6 Market Approaches to the Measurement of the Benefits of Air Pollution Abatement

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Introduction and Summary

Recent policy decisions concerning the nature of standards and other regulatory policies to control air pollution have made little or no use of explicit cost-benefit analyses. This reality may not be surprising given the political setting in which these policy decisions were made.[1] However, there are economic as well as political factors that might argue against the explicit use of cost-benefit analyses. One argument, in its most simplistic form, states that it is impossible to obtain quantitative estimates of the benefits of air pollution control, first because individuals (as well as researchers) are simply unaware of all of the potential benefits and, second, because it is likely to be difficult to quantify those benefits about which individuals are aware. Despite the admittedly serious difficulties, economists are generally reluctant to give up the use of such a potentially powerful tool as cost-benefit analysis. Clearly some of the benefits from air pollution control are likely to be extremely difficult, if not impossible, to quantify. But even a crude quantitative estimate of these benefits, with the appropriate caveats, would be more useful for public policy than no estimate at all.

This paper seeks to shed some light on this issue by assessing the methods of measuring pollution control benefits that rely most directly on information obtained from the market process. This is clearly a difficult problem because there is no explicit market for the amenities associated with clean air, and thus there are no directly observable market prices that can be interpreted as the rate at which individuals are willing to trade clean air for other commodities. However, two approaches have received serious attention from economists and have proved successful in providing quantitative benefit estimates. The first approach involves *property-value studies,* in which the willingness to pay for clean air is inferred from the housing market (usually in an urban area), on the presumption that individual households will pay more for a housing unit located in an area with good air quality than for an otherwise identical unit located in an area with poor air quality.[2] A second approach involves *wage-rate studies,* in which wage differentials among

urban areas (adjusted for labor quality and other factors) are used to impute the willingness to pay for clear air, on the presumption that individual households will accept a lower wage to work in an urban area in which the air quality level is good.[3]

There are, of course, other approaches that have been and are being used to obtain quantitative benefit estimates, the primary of which focuses on the health benefits of pollution control.[4] The health, market, and other approaches all involve substantial difficulties, both in terms of the conceptual framework and in terms of the specific technical and statistical problems involved in the analysis. However, the two market-oriented approaches (wage-rate and property-value studies) are perhaps the most controversial because there appears to be a wide range of opinion about whether one can place any reliance on the benefit estimates that they yield. For example, Lave argues, "Certainly the former [property-value] approach is simpler and closer to a classical economic approach. It focuses our attention on the things that economists have the most experience with, namely estimating utility functions, demand functions, and splitting the pollution component of a price from other factors. However, I believe that this approach is not likely to lead to fruitful results."[5]

On the other hand, Waddell concludes, "Because of its general ease of measurement and inclusiveness, the property value, or site value differential technique, is one of the most promising approaches to the estimation of the economic losses due to air pollution. The advantage of this method is that the investigator does not have to discover and evaluate the pollution sufferers' adjustment possibilities, nor does he have to worry about how to make individual properties commensurate so that he can aggregate them."[6] This wide variety of opinion arises not only because of the difficult set of empirical problems but also as a result of the difficult theoretical problems that are implicit in these approaches.

Perhaps the most important issue surrounds the so-called double-counting issue—whether and to what extent wage- and property-value benefits overlap the benefits obtained from health and related studies. To be specific, consider the property-value approach. Most studies of this sort have specifically focused on the residential-housing market. As a result, they do not provide estimates of the air-quality improvement benefits associated with households' work places or shopping areas. In addition, they do not measure benefits that might accrue to businesses in the form of lower costs of production. In order for the housing market to capture some of the effects of air pollution, detailed knowledge of the specifics of air pollution is not necessary. However, it is important that some households are willing to pay more

for houses in less polluted areas than for equivalent quality houses in highly polluted areas. Thus, it seems likely that households will be aware to some extent of the extra cleaning and maintenance costs associated with poor air quality, as well as the soiling, odor, eye irritation, and lack of visibility that it causes. What is not clear is the extent to which these measured benefits overlap the benefits obtained from health studies. Under the assumption that households don't perceive well the health effects of air pollution and have no adverse expectation about these effects, the property-value benefit estimates ought to be added to the benefit estimates obtained through epidemiological studies. However, to the extent that households respond to known adverse health effects or simply expect health effects to be serious in highly polluted areas without specific knowledge, the property-value and health benefits are likely to substantially overlap.

The automobile emissions study of the National Academy of Sciences was concerned with these issues and argued, "Some double counting may be involved, however, in the simple addition of the two estimates. A point estimate nearer the lower middle of the range . . . would thus seem to be a reasonable guess of total benefits due to the federal emissions program."[7]

Waddell, in his survey of air-pollution damage studies, took the view that double counting is not a serious problem and argued, "While the evidence is far from clear, it is reasoned that as interpreted in this study, the estimates determined via the site differential and technical coefficients methods should be considered additive, with only minor adjustment for obvious areas of overlap."[8]

Waddell is correct in stating that the evidence is far from clear. Some of the acute symptoms associated with poor air quality are likely to affect households' location decisions, but many other known adverse health effects seem unlikely to show up in property-value studies. This expectation seems especially reasonable in the case of carbon monoxide because CO is odorless and tasteless, but it is less clear in the case of particulates and sulfur oxides, for example. In this author's view, however, Waddell's point of view is likely to involve less error than an approach that argued that health and property-value benefit estimates entirely duplicated one another. A good portion of the benefits that show up in property-value studies are aesthetic benefits that are unrelated to households' direct fears about health effects. As a result, the addition of a *correctly* estimated property-value benefit measure to the benefit measures obtained from health and other cost studies may not seriously overestimate benefits. Of course, this judgment may change as information improves and households respond more directly to the health

hazards associated with air pollution. Whatever one's opinion on the double-counting issue, it should be clear that quantitative estimates of both health and market-related benefits should provide useful inputs into cost-benefit analyses of air pollution control and therefore should be seriously evaluated by policy makers involved in the regulatory process.

This paper summarizes some recent evidence concerning the nature of air-pollution-control benefits that can be obtained from property-value data and assesses the theoretical and empirical difficulties that are inherent in such studies. Despite the rather substantial list of complexities involved, these recent results are quite promising from a policy viewpoint. Not only are quantitative estimates of the benefits of reductions in air pollution concentrations obtained, but more important, quantitative estimates of the sensitivity of the results to some of the underlying assumptions are also available. As a consequence, policy makers should have sufficient perspective to make proper use of the numbers that are available. Even a crude guess about the facts, with the appropriate caveats, should be more useful than a guess based purely on whim. This guarded optimism must be qualified in one important respect, however. The results of the study are discouraging in that they suggest that property-value studies are likely to fail at providing policy makers with a list of benefits associated with the reduction of concentration levels of individual pollutants. Further information is likely to be necessary if reasonable guesses are to be made along these lines.

The organization of the paper is as follows. The first section discusses in some detail the conceptual issues involved in the market studies. An examination of the extent to which property-value studies can be utilized to estimate individual households' willingness to pay for both small and large improvements in air quality in one urban area and throughout the United States leads into an analysis of the conditions under which wage-rate differentials can be used to estimate benefits and the relationship between the wage-rate and property-value approaches. The second major section considers the empirical results of property-value studies.[9] Rather than reviewing a long list of studies that are not comparable, the section provides a focus by concentrating on the recent analysis of a data set for the Boston metropolitan area. This focus allows estimates to be obtained for the magnitudes of some of the biases that arise in the property-value studies. The objective is to obtain some reasonable statistical bounds for the property-value-related benefits of an improved environment and to see to what extent these benefits can be attributed to improvements in specific pollutant levels. The final section summarizes the major conclusions.

Conceptual Issues

Economists argue that environmental decision making must involve a comparison of benefits as well as costs. Typically, the set of available policy choices may involve various levels of technology and various corresponding degrees of pollution control. As a consequence, the analysis of such policy choices involves a calculation of the benefits of pollution reduction for various degrees of reduction. A useful first step in the analysis of the benefit side of a cost-benefit analysis might involve the determination of the benefit to society of a small amount of pollution abatement, that is, the marginal benefit. However, this step is only a first step, because most reduction programs involve substantial abatement. The marginal benefit of pollution reduction may change when reductions occur, so the estimation of the total benefits associated with a large, or *nonmarginal,* reduction in air pollution levels is a more important and yet a more complex problem.[10]

This section addresses the question of whether market approaches can be used to derive estimates of the benefits of improved urban air quality. The first issue discussed is whether property-value studies can be utilized to measure the willingness to pay for nonmarginal air quality improvements. Most existing studies yield estimates that provide correct measures of the marginal benefits of environmental improvements but provide biased estimates when the improvements are nonmarginal. Following this discussion, the methodological problems associated with extrapolating benefits calculated for one urban area to benefits for the entire United States are briefly outlined. Finally, the wage-rate approach to benefit measurement is analyzed and special attention given to the methodological problems involved and to the relationship between wage and property-value studies.

