Can Markets Value Air Quality? A Meta-Analysis of Hedonic Property Value Models

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This paper reports the results of a statistical summary of estimates of the marginal willingness to pay (MWTP) for reducing particulate matter from hedonic property value models developed between 1967 and 1988. Results using both ordinary least squares and minimum absolute deviation estimators suggest that market conditions and the procedures used to implement the hedonic models were important to the resulting MWTP estimates. The interquartile range for these estimated marginal values (measured as a change in asset prices) lies between zero and $98.52 (in 1982–84 dollars) for a one-unit reduction in total suspended particulates (in micrograms per cubic meter). The mean MWTP is nearly five times the median ($109.90 vs. $22.40), suggesting that outliers are important influences to any summary statistics for these estimates.

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I. Introduction

Nearly 30 years ago, Ridker and Henning (1967) suggested that property value differences as a result of variations in air pollution with location could be used to estimate the benefits from policies intended to reduce that pollution.[1] This proposal, along with the theoretical framework for interpreting hedonic models' coefficients (Rosen 1974), contributed to changing economists' views about the likelihood of measuring the willingness to pay for environmental public goods.[2] Current environmental policy analyses take these results seriously. Moreover, this effect is not limited to the benefit-cost analysis but has expanded to include environmental costing for electric utilities (see Freeman et al. 1992) as well as to incorporate the monetary values for changes in environmental resources into the national accounts (see Congressional Budget Office 1994). Because many of these applications rely on judgmental evaluations of hedonic estimates, this paper proposes an alternative summary, using meta-analysis to describe the existing estimates of the marginal value of reducing air pollution. We illustrate how extrapolations from these models can be used in benefit transfers and compare them with using damage functions and point estimates in measuring the benefits from reducing air pollution in four cities classified as nonattainment areas, on the basis of the current Primary National Air Quality Standards.

Thirty-seven studies were reviewed to provide 86 estimates for the marginal willingness to pay (MWTP) for reductions in air pollution (measured by particulate matter). Our findings suggest that there is a consistent relationship between these measures of the incremental value of reducing air pollution and the level of air pollution in each city, the average income of its residents (measured at the time of each study), as well as a number of other variables describing the decisions made in implementing the hedonic models. After describing the model and criteria used in composing our sample of past studies in Section II, we discuss in Section III our summaries and an application

[1] Ridker (1967) develops the issues motivating the Ridker-Henning research as involving three interrelated questions: Would environmental variables such as air pollution have systematic effects on property prices? Given an affirmative response to this query, would knowledge of this relationship be sufficient to predict changes in property prices in response to changes in that variable? And, finally, do these predicted price changes accurately measure welfare changes? Freeman's (1993) expanded book on nonmarket valuation traces this history of the hedonic method. Another paper, Smith and Huang (1993), considers how the existing record would answer the first question.

[2] The early literature on benefit-cost analysis regarded as questionable all approaches involving the use of indirect methods to measure the value of nonmarketed goods. See Hanemann (1994) for a historical overview comparing travel cost and contingent valuation methods.

using them to estimate MWTP based on current conditions. Section IV discusses the overall implications of our findings.

II. The Hedonic Model and the Sample for Meta-Analysis

Under competitive conditions, a hedonic equilibrium requires that the change in price of a house in response to a change in any attribute (at given levels of the other attributes) exactly equal the marginal bid and marginal offer of the buyers and sellers for that characteristic. Thus the hedonic price function $P(a)$ "defines" the market equilibrium, and its slope with respect to each characteristic provides an estimate of buyers' MWTP for changes in that attribute. A meta-analysis provides a statistical synthesis of empirical research focused on a common hypothesis or model (see Cook et al. 1992). Most such analyses have summarized effect sizes (for applications in education or psychology) or evaluated the evidence from test results across a variety of different types of experiments.

