, but tends to be influenced by outlying observations.

[7] Smith and Huang (1995 note that "the MWTP estimates [from a meta-analysis] offer a crude average of the marginal values estimated under specific circumstances...[meta-analysis] is best interpreted as a statistical summary of the role of economic factors and modeling decisions for the *average* measures of MWTP for a set of individual single markets." (p. 211, italics added)

[8] This actually is easier than estimating the relationship between emissions and visual range, which is what would have been required with the Trijonis et al. (1985) equation.

13.3 METHODS AND DATA OF OUR ANALYSIS

We model the net visibility benefits of three pollution-reduction scenarios:

I) eliminate all anthropogenic air pollution;
IIA) eliminate 10% of emissions attributable to motor-vehicle use;
IIB) eliminate 100% of emissions attributable to motor-vehicle use.

Occasionally, we will for simplicity refer to scenarios IIA and IIB together as scenario II. We will model 1990 conditions (air quality, emissions, income, and population), and express our results in 1991 dollars.

13.3.1 The visibility cost of pollution, as reflected in housing prices

To estimate the visibility cost of pollution in the U.S., we begin with the simple MAD air-quality demand equation, developed by Smith and Huang (1995), and discussed above. (We use the MAD rather than the OLS model because in the two-independent-variable MAD model the coefficients were significant, whereas in the two-independent-variable OLS model they were not. Also, MAD is less sensitive to outlying observations, which were a serious problem in Smith and Huang's meta-analysis.) This equation estimates the marginal willingness-to-pay per household, in 1982-1984$, per $\mu g / m^3$ of TSP, as a function of the per-capita income and the TSP level:

$$V_{83} = \alpha + \beta 1 \cdot P + \beta 2 \cdot Y_{83} \qquad \textbf{[1]}$$

where:

V_{83} = the shadow price of visibility: the change in the asset value of the house per unit of pollution ($\$ / [\mu g / m^3]$), at TSP level T, in 1982-1984 prices (we take 1983 as the base year)
α = intercept (-49.31 in simple MAD model)
$\beta 1$ = coefficient on TSP (-0.23 in the simple MAD model)
$\beta 2$ = coefficient on income (0.01) in the simple MAD model)
P = total suspended particulates (in micrograms per cubic meter)[9]

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[9] Smith and Huang (1995) state the "the data are taken from table 5-6 in the *1992 Metropolitan Statistical Area Air Quality Factbook Peak Statistics for Selected Pollutants*, by metropolitan area. They relate the highest second maximum 24-hour concentration in PM_{10} (in micrograms per cubic meter). This was the closest measuring format available for the data used in our summaries. The source was the U.S. Environmental Protection Agency (1993)" (p. 220). The EPA document referred to is the *National Air Quality and Emissions Trends Report 1992* , the latest version of which is through 1994 (EPA, 1995a). Smith and Huang (1995) convert PM10 to TSP assuming the former is 55% of the latter.

Y_{83} = average per-capita income in 1982-1984 (we take 1983 as the base year)

As mentioned above, we will use 1990 data on income and TSP pollution, but will express the results in 1991$. To do this, we first must estimate 1990 income in 1983 dollars, and then convert the calculated V_{83}, which will be in 1983 dollars, to 1991 dollars:

$$V_{91} = V_{83} \cdot K1$$

$$Y_{90} = Y_{83} \cdot K2$$

$$V_{91} = \alpha \cdot K1 + \beta 1 \cdot P \cdot K1 + \frac{K1 \cdot \beta 2 \cdot Y_{90}}{K2}$$

where:

V_{91} = the shadow price of visibility: the change in the asset value of the house per unit of pollution ($/[μg / m^3]), at TSP level T, at 1991 prices
P = total suspended particulates (μg / m^3)
Y_{90} = average per-capita income in 1990
K1 = Price deflator to estimate 1991 WTP given 1983 prices (GNP implicit price deflator = 1.322)
K2 = Price deflator to estimate 1990 income given 1983 prices (GNP implicit price deflator = 1.264)[10]

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[10] Smith and Huang's (1995) model is estimated with 1982-1984 (we assume 1983) data. Given this, we have two choices. First, we can use actual 1983 per-capita income, calculate the MWTP results in 1983 dollars, and then covert the 1983-dollar results to 1991-dollar results. However, this approach ipso facto tells about MWTP at 1983 real income, not at 1990 real income, and presumably we wish to know about MWTP given the world as it was in the more recent year. Real average per-capita income actually increased between 1983 and 1990 (i.e., the ratio of nominal 1990 income to nominal 1983 income exceeds the CPI ratio for these two years) , and as a result, according to the Smith and Huang (1995) equation, real MWTP for improved air quality increased. If we use 1983 income data we ignore the increase in real income and thus underestimate more recent real MWTP.

The second approach, which we adopt here, is to capture the effect of the increase in real per-capita income. To do this, we use actual 1990 income, but deflated to what it would be at 1983 price levels. The deflated 1983-price-level income is the amount of income, given 1983 rather than 1990 prices, with which we could have bought the same amount of goods and services as was or could have been bought with actual 1990 income and prices.

Now, given this, there are in general two ways to deflate 1990 income: with a fixed-weight index like the CPI, or with the GNP implicit price deflators. The CPI tracks price changes in a fixed basket of goods. Thus, if we deflate with the CPI, we derive the amount of income, given 1983 rather than 1990 prices, with which we could have bought the same amount of the *fixed basket* as could have been bought with actual 1990 income and prices.

The GNP implicit price deflators are a weighted average of the detailed price indexes used in deflating the GNP, combined according to the actual composition of GNP in each period. They thus differ

(From here on we will drop the 1991 ($) and 1990 (TSP, income) subscripts.)

We treat equation **[1]** as the household demand function for TSP reductions. To calculate how much households in the U.S. are willing to pay for an improvement in TSP (VT), we integrate the household demand function between the two TSP levels, and multiply by all households in the U.S. We will estimate the cost of all anthropogenic visibility pollution, and the cost of motor-vehicle visibility pollution:

$$VT = \sum_c \left(H_c \cdot \int_{PP_c}^{PI_c} \left(\alpha \cdot K1 + \beta 1 \cdot P_c \cdot K1 + \frac{K1}{K2} \cdot \beta 2 \cdot Y_c \right) dP_c \right) =$$

$$\sum_c \left(H_c \cdot \Big|_{PP_c}^{PI_c} \alpha \cdot K1 \cdot P_c + \frac{\beta 1 \cdot K1 \cdot P_c^{\,2}}{2} + \frac{K1}{K2} \cdot \beta 2 \cdot Y_c \cdot P_c \right) =$$

$$\sum_c \left(H_c \cdot \left(\alpha \cdot K1 \cdot \left(PI_c - PP_c\right) + \frac{\beta 1}{2} \cdot K1 \cdot \left(PI_c^{\,2} - PP_c^{\,2}\right) + \frac{K1}{K2} \cdot \beta 2 \cdot Y_c \cdot \left(PI_c - PP_c\right) \right) \right)$$

[2]

where:

subscript c = counties in the U.S.

α, $\beta 1$, $\beta 2$, K1, and K2 are as defined above

VT = the total amount extra that all households in the U. S. would have been willing to pay for their homes, if they had bought their homes outright in 1991, if TSP in each county were at the level represented by PP instead of the level represented by PI

H_c = the number of households in county c in the U. S. in 1990 (Bureau of the Census, 1994)

PP_c = what the TSP level in county c would have been in 1990 given no anthropogenic (case I) or motor-vehicle-related (case II) emissions (discussed below)

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from the CPI in two respects: they are “broader,” and they are based on the current mix of products rather than a fixed mix (or basket). Thus, if we deflate with the GNP implicit price deflators, we derive something like the amount of income, given 1983 rather than 1990 prices, with which we could have bought the actual goods and services that were bought with 1990 income and prices.