The Willingness to Pay for Clean Air

Implicit in the property-value approach is the assumption that market prices (or imputed market prices) provide a meaningful basis for measuring the benefits of an environmental improvement.[11] To correctly utilize this price information, the concept of willingness to pay for an air quality improvement must be explicitly defined. Consider a household at a particular location in an urban area in which the level of air pollution is represented by the index A. Hold all prices and the household's money income constant and gradually decrease the level of air pollution. The household's *total* willingness to pay for the air quality improvement is defined as the maximum amount of income that can be taken after the air quality improvement without leaving the household worse off.[12] The household's marginal willingness

to pay for small improvements in the environment can be found by calculating the derivative of total willingness to pay with respect to the level of air pollution. This relationship is called the household's *willingness-to-pay function* because it emphasizes the link between the physical level of air pollution and the marginal benefit associated with small improvements at each level. It is also known as the *marginal damage function* because it measures the household's valuation of marginal reductions in pollution damages.[13] In economic terms, the willingness-to-pay function is equivalent to a compensated demand curve for reductions in air pollution because money income has been allowed to adjust so that real income (utility) remains constant.

Calculation of Total Benefits If one can statistically estimate the willingness-to-pay function for each household, it is relatively straightforward to calculate the aggregate benefits associated with both marginal and nonmarginal improvements in air quality throughout an urban area. If $W_i(A_i)$ represents the marginal willingness to pay for a unit reduction in air pollution by the household residing at location i (where air pollution is at level A_i), then the dollar value of a marginal reduction in air quality is simply $W_i(A_i)$. To obtain the benefits associated with a nonmarginal change, the values of these marginal willingnesses to pay must be summed from the original to the new level of air pollution, that is, the W_i function must be integrated from the original to the new level of air pollution.[14]

If the willingness-to-pay function is independent of the level of air pollution, then the total benefits will simply equal the product of the marginal willingness to pay and the total reduction in air pollution. This equality is illustrated as Case 1 in figure 6.1.[15] However, if the marginal willingness to pay decreases as the level of air pollution is reduced, the total benefits will be lower than in Case 1,[16] so that the incorrect assumption of a constant marginal willingness to pay will cause total benefits to be overestimated. Finally, if (as in Case 3) marginal willingness to pay increases as the level of air pollution is reduced, the assumption of a constant marginal willingness to pay will lead to an underestimate of total benefits. The analysis suggests that, for small air quality improvements, the shape of the willingness-to-pay function is not likely to be relevant, but when the improvement is large, the relationship between a reduction in pollution and willingness to pay may be important. Thus, one of the objectives of any market analysis of air pollution (as with nonmarket studies) should be to ascertain the shape of the air-pollution willingness-to-pay or damage function.

One important methodological question is whether, and if so under what conditions, it is possible to estimate the willingness-to-pay function for urban households. The problem is a difficult one because marginal willing-

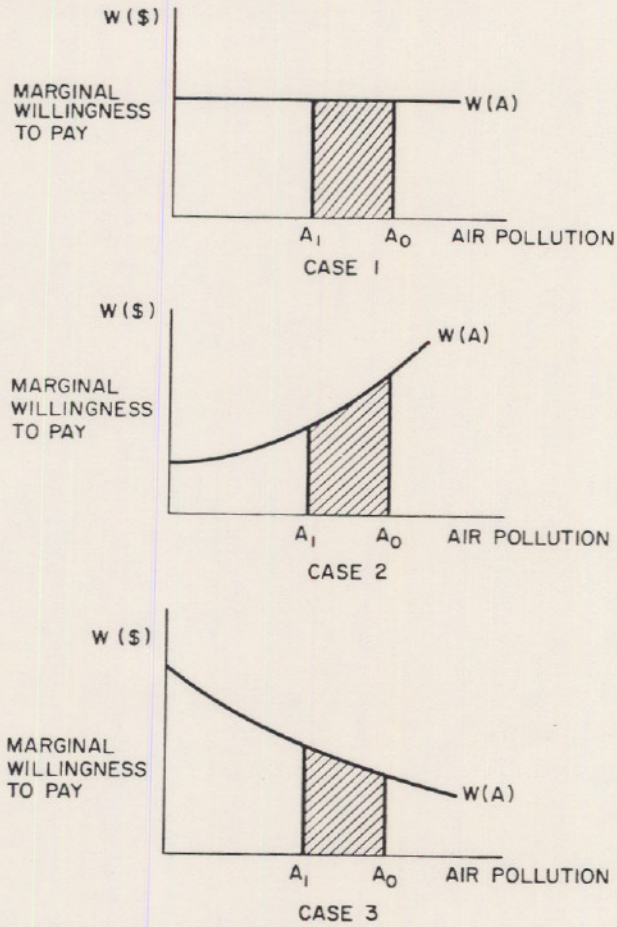

Figure 6.1. Willingness to pay for reductions in air pollution. (A_0 = original pollution level; A_1 = improved pollution level)

ness to pay will depend not only on the level of air pollution (a movement along the "demand" curve) but also on taste variables such as income (a shift of the "demand" curve). For example, if air quality is a normal good, then the marginal willingness to pay for clean air will increase as household income increases. Unfortunately, it isn't possible to carry on a controlled experiment, that is, to study identical households simultaneously consuming (purchasing or renting) housing at locations with different levels of air quality at the same point in time. However, if households with similar taste structures are known to consume different levels of air quality and other attributes associated with housing, it may still be possible to determine the willingness-to-pay function.[17] This section describes how such an estimation procedure might be accomplished and at the same time stresses the rather strong set of assumptions that are necessary for such a procedure to be appropriate.[18] A later section includes empirical estimates of the magnitude of the difficulties that arise when some of the underlying assumptions are not satisfied.

Estimating the Willingness-to-Pay Function Assume that the housing (owner plus rental) market is in short-run equilibrium so that housing values (and rental prices) equate the demand and supply of housing services.[19] To simplify, assume that in the short run the supply of air pollution and the housing stock at every location in the urban area is fixed, so that the movement of households among locations serves as the mechanism that equates housing demand to housing supply. Individual households are assumed to maximize their utility by selecting their residential location and, in the process, trading off variations in housing and neighborhood attributes with accessibility to work place.[20] Rather than imagining housing as a commodity with a known, measurable output, it is more useful to conceive of housing as composed of a bundle of attributes, which include not only structural characteristics but also neighborhood and accessibility characteristics and, of course, one or more indices of the level of air pollution. The relationship between equilibrium housing values and the level of each housing characteristic (alternatively called a *housing-value, property-value,* or *hedonic-value* equation) might be represented as:

$$V_i = f(S_i, N_i, A_i)$$

where V_i is the residential property value[21] (that is, value of land and improvements) at location i, S_i, the structural characteristics of location i, N_i the neighborhood and accessibility characteristics of location i, and A_i the air pollution level (or levels) at location i.

Because individuals are assumed to take into account air quality variations

as they are making their housing choices, we expect that, everything else equal, the change in property values with respect to a change in air pollution ($\partial V_i/\partial A_i$) will be negative; in other words, households living in low-air-pollution areas (other things equal) will pay more for their houses than households living in high-pollution areas. A necessary condition for equilibrium to be attained is that, at each location, the household's marginal willingness to pay for a unit reduction in air pollution must be identically equal to the marginal cost incurred in purchasing a different house if all attributes are the same except that air pollution is reduced by a unit.[22] In mathematical terms,

$$W_i(A_i(= - \partial V_i/\partial A_i = V_{Ai}$$

If the housing-value function (f) were linear in each of the housing attributes and households were assumed to be identical, then the marginal willingness to pay for air pollution reductions would be identical for each household and at every location. Thus $W_i(A_i)$ would be the (horizontal) willingness-to-pay function from which we could accurately measure the benefits of both marginal and nonmarginal improvements in air quality. However, there is reason to believe that the housing-value function may be nonlinear. Nonlinearities arise because the housing market may not be in long-run equilibrium. Unlike the attributes of less durable commodities, housing attributes cannot be untied and repackaged to produce an arbitrary set of attributes at all locations. As a consequence, the marginal valuation placed by consumers on a given housing attribute (including air quality) may depend upon the particular combination of housing attributes at that location. For example, good air quality may be more highly valued at locations in which there is a view of mountains than at locations in which the view is blocked by a series of high-rise apartment houses.