A summary of MWTP estimates from the available hedonic studies, each involving different housing markets, bears a close resemblance to the approach recommended for estimating a marginal willingness to pay function as a behavioral relationship. Unfortunately, a research synthesis cannot realize this objective because there is insufficient information to estimate such a behavioral model. To do so would require micro information linking each individual's implied MWTP to the site-specific amenity and the economic variables describing his or her constraints and taste-related demographic characteristics. This type of information is not available. At best, the MWTP estimates offer a crude average of the marginal values estimated under specific circumstances. The available supplementary information may include some of the economic variables that would be part of a multimarket study but does not permit reconstruction of the required micro records (see Epple 1987; Palmquist 1991). Thus it is best interpreted as a statistical summary of the role of economic factors and modeling decisions for these average measures of MWTP for each of a set of individual single markets.

To develop estimates for the marginal value of reducing air pollution, we reviewed over 50 studies (37 had some empirical estimates involving hedonic price functions with some measure of air pollution), including published and unpublished papers and reports as well as Ph.D. dissertations, beginning with the Ridker and Henning study in 1967 to those published or circulated in 1988. One hundred sixty-seven estimated hedonic models, pooling estimates across cities and model specifications, were then used to reconstruct 86 estimates of the marginal willingness to pay for reducing total suspended particulates (TSP).[3] The MWTP is estimated as $-\partial P(a)/\partial a_i$ from the hedonic models, where a_i is a measure of TSP, adjusted to be in comparable units across studies.

Marginal willingness to pay is measured as the change in the asset value of the house. In those cases in which rent or an imputed rent was used in the primary hedonic price function, we converted the estimates to the change in housing price. A box plot given in figure 1 displays the variability in these estimates by city (the cities are identified in the legend). The horizontal size of each box indicates the number of estimates available for each city, and the vertical size is defined by the interquartile range of estimates for MWTP for each city. The lines inside each box reflect the city-specific medians. The adjacent values (i.e., lines extending outside the box) are three-halves the interquartile range moved back to the nearest actual observation at this spread outside the interquartile range. The other points display outlying observations. While the estimates may seem tightly clustered around the line inserted at $22.40 for the overall sample median, this would not be a correct interpretation of the plot. The vertical scale is compressed to plot them on one graph. Thus there is substantial dispersion in the estimates.

Table 1 reinforces the summary by city in figure 1 by reporting the range of estimated MWTPs in constant 1982–84 dollars, the year of the sales, and the city (or cities) involved with each study. These results indicate the potential for several outlying estimates (i.e., the MWTPs associated with ID numbers 27 and 33 are notable examples) that could well become influential observations in any attempt to develop a statistical summary of the MWTP estimates. Negative MWTP estimates in the table indicate hedonic estimates that would be inconsistent with a priori expectations.

In addition to developing qualitative variables describing the characteristics of each study's implementation of the hedonic model, we matched information for the geometric mean of the second high concentrations of TSP by city for the closest year to the date of the sample, per capita income for each city in the year closest to the date for the housing prices, and the vacancy rate from the State and

[3] To recover the MWTP estimate using the estimated parameters from nonlinear specifications for the price functions, the mean housing price or the mean particulate measure reported in each study was used to estimate $-\partial P(a)/\partial a_i$. In those cases in which we were unable to use the means for these variables, we used an estimate of the mean price and particulate matter for each city. We attempted to select comparable years. For most of these cases, we were able to use the detailed summaries reported in Palmquist (1982, 1983).