In essence, the GNP price deflators tell us real income given the real mix of goods and services in 1990, rather than the fixed-basket mix. We believe that this is the appropriate deflator for our purposes.

PI_c = the actual TSP level in county c in 1990 (discussed below)
Y_c = average annual per capita income in county c in 1990 ($/year) (Bureau of the Census, 1994)

Equation **[2]** is our cost model. Note that the estimated total willingness to pay, VT, represents a one-time payment for a commodity (a home) that lasts many years. Thus, to calculate an annual WTP, the one-time total WTP, VT, must be amortized, or annualized, over the economic life of the home. This is discussed more below.

Note too that equation **[2]** uses TSP, not visibility, as an explanatory variable. However, not only are TSP and visibility highly correlated, they in fact are physically related -- as mentioned above, particulate matter scatters light and thereby reduces visibility -- which means that we can estimate how TSP affects visibility. The real difficulty will be to determine how much of the WTP to reduce TSP is WTP for visibility per se, as opposed to WTP to reduce the health and other effects of air pollution. We will analyze this below.

13.3.2 Annualizing the cost over the life of the home

One must translate the one-time willingness-to-pay for a home (VT) into an annualized payment (VA). An annualized payment is equal to full asset value (or one-time payment) multiplied by an annualization factor, AF:

$$VA = VT \cdot AF$$

$$AF = \frac{i}{1-(1+i)^{-t}} \qquad [3]$$

where:

VA = the annualized WTP of households
VT = as defined above
AF = the annualization factor
i = the annual interest rate for investment in homes (4% [low] or 7% [high]; Report #2 of this social-cost series)
t = the term of the investment in homes (40 [low] or 30 [high] years; our assumption; see also Report #14 of this social–cost series, which also uses a hedonic price model)

With these assumptions, the annualization factor AF is 0.0505 in the low case, and 0.0806 in the high-cost case.

13.3.3 The portion of the total WTP that is for visibility per se.

Hedonic price analyses relate changes in house values to changes in some measure of air quality. Given any such estimated relationship, and keeping in mind that our objective is to estimate the cost of visibility degradation, we are faced with two questions: First, is the TSP measure of air quality in the meta-analysis model of Smith and Huang (1995) the right one? Second, what is it about air quality that people value?

The right air-quality measure? Ideally, one would use as an explanatory variable the measure of air quality that people actually have in mind when they buy a house. To the extent that the air-quality explanatory variable in a hedonic model is *not* correlated with the real air-quality variables in people's minds, the model will mis-estimate the relationship between housing value and air quality

Most likely, prospective home buyers do not actually consult statistics from air-quality monitors, but rather judge air quality on the basis of whether or not the air appears polluted, and what people and the media say about the local air pollution. If this is so, then visual range, or some close proxy, probably represents reasonably well "air quality" as perceived and evaluated by people. Because TSP is closely correlated with visibility, we assume that it adequately represents the air quality that people actually are evaluating.

What do people value about good air quality? Even if we have the right measure of air quality, we still need to identify the "components" of air quality that people care about. When people pay more for a house in an area with cleaner air, what benefits do they think that they are buying? Better health? Reduced soiling of clothes and materials? Or just better visibility?

The question is important to us because our goal here is to measure the value of visibility or aesthetics per se. (In separate reports, we estimate the other effects of air pollution.)[11] It might be tempting to assume that, because people most likely *assess* air quality on the basis of visibility, they most likely *value* improved air quality mainly because it means improved visibility. If this assumption were correct, then we could interpret the MWTP for "air quality", as estimated from the hedonic model, as the MWTP for visibility per se, apart from MWTP for anything else, such as health. However, the assumption probably is not correct, and consequently we must separate the pure visibility component of the total WTP for improved air quality.

Most likely, the visibility benefit is not the bulk of the total air quality benefit. Smith and Huang (1995) argue that the "hedonic models....reflect aesthetics, materials, and soiling effects, and, to some degree, perhaps perceived health effects, although the latter may well be incomplete" (p. 223)[12]. We think that this is broadly correct.

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[11] Cropper and Oates (1992) make the same point, observing that "it is difficult to note what the pollution (or visibility) coefficient captures and, therefore, difficult to aggregate benefit estimates obtained from these studies with those obtained from other approaches" (p. 718)

[12] Harrison and Rubinfeld (1978) agree that individuals typically do not preceive all of the health damages of pollution: "We stress that housing market studies of this type can ony ascertain those benefits which are perceived by households. Itis clear that individuals are not aware of all potential health hazards

Certainly, we cannot assume that the "air quality" measured in the hedonic model that we use is valued *only* with respect to visibility or aesthetics per se, and not at all with respect to human health, soiling, and so on -- even if people are judging air quality on the basis of visibility, which seems likely. People undoubtedly know that the pollutants that cause haze and reduce visibility also harm persons, plants, animals, and materials. We suspect that most people use visibility as an indicator for a variety of effects.

But which effects, with what importance? The contingent valuation survey conducted by Brookshire et al. (1979, 1982), and the survey of Loehman et al. (1994), suggest the extent to which the value of "air quality" might include health effects and other attributes of air pollution besides visibility per se.

As discussed in the literature review above, Brookshire et al. (1979, 1982) found that, of the estimated total willingness-to-pay for improved air quality in the South Coast Air Basin, about 34% was for improved aesthetics, which we would call visibility per se. The remaining 66% was for improved health. Similarly, Loehman et al. (1994) found that for the average person in the western San Francisco Bay area, the bid to avoid a loss of nonpolluted visibility days was about 2/3 of the bid to avoid a loss of good health days, and the bid to obtain an increase in nonpolluted visibility days was about 10% of the bid to obtain an increase in good health days. Thus, in the Loehman et al. (1994) study, the value of visibility was 10% to 40% of the total health+visibility value of air quality.

If home buyers nationally are similar to the persons from Los Angeles and San Francisco who responded to the Brookshire et al. (1979, 1982) and the Loehman et al. (1994) surveys, and if the evaluation of air quality explicit in these surveys is similar to the evaluation implicit in the choice of a home, then we may apply these survey findings to the hedonic study of Smith and Huang (1995). Thus, we assume that value of visibility per se constitutes 20% to 40% of the total value of "air quality" estimated by the Smith and Huang (1995) hedonic model.

13.3.4 The value of visibility outside of the local housing market.

Another shortcoming of the hedonic-price approach is that it captures the value of air quality, or visibility, in housing markets only; it does not capture any visibility value in other markets (Cropper and Oates, 1992).

When people assess visibility when they shop for a home, they assess the differences in the "visibility experiences" that will result from choosing one home over another. For example, they certainly will compare visibility in and around the candidate houses, because those local visibility experiences will depend on which home they buy. But buyers will not consider visibility in areas that they will visit (or, more generally, that they will care about) *regardless* of which home they buy. For example, if a person shopping for a home in Arizona intends to visit the Grand Canyon and Los Angeles once a year, regardless of which home he or she buys in Arizona, then visibility

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associated with air pollution and are often ignorant of the degree to which the air they breathe is polluted" (p. 82).

conditions in the Grand Canyon and Los Angeles -- although of value to the person -- will not affect his or her choice of home in Arizona, and will not affect prices in the Arizona housing market -- and, therefore, will not be included in the MWTP for visibility or air quality estimated from a database that includes the housing market in Arizona.