In the general case, the slope of the housing-value equation does not describe a demand or willingness-to-pay function; rather it represents the locus of equilibrium marginal willingnesses to pay for all households. In order to identify the willingness-to-pay function for each household, it is necessary to identify household groups on the basis of tastes and incomes.[23] Only by examining variations in $W_i(A_i)$ within each household group is there hope of identifying the willingness-to-pay function of that group. For example, assume that all households have identical tastes but different incomes. By accounting for the fact that the willingness-to-pay function shifts as income changes it may be possible to estimate the relationship between $W_i(A_i)$ and A_i. Specifically, consider the functional relationship

$$W_i(A_i) = g(A_i, Y_i, Q_i)$$

where Y_i equals income and Q_i a vector of housing attributes that are complementary or substitutable with air pollution. Given a level of income for the household located at i, the function g associates a marginal willingness to pay with each level of air pollution A_i. If g is properly specified, it will in fact represent the desired willingness-to-pay function. However, if taste differences are not properly taken into account, g at best will represent an average willingness-to-pay function over several household groups.[24]

To the extent that any of the assumptions in the willingness-to-pay approach are violated, empirical estimates of the benefits of improved air quality may be biased. If, for example, the housing market were not close to short-run equilibrium (due to factors such as high moving costs), the change in house values with respect to a change in air pollution might not reflect the benefits of better air quality. In addition, to the extent that households do not have perfect information about air quality (and other data), low values of marginal willingness to pay may reflect imperfect knowledge rather than a lack of concern for air quality. Finally, the theory presumes that the levels of air pollution are correctly measured. To the extent that the level of air pollution varies over time and with climatic conditions, the use of any single index of air quality may lead to biased results.[25]

Assuming that the air-pollution damage function has been correctly estimated, the final conceptual step is to use the damage function to calculate the dollar benefits associated with a particular scheme for improving air quality. The per-household willingness to pay for nonmarginal reductions in air pollution (in principle) can be calculated for households at each location in the urban area by finding the area under the willingness-to-pay curve from the old to the new level of pollution, that is, by integrating the function g and evaluating the integral at the appropriate pollution levels. Because the conceptual model has been written with property value as the dependent variable (rather than rental price), the integrated willingness to pay is an estimate of the capitalized (as opposed to annual) value of the air quality improvement to each household.

Implicit in the willingness-to-pay approach is the assumption that households living in an improved area do not move when the improvement occurs. This is a reasonable assumption, given the difficulties involved with the prediction of household moving behavior, but it does suggest a possible bias in the benefit calculations. Assume, for example, that households living in highly polluted areas before the improvement in air quality do not place great value on clean air. After the improvement, families that place greater value on clean air may move into the area. As a result, the estimated willingness to pay of the original occupants of the area will be lower than

the willingness to pay of the new residents. Although the general equilibrium nature of the economic system makes generalization of this example difficult, it seems reasonable to expect that benefit estimates that fail to account for such household adjustment will underestimate benefits.

Obtaining an Aggregate U.S. Benefit Measure

One difficulty associated with the property-value approach is that in order to obtain an estimate of the benefits of a national air-pollution-reduction program, data and cost limitations force one to extrapolate the experience in one or several urban areas to all urban areas in the United States. For example, in the National Academy of Sciences study of the benefits of automobile emissions controls, a national estimate of benefits was obtained by multiplying the estimated average benefits per household in Boston by the estimated total number of households living in U.S. urban areas and thus likely to be affected by air pollution.[26] Unfortunately, however, there are strong reasons to believe that such linear extrapolation may result in serious biases. Urban areas throughout the United States clearly differ in the levels of various pollutants as well as in the distribution of those pollutants over space. In addition, the degree of reduction of pollutants in each urban area is likely to vary substantially depending upon the specific nature of the legislated air pollution controls. Finally, there is reason to believe that individuals have to some extent sorted themselves out geographically on the basis of their specific tastes for climate, location, and possibly the level of air quality. All of these difficulties suggest that one ought to base national estimates of benefits upon studies of several urban areas that differ in terms of population characteristics and the levels of various pollutants.[27]

Predicting Changes in Residential Property Values

A number of empirical studies of the benefits of air quality improvements within an urban area have argued that the sum of the changes in property values arising from an air quality improvement provide a good estimate of the total benefits of the improvement.[28] The argument for this approach is stated clearly by Ridker as follows:

> If the land market were to work perfectly, the price of a plot of land would equal the sum of the present discounted streams of benefits and costs derivable from it. If some of its costs rise . . . or if some of its benefits fall . . . the property will be discounted in the market to reflect people's evaluation of these changes. Since air pollution is specific to locations and the supply of locations is fixed, there is less likelihood that the negative effects of pollution can be significantly shifted onto other markets. We should therefore

expect to find the majority of effects reflected in this market, and can measure them by observing associated changes in property values.[29]

The procedure utilized to predict the change in property values is simply to multiply V_{Ai}, the change in property values resulting from a change in air pollution obtained from the estimation of a hedonic-value equation, by the change in air pollution at every site in the urban area. As outlined in the previous section, this is the correct procedure for determining the total benefits associated with a marginal improvement in the environment, but it is likely to lead to biased results if the environmental change is nonmarginal. Thus, for marginal changes, the procedure utilized by most empirical studies of air pollution correctly estimates benefits.[30]

Two questions remained unanswered. First, do the empirical studies accurately predict changes in property values; second (and more relevant for this paper), would the correctly estimated predicted change in property values provide a useful measure of the willingness to pay for nonmarginal air quality improvements. Unfortunately, both questions must be answered in the negative. The problem with attempting to predict property values from a hedonic-value equation is that the V_{A_i} are calculated on the presumption that all housing attributes (including air quality) at other locations in the urban area are held constant. As a result, the hedonic approach cannot take into account the important general equilibrium impacts likely to occur when there is a substantial improvement in air quality throughout the urban area. This point was clarified by Polinsky and Rubinfeld, who argue:

> Consider an urban area with a fixed population and fixed boundary in which air quality improves with distance from the center. If air quality is then raised throughout the area to a uniform level, say to the level at the boundary, this would induce an excess demand for land in the inner part of the urban area bidding up property values there, but also an excess supply of land in the outer area, lowering property values there (even though air quality also improved). . . . Thus, it appears that the estimated coefficients of the (hedonic) equation cannot be used in this way to predict the pattern of property value changes throughout the urban area.[31]

Even if the aggregate change in property values could be predicted, this change will not in general correspond to a correct measure of total benefits. The difficulty arises because, as a rule, the improvement in air quality throughout the urban area generates not only changes in property values (surpluses to landlords) but also producer surpluses and consumer surpluses. Only in the special case in which consumer and producer surpluses are identically zero will the aggregate change in property values correctly measure

benefits. In the general case, changes in property values may provide seriously misleading benefit estimates. For example, Polinsky and Shavell cite a hypothetical example in which air quality is improved everywhere but the aggregate change in property values remains constant.[32]

Polinsky and Shavell and Polinsky and Rubinfield point out that the validity of using cross-section hedonic equations to predict changes in property values depends crucially on one's assumption about the mobility of households among (as well as within) urban areas.[33] In the special case in which the labor market is exogenous so that wage rates are fixed and migration is costless between any two urban areas, property-value changes will accurately measure benefits. However, to the extent that interurban migration is costly or labor-market adjustments are taken into account, changes in residential property values may provide seriously biased estimates of benefits. The costless mobility assumption is crucial because it guarantees that all of the benefits of the environmental improvement will appear in property values, whereas consumer and producer surpluses will not change. The exogenous labor-market assumption is crucial because it guarantees that wage changes will not absorb a portion of the benefits of the environmental improvement.

Interurban Wage-Rate Differentials

Several authors have argued that, when adjusted to hold labor quality and certain other factors constant, wage differentials among urban areas may provide an estimate of the willingness to pay of households for an environmental improvement.[34] For example, the National Academy of Sciences report on Automobile Emissions argues, "Returns to labor consist of real wages and non-monetary consumption goods. Assuming that information on wages and price differences between cities is available, and that there are no barriers to mobility, wages should be negatively correlated with amenities in order to equalize returns to labor between cities and "clear" the labor market. For example, one expects higher real wages to compensate for living in a city where there is a higher probability of personal injury. Hence, we can place at least a rough value on amenities by comparing real wages and amenities among cities."[35]

The empirical difficulties with such cross-sectional studies (in which the units of observation are usually SMSAs) are great. Such studies rely explicitly on the assumption that migration among urban areas is costless and information is sufficiently perfect that the general system of urban areas is in equilibrium. This assumption seems to be more questionable than the assumption that a single urban housing market is in equilibrium. Such

studies must also (at a highly aggregated level) hold constant differences among urban areas in climate, transportation, the provision of public services, and other non-air-quality amenities.

In addition to these empirical difficulties, there are some serious methodological problems inherent in the wage-rate studies. The most important weakness of the wage-differential argument is that the underlying model does not account explicitly for the factors that might restrict mobility. The authors of the National Academy report were aware of this difficulty: "With factor mobility, prices, or in this case wages, ultimately adjust so as to equate the utilities of similar households or workers across different urban areas. If there are certain limitations upon factor mobility, some urban productivity and amenity differentials could be captured as land rents. Similarly, certain kinds of "frictions," particularly transportation cost differences within and among urban areas, could cause any potential rents attributable to factor immobility to be shared between land and other sectors, such as transport."[36]

To clarify this issue consider a simple long-run model of an urban area that includes a single homogeneous labor market and a residential-housing market.[37] The wage that firms pay to their employees depends on the marginal product of the workers, which depends, other things equal, on the size of the employable population in the urban area. Now assume that the environment is improved throughout the urban area. One possible outcome is that property values will rise throughout the urban area. However, if migration among urban areas is costless, additional households will be attracted to the cleaner environment. Other things equal (that is, the land area of the urban area allocated to business use), the increased supply of labor will cause the marginal product of labor and thus the wage rate to fall. Immigrants will be willing to accept this lower wage, however, because they are receiving improved air quality in exchange. Thus, the environment improvement results in *both* a fall in the wage and an increase in property values. Only in the special case in which property values remain unchanged would the full extent of the benefits associated with the environmental improvement show up as a reduced wage in the improved urban area. Depending upon the labor-market conditions and the nature of demand for residential housing, it seems entirely possible that most of the adjustments to the air quality improvement will occur in the local land market and not through the labor market.[38]