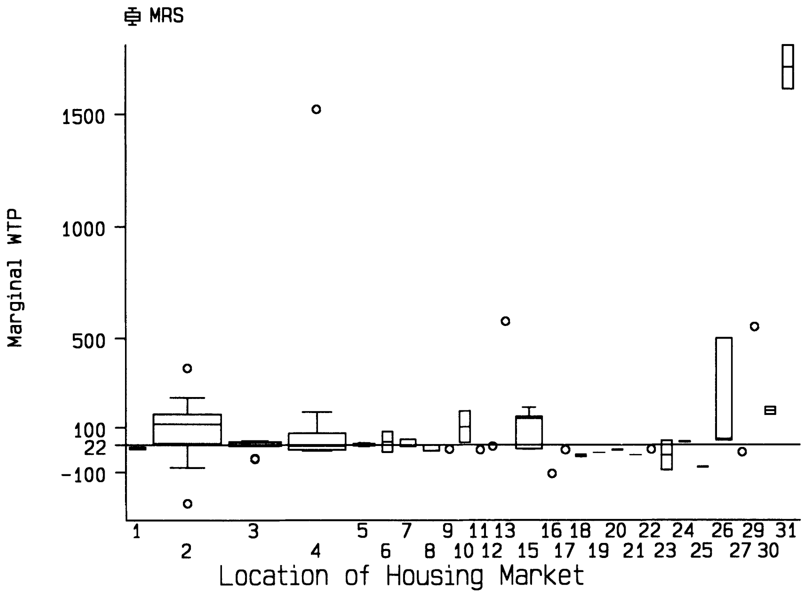

FIG. 1.—Marginal willingness to pay for reductions in TSP, 1982–84 dollars. 1 = Boston, 2 = Chicago, 3 = St. Louis, 4 = Washington, 5 = Kansas City, 6 = Atlanta, 7 = Denver, 8 = Houston, 9 = Louisville, 10 = Miami, 11 = Oklahoma City, 12 = Seattle, 13 = Southern California Air Basin, 15 = Los Angeles, 16 = Anaheim, 17 = Baltimore, 18 = Cincinnati, 19 = Dallas, 20 = Detroit, 21 = Indianapolis, 22 = Minneapolis, 23 = Philadelphia, 24 = Portland, 25 = San Bernardino, 26 = San Francisco, 27 = Tacoma, 29 = Milwaukee, 30 = New York, and 31 = Hartford.

Metropolitan Area Data book for the year closest to the date of the housing sales.[4]

Because the parameters underlying our measures of MWTP were estimated with varying levels of precision, the marginal value can be expected to be a heteroscedastic random variable. There are multiple reasons for this conclusion. Even if all the hedonic models used a linear specification, differences in the relative precision in estimating the coefficient for the air pollution variable with each sample would imply heteroscedasticity. Moreover, most studies have used more

[4] The total shelter component of the consumer price index was used as our deflator. Where a measure of the vacancy rate was not available, we treated the variable as having a missing value and in this case replaced it with the sample mean for the cities in our sample for which it was possible to obtain an estimate. We also investigated the sensitivity of our summary functions to these assignments by including a dummy variable to indicate where the vacancy rate was missing. Including this variable influenced the size and relative significance of the vacancy variable but did not alter conclusions about the direction or statistical significance of its or any other variable's effects on MWTP.

TABLE 1

SUMMARY OF THE HEDONIC STUDIES INCLUDED IN SAMPLE

ID	Study	Year*	Location	Number of Estimates	MWTP Range (1982–84 dollars)
3	Bender, Gronberg, and Hwang (1980)	1970	Chicago	3	159.8 to 234.0
5	Nelson (1978)	1970	Washington	4	0 to 1,522.0
6	Anderson and Crocker (1971)	1960	Washington	4	−4.9 to 169.3
6	Anderson and Crocker (1971)	1960	Kansas City	4	16.4 to 31.6
6	Anderson and Crocker (1971)	1960	St. Louis	4	17.0 to 32.7
7	Smith (1978)		Chicago	2	116.0 to 138.1
8	Krumm (1980)	1971	Chicago	1	29.0
11	Li and Brown (1980)	1971	Boston	3	2.7 to 10.8
13	Polinsky and Rubinfeld (1977)	1960	St. Louis	4	35.7 to 37.9
15	Palmquist (1984)	1977	Multiple cities†	7	.4 to 173.7
16	Brookshire et al. (1979)	1977	Southern California Air Basin	1	577.2
20	Palmquist (1982)	1977	Multiple cities‡	20	−89.5 to 108.9
21	Palmquist (1983)	1977	Multiple cities§	14	−76.1 to 98.5
22	Atkinson and Crocker (1982)	1964	Chicago	1	366.2
24	Brookshire et al. (1982)	1977	Los Angeles	1	149.2
27	McDonald (1980)	1970	Chicago	3	−239.8 to 159.8
28	Berry (1976)	1968	Chicago	1	−1.38
29	Jackson (1979)	1970	Milwaukee	1	551.4
31	Appel (1980)	1970	New York	2	159.0 to 191.3
32	Soskin (1979)	1970	Washington	1	73.9
33	Egan (1973)	1960	Hartford	2	1612 to 1807.8
37	Brucato et al. (1990)	1972	Los Angeles	2	140.7 to 190.6
37	Brucato et al. (1990)	1978	San Francisco	1	500.2

NOTE.—The citations for all the studies reviewed in assembling the data for our sample are given in the Appendix.