In general, people might positively value many "visibility experiences" but not consider them when choosing a home, because the experiences will not be affected by the choice of home. This means that the hedonic-price method, which captures the implicit value of visibility in a particular housing market or set of markets, does not capture the value of visibility *independent* of that housing market. Thus, to the extent that persons care about visibility outside of their home region (or housing market), the hedonic-price estimate, used by itself, will underestimate the total value of visibility *everywhere*.

It seems clear to us that people and environmental regulators care about visibility in wildernesses, National Parks, scenic areas, and urban areas outside of their home region or housing market. For example, the Prevention of Significant Deterioration amendments of the Clean Air Act have a specific goal of protecting air quality in special natural areas, and the EPA has identified 156 Class 1 (national parks, scenic wilderness) as areas in which good visibility is necessary and must be protected.

But how *much* do they care? At least one study suggests that people care a lot about visibility in parks and wildernesses: as noted in the literature review above, Schulze et al. (1983) found that non-users were willing to pay $4 billion, and users $2 billion, to preserve visibility in all National Parks in the Southwest (1980 dollars). Less relevantly, Peterson et al. (1989) report that more than half of the respondents to a survey about WTP for forest quality stated that they cared mainly about the "existence value" of the forest. (This is less relevant because it pertains to "existence value" rather than just "visibility value".) On other hand, in a CV study of WTP for improved visibility in an Oregon wilderness, Crocker and Shogren (1991) found that existence value was only 10% of the total WTP for visibility.

Obviously, it is difficult to use this information to extrapolate the hedonic results to include visibility values not captured in housing markets. We know nothing about the value of visibility in other National Parks or scenic areas, or in urban areas outside of particular local housing markets (i.e., as per the example above, we don't know the value to an Arizonan of visibility in Los Angeles). We are forced, then, to supposition: we judge that visibility value not captured by housing markets is 50% to 100% of the value estimated by the hedonic model.

13.3.5 Other problems with our application of the hedonic model

There are yet other difficulties in our application of the Smith and Huang (1995) meta-model.

First, with some combination of parameter values -- high TSP, low income, and low share of pollution due to motor vehicles -- the model estimates a negative WTP for reductions in light-scattering pollution from motor vehicles. Given that these problematic combinations of parameter values probably are *not* outside the range of values in the original database from which Smith and Huang (1995) built their model, we may assume that Smith and Huang (1995) model simply does not fit the outlying data well. Consequently, we discard all of the negative WTP estimates from the model, and in Case II make the following adjustment to account for the real, positive WTP in the counties for which the model estimates negative WTP:

$$VA_{TA} = VA \cdot \frac{\sum_{c} Y_c \cdot H_c}{\sum_{c} Y_c \cdot H_c - \sum_{cn} Y_{cn} \cdot H_{cn}}$$

$$\sum_{c} Y_c \cdot H_c = \$1715.30 \cdot 10^9 \qquad \textbf{[4]}$$

$$\sum_{cn} Y_{cn} \cdot H_{cn} = \$31.14 \cdot 10^9$$

where:

VA_{TA} = total adjusted willingness-to-pay for visibility improvements, with results for negative-WTP counties scaled up

VA, Y_c, and H_c are as defined above (note that VA is positive willingness to pay estimated by the model -- i.e., model results, with negative WTP zeroed out)

H_{cn} = number of households in a county for which the model estimates a negative WTP

Y_{cn} = average annual per-capita income in a county for which the model estimates a negative WTP

This method simply scales up the estimated positive WTP in proportion to the total wealth (households multiplied by per-capita income) in the areas for which the model estimates a negative WTP. We scale with respect to total wealth because WTP for visibility is proportional to total wealth (the product of income and households -- see equation **[2]**).

Note that the problem of negative WTP arises only in Cases IIA and IIB. In Case I, in which the visibility cost of all anthropogenic emissions is estimated, the estimated negative WTP is so small -- about 0.1% of the total -- that we ignore it.

Second, the sample of home buyers whose purchase decisions are the raw data of the analysis might not be representative of the whole population to which the results are generalized. For example, the WTP function ($WTP = f(TSP, income)$) for renters might not be the same as the WTP function for homeowners, perhaps because renters in general care less about amenities of home, all else equal. Nevertheless, we apply the household-WTP function, which is derived from the choices of home buyers, to renting households.

Third, the estimated TSP-value function really is valid only over the range of TSP experiences in the housing areas studied in the original hedonic-price analyses. Therefore, if some housing areas experience significantly different TSP levels than did the residential areas analyzed in the hedonic-price analyses, the TSP-value function might not accurately represent the dollar value of TSP levels in these other areas. We recognize this possibility but do not adjust for it.

Finally, the use of property-value differences to estimate the benefits of air quality usually assumes that prices and quantities of other things are not affected by changes in air quality. If this assumption is violated, the change in property values may not reflect the household's full WTP for air quality. People may respond to changes in air quality in ways that do not affect the value of their residences but affect the value of other goods. For example, the demand for some outdoor activities, such as golfing and jogging, may be affected by changes in air quality and cause changes in the prices of goods associated with these activities. If this occurs to any great extent, property value studies can capture only part of the benefits of a change in air quality.

13.3.6 Estimating TSP levels: actual 1990 levels, and levels without anthropogenic pollution or motor-vehicle related pollution

The WTP model derived above (equation **[2]**) estimates the total annual household WTP for a change in TSP from PI to PP, where PI is the TSP level in 1990, and PP is the TSP level after all anthropogenic emissions (case I) or all motor-vehicle related emissions (case II) have been eliminated. In this section we explain how we estimate PI and PP for each county c in the U. S. in 1990.

We specify the initial pollution level, PI, to be the actual ambient air quality in each county in the U. S. in 1990. These data are discussed below. We estimate PP, in each county, on the assumption that the ratio of PP to PI is equal to the ratio of the *modeled* PP to *modeled* PI:

$$\text{Assume}: \frac{PP}{PI} = \frac{PP*}{PI*} \qquad \textbf{[5]}$$

$$PP = PI \cdot \frac{PP*}{PI*}$$

where:

PP = the estimated actual TSP level after the change in emissions (eliminate all anthropogenic emissions, or eliminate 10% or 100% of motor-vehicle-related emissions)

PI = the actual ambient TSP level (data from air-quality monitors [EPA, 1993]; discussed below)

PP* = the modeled level of TSP after the change in emissions (summarized below; see Report #16 for details)

PI* = the modeled level of ambient TSP (Report #16)

We model three different TSP-reduction scenarios (i.e., three different values of PP):

I) ozone reduced from 1990 levels to the natural background levels, with no anthropogenic emissions, and
II) ozone reduced from 1990 levels to the levels that would have resulted had
  A) 10% of motor-vehicle related emissions had been eliminated, or
  B) 100% of motor-vehicle related emissions had been eliminated.

In Report #16, we develop our models of PP* and PI*.

Note that, when we estimate the TSP level after removing motor-vehicle related emissions, we estimate the effects of a specific, "marginal" change in pollution: the difference between actual TSP (PI) and, what TSP levels would have been had motor-vehicle-related emissions been reduced by 10% or 100% (PP).