To the extent that the wage rate falls, business property values must increase to keep firms in their equivalent competitive positions. This relationship suggests that, to the extent that migration among cities in the urban system is costless (that is, the urban areas are *open*), one can measure bene-

fits by adding the benefits associated with the change in residential property values to the benefits associated with the wage differentials. Because wage-related benefits correspond to benefits associated with business property values, in this special case the sum of the change in residential and business property values within the impacted urban area will provide a correct benefit measure. Unfortunately, this result depends crucially upon the assumption that migration among the system of urban areas is costless and that the number of urban areas is "large." As mentioned previously, the strong mobility assumption guarantees that the environmental change will not alter producer and consumer surpluses.[39] The assumption of a large number of urban areas is important because, for nonmarginal environmental improvements in a finite system or in urban areas, capital market adjustments throughout the system of urban areas may cause a substantial portion of the benefits to be obtained by those residing outside the area in which the improvement occurred.[40]

The previous analysis suggests that benefit estimates based on wage differentials will understate the true willingness to pay for cleaner air. This conclusion seems quite plausible, but given the empirical difficulties, it does not necessarily follow from the theoretical model just outlined. Imagine an improvement in air quality in a situation in which clean air and housing are highly substitutable. As air quality in one urban area is improved, households (over the long run) tend to purchase houses with smaller lots (for example, they enjoy greater use of parks). The net outcome of the market process might be that property values fall throughout the residential urban area. Because each household consumes less housing, there is sufficient space in the urban area for a large immigration of those who value highly the cleaner environment. This influx results in a decline in the wage rate, which is greater than the decline that would occur if property values were unaffected by the air quality improvement. The result is that the correctly measured wage differential will overstate the true measure of benefits. Although admittedly somewhat artificial, this example is useful because it suggests that to be fully correct any wage-differential measurements should be made in combination with estimates of the predicted change in property values in the affected urban areas. Given the previous discussion, this is likely to be a very difficult task.

Empirical Issues

Relatively little is known about the shape of the air-pollution damage function. However, information concerning the aesthetic and other market-

oriented damages from air pollution can be obtained from the housing-value approach described in the preceding section. The first part of this section presents empirical results of a recent analysis of housing data in the Boston metropolitan area conducted by the author and David Harrison.[41] These results not only suggest that air-pollution damage functions are nonlinear but also provide estimates of the magnitude of the bias involved when benefit estimation fails to take account of such nonlinearities.

The first two parts of the section are generally self-contained and serve to provide a general overview of the empirical results. However, such results must be placed in their proper perspective by giving serious consideration to the underlying empirical problems. This task is done in the remaining part, which concentrates on more technical issues relating to the air pollution data and to the nature of the housing market. Most of the empirical issues raised in this secion are not new, but little is known about the quantitative importance of the specific problems associated with the property-value approach. This recent information partially fills the gap.

The Data

The basic unit of observation for the Boston study (as in most other studies) is the census tract.[42] The use of census-tract data rather than individual housing data poses certain empirical problems for property-value studies, first because the use of median census-tract observations eliminates information about the variance of individual variables within census tracts (and thus may cause correlations between variables to differ at the micro and census-tract levels) and, second, because it is difficult to properly control for certain nonpollution variables, such as structural and neighborhood characteristics, as a result of data limitations.[43]

Measuring Air Pollution Most property-value studies rely exclusively on monitoring data to obtain quantitative measures of pollutant levels. Aside from the technical difficulties associated with attempts to monitor pollutant levels, there are some important problems that arise when such data are used. Property-value studies typically utilize annual averages of pollutant levels (often geometric means) as point estimates of pollutant levels. Conceptually this practice appears to be a serious source of misspecification because there is reason to believe that households are more sensitive to unusually bad air pollution episodes than they are to average levels. Thus, a measure of the variance in pollution levels might also have an impact on property values. As a practical matter, however, this issue may not be very important. In the Boston data set, the distribution of pollutant levels is approximately lognormal and variances are roughly constant over space.[44] To

the extent that this is true, the inclusion of variance in the property-value studies would have no effect on the results. A more serious problem arises because of the relative scarcity of monitoring stations in each urban area.[45] As a result, researchers are forced to extrapolate to obtain estimates of air pollution levels in many of the census tracts in the urban area. Without a proper correction, the statistical significance of the results will be overstated.

The problem of relying directly on monitoring data for a few stations was circumvented in the Harrison and Rubinfeld Boston study by using information on 1970 air pollution concentrations obtained from a meteorological model of the Boston air shed. The Transportation and Air Shed Simulation Model (TASSIM) generates information on the mean air pollutant concentrations in 122 zones in the Boston SMSA from internally generated estimates of vehicle miles of travel by zone, emissions characteristics of the 1970 automobile fleet supplied by the U.S. Environmental Protection Agency, and estimates of emissions from nonautomobile area sources, including almost 400 stationary sources.[46] The air shed model was calibrated using Boston monitoring data, so that some difficulties inherent in using monitoring data still remain.

In addition to providing more degrees of freedom in the air pollution data, the meteorological model provides estimates of concentrations for a broad set of pollutants. Use of the meteorological data allows for a close examination of the degree of multicollinearity that is likely to arise when one attempts to distinguish among various pollutants in a property-value analysis. Table 6.1 lists the simple correlations among the various pollutant concentrations predicted by the Boston TASSIM model. It is not very surprising to find that NO_x and HC, two of the automobile emission pollutants, are highly correlated, as are PART and SO_2, two of the major stationary-source pollutants. What is somewhat surprising, however, is the high correlation between mobile-source and stationary-source pollutants (see note b of table 6.1 for a partial explanation). These simple correlations suggest that it is likely to be very difficult to distinguish between the impacts of individual pollutants on property values in a cross-section study of an urban area. The analysis of the Boston data set confirmed this expectation. When two or more individual pollutant variables are included in the hedonic housing equation, multicollinearity becomes a serious problem. One of the pollutant variables often takes on the wrong sign, and the values of the pollutant coefficients become very sensitive to the specific functional form of the hedonic equation. The pollutant that is least highly correlated with the others is carbon monoxide. However, the CO variable should not enter significantly in the housing-value equation as a pollutant measure because CO is odorless

Table 6.1 Correlations among Pollutants

	NO_x	HC	O_x	PART	SO_2	CO
NO_x	1.00					
HC	.93	1.00				
O_x	.97	.98	1.00			
PART	.96	.90	.92	1.00		
SO_2	.96	.85	.90	.97	1.00	
CO	.88	.93	.93	.79	.78	1.00

[a]NO_x = nitrogen oxide concentrations in parts per hundred million (pphm) (partially from automobile emissions and partially from stationary sources); HC = hydrocarbon concentrations (mg/cm^3) (partially from auto emissions and partially from stationary sources); O_x = crude index of oxidant levels = $HC*NO_x$ (attempts to account for the fact that hydrocarbons and nitrogen oxides react to form ozone and other oxidants); PART = particulate concentrations (mg/cm^3) (primarily a stationary-source pollutant); SO_2 = sulphur dioxide concentrations (ppm) (primarily a stationary-source pollutant); and CO = carbon monoxide concentrations (ppm) (primarily due to automobile emissions).

[b]The correlation matrix tends to overstate the true correlations among pollutants somewhat because the TASSIM model generated data for 122 zones rather than 506 census tracts. Translating zonal data into census-tract data tends to overstate the correlations because relatively more census tracts are located in center city zones in which pollutant levels are most highly correlated.

and colorless and thus would not be recognized by households. In fact, when CO is entered in the equation, it typically shows up (insignificantly) with a positive sign. The CO variable probably represents a combined measure of accessibility and the noise levels (and other disamenities) associated with automobile traffic because CO provides a good measure of access to major highway arteries.

Even if the simple correlations among pollutants were not so high, it would be very difficult to distinguish between the individual effects of various pollutants because of measurement problems and because the pollutants often act in combination to cause damage to the environment. According to Waddell,

> Research has shown that SO_x, NO_x, and HC all break down to the particulate state; thus, any individual particulate air quality measurement might also be representative of those pollutants that were originally emitted as gases. This possibility, then, complicates and raises serious questions of the validity of allocating costs by pollutant. . . . Also, these pollutants act synergistically to cause damage that perhaps would not occur when acting independently. So again, we have the problem of attaching weights to the different pollutants, which, by themselves are perhaps harmless, but which, in the presence of other pollutants become harmful.[47]

The Air-Pollution Damage Function Most property value studies implicitly assume that the air-pollution damage function is linear, that is, the marginal willingness to pay for an improvement in air quality is independent of the level of air quality. To test whether this assumption is reasonable, the methodological procedure outlined earlier was followed. As a first step, a nonlinear housing equation was estimated and used to calculate the marginal willingness to pay for an air quality improvement at each location. The data used were identical to the data used in the National Academy of Sciences Boston study, so that a direct comparison between the damage function estimated here and the damage function obtained in the academy report is possible.[48] The dependent variable is the median value of the owner-occupied homes in each census tract and the independent variables include two structural attribute variables, eight neighborhood variables, two accessibility variables, and one air pollution variable.[49] To make the results comparable to the National Academy study, the nitrogen oxide level NO_x was chosen as the pollution variable. However, NO_x is used solely to proxy air pollution because the high correlation among pollutants makes it extremely difficult to separate the independent impacts of pollutant variables.