* The year corresponds to the year of the housing prices used in each study. For those studies using census tract data, it is the year of the census. With studies using housing sales, it is the year of these sales.

† The cities included in Palmquist (1984) were Miami, Houston, Atlanta, Denver, Seattle, Louisville, and Oklahoma City.

‡ The cities included in Palmquist (1982) were Minneapolis, Houston, Dallas, San Francisco, Miami, Los Angeles, Portland, Chicago, Philadelphia, Atlanta, Anaheim, Washington, D.C., Cincinnati, San Bernardino, Indianapolis, St. Louis, Baltimore, Detroit, Denver, and Tacoma.

§ The cities included in Palmquist (1983) were Chicago, Los Angeles, Philadelphia, San Bernardino, Portland, Denver, Detroit, Dallas, Washington, D.C., Indianapolis, Houston, St. Louis, Cincinnati, and San Francisco.

complex specifications than linear. Indeed, the available studies often report several different price function specifications, each requiring a different transformation to the estimated parameters to measure MWTP. The observations composing our sample are also not independent. The same sales data led to different estimates with different model specifications or, in some cases, different analysts. In other studies, such as Palmquist's work or the early Anderson and Crocker study, estimates from different cities with independent records of sales are reported.

Our analysis considered the effects of these influences by applying two separate estimators to a common set of models. The first approach uses a minimum absolute deviation (MAD) estimator describing the relationship between the conditional median of the MWTP estimates and real per capita income, the conditions of local housing markets, air pollution, and the features of each hedonic model's implementation (i.e., type of data, model specification decisions, publication status, and estimator used in the original study). The outlying observations provide an important motivation for the MAD estimator. That is, they would seem to suggest that our model's errors are unlikely to be consistent with a normal distribution. To test this hypothesis, we applied a Shapiro-Wilk (1965) test to a standardized residual and decisively rejected normality at a p-value of .001 (the Shapiro-Wilk statistic is .790).[5] The second approach is the OLS estimator with a Huber (1967) consistent covariance matrix for the parameter estimates. Our application treats each study's MWTP estimates as equivalent to a set of sampling clusters. This approach recognizes the potential intercorrelation between observations in estimating the diagonal elements to develop a consistent covariance matrix (under the assumption of heteroscedasticity) but does not include off-diagonal elements to take account of these cross-correlations. The estimated coefficients' covariance matrix, $\hat{\boldsymbol{\Sigma}}$, is

$$\hat{\boldsymbol{\Sigma}} = S^{-1}\left(\sum_{j=1}^{k}\sum_{i=1}^{n_j}\hat{e}_{ij}\mathbf{x}_{ij}^{T}\mathbf{x}_{ij}\hat{e}_{ij}\right)S^{-1}, \tag{1}$$

where $\hat{e}_{ij}$ is the OLS residual for the ith observation from the jth grouping (i.e., study or set of studies); $\mathbf{x}_{ij}$ is a $1 \times K$ vector of values for each of the K independent variables (including one for the intercept for the ith observation from the jth grouping); $S = \Sigma_{j=1}^{k}\Sigma_{i=1}^{nj}$ $\mathbf{x}_{ij}^{T}\mathbf{x}_{ij}$; n_j is the number of estimates of MWTP classified as derived

[5] The standardized residuals transform the ordinary least squares (OLS) residuals to adjust for heteroscedasticity.

from the jth cluster (i.e., study or data set); and k is the number of independent clusters.