Current (1990) TSP levels. (PI) As noted above, the pollution variable in Smith and Huang's (1995) hedonic model (our equation **[2]**) is the so-called "highest second maximum" 24-hour concentration of TSP, in $\mu g / m^3$. The "highest second maximum" in a particular region is the highest value out of the set of readings that comprises the second-highest value in the year for each air-quality monitor in the region.

The EPA (1993) measures 24-hour concentrations of TSP and PM_{10} at some of its ambient air-quality monitors throughout the country. We use these measurements to estimate the highest second maximum 24-hour concentration of TSP for each county in the U.S. in 1990. For each TSP monitoring site that has at least ten 24-hour readings in 1990[13] , we note the second-highest reading for the year, and then select the highest of all these second-highest site readings in the county. This is the so-called highest second maximum.

If a county does not have TSP measurements, but does have PM_{10} measurements, we assume that TSP is 1.72 times PM_{10},[14] and then proceed to estimate the highest second maximum as above. If a county has neither TSP nor PM_{10} data (and most counties have neither), we first designate it as an urban or a rural county, and then identify all of the other urban or rural counties in the same EPA region as the county in question. (There are 10 EPA regions in the U.S.) Then, we assume for the county in question (which lacks TSP or PM_{10} data of its own) the *lowest* of the highest second

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[13] We required that a site have at least 10 readings so as to avoid including unrepresentative readings in our sample.

[14] We chose 1.72 because it is the average ratio of TSP to PM_{10} in all counties of the U.S. for which we have data on both pollutants. Smith and Huang (1995) assumed a ratio of 1.82.

maximum readings from the other urban or rural counties in the same EPA region as the county in question.

PP Case I: natural background TSP level. In case I, we estimate the visibility cost of all anthropogenic TSP pollution, which is the difference between current levels and the natural, or "background," level. The natural level of TSP is a function of natural (geogenic) emissions of TSP. We model the natural background TSP level (PP*) in each county c as:

$$PP_{TSP,N,c}{*} = C_{P'\rightarrow TSP}\begin{pmatrix}\left(E_{P1',N,c}\cdot D_{P1',N,c}+E_{P1',N,oc}\cdot D_{P1',N,oc}\right), \\ \\ \left(E_{P2',N,c}\cdot D_{P2',N,c}+E_{P2',N,oc}\cdot D_{P2',N,oc}\right),\ldots\end{pmatrix} \qquad \textbf{[6]}$$

where:

subscript TSP = TSP air pollution

subscripts P1', P2' = the emitted TSP precursors: particulate matter less than 10 µm in aerodynamic diameter (PM_{10}), particulate matter less than 2.5 µm in aerodynamic diameter ($PM_{2.5}$), sulfur oxides (SO_X) nitrogen oxides (NO_X), volatile organic compounds (VOCs), and ammonia (NH_3)[15]

subscript N = natural (geogenic) sources

subscript C = the county of interest (i.e., the county for which air quality is modeled and the cost of pollution damage to crops is estimated)

subscript OC = all counties other than county C in the same Air Quality Control Region (AQCR) as C

* = modeled as opposed to measured air quality

$PP_{TSP,N,C}*$ = the modeled level of total ambient TSP received or formed at air-quality monitors in county C, in a year, due only to natural emissions

$C_{P'\text{-->}TSP}$ = the chemical transformation of precursor pollutants P' to ambient TSP (discussed in Report #16)

$E_{P1',N,C}$, $E_{P2',N,C}$... = yearly emissions of P1', P2'.. from natural (geogenic) sources in county C (EPA, 1995b, 1995c)

$E_{P1',N,OC}$, $E_{P2',N,OC}$... = yearly emissions of P1', P2'.. from natural (geogenic) sources in all counties except C, in the AQCR of county C (EPA, 1995b, 1995c)

$D_{P1',N,C}$, $D_{P2',N,C}$... = the fraction of emissions of P1', P2'...from natural sources in county C that reaches the ambient air-quality monitor in county C (estimated on the basis of simple dispersion modeling, presented in Report #16)

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[15] We do not have data on emissions of particles coarser than PM_{10}. Hence, we estimate TSP levels on the basis of PM_{10} emissions.

$D_{P1',N,oc}$, $D_{P2',N,oc}$... = the fraction of emissions of P1', P2'...from natural sources in all counties except C, in the AQCR of C, that reaches the ambient air-quality monitor in county C (estimated on the basis of simple dispersion modeling, presented in Report #16)

We model PI* (in equation **[5]**) similarly. See Report #16 for details.

PP Case II: TSP levels with 100% or 10% of motor-vehicle-related emissions eliminated. In case II, we estimate the visibility cost of motor-vehicle related TSP pollution. We use a simple model of emissions, dispersion, and atmospheric chemistry, developed in Report #16. In this model, we estimate PP* as follows:

$$PP_{TSP,c}{}^{*} = C_{P' \rightarrow TSP}\left(P1', P2' \ldots\right)$$

$$P' = \sum_{i} EC_{P',i} \cdot \left(1 - MS_{P',i}\right) \cdot \left(D_{P',i,c} \cdot OEI_{P',i,c} + D_{P',i,oc} \cdot \sum_{o \,\in\, R_C} OEI_{P',i,o} \right) \qquad \textbf{[7]}$$

where:

subscripts TSP, P', C, and OC are as defined above
subscript i = sources of emissions of P' (includes all sources in the emissions inventory: motor vehicles, power plants, industries, businesses, farms, and so on).
subscript o = any county other than C in AQCR R
subscript R = AQCR R
$PP_{TSP,C}{}^{*}$ = the modeled level of total ambient TSP received or formed at air-quality monitors in county C, in a year
$C_{P'\text{-->}TSP}$ = the chemical transformation of precursor pollutants P' to TSP (discussed in Report #16)
$OEI_{P',i,C}$ = the EPA's official emission-inventory estimates of emissions of P' from source i in county C (EPA, 1995b, 1995c)
$OEI_{P',i,O}$ = the EPA's official emission-inventory estimates of emissions of P' from source i in county O (EPA, 1995b, 1995c)
$EC_{P',i}$ = our emissions-inventory correction factor, equal to the ratio of our estimate of true emissions of P' from source i to the EPA's official estimate (discussed in Report #16; this factor is 1.0 for most sources i, and is assumed to be the same in every county).
$MS_{P',i}$ = the motor-vehicle-related fraction of emissions of P' from emissions source i; that is, of the emissions of P' from source i, MS is the fraction that is related to motor-vehicle use (e.g., all tailpipe emissions from motor-vehicles are related to motor-vehicle use; some fraction of refinery emissions is related to motor-vehicle use, and no fraction of emissions from agricultural tillage is related to motor-vehicle use) (estimated in

Report #10; in case IIA, we count 10% of this fraction; in case IIB, we count 100%)

$D_{P',i,C}$ = the fraction of emissions of P' from source i in county C that reaches the ambient air-quality monitor in county C (estimated on the basis of simple dispersion modeling, presented in Report #16)

$D_{P',i,OC}$ = the fraction of emissions of VOCs and NOx from source i in all counties except C, in the AQCR of C, that reaches the ambient air-quality monitor in county C (estimated on the basis of simple dispersion modeling, presented in Report #16)

We use this model to estimate the contribution of motor-vehicles to TSP air pollution. We specify this model (specifically, the parameters that determine the $D_{P',i,C}$) to represent urban and suburban situations, because the hedonic price model presented above estimates the WTP for reductions in TSP levels in areas where people buy property[16].