Nonlinearities in the Air Pollution Variable Because the marginal willingness to pay for clean air may not be constant over urban space, nonlinear forms were estimated for the housing-value equation and special focus was given to nonlinearities in the pollution term. The best-fitting equation yielded a negative coefficient on the pollution variable suggesting that (on the margin) increases in the level of pollution result in decreased property values.[50] Because the equation was nonlinear, the calculated willingness to pay varied spatially. Specifically, when air pollution and the other variables take on their mean values, the average willingness to pay for a marginal improvement (one part per hundred million decrease in pollution) was $1613.[51] This figure was substantially lower (21 percent) than the $2052 (assumed constant over space) obtained in the National Academy study from a linear specification of the housing-value equation. Thus, allowing for the nonlinear interaction between pollutant levels and property values, the estimate of marginal benefits falls roughly 20 percent.

A test for the sensitivity of the estimated marginal willingness to pay suggested that with reasonable changes in the functional form of the pollution variable, the estimated marginal willingness to pay (averaged over all individuals) could easily be as high as $2040 or as low as $1186. In order to illustrate the importance for policy of differences in these functions, alternative marginal willingness-to-pay relationships were used to estimate the benefits associated with a program to improve Boston air quality. To distinguish

this sensitivity experiment from others, all damage functions faced by households were assumed to be linear (of course, the average damage level was allowed to vary by location). To make the results comparable to the National Academy of Sciences study, the expected pollutant level was chosen to be the level of nitrogen oxides predicted by the TASSIM model for 1990, on the presumption that federal automobile emissions standards would lead to a 90 percent reduction in the 1970 levels of nitrogen oxides emitted from mobile sources.[52] However, the benefit measures used do *not* determine the dollar value of benefits for a particular emissions control strategy. Much greater care would have to be taken to separate out the independent influence of the automobile pollutants from the overall air pollution in Boston if a precise dollar value for the benefits of the federal automobile-emission-control program were needed.[53]

Under the assumption that hedonic-value equation was linear, total (not marginal) benefits were determined to be $1180 per household in the Boston SMSA (the average improvement in nitrogen oxides throughout the urban area was approximately .06). Using the best-fitting nonlinear functional form, reasonable bounds on the benefit estimate were calculated to range from a low of $783 per household to a high of $1053 per household. Thus, solely on the basis of the functional specification of the pollution variable, benefit estimates fall approximately 22 percent below those based on the linear specification and may fall as much as 34 percent. This sensitivity analysis is not complete, however, because it does not account for biases due to nonlinearities in household willingness-to-pay or *damage* function. This omission will be explained.

The Shape of the Damage Function On the assumption that changes in supply (levels of pollution) from location to location are sufficient to identify the willingness to pay for clean air, the willingness-to-pay or damage function was estimated by regressing $W_i(A_i)$, the marginal willingness to pay in each census tract, on the level of air pollution (proxied by the level of nitrogen oxide in each tract, NO_{x_i}), and median household income (INC_i) in logarithmic form.[54] The results are depicted graphically in figure 6.2.

The horizontal line indicates the linear air-pollution damage function obtaining from a linear specification of the housing-value equation. The three curves illustrate the willingness to pay as a function of air pollution for three income levels: ($8,500 per year), middle ($11,500), and high ($15,000). The positive slope for all curves implies that households perceive the damages from air pollution and thus the willingness to pay for marginal reductions to be greater at higher pollution levels. Moreover, these differences are substantial for the pollution levels in Boston in 1970, where nitrogen oxide

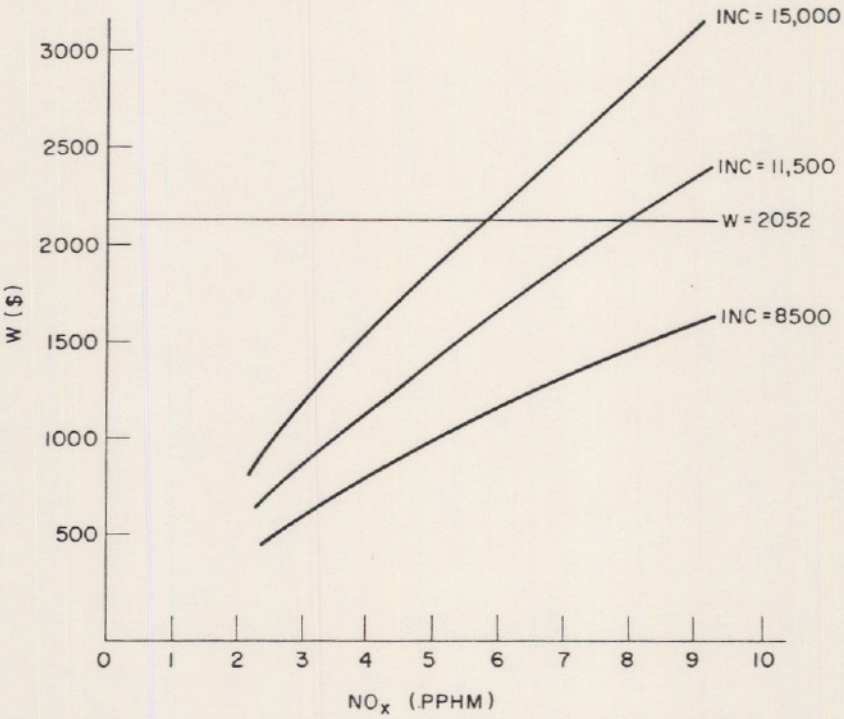

Figure 6.2 Willingness to pay for a 1 pphm improvement in NO_x concentration by income levels. (Note: pphm = parts per hundred million)

levels ranged from 3 to 9 parts per hundred million (pphm). For example, a middle-income household earning $11,500 per year would be willing to pay roughly $800 for a 1 pphm improvement in NO_x when the NO_x level was 3 pphm, but the willingness-to-pay figure would jump to approximately $2200 when the NO_x level was 9 pphm. Figure 6.2 also shows that the willingness-to-pay schedule for a marginal improvement in NO_x concentration is greater for households in higher-income groups. In this specification, the premium that high-income households are prepared to pay rises as the NO_x level increases. At low NO_x levels (3 pphm), the differential for households earning $8500 is only $200, but at high NO_x levels (9 pphm), the differential is about $700. Qualitatively speaking, it seems clear that the air-quality damage function determined from property-value data is nonlinear; that is, the marginal willingness to pay varies substantially with the level of air pollution and the level of household income.

The fact that the willingness-to-pay function slopes upward suggests that

the assumption of a linear damage function will cause the benefits of a nonmarginal air quality improvement to be overestimated. On the other hand, the impact of allowing for a shifting damage function (due to income changes) is not clear from the graph. To quantify the nature of the bias implicit in the assumption of a linear damage function, calculations were made of the average household benefits associated with the automobile emissions example described previously. Average household benefits were $830 (capitalized), compared to $920 when the damage function was presumed to be nonlinear. This difference suggests that property-value studies that do not take into account the nonlinearity in the air-pollution damage function are likely to overestimate benefits by 10 percent when the air quality improvement is a substantial one. It seems, therefore, that the failure to account for nonlinearities in the damage function does not seriously bias the benefits estimates obtained from previous studies.

Some Further Empirical Issues

Values or Rents? There are data problems associated with each of the variables included in a cross-section property-value study. One of the most important involves the dependent variable choice in the housing-value equation. Most property-value studies based on census tracts utilize median property value as the dependent variable.[55] The decision to examine home-owner data rather than renter data seems to be a reasonable one because these studies concentrate on the impact of air pollution on residential property values. However, because the emphasis in this paper is on the willingness to pay rather than the change in property values, there is no reason why the analysis should not be expanded to test whether the tastes of renters differ from those of home owners.[56] Doing so would introduce new issues about the measurement of the dependent variable (gross rent or contract rent?) and the choice of census tracts to be included in the sample. Therefore, to facilitate comparison with most other studies (which do not examine rental data), the matter will not be pursued empirically in this paper.

A related issue in studies that focus on home owners' willingness to pay is whether value (the capitalized stream of annual rentals) or annual rent is the appropriate choice for a dependent variable. In principle, rent is the correct measure because current rent reflects the market's implicit valuation of the current levels of air pollution as well as other housing attributes, whereas capitalized values measure the market's expectation about future levels of air quality as well as other housing and neighborhood characteristics. In fact, there is solid empirical evidence suggesting that the expectation of an improvement in neighborhood quality causes annual rents to be discounted at a

low rate relative to the capitalization of annual rents in neighborhoods that are deteriorating in quality.[57] This may cause the air-quality benefit estimates obtained from property-value studies to be overestimated. To understand why, recall that the marginal willingness to pay for clean air is measured by the change in property values associated with a small change in air quality. To the extent that improving neighborhoods (in which property values provide overestimates of annual rents) have low air quality, the property-value response to a change in air pollution will be overstated. The conclusion concerning bias follows from the empirical fact that neighborhoods in downward transition tend to be located in areas in which air pollution concentrations are high.