Neither approach comprehensively addresses all potential estimation issues. Because we do not have an estimator that deals with all aspects of the sample in a conclusive way, our analysis of the findings will primarily focus on the points of consistency between the two methods' summaries. The first (MAD) is less sensitive to outlying observations and the implied thick tails for the model's errors' distributions but does not explicitly adjust for heteroscedasticity. Ordinary least squares with adjusted estimates for coefficient variance takes account of heteroscedasticity (in judging statistically significant factors for estimated MWTP) but can be expected to be influenced by outlying observations.

III. Results

It is reasonable to expect that the hedonic price function will be affected by the nature of the distributions of bid and offer functions over market participants (see Tinbergen 1956; Epple 1987). All else equal, equilibrium MWTPs seem likely to be higher for wealthier than for poorer communities (even if they could be evaluated at a comparable level of income for a "representative" buyer). Similarly, we might expect that if the full set of conditions describing local air shed conditions, industrial location decisions, and commuting patterns imply that a community must "tolerate" a higher level of air pollution, then the typical individual who lives in that area "must have" lower values for reductions in air pollution than those people in areas with better air quality. Otherwise, with free mobility one might argue that they would not choose to live there. Beyond these rather general qualitative interpretations of the effects of air quality conditions and incomes, it seems reasonable to argue that higher vacancy rates reduce marginal values (i.e., there are more available housing options). But none of these hypotheses is more than a conjecture. The hedonic framework does not unambiguously imply these patterns.

Table 2 summarizes our OLS and MAD estimates for each of the two models. The models labeled equation 1 in the table are specifications that include variables describing the "economic" influences on MWTP estimates as well as variables identifying implementation (or specification) decisions. Those labeled as equation 2 include only the measure of air pollution and real income relevant for each city at the time the study was conducted. With OLS estimates, the more complete specification is required to isolate the effect of average air pollution on the estimated MWTP. By contrast, with a MAD estimator, a simple specification (eq. 2) indicates that both air pollution and real income were significant determinants of the marginal values of reducing air pollution.

Two types of variables for implementation decisions are represented in the more complete specifications: (*a*) the hedonic function's specification and price measure used and (*b*) the type and year of the sample. The conclusions drawn from this complete specification with either OLS or MAD are similar for these variables. As a rule, the MAD estimator seems to provide more precise estimates of the determinants of the MWTP.[6] Use of 1960 census data has the largest overall impact on the size of the estimated MWTP, with the impact of linear specification for the hedonic function next in quantitative importance. As more current sample years are considered, the estimated (real) MWTP seems to increase in absolute magnitude. Because studies with more recent data have tended to use actual prices, more complete specifications, and improved model specifications (based on the Cropper, Deck, and McConnell [1988] evaluation of the performance of the hedonic model under controlled conditions), the coefficient for the year of the data is likely to reflect a composite of these effects and not necessarily evidence of increasing "scarcity" of air quality. Our findings indicate smaller estimates of MWTP for published studies, suggesting that size of the estimated marginal values in hedonic functions may well serve as an implicit screen in which some estimates are systematically dropped. This may well be another form of the publication bias that has been detected in meta-analyses of other subjects (see Begg 1994).[7]

To evaluate the importance of the screening process used to compose our sample of estimates (i.e., dropping results from studies in which the air pollution, city characteristics, or model and data variables could not be reconstructed), we included an inverse Mills ratio from a probit sample selection model. This model examined a limited set of characteristics for each study as potential determinants of a study reporting sufficient information to be included in our sample. With OLS, we would conclude that this selection effect was not significant. However, with MAD, it is clearly significant and is approximately the same impact as found with OLS, suggesting a conclusion

[6] There is some evidence that these asymptotic approximations for the MAD covariance matrix may be sensitive to heteroscedasticity. Gould (1992) has suggested a bootstrap covariance matrix. We considered the bootstrap estimates as well and found them to substantially increase the variance estimates, more consistent with our small sample. Given the consistency in judgments about significant determinants between OLS (with covariance adjusted for heteroscedasticity) and MAD, we have retained the Koenker-Bassett (1982) form for the standard errors.

[7] It could also be due to the timing of the unpublished papers in relation to those published. We cannot discriminate between these interpretations.