13.3.7 Weighting TSP emissions by the contribution to light extinction

TSP consists of a wide range of particulate matter: fine particles, coarse particles, sulfates, nitrates, organic aerosols, carbon particles, and more. These different kinds of particles scatter and absorb light differently, and so contribute differently to the degradation of visibility. For example, fine particles scatter light more than do coarse particles, and so reduce visibility more. Because different sources of particulate pollution emit different mixtures of the various classes of particulates, a given amount of TSP from, say motor vehicles, will have a different effect on visibility than will the same amount of TSP, emitted at the same time and place, from, say, power plants. And because we care about visibility, and not TSP levels per se, we need to account for the differences in effect on visibility of different particle classes when we estimate the change, due to motor-vehicle emissions, in TSP as a proxy for visibility.

We can account for the differential visibility effects of particle classes by multiplying emissions of each class by a factor that represents the contribution of the particle class to light extinction. This factor is the “light-extinction efficiency,” a

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[16] We assume that most people buy homes in urban and suburban areas. Of course, this is not the end of the story. In the first place, some housing markets are in rural areas. Beyond that, the hedonic model, as discussed in section 1.3.4, does not capture WTP for visibility (air quality) outside of housing markets. The motor-vehicle contribution to those visibility damages that are *not* captured by the hedonic model might be different from the motor-vehicle contribution to the largely urban and suburban visibility damages that *are* estimated by the hedonic model. If so, then it might be inappropriate to apply an urban and suburban air-quality model to estimate the contribution of motor vehicles to visibility damages everywhere. It would be better, in this case, to estimate separate motor-vehicle contributions for, say, urban and rural areas. However, it turns out that, at least according to our simple model, the motor-vehicle contribution to rural air quality is not greatly different from the motor-vehicle contribution to urban and suburban air quality, and so for simplicity, we use one set of parameter values, and generate one set of $D_{P',i,C}$ to estimate the contribution of motor vehicles everywhere.

theoretical or empirical expression of the relationship between the atmospheric concentration of a chemical compound and the extinction of light due to scattering and absorption (Lowenthal et al., 1995; Watson and Chow, 1994; Richards et al., 1990).

The extinction efficiency can be affected strongly by relative humidity. For example, Richards et al. (1990) estimated that the scattering efficiency (in 1/µm per µg/m^3, or m^2/g) of fine particles is equal to 0.25 + 0.052RH, where RH is the percent relative humidity. Trijonis (1982) shows similar equations. On the basis of estimates and data in Trijonis (1982), Ozkaynak et al. (1985), Richards et al. (1990), the National Research Council (1991), Watson and Chow (1994), and Lowenthal et al. (1995), we assume the following total light-extinction efficiencies (m^2/g):

Pollutant	Total extinction efficiency (m^2/g)
NO_2	0.17 (absorption)
Very coarse PM (greater than 10µm)[17]	0.0
Coarse PM (between 2.5 µm and 10µm)	0.2 to 1.0 (mainly scattering)
Fine PM (less than 2.5 µm) (primary emissions)	1.0 to 5.0 (mainly scattering)
secondary ammonium nitrate and secondary organic aerosols	2.0 to 8.0 (mainly scattering)
secondary ammonium sulfate	3.0 to 10.0 (mainly scattering)
elemental carbon[18]	9.0 (absorption) + 1.0 (scattering) = 10.0

In the calculation of $PP_{TSP,N,C}$* and $PP_{TSP,C}$* above we multiply emissions of particles in each class by these extinction efficiencies[19]. Where a range is shown, we use the numerically lower value in our low-cost case, the other value in our high-cost case.

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[17] Although we did not find estimates of the extinction coefficient for PM>10 µm, it is likely that the coefficient is less than the coefficient for coarse PM, and hence close to zero. In any event, we do not have data on emissions of PM>10 µm.

[18] In the present analysis, we do not actually use the coefficient for elemental carbon, because we do not estimate emissions of elemental carbon.

[19] Notice that the product of the extinction coefficient (m^2/g) and emissions (grams) is m^2, which is not a measure of concentration. However, as shown by equation **[5]** and discussed in Report #16, we estimate the new pollution level, PP by modeling the ratio PP*/PI* and multiplying this ratio by the actual 1990 pollution level, PI. That is, what we actually model is the *ratio* of PP*/PI*, not the absolute concentration. In the calculation of the ratio PP*/PI* of equation **[5]**, the product of extinction weights (m^2/grams) and emissions (grams) appears in both the numerator and the denominator, so that we are left with a dimensionless ratio. This dimensionless ratio then is multiplied by the actual measured ambient

13.4 RESULTS OF THE ANALYSIS

The results of the analysis for cases I, IIA, and IIB are presented in Tables 13-1 to 13-3. Costs are presented for four pollutants, six vehicle types, and for upstream and road-dust emission categories.

We estimate that the cost of light extinction due to emissions attributable to motor-vehicles ranges from $5 to $40 billion per year (Table 13-2c). The uncertainty in this estimate is due in large part to uncertainty regarding the visibility fraction of the total damages estimated by the hedonic model. Considering that the $5 to $40 billion is an estimate of the value of visibility per se, exclusive of the value of all of the other effects of air pollution, we believe that the upper bound of $40/billion per year is implausible.

Table 13-1 shows the effect of the nonlinearity of the WTP function: the visibility value of each of the pollutants removed one-by-one is less than the visibility value of all of the pollutants removed simultaneously.

Table 13-1 shows that the total cost of anthropogenic TSP pollution, according to the hedonic property-value model used here, is on the order of $50 to $90 billion in 1990. (It is encouraging that the Trijonis et al. [1985] equation, shown in Appendix A, gives similar results.) If, as we assume, 20% to 40% of this total is the cost of visibility "damage" specifically, then 60% to 80%, or $30 to $70 billion, pertains to other costs -- most likely, health costs. However, as mentioned in section 13.3.3, it is likely that the housing market does not capture the full cost of the health effects of air pollution, primarily because people are not aware of the all of the health effects of air pollution. Thus, we expect our damage-function estimate (in Report #11) of the cost of the health effects of air pollution to be equal to or greater than the $30 to $70 billion health cost implied here by the hedonic model. This expectation is borne out by the analysis in Report #11, in which we use damage functions to estimate that the health cost of anthropogenic air pollution is $50 to $700 billion per year. Thus, the health-cost portion of the total pollution cost estimated by the hedonic model does indeed at the low end of the range of health costs estimated by the damage-function approach[20].

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concentration, PI, in 1990, in µg/m^3. Hence, the extinction coefficients are used to weight emissions from different sources in the calculation of the share of ambient pollution attributable to different sources.

[20] Note that the hedonic model estimates damages captured by the housing market -- i.e., in the home region -- only, whereas the damage-function model estimates damages everywhere, nationally. Thus, the hedonic model does not account for the cost, to a person in housing-market region R, of air pollution *outside* of region R -- for example, in scenic rural areas. However, while this omission undoubtedly matters greatly in the analysis of visibility, it probably matters little in the analysis of health. To a first approximation, the probability of being made ill by air pollution is proportional to the time of exposure. Since most people probably spend at least 90% of their time in the air basin of their home, pollution outside of their air basin will have relatively little effect on their health. Hence, the hedonic property-value model probably captures at least 90% of the health costs *that people recognize.* (We emphasize "that

As can be seen by comparing the results of Table 13-1 with the results of 13-2c, our model estimates that motor vehicles, including upstream emissions and road dust, are responsible for about one half of all anthropogenic visibility damages. In turn, light-duty gasoline autos (passenger cars and associated upstream and road-dust emissions) account for roughly half of all motor-vehicle-related visibility damages (13-2a vs. 13-2c). Tailpipe emissions from motor vehicles account for a bit more than half of the total motor-vehicle-related damages (Table 13-2c), and road-dust emission for somewhat less than half (Table 13-2c). (There are two opposing factors here: road-dust mass emissions greatly exceed tailpipe mass emissions, but cause less light-extinction per unit of mass.) Upstream emissions related to motor-vehicle use occasion insignificant visibility costs (Table 13-2c).