The arguments just presented suggest that a careful study of the rental-housing market for which monthly rental data are available should tell something about the nature of the bias involved when property-value data are used. However, there are practical problems with rental data that would leave any such direct comparisons suspect. First, such an analysis would implicitly make the questionable assumption that the tastes of home owners and renters are identical. Second, there are measurement problems relating to the inclusion or exclusion of utilities and payments for services in the choice of either contract rent or gross rent to measure. Finally, rents in Boston and Cambridge (which contain many of the census tracts in the Boston SMSA sample) may have been distorted by the presence of rent control. Although these arguments suggest that serious discrepancies may exist when property-value and rental studies are compared, the results of a study by Anderson and Crocker suggest that these discrepancies may not be important.[58] Using data for Washington, D.C., Kansas City, and St. Louis, Anderson and Crocker found that benefit estimates obtained from rental data are roughly consistent with benefit estimates obtained from property-value data (they are lower for Washington, D.C., and St. Louis but higher for Kansas City).

Omitted Variables One of the serious criticisms of the property-value literature is that the effect of air pollution on property values overestimates benefits because the air pollution variable is highly correlated with important omitted variables, such as the level of noise, proximity to industry, and other measures of neighborhood quality. Because it is difficult to obtain measurements for these omitted variables at the census-tract level, it is not possible to settle this troublesome issue.[59] However, two types of experiments do allow for some crude quantitative guesses as to the magnitude of the problem. First, Harrison and Rubinfeld reestimated the housing-value equation after omitting intentionally some important accessibility and

neighborhood characteristics.[60] Because pollution concentrations are higher in areas closest to locations with good accessibility, the deletion of the two accessibility variables reduced the measured impact of pollution on housing values. The pollution coefficient then reflected both the disadvantages of greater pollution concentrations and the advantages of greater accessibility. The deletion of the accessibility characteristics lowered the estimated marginal willingness to pay and the estimated total benefits by 43 percent. In a separate experiment, one of the most important neighborhood variables (a measure of the class status of the neighborhood residents) was omitted. Deleting this variable tends to credit the pollution variable with some of the neighborhood disamenities that result from a lower-class population. The deletion increased the estimated marginal willingness to pay by 26 percent and the estimated average benefits of a nonmarginal improvement by 25 percent.

The second experiment was to consider the correlation between air pollution and those neighborhood variables included in the property-value specification.[61] Because air pollution and included variables tend to be reasonably highly correlated, one might argue (given a correct specification) that the only sure conclusion about the impact of air pollution can be obtained by replacing the original variable with that portion of the air pollution variable that is uncorrelated with the other housing characteristics in the equation. This conservative estimation procedure was used by both Ridker and Henning and by the National Academy of Sciences. Ridker and Henning found that their most conservative estimate of marginal willingness to pay was just over one-third of their most favored estimate.[62] Likewise, the National Academy found that their most conservative estimate was less than one-quarter of their most reasonable estimate.[63]

Market Segmentation Most property-value studies implicitly assume that it is correct to estimate a single hedonic housing equation for the entire urban area. However, a number of authors have argued that it would be proper to view the urban housing market as a distinct set of housing submarkets, in which the submarkets are defined on the assumption that groups of individuals will (by choice or by restriction) only purchase or rent certain types of housing in certain geographical locations.[64] Unfortunately, the aggregative census-tract data do not allow for the detailed specification of housing submarkets. However, in order to get some crude estimates of the sensitivity of the benefit estimation procedure to the submarket issue, average benefits were calculated when the housing market was stratified on the basis of household income (3 categories), accessibility to employment (2 categories), and on household social status (2 categories). In each case, our

estimate of the average benefits of a nonmarginal change in air pollution fell substantially, by 28 percent when the income stratification was used, by 41 percent when the accessibility stratification was used, and by 10 percent when the market was stratified on the basis of social status.[65] These calculations are admittedly quite crude, but they do suggest that the housing-submarket issue is an important one.

Damage Function Sensitivity In order to test further for the sensitivity of the shape of the air-pollution damage function described in figure 6.2, several experiments were tried. First, the willingness-to-pay equations that are associated with the alternative functional forms of the housing-value equation were reestimated. The shape of the damage function (and the resulting benefit estimates) was quite sensitive to the form in which the pollution variable entered the housing-value equation. As a consequence, the possibility that the damage function is linear could not be ruled out with great confidence, although the results suggest strongly that the function does shift with income changes. In this case, an average benefit estimate of $1013—22 percent higher than the results implicit in figure 6.2—was obtained. On the other hand, one cannot rule out the possibility that the damage function is much steeper than the one depicted in figure 6.2, in which case the average benefits are $592—29 percent lower than the most likely case.

In a second experiment, the willingness-to-pay equation was reestimated by including in the equation other housing attributes thought to be complimentary with air quality and by allowing the NO_x elasticity to vary with income.[66] Although the respecification led to changes in the elasticities on NO_x and INC, the impact on average benefits estimated in the automobile emissions example was not substantially affected.[67] (Most benefit changes were on the order of 1 percent.) These results make it clear that the shape of the damage function is quite sensitive to the form of the hedonic housing-value equation but that it is largely insensitive to changes in the exact functional form of the damage function itself.

Conclusions

This paper has critically examined the market approaches to estimating the benefits of improved urban air quality from both a conceptual and an empirical perspective. Of the two market-oriented approaches, the property-value approach appears more promising than the wage-differential approach. The wage view has, at best, a weak conceptual foundation and faces serious empirical problems that are not likely to be easily resolved. From a theoretical viewpoint, the property-value approach is more promising. When cor-

rectly interpreted, property-value studies can provide conceptually correct estimates of the willingness to pay for clean air.

The empirical evidence presented in this paper indicates that perceived marginal air pollution damages increase with the pollution level and increase with income. However, estimates of the shape of the damage function as well as the benefits associated with a nonmarginal improvement in air quality are quite sensitive to the specification of the property-value or housing-value equation. Plausible specifications of the housing-value equation may reduce aggregate benefit estimates by as much as 60 percent below the results obtained if one assumes a linear damage function that is identical for all households. In addition, the omission of variables that are highly correlated with air pollution, the possible existence of housing submarkets, and the problems inherent in the use of median property-value data all suggest that most property-value benefit estimates may be even more biased. Some specification errors and choice of functional forms support the view that property-value-related benefits are underestimated, the evidence strongly suggests that most benefit estimates obtained from property-value studies are too high, perhaps by a factor of two or more.

The results of the study appear to be somewhat discouraging, especially if one expects the property-value approach to provide an itemized list of benefits associated with each of the major pollutants in the urban area. The problem of distinguishing among the effects of various pollutants does not appear likely to be resolved with the use of housing-market information although other information may permit reasonable guesses. However, from a more realistic point of view, the results are much more promising. The estimates of housing-value-related benefits (using the air pollution proxy) obtained in the air quality example are within an order of magnitude of one another. For application to particular policy questions, the variability in the benefit estimates figures may be small relative to the uncertainty that surrounds the other parameters of a policy decision. For example, if one were attempting to determine whether the costs of instituting an inspection-maintenance scheme to reduce air pollution were greater than the benefits from improved air quality, the uncertainties associated with estimating the "true" costs of the program might be even greater than the uncertainties associated with estimating the "true" aggregate willingness to pay for the improvement in air quality.

In conclusion, despite the rather serious limitations of the property-value approach, such an approach provides a useful addition to other air-pollution-reduction benefit studies. If correctly carried out, property-value studies measure a portion of the benefits associated with air quality im-

provements that are not likely to be taken into account in health, vegetation, and other cost studies. Further research directed towards the problem of overlapping benefits, the question of how to impute benefits to individual pollutants, and the statistical problem of how to place reasonable bounds on the property-value estimates is likely to be worthwhile.

Notes

This paper represents a review and extension of work undertaken by the author and by A. Mitchell Polinsky and David Harrison, Jr. All statistical analyses were performed on the NBER Center for Computational Research's TROLL system, with the assistance of Laxmi Rao. The author wishes to thank A. M. Freeman, D. Harrison, and A. M. Polinsky for their helpful comments.

1. See Helen Ingram, Chapter 2 of this volume, for details.

2. See, for example, Ronald G. Ridker and John A. Henning, "The Determinants of Residential Property Values with Special Reference to Air Pollution," *Review of Economics and Statistics* 49 (May 1967): 246–257. For a general overview of the property-value studies, see Thomas D. Crocker, *Urban Air Pollution Damage Functions: Theory and Measurement* (Washington, D.C.: National Air Pollution Control Administration, June 1971); Thomas Waddell, *The Economic Damages of Air Pollution* (Washington, D.C.: Environmental Protection Agency, May 1974); Jon P. Nelson, *The Effects of Mobile-Source Air and Noise Pollution on Residential Property Values* (University Park, Pa.: Institute for Research on Human Resources, Pennsylvania State University, April 1975); and V. Kerry Smith, *The Economic Consequences of Air Pollution* (Cambridge, Mass.: Ballinger, 1976).