TABLE 2

META-ANALYSIS OF HEDONIC ESTIMATES OF MARGINAL WILLINGNESS TO PAY FOR TSP, 1982–84 (Number of Observations = 86)

	OLS		MAD	
INDEPENDENT VARIABLES	(1)	(2)	(1)	(2)
Intercept	−4,739.02***	−73.06	−2,536.90***	−49.31
	(−3.22)	(.25)	(−9.76)	(−1.82)
Characteristics of city/consumers:				
TSP, geometric mean of the second high readings	−1.44**	−2.83	−.311**	−.23*
	(−2.35)	(−1.46)	(−2.02)	(−1.89)
Real income	.02	.04	.002	.01***
	(1.48)	(1.11)	(.64)	(3.93)
Vacancy rate	−73.01		−20.22**	
	(−1.48)		(−2.61)	
Characteristics of model/estimator:				
Number of neighborhood characteristics in hedonic price equation	199.48***		156.05***	
	(4.53)		(19.90)	
Number of air pollution variables in hedonic price equation	−24.38		−13.45**	
	(−.74)		(−2.11)	
Actual price (= 1)	3.15		95.92**	
	(.02)		(2.10)	
Linear model (= 1)	936.66***		690.21***	
	(7.38)		(19.43)	

Semilog (= 1)	832.17***		681.03***	
	(3.29)		(21.51)	
Log-linear (= 1)	278.65**		244.14***	
	(2.20)		(8.99)	
OLS estimator (= 1)	−163.70*		−.21	
	(−1.77)		(−.01)	
Characteristics of the data:				
Census 1960 (= 1)	1,470.44***		915.79***	
	(4.10)		(15.23)	
Census 1970 (= 1)	456.27***		304.45***	
	(3.94)		(11.23)	
Year of data (last two digits)	51.96**		23.10***	
	(2.48)		(6.32)	
Characteristics of meta-sample:				
Unpublished study (= 1)	247.67*		230.12***	
	(1.66)		(8.47)	
Inverse Mills ratio	205.22		205.19***	
	(1.57)		(3.99)	
R^2	.688	.173	.337	.026

NOTE.—Numbers in parentheses below the estimated coefficients are the ratios of the estimated parameter to its estimated standard error. In the case of the MAD estimates, the covariance matrix was estimated using the approach suggested by Koenker and Bassett (1982) with $\hat{\boldsymbol{\Sigma}} = A^{-1}BA^{-1}$, where $B = \mathbf{X}^T\mathbf{W}\mathbf{W}^T\mathbf{X}$, $A = \mathbf{X}^T\mathbf{X}$, $\mathbf{W}$ is the diagonal matrix whose diagonal elements are based on the size of the residuals (i.e., absolute value of the residual and an adjustment for the zero residuals), and $\mathbf{X}$ is the matrix of independent variables. The R^2 are not comparable between the two sets of models. It is conventionally defined for the adjusted OLS estimate as a pseudo R^2 for the MAD. It is one minus the sum of the weighted deviations about the estimated median relative to the sum of the weighted deviations about the raw median.

* $p = .10$.
** $p = .05$.
*** $p = .01$.

TABLE 3

MWTP Estimates for Selected Nonattainment Areas

City	PM10* (1)	$\widehat{\text{TSP}}$ (2)	Real Income† (3)	$\widehat{\text{MWTP}}$ (1982–84) (4)
Anaheim	85	154.5	17,526	84.37
Ann Arbor	115	209.1	15,012	69.19
Atlanta	69	125.4	14,669	94.50
Baltimore	71	129.1	17,101	98.25
Boston	69	125.4	15,801	96.78
Charlotte	57	103.6	15,605	103.17
Chicago	181	329.1	14,658	31.16
Dallas	92	167.3	15,054	82.28
Detroit	89	161.8	15,012	83.89
Indianapolis	80	145.4	14,776	88.51
Los Angeles	176	320.0	14,118	32.91
Miami	62	112.7	14,855	98.85
Minneapolis	73	132.7	16,048	95.01
New York	96	174.5	17,117	84.15
Philadelphia	168	305.4	15,092	39.38
Pittsburgh	129	234.5	14,396	60.04
St. Louis	90	163.6	15,224	83.75
Washington	60	109.1	16,558	103.38

* These data are taken from table 5-6 in the *1992 Metropolitan Statistical Area Air Quality Factbook Peak Statistics for Selected Pollutants* by metropolitan statistical area. They relate to the highest second maximum 24-hour concentration in PM10 (in micrograms per cubic meter). This was the closest measuring format available for the data used in our summaries. The source was U.S. Environmental Protection Agency (1993).