Table 13-3 indicates that, per kilogram of emission, direct PM and SO_X emissions have the largest visibility costs. The $/kg cost of SO_X exceeds the $/kg cost of NO_X because the fraction of SO_X that becomes particulate sulfate (which causes the reduction in visibility) exceeds the fraction of NO_X that becomes particulate nitrate (which causes the reduction in visibility) (see Report #16). The $/kg cost of VOCs is so small because such a small fraction of VOC emissions becomes organic aerosol (which causes the reduction invisibility).

The $/kg cost including emissions from paved and unpaved roads is much smaller than the $/kg cost of vehicular tailpipe emissions only (or tailpipe plus upstream emissions), because particulate matter from vehicles and upstream sources generally is fine, whereas most road dust PM is coarse, and the light-extinction coefficient for coarse particles is much less than the coefficient for fine particles (section 13.3.7).

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people recognize” because, as mentioned in the text, most people probably are not aware of all of the health effects of air pollution.) By contrast, vista-marring pollution can ruin the aesthetic enjoyment of those few days a year that people vacation outside of their home region -- for example, in pristine, scenic areas such as the Grand Canyon. Thus, the hedonic property-value model does not account for some significant visibility costs of pollution.

13.5 REFERENCES

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TABLE 13-1. THE VISIBILITY COST OF ANTHROPOGENIC EMISSIONS (BILLION 1991$ IN THE YEAR 1990)

	Visibility only cost[a]		Total TSP cost[b]	
	Low	*High*	*Low*	*High*
PM_{10}(c)	7.6	37.7	25.5	47.1
NO_x(d)	2.9	15.5	9.8	19.4
SO_x(e)	3.1	8.0	10.5	10.0
VOC(f)	0.2	0.9	0.7	1.1
All pollutants simultaneously[g]	*15.8*	*70.2*	*52.5*	*87.7*
Sum of pollutants individually[h]	*13.9*	*62.1*	*46.4*	*77.6*

Note that the year of the analysis is 1990 (i.e., 1990 data for emissions, air quality, and income), but the year of the dollars is 1991. See the text for further details.

[a] This is the total, adjusted, annualized visibility cost of anthropogenic emissions, equal to VA_{TA} (equation **[4]**) multiplied by the visibility share of total costs (0.10 to 0.40; section 13.3.3) and the outside-the-home area factor (1.25 to 2.00; section 13.3.4).

[b] This is the total annualized WTP to eliminate anthropogenic TSP pollution -- VA in equation (3). It is *not* the WTP for visibility only, and does not include any adjustment for pollution outside of the home area.

[c] Includes fine PM (less than 2.5 µm) and coarse PM (between 2.5 µm and 10 µm).

[d] Includes the absorption effect of NO_2, and the scattering effect of particulate nitrate.

[e] The scattering effect of particulate sulfate.

[f] The scattering effect of secondary organic aerosols.

[g] The effect of removing all pollutants at once.

[h] The sum of the effects of removing pollutants one by one. This is not the same as the effect of removing all of them at once, because the damage function is nonlinear.

TABLE 13-2A. THE VISIBILITY COST OF EMISSIONS ATTRIBUTABLE TO GASOLINE VEHICLES (YEAR 1990; 1991 $)

	Case IIA: 10% reduction in emissions attributable to motor vehicles				**Case IIB: 100% reduction in emissions attributable to motor vehicles**			
	10^9 $		$/1000-VMT		10^9 $		$/1000-VMT	
Emissions source	*Low*	*High*	*Low*	*High*	*Low*	*High*	*Low*	*High*
LDGAs	0.157	0.892	1.00	5.72	1.60	9.16	1.03	5.87
LDGAs + U	0.176	0.948	1.13	6.08	1.80	9.73	1.16	6.24
LDGAs + U + RDP	0.209	1.438	1.34	9.22	2.14	14.80	1.37	9.49
LDGAs + U + RDP +RDU	0.248	1.606	1.59	10.30	2.53	16.55	1.62	10.61
LDGTs	0.058	0.330	1.47	8.43	0.58	3.33	1.48	8.50
LDGTs + U	0.067	0.353	1.71	9.03	0.67	3.56	1.72	9.11
LDGTs + U + RDP	0.078	0.518	1.99	13.22	0.78	5.23	2.00	13.35
LDGTs + U + RDP +RDU	0.091	0.574	2.32	14.65	0.92	5.79	2.34	14.80
HDGVs	0.007	0.056	2.83	21.88	0.07	0.56	2.83	21.91
HDGVs + U	0.008	0.058	3.18	22.77	0.08	0.58	3.18	22.80
HDGVs + U + RDP	0.010	0.084	3.86	32.91	0.10	0.84	3.87	32.96
HDGVs + U + RDP +RDU	0.012	0.093	4.67	36.37	0.12	0.93	4.67	36.43
All GVs	0.222	1.280	1.12	6.47	2.29	13.29	1.16	6.72
All GVs + U	0.252	1.362	1.27	6.89	2.60	14.12	1.31	7.14
All GVs + U + RDP	0.297	2.044	1.50	10.34	3.06	21.28	1.55	10.77
All GVs + U + RDP +RDU	0.351	2.277	1.78	11.52	3.62	23.76	1.83	12.02

LDGA = light-duty diesel automobile; LGDT = light-duty diesel truck; HDGV = heavy-duty diesel vehicle; GV = diesel vehicle; U = upstream; RDP = road dust from paved roads; RDU = road dust from unpaved roads

Note that in all cases, the year of the analysis is 1990 (i.e., 1990 data for emissions, air quality, and income), but the year of the dollars is 1991.

See the text for further details.

TABLE 13-2B THE VISIBILITY COST OF EMISSIONS ATTRIBUTABLE TO DIESEL VEHICLES (YEAR 1990; 1991 $)

	Case IIA: 10% reduction in emissions attributable to motor vehicles				**Case IIB: 100% reduction in emissions attributable to motor vehicles**			
	10^9 $		$ / 1000-VMT		10^9 $		$ / 1000-VMT	
Emissions source	*Low*	*High*	*Low*	*High*	*Low*	*High*	*Low*	*High*
LDDAs	0.004	0.025	1.83	10.21	0.05	0.25	1.83	10.21
LDDAs + U	0.005	0.025	1.88	10.37	0.05	0.25	1.88	10.38
LDDAs + U + RDP	0.005	0.031	2.04	12.80	0.05	0.31	2.05	12.81
LDDAs + U + RDP +RDU	0.005	0.034	2.24	13.63	0.06	0.34	2.24	13.64
LDDTs	0.001	0.005	0.60	3.24	0.01	0.05	0.60	3.24
LDDTs + U	0.001	0.005	0.69	3.52	0.01	0.05	0.69	3.52
LDDTs + U + RDP	0.001	0.010	0.94	7.16	0.01	0.10	0.94	7.16
LDDTs + U + RDP +RDU	0.002	0.012	1.23	8.40	0.02	0.12	1.23	8.40
HDDVs	0.078	0.626	5.88	47.36	0.78	6.32	5.92	47.84
HDDVs + U	0.083	0.639	6.29	48.39	0.84	6.46	6.33	48.89
HDDVs + U + RDP	0.107	1.000	8.12	75.71	1.08	10.22	8.19	77.35
HDDVs + U + RDP +RDU	0.136	1.123	10.28	85.03	1.37	11.50	10.39	87.07
All DVs	0.083	0.655	4.86	38.31	0.84	6.62	4.89	38.72
All DVs + U	0.089	0.670	5.18	39.15	0.89	6.77	5.22	39.57
All DVs + U + RDP	0.114	1.042	6.64	60.91	1.15	10.66	6.70	62.29
All DVs + U + RDP +RDU	0.143	1.169	8.36	68.33	1.45	11.98	8.45	70.04

LDDA = light-duty diesel automobile; LDDT = light-duty diesel truck; HDDV = heavy-duty diesel vehicle; DV = diesel vehicle; U = upstream; RDP = road dust from paved roads; RDU = road dust from unpaved roads.