3. See, for example, William Nordhaus and James Tobin, "Is Growth Obsolete?" in *Economic Growth* (New York: National Bureau of Economic Research, 1972), pp. 12–13, 49–54; and John R. Meyer and Robert A. Leone, "The Urban Disamenity Revisited," in Wingo and Evans, eds., *Public Economics and the Quality of Life* (Baltimore: Johns Hopkins, 1977). For a more general analysis of wage differentials, see Irving Hoch, "Climate, Wages and the Quality of Life," in Wingo and Evans, eds., *Public Economics and the Quality of Life* (Baltimore: Johns Hopkins, 1977).

4. In most health studies, statistical estimates of the effect of air pollution on morbidity and mortality are used to compute increases in health costs and decreases in earning capacity that result from increases in pollution levels. See, for example, Lester B. Lave and Eugene P. Seskin, "Air Pollution and Human Health," *Science* 169 (21 August 1970): 723–733. For more general discussions of our knowledge concerning the effects of air pollution on human health, see Lester B. Lave and Eugene P. Seskin, *Air Pollution and Human Health* (Baltimore: Johns Hopkins, forthcoming); William R. Ahern, Jr., "Health Effects of Automotive Air Pollution," in Henry D. Jacoby et al., eds., *Clearing the Air: Federal Policy on Automotive Emissions Control* (Cambridge, Mass.: Ballinger, 1974); David Harrison, Jr., *Who Pays for Clean Air: The Cost and Benefit Distribution of Federal Automobile Emission Standards* (Cambridge, Mass.: Ballinger, 1975), Appendix A; Brian J. L. Berry

and Frank E. Horton, *Urban Environmental Management* (Englewood Cliffs, N.J.: Prentice-Hall, 1974), Chapter 4; Waddell, *The Economic Damages of Air Pollution;* and Ronald G. Ridker, *Economic Costs of Air Pollution* (New York: Praeger, 1967), Chapter 3. In other cost studies, attempts are made to analyze the physical effects of increased air pollution (on structures, for example) and to place dollar values on the costs involved. See, for example, Richard L. Salmon, *Systems Analysis of the Effects of Air Pollution on Materials* (Kansas City, Mo., Midwest Research Institute, January 1970). For a more general overview of these cost studies, see Berry and Horton, *Urban Environmental Management,* Chapter 4; Waddell, *The Economic Damages of Air Pollution;* and Kenneth A. Small, "Air Pollution and Property Values: Further Comment," *Review of Economics and Statistics* 57 (1975): 105–107. Other benefit estimates have been obtained from opinion surveys of those residing in highly polluted areas. See, for example, Andris Auliciems and Ian Burton, "Perception and Awareness of Air Pollution in Toronto," Working Paper Series No. 13, Natural Hazard Research Series, University of Toronto, 1970; for a general overview of studies in the area, see Berry and Horton, *Urban Environmental Management,* Chapter 4, and Waddell, *The Economic Damages of Air Pollution.* Additional surveys have been made by examining the outcomes of litigation in which plaintiffs sued for damages resulting from occupational hazards. See, for example, U.S. Senate, Committee of Public Works, *Air Quality and Automobile Emission Control,* vol. 4 (Washington, D.C.: U.S. Government Printing Office, September 1974) (hereafter cited as U.S. Senate, Committee on Public Works, *Air Quality and Automobile Emissions Control*).

5. Lester B. Lave, "Air Pollution Damage: Some Difficulties in Estimating the Value of Abatement," in Allen V. Kneese and Blair T. Bower, eds., *Environmental Quality Analysis* (Baltimore: Johns Hopkins, 1972), pp. 213–242.

6. Waddell, *The Economic Damages of Air Pollution,* p. 35.

7. U.S. Senate, Committee on Public Works, *Air Quality and Automobile Emissions Control,* p. 412.

8. Waddell, *The Economic Damages of Air Pollution,* p. 2.

9. To reiterate, nonmarket benefit estimation techniques are not discussed here, nor is there a treatment of those benefits that are unlikely to be quantifiable. For example, it would be extremely difficult to quantify the benefits obtained by residents throughout the United States when air quality in one urban area is improved. These "nonresidents" might be better off because their options concerning the possibility of future visits or job location moves to the urban area with improved air quality would be altered.

10. See Donald Dewees, Chapter 7 of this volume, for a corresponding argument on the cost side.

11. This assumption has important income distributional consequences because market prices are dependent upon the existing distribution of income. In addition, attempts to determine implicit market prices presume that market distortions unrelated to air quality are not present. To the extent that transportation congestion and other

externalities are not fully accounted for, the use of property-value data to estimate benefits is likely to lead to biased results.

12. This is not the only possible measure of willingness to pay (or consumer surplus), but it is a convenient one.

13. The total damage function corresponds to the textual definition of total willingness to pay.

14. A different estimate of benefits would result if the willingness-to-pay function were calculated by examining the housing market after the environmental improvement took place and asking households how much they would pay, given the new set of prices that they face, in order to avoid an increased level of air pollution.

15. Case 1 is often said to describe a *linear* damage function because *total* damages are linearly related to the level of air pollution.

16. This assumes that the marginal willingnesses to pay are equal at the *original* level of air pollution.

17. For a technical discussion of the conditions under which demand is identified, see Sherwin Rosen, "Hedonic Prices and Implicit Markets," *Journal of Political Economy*, 82 (January 1974): 35–55. In a more general context, he argues (p. 51) that "if buyers are identical, but sellers differ, . . . single cross-sectional observations trace out compensated demand functions."

18. The discussion that follows relies on A. Myrick Freeman, "On Estimating Air Pollution Control Benefits from Land Values Studies," *Journal of Environmental Economics and Management*, 1 (May 1974): 74–83; Rosen, "Hedonic Prices and Implicit Markets"; A. Mitchell Polinsky and Steven Shavell, "Amenities and Property Values in a General Equilibrium Model of an Urban Area," *Journal of Public Economics*, 5 (January–February 1976): 119–129; A. Mitchell Polinsky and Daniel L. Rubinfeld, "Property Values and the Benefits of Environmental Improvements: Theory and Measurement," in Wingo and Evans, eds. *Public Economics and the Quality of Life* (Baltimore: Johns Hopkins, 1977); and David Harrison, Jr., and Daniel L. Rubinfeld, "Housing Values and the Willingness to Pay for Clean Air," *Journal of Environmental Economics and Management*, forthcoming.

19. Housing or property values are the present discounted or capitalized value of the stream of annual housing expenditures. The analysis contained in this paper considers the market for home owners rather than the market for renters.

20. To simplify, it is assumed initially that work-place choices are given.

21. Because residential property values are utilized, the health and aesthetic benefits associated with work-place location (and shopping location) are not captured by this approach.

22. Of course, there will be equivalent conditions for each of the housing attributes.

23. Estimation of the willingness-to-pay function presumes that the "demand for clean air" can be identified econometrically, that is, distinguished statistically from the supply of clean air. This assumption presents no difficulty if the level of air pollution is assumed to be fixed in the cross-section analysis but does cause difficul-

ties if air pollution adjustments are built into the model. This issue has troubled a number of authors, including Freeman, "Estimating Air Pollution Control Benefits," pp. 74–79, and Small, "Air Pollution and Property Values: Further Comment." Small argues that the demand curve is unlikely to be identified within a single urban-housing market. He feels (p. 106) that "a much more plausible assumption is that we are observing a single housing market, in which the consumer faces an entire price schedule, and that the variety observed in the choices made by people of a given income class reflects not different constraints but different preferences."

24. This problem is explicitly considered by John Muellbauer, "Household Production Theory, Quality, and the 'Hedonic Technique,'" *American Economic Review,* 64 (December 1974): 977–993, who argues that the marginal willingness to pay at each location will depend upon the utility level attained, as well as tastes (and possibly income). To the extent that it is so, Muellbauer concludes (p. 980) that "at the very least, careful attention should be paid to cross-sectional disaggregation. As far as possible, markets should be broken into segments based on commodity groupings which make it likely that their consumers have similar MRS and these segments should be studied separately." Note also that when Y is included in the willingness-to-pay function the implicit demand function is uncompensated, because money rather than real income is held constant.

25. For further discussions of these and other related issues, see Matthew Edel, "Land Values and the Costs of Urban Congestion: Measurement and Distribution," *Social Science Information,* 10 (1971): 9–12; Lave, "Air Pollution Damage: Some Difficulties in Estimating the Value of Abatement," pp. 213–215, 234–236; Thomas D. Crocker, "The Measurement of Economic Losses from Uncompensated Externalities," in William R. Walker, ed., *Economics of Air and Water Pollution* (Springfield, Va.: National Technical Information Service, 1969), pp. 192–193; Small, "Air Pollution and Property Values: Further Comment"; and Robert J. Anderson and Thomas D. Crocker, "Air Pollution and Residential Property Values," *Urban Studies* 8 (October 1971) 171–173.

26. U.S. Senate, Committee on Public Works, *Air Quality and Automobile Emissions Control,* p. 237.

27. The National Academy of Sciences study analyzed data for Los Angeles as well as Boston. They found average benefits per household to be lower in Los Angeles than in Boston, despite the greater pollutant reductions resulting from the imposition of controls. This phenomenon may be due in part to taste differences.