† The real income was computed per capita for each city in 1991 deflated by the consumer price index to be consistent with our model in 1982–84 dollars.

consistent with recent summaries of meta-analyses in other contexts.[8] That is, finding alternatives to dropping incomplete observations from research synthesis studies is an important area for future research.

Finally, to gauge the potential effectiveness of meta-analysis summaries in approximating marginal valuation estimates for new cir-

[8] It might be suggested that the process giving rise to our sample of 86 estimates may induce a selection effect in any summary of the MWTP estimates. To investigate this issue, we estimated a probit model with the outcome of interest inclusion in our MWTP sample (y). We consider the year of the data (year) use of actual prices (actual), and statistical significance (at a p-value of .10) and consistent sign for the TSP pollution coefficient (SIG10) as potential determinants with results as follows:

$$\underset{(2.95)(-2.71)}{y = 6.866 - .093\text{year}} + \underset{(3.84)}{1.55\text{actual}} - \underset{(-2.5)}{.611\text{SIG10}};$$

$$\text{pseudo}\, R^2 = .55.$$

The rationale for including the inverse Mills ratio in the MAD estimator as an approximate adjustment for selection effects follows from White's (1982) development of the asymptotic properties of tests for specification errors with maximum likelihood estimators.

cumstances, we used the complete MAD specification to "predict" marginal values. The process sets most model characteristics to sample means, sets the inverse Mills ratio at its mean, and uses the actual measures for particulate matter and real income to estimate marginal values for 18 cities with nonattainment problems for at least one of the criteria's air pollutants. Table 3 presents these results along with the particulate matter and income measures used to develop them.

The estimates from MAD's equation 1 are given in column 4 of the table. Aside from noting that they tend to fall in the low end of the range of estimates taken directly from past hedonic studies (see table 1), one cannot easily evaluate them without a specific policy context. As a result, we developed a simple benefits transfer to compare them with two other approaches for estimating the benefits from reducing air pollution in several of these nonattainment cities. We considered the task of meeting the Primary National Ambient Air Quality Standard for particulate matter in these cities. This standard is defined by two criteria: an annual average and a daily maximum. The former requires the annual arithmetic mean for particulates (measured as particles less than 10 microns, PM10) to be less than 50 micrograms per cubic meter. The latter requires that the expected number of days above 150 micrograms per cubic meter (PM10) be equal to, or less than, one.

On the basis of summary statistics for both measures of particulates in 1992, the PM10 nonattainment problems of most of the cities appear to be due to the daily maximum standard. Therefore, we considered a scenario that evaluates the annual benefits arising for a policy that would cause the maximum concentration to decrease to the standard (150). Benefit estimates are based on three methods: the reduced mortality impacts, valued using the midrange of Viscusi's (1993) summary of the values for statistical lives; the mean reported MWTP from past hedonic property value studies ($109.90); and the predictions for MWTP based on our MAD model (both of these last two estimates are stated in annualized terms).[9] Table 4 summarizes the results for the four cities for which improvements in the daily maximum are estimated to improve the annual average so that it would fall below the levels measured for 1992.

These comparisons illustrate the variability in estimates across the methods selected to evaluate the same improvement. To the extent we assume that people recognize the health effects due to air pollution, we would expect the property value measures to capture some

[9] The annualization factor assumed a mortgage interest rate of 8 percent and a 30-year term. Applying these to the median and capitalized estimates would imply a median annual value of $1.99, a mean of $9.76, and an interquartile range of zero to $8.75.