Note that in all cases, the year of the analysis is 1990 (i.e., 1990 data for emissions, air quality, and income), but the year of the dollars is 1991.

See the text for further details.

TABLE 13-2C. THE VISIBILITY COST OF EMISSIONS ATTRIBUTABLE TO ALL MOTOR VEHICLES (YEAR 1990; 1991 $)

	Case IIA: 10% reduction in emissions attributable to motor vehicles				**Case IIB: 100% reduction in emissions attributable to motor vehicles**			
	10^9 $		$ / 1000-VMT		10^9 $		$ / 1000-VMT	
Emissions source	*Low*	*High*	*Low*	*High*	*Low*	*High*	*Low*	*High*
MVs	0.305	1.938	1.42	9.02	3.17	20.25	1.47	9.43
MVs + U	0.341	2.035	1.59	9.47	3.53	21.25	1.65	9.89
MVs + U + RDP	0.412	3.094	1.92	14.41	4.27	32.86	1.99	15.30
MVs + U + RDP +RDU	0.495	3.456	2.31	16.09	5.15	36.88	2.40	17.17

MVs = motor vehicles; U = upstream; RDP = road dust from paved roads; RDU = road dust from unpaved roads; PM_{10} = particulate matter of aerodynamic diameter of 10 microns or less; NO_X = nitrogen oxides; SO_X = sulfur oxides; VOCs = volatile organic compounds.

Note that in all cases, the year of the analysis is 1990 (i.e., 1990 data for emissions, air quality, and income), but the year of the dollars is 1991.

See the text for further details.

TABLE 13-3A. THE VISIBILITY COST OF A KILOGRAM OF EMISSIONS ATTRIBUTABLE TO GASOLINE VEHICLES, GIVEN A 10% REDUCTION IN EMISSIONS RELATED TO GASOLINE VEHICLES (YEAR 1990; 1991 \$/KG-EMITTED)

Emissions source	**\$/kg-PM$_{10}$**[a]		**\$/kg-NO$_x$**(b)		**\$/kg-SO$_x$**(c)		**\$/kg-VOCs**[d]	
	Low	*High*	*Low*	*High*	*Low*	*High*	*Low*	*High*
LDGAs	0.83	5.50	0.32	1.63	1.93	6.73	0.01	0.06
LDGAs + U	0.66	4.08	0.30	1.52	0.49	1.45	0.01	0.05
LDGAs + U + RDP	0.47	2.58	0.30	1.52	0.49	1.45	0.01	0.05
LDGAs + U + RDP +RDU	0.13	0.99	0.30	1.52	0.49	1.45	0.01	0.05
LDGTs	0.79	5.34	0.29	1.49	1.78	6.21	0.01	0.06
LDGTs + U	0.61	4.01	0.27	1.37	0.39	1.10	0.01	0.05
LDGTs + U + RDP	0.47	2.61	0.27	1.37	0.39	1.10	0.01	0.05
LDGTs + U + RDP +RDU	0.14	1.02	0.27	1.37	0.39	1.10	0.01	0.05
HDGVs	0.44	4.40	0.17	1.28	0.98	5.03	0.01	0.08
HDGVs + U	0.41	4.05	0.17	1.23	0.40	1.56	0.01	0.06
HDGVs + U + RDP	0.43	2.70	0.17	1.23	0.40	1.56	0.01	0.06
HDGVs + U + RDP +RDU	0.13	1.08	0.17	1.23	0.40	1.56	0.01	0.06
All GVs	0.78	5.34	0.30	1.58	1.84	6.50	0.01	0.06
All GVs + U	0.62	4.06	0.28	1.47	0.45	1.34	0.01	0.05
All GVs + U + RDP	0.47	2.60	0.28	1.47	0.45	1.34	0.01	0.05
All GVs + U + RDP +RDU	0.13	1.01	0.28	1.47	0.45	1.34	0.01	0.05

LDGA = light-duty diesel automobile; LGDT = light-duty diesel truck; HDGV = heavy-duty diesel vehicle; GV = diesel vehicle; U = upstream; RDP = road dust from paved roads; RDU = road dust from unpaved roads; PM$_{10}$ = particulate matter of aerodynamic diameter of 10 microns or less; NO$_X$ = nitrogen oxides; SO$_X$ = sulfur oxides; VOCs = volatile organic compounds.

Note that in all cases, the year of the analysis is 1990 (i.e., 1990 data for emissions, air quality, and income), but the year of the dollars is 1991.

[a] Equal to the dollar cost of light extinction caused by 10% of the primary ambient PM$_{10}$ attributable to motor vehicles, divided by 10% of PM$_{10}$ emissions attributable to motor vehicles. Primary or direct PM is PM that is emitted as such, as distinguished from PM that is formed in the atmosphere.

[b] NO_x emissions can become ambient NO_2 or form particulate nitrate aerosols. The $/kg estimate here is equal to the dollar cost of light extinction caused by 10% of the ambient NO_2 and 10% of the ambient particulate nitrate attributable to motor vehicles, divided by 10% of NO_x emissions attributable to motor vehicles.

[c] SO_x emissions can form particulate sulfate aerosols, which scatter light and reduce visibility. The $/kg estimate here is equal to the dollar cost of light extinction caused by 10% of the ambient particulate sulfate attributable to motor vehicles, divided by 10% of SO_x emissions attributable to motor vehicles.

[d] VOC emissions can form secondary organic aerosols, which scatter light and reduce visibility. The $/kg estimate here is equal to the dollar cost of light extinction caused by 10% of the ambient organic aerosol attributed to motor vehicles, divided by 10% of VOC emissions attributed to motor vehicles.