28. For representative examples of these studies, see Ridker and Henning, "Determinants of Residential Property Values," and Anderson and Crocker, "Air Pollution and Residential Property Values." For detailed surveys of a larger set of empirical studies, see Waddell, *The Economic Damages of Air Pollution;* Nelson, *The Effects of Mobile-Source Air and Noise Pollution on Residential Property Values;* and Smith, *The Economic Consequences of Air Pollution.*

29. Ridker, *Economic Costs of Air Pollution,* p. 25.

30. For further discussion of this issue, see, for example, Freeman, "Estimating Air Pollution Control Benefits"; Small, "Air Pollution and Property Values: Further

Comment"; David Pines and Yoram Weiss, "Land Improvement Projects and Land Values," *Journal of Urban Economics*, 3 (January 1976): 1–13; and A. Mitchell Polinsky and Daniel L. Rubinfeld, "The Long Run Effects of a Residential Property Tax and Local Public Services," *Journal of Urban Economics*, forthcoming 1978.

31. Polinsky and Rubinfeld, "Property Values and the Benefits of Environmental Improvements."

32. Polinsky and Shavell, "Amenities and Property Values." For other discussions on this subject, see Yitzhak Oron, David Pines, and Eytan Sheshinski, "The Effect of Nuisances Associated with Urban Traffic on Suburbanization and Land Values," *Journal of Urban Economics*, 1 (October 1974): 391–394, and Pines and Weiss, "Land Improvement Projects and Land Values."

33. Polinsky and Shavell, "Amenities and Property Values," and Polinsky and Rubinfeld, "Property Values and the Benefits of Environmental Improvements."

34. See Oded Izraeli, "Differentials in Nominal Incomes and Prices Between Cities," Ph.D. dissertation, University of Chicago, 1973.

35. U.S. Senate, Committee on Public Works, *Air Quality and Automobile Emissions Control*, p. 244.

36. Ibid., p. 244.

37. This model is spelled out in much greater detail in Polinsky and Rubinfeld, "The Long Run Effects of a Residential Property Tax and Local Public Services."

38. It might appear that the presence of labor-market adjustments invalidates the willingness-to-pay approach described earlier. However, the property-value approach does not depend upon the assumption that all the impact of the air quality improvement is felt in the land market. It depends solely on the assumption that existing *differentials* in property values in urban areas correspond to differences in air quality. Only to the extent that complex labor-market conditions might mask the true relationship between property value and air quality differentials is the property-value approach suspect.

39. See Polinsky and Rubinfeld, "Property Values and the Benefits of Environmental Improvements," for an explanation of the impact of an environmental improvement on wages and property values in a closed model of an urban area.

40. For details see Paul N. Courant and Daniel L. Rubinfeld, "On the Measurement of Benefits in an Urban Context: Some General Equilibrium Issues," *Journal of Urban Economics*, forthcoming 1978.

41. The results to be described are discussed in greater depth in Harrison and Rubinfeld, "Housing Values and the Willingness to Pay for Clean Air." The Boston data base is particularly interesting because it was used (along with Los Angeles data) by the National Academy of Sciences in their study of the benefits of automobile emissions controls (see U.S. Senate, Committee on Public Works, *Air Quality and Automobile Emissions Control*). Roughly comparable results were obtained in a recent study of the Washington, D.C., area in Jon P. Nelson, "Residential Choice, Hedonic

Prices, and the Demand for Urban Air Quality," *Journal of Urban Economics*, forthcoming.

42. Excluding tracts containing no housing units or comprised entirely of institutions, the Boston sample contains 506 census tracts.

43. On the other hand, one can argue that most neighborhood characteristics, including air pollution, are meaningful to households at an aggregated, rather than a micro level.

44. For technical details on this matter, see R. D. Larsen, "A Mathematical Model for Relating Air Quality Measurements to Air Quality Standards" (Washington, D.C.: U.S. Environmental Protection Agency Report AP-89, November 1971).

45. Ridker and Henning, "Determinants of Residential Property Values," used sulfation data from forty-one monitoring stations to create an air pollution index that takes on one of eight distinct values. However, their particulate data came from only sixteen monitoring stations.

46. Two meteorological models, one for the stationary sources and one for the automobile emissions and other area sources, are used to translate emissions by zone into pollutant concentrations by zone. These meteorological models take into account information on wind speed, wind direction, and atmospheric stability. In addition, the stationary-source model includes information on the stack height of stationary sources. Both meteorological models assume that pollutant levels are linearly related to emissions, that is, that pollutants are nonreactive. For further details, see Gregory D. Ingram and Gary F. Fauth, *TASSIM: A Transportation and Air Shed Simulation Model*, Final Report to the U.S. Department of Transportation (Springfield, Va.. National Technical Information Service, May 1974).

47. Waddell, *The Economic Damages of Air Pollution*, pp. 132–133. For other discussions of the interactions among pollutants, see Robert U. Ayres, "Air Pollution in Cities," *Natural Resources Journal* 9 (January 1969):1–22, and Jack G. Calvert, "Interactions of Air Pollutants," in National Academy of Sciences, Proceedings of the Conference on Health Effects of Air Pollutants prepared for the U.S. Senate Committee on Public Works (Washington, D.C.: U.S. Government Printing Office, 1973).

48. U.S. Senate, Committee on Public Works, *Air Quality and Automobile Emissions Control*.

49. The structural attribute variables are the average number of rooms in owner units and the proportion of owner units built prior to 1940. The neighborhood variables are the black proportion of the population, the proportion of the population that is lower status, the crime rate, a large-lot zoning variable, the proportion of nonretail business acreage in the community, the full-value property-tax rate, the pupil-teacher ratio, and a dummy measure of the amenities associated with the Charles River. The accessibility variables were a measure of the weighted distance from five employment centers and an index of accessibility to radial highways. For further details, see

Harrison and Rubinfeld, "Housing Values and the Willingness to Pay for Clean Air."

50. The t-statistic on the pollution term was 5.6. Of all the explanatory variables, only the weighted distance-accessibility variable, the property-tax variable, the class-status variable, and the crime variable contributed more to the explained variation of 81 percent in the log-linear version of the equation.

51. This is a capitalized value. It would be equivalent to a figure of $161 per year if, for example, a 10 percent discount rate were applied. The willingness-to-pay estimate seems high because a 1 pphm improvement is greater than the average improvement implied by the 1970 Clear Air Act.

52. The estimates of 1990 NO_x concentrations were obtained by substituting the emissions characteristics of the 1990 controlled automobile fleet for the 1970 fleet emissions figures. However, the actual 1990 concentrations will differ from the calculated ones because the number of households, number of cars, travel characteristics, stationary-source emissions, and other characteristics of the urban area will change between 1970 and 1990.

53. The National Academy of Sciences study attributed one-third of the benefits to reduced automobile emissions, but their results were extremely sensitive to the particular equation specification chosen..

54. The estimated NO_x elasticity was .87 and the estimated INC elasticity was 1.00. Note, however, that the latter represents the elasticity of willingness to pay with respect to income. If we were to use this equation to calculate the NO_x income elasticity, we would find that air quality is a superior good, that is, that the NO_x income elasticity is greater than one.

55. Examples of such studies are Ridker and Henning, "Determinants of Residential Property Values"; Anderson and Crocker, "Air Pollution and Residential Property Values"; and Nelson, *The Effects of Mobile-Source Air and Noise Pollution on Residential Property Values*.

56. This test would most likely necessitate a different choice of census tracts for inclusion in the model because many suburban tracts contain very few rental-housing units.

57. For a detailed discussion of this issue, see George E. Peterson, Arthur P. Solomon, Hadi Madjid, and William C. Apgar, Jr., *Property Taxes, Housing, and the Cities* (Lexington, Mass.: D. C. Heath, 1973), p. 25.

58. Anderson and Crocker, "Air Pollution and Residential Property Values."

59. Nelson, *The Effects of Mobile-Source Air and Noise Pollution on Residential Property Values,* include a noise measure in his property-value study and still found a significant impact of air pollution on property values.

60. See note 49 for descriptions of these variables.

61. For example, the correlation between NO_x and the accessibility variables is .83

and .61, in absolute value, while the correlation between NO_x and the class status variable is .59.

62. Ridker and Henning, "Determinants of Residential Property Values," p. 254.

63. U.S. Senate. Committee on Public Works, *Air Quality and Automobile Emissions Control*, pp. 237, 288.

64. For details, see Mahlon R. Straszheim, "Hedonic Estimation of Housing Market Prices: A Further Comment," *Review of Economics and Statistics*, 1 (August 1974): 404–406. Muellbauer, "Household Production Theory, Quality, and the 'Hedonic Technique'," argues for stratification because of complications arising from the willingness-to-pay calculation.

65. Details of how these calculations were made appear in Harrison and Rubinfeld, "Housing Values and the Willingness to Pay for Clear Air."

66. For example, when the number of rooms was included in the willingness-to-pay equation we found that the NO_x elasticity fell to .81, the INC elasticity fell to .78, and the rooms elasticity was .84. However, average benefits were largely unchanged.

67. Adjustments were also made for heteroscedasticity and simultaneity (in the NO_x variable) but the outcome was not very different.