TABLE 4

AN ILLUSTRATIVE BENEFITS TRANSFER

City	Estimated Percentage Reduction in Average PM10 (1)	Annual Benefits (1982–84 10^6 Dollars): Value of Statistical Life (2)	Mean MWTP (3)	Meta MWTP (4)
Anaheim	.5	8.2	2.2	1.7
Chicago	5.3	180.0	40.6	11.5
Los Angeles	18.8	781.0	254.4	76.2
St. Louis*	20.5	367.0	87.2	66.5

NOTE.—These estimates were developed recognizing the units of measurement for each of the air pollution measures, risk models, total mortality, and estimated number of homeowning households in each city. The value of statistical life estimates used the percentage change in the estimated arithmetic mean concentration for PM10 from 1992 levels under the assumption that the daily maximum was attained. Changes in these air pollution measures were used to compute the mortality risk change. To estimate the average level of PM10 based on the daily maximum, we used a simple regression relating the arithmetic average to the daily maximum for 20 nonattainment cities, i.e., arithmetic average

$$\underset{}{\text{PM10}} = \underset{(5.39)}{23.4} + \underset{(2.67)}{.109}\,\text{max of PM10}, \quad R^2 = .28$$

(t-statistics are in parentheses below coefficients). Col. 1 reports these percentages. These estimates were used with Freeman's (1982) consensus estimate of the elasticity of the mortality rate with respect to particulate matter (.05). His summary was based on total suspended particulates. Because it was expressed in elasticity form and the Environmental Protection Agency (1982) has used a constant conversion (.55) to estimate PM10 from early measures of total suspended particulates, we assumed that the PM10 measure does not affect the calculation. However, this conversion factor was used for the other calculations. Applying the risk estimate to the estimated total mortality level in each city yields the change in mortality (i.e., statistical lives "saved" with a reduction in air pollution). These estimates were valued by the middle value in Viscusi's (1993) estimates of the statistical value of lives ($5 million in 1990 dollars) adjusted to 1982–84 dollars. This approach follows the logic developed by Freeman (1982) in his evaluation of air pollution control policies. We also adjusted down the relevant population so that it would correspond to the homeowners, assuming the percentage of owner-occupied dwellings would correspond to the percentage of homeowners, given a constant number of people in each household.

The two sets of estimates from the hedonic models were derived for cities for which the reduction in daily maximum concentrations would improve average concentrations from the 1992 levels. The average reduction in particulate matter (converted to TSP) was scaled by the mean MWTP estimate ($109.90) for col. 3 estimates and the relevant predicted values from table 3 for col. 4. They were assumed to hold for an estimate of all homeowning households. This was developed using the percentage of housing that is owner-occupied times an estimate of households in each city to provide an approximate measure of the homeowning households.

* This case is somewhat different from the other three in that it would not be a nonattainment area based on particulate matter in 1992. Also, the maximum levels of particulate matter (PM10) are closer to the average level for 1992 in St. Louis than in the other cities. Because our regression model used to forecast the effects of meeting the standard defined by the maximum is based on a sample with wider disparities between the average level and the maximum, it predicts a reduction for the average in St. Louis for a maximum (150) that is higher than the measured level for the city. In an actual policy evaluation, this inconsistency would call into question the likelihood of the predicted decrease for this city. Because our objective is illustrated, we have included it.

of these effects as well as aesthetic impacts on homeowners. Because the hedonic estimates are not relevant to the complete population of each city, these estimates were aggregated over homeowners only. For comparability we limited our aggregate estimate based on the mortality/air pollution risk changes to the same group, assuming that the health effects applied equally to homeowners and renters. There are a number of assumptions underlying both sets of estimates. Even if we acknowledge all of them, it is clear that the estimates are quite different. Even with adjustment to approximate comparable groups for aggregation, the benefit estimates based on the value of statistical lives are nearly four times greater than those from the hedonic property models using the overall mean MWTP for all groups. Comparison with the meta model indicates a much wider discrepancy that differs depending on local conditions.

Some of these differences arise from the assumption of the value of statistical life approach that people know the risk change and respond so that their behavior permits measurement of an ex ante marginal valuation. The hedonic models are more likely to reflect aesthetics, materials and soiling effects, and, to some degree, perceived health effects, but the latter may well be incomplete. For our purposes