TABLE 13-3B. THE VISIBILITY COST OF A KILOGRAM OF EMISSIONS ATTRIBUTABLE TO DIESEL VEHICLES, GIVEN A 10% REDUCTION IN EMISSIONS RELATED TO DIESEL VEHICLES (YEAR 1990; 1991 $/KG-EMITTED)

Emissions source	**$/kg-$PM_{10}$**[a]		**$/kg-$NO_X$**(b)		**$/kg-$SO_X$**(c)		**$/kg-VOCs**[d]	
	Low	*High*	*Low*	*High*	*Low*	*High*	*Low*	*High*
LDDAs	0.98	7.34	0.33	1.67	1.93	6.72	0.01	0.08
LDDAs + U	0.97	7.17	0.32	1.60	1.57	5.37	0.01	0.06
LDDAs + U + RDP	0.74	4.33	0.32	1.60	1.57	5.37	0.01	0.06
LDDAs + U + RDP +RDU	0.24	1.90	0.32	1.60	1.57	5.37	0.01	0.06
LDDTs	0.91	6.78	0.30	1.53	1.78	6.19	0.01	0.07
LDDTs + U	0.84	6.07	0.23	1.17	0.73	2.37	0.01	0.05
LDDTs + U + RDP	0.53	2.94	0.23	1.17	0.73	2.37	0.01	0.05
LDDTs + U + RDP +RDU	0.15	1.14	0.23	1.17	0.73	2.37	0.01	0.05
HDDVs	0.46	5.10	0.16	1.21	0.89	4.55	0.02	0.22
HDDVs + U	0.45	4.96	0.16	1.17	0.61	2.88	0.02	0.13
HDDVs + U + RDP	0.44	3.02	0.16	1.17	0.61	2.88	0.02	0.13
HDDVs + U + RDP +RDU	0.14	1.23	0.16	1.17	0.61	2.88	0.02	0.13
All DVs	0.48	5.19	0.17	1.22	0.93	4.64	0.02	0.22
All DVs + U	0.47	5.05	0.16	1.17	0.64	2.95	0.02	0.13
All DVs + U + RDP	0.45	3.05	0.16	1.17	0.64	2.95	0.02	0.13
All DVs + U + RDP +RDU	0.15	1.24	0.16	1.17	0.64	2.95	0.02	0.13

LDDA = light-duty diesel automobile; LDDT = light-duty diesel truck; HDDV = heavy-duty diesel vehicle; DV = diesel vehicle; U = upstream; RDP = road dust from paved roads; RDU = road dust from unpaved roads; PM_{10} = particulate matter of aerodynamic diameter of 10 microns or less; NO_X = nitrogen oxides; SO_X = sulfur oxides; VOCs = volatile organic compounds.

Note that in all cases, the year of the analysis is 1990 (i.e., 1990 data for emissions, air quality, and income), but the year of the dollars is 1991.

[a,b,c,d] See notes to Table 13-3a.

TABLE 13-3C. THE VISIBILITY COST OF A KILOGRAM OF EMISSIONS ATTRIBUTABLE TO ALL MOTOR VEHICLES, GIVEN A 10% REDUCTION IN EMISSIONS RELATED TO ALL MOTOR VEHICLES (YEAR 1990; 1991 $/KG-EMITTED)

Emissions source	**\$/kg-PM$_{10}$**[a]		**\$/kg-NO$_x$**(b)		**\$/kg-SO$_x$**(c)		**\$/kg-VOCs**[d]	
	Low	*High*	*Low*	*High*	*Low*	*High*	*Low*	*High*
MVs	0.57	5.24	0.27	1.49	1.27	5.34	0.01	0.07
MVs + U	0.53	4.67	0.25	1.40	0.51	1.81	0.01	0.06
MVs + U + RDP	0.46	2.78	0.25	1.40	0.51	1.81	0.01	0.06
MVs + U + RDP +RDU	0.14	1.10	0.25	1.40	0.51	1.81	0.01	0.06

MVs = motor vehicles; U = upstream; RDP = road dust from paved roads; RDU = road dust from unpaved roads; PM$_{10}$ = particulate matter of aerodynamic diameter of 10 microns or less; NO$_X$ = nitrogen oxides; SO$_X$ = sulfur oxides; VOCs = volatile organic compounds.

Note that in all cases, the year of the analysis is 1990 (i.e., 1990 data for emissions, air quality, and income), but the year of the dollars is 1991.

[a,b,c,d] See notes to Table 13-3a.

APPENDIX: APPLICATION OF TRIJONIS ET AL. (1985) VISIBILITY DEMAND EQUATION

The second-stage visibility equation, developed by Trijonis et al. (1985), estimates the willingness to pay for visibility per household:

$$Vh = 11139 - 6006L + 0.178Y$$

$$L = \frac{KM}{V}$$

[A1]

where:

Vh = the amount extra that a household is willing to pay for a home, per unit of light-extinction L, at the particular visibility level represented by L (1978-1979$)

L = median light-extinction coefficient

Y = average annual household income ($)

V = the visual range (miles)

KM = Koschmeider constant (18.65 miles; for airport visibility data)

The light-extinction coefficient L is the fraction of light that is attenuated per unit distance as a light beam traverses the atmosphere. In a uniform atmosphere, the extinction coefficient is inversely proportional to the visual range, according to the Koschmeider formula given here.

Equation (A1) is the household demand function for visibility. The area under this demand curve, between light-extinction level 1 and light-extinction level 2, is the total dollar cost per household of the difference between the two light-extinction (visibility) levels. The cost per household multiplied by the number of households gives the grand total for the region of households.

Because equation A1 here has the same functional form as equation 1 in the text, the integration and evaluation of A1 (willingness-to-pay with respect to light extinction) results in the following analog of equation 2 in the text:

$$VT = \sum_c \left(H_c \cdot \left(11139 \cdot K1 \cdot \left(L_{1c} - L_{2c}\right) - \frac{6006}{2} \cdot K1 \cdot \left({L_{1c}}^2 - {L_{2c}}^2\right) + \frac{K1}{K2} \cdot 0.178 \cdot Y_c \cdot \left(L_{1c} - L_{2c}\right) \right) \right)$$

$$L_{1c} = \frac{KM}{V_{1c}} \text{ and } L_{2c} = \frac{KM}{V_{2c}}$$

[A2]

where:

subscript c = counties in the U.S.

VT = the total amount extra that all households in the U. S. would have been willing to pay for their homes, if light extinction in each county were at the level represented by L_2 instead of the level represented by L_1 (1991 $)

H_c = the number of households in county c in the U. S. in 1990

L_{1c} = the actual light extinction in county c in 1990

L_{2c} = the hypothetical new light extinction in county c in 1990

Y_c = average annual household income in county c in 1990 ($/year)

V_{1c} = the actual visual range in county c in 1990 (miles; data discussed below)

V_{2c} = the hypothetical new visual range in county c in 1990

K1 = price deflator to estimate 1991 WTP given 1978-79 prices (GNP implicit price deflator = 1.81 [interpolate between 1978 and 1979 values])

K2 = price deflator to estimate 1990 income given 1978-79 prices (GNP implicit price deflator = 1.73 [interpolate between 1978 and 1979 values])

Visual range. The National Climatic Data Center (1991), provides hourly horizontal visual range for 187 sites in the U.S. in 1990, on 3 CD -ROMs. Visual range is the median of the 365 calculated daily visibility values, in miles, where the daily visibility is calculated as the average of the visibility readings at 10:00 AM, 1:00 PM, and 4:00 PM each day. Visual range typically is between 10 and 100 miles, and generally less than 50 miles.

llustrative calculation. In order to compare the results of equation A2 with the results of equation 2, we calculate national willingness-to-pay, VT (equation A2), for national parameter values:

H = total households in the U. S. in 1990 ($94.3 \cdot 10^6$; Bureau of the Census, 1992)

Y = average household income in 1990 ($37,403; Bureau of the Census, 1992)

V_1 = typical visual ranges in 1990 (15 miles [high-cost case] to 25 [low-cost case] miles; Trijonis, 1982; Ozkaynak et al., 1985; National Climatic Data Center, 1991; Watson and Chow, 1994)

V_2 = visual range in clean air (assume 75 miles)

We then use equation 4 to annualize the calculated total VT. The result is an annual visibility cost of $52 to $144 billion (1991 $) per year. (Note that this does not include costs outside the home area.) This range is similar to the range estimated with equation 2 (see Table 13-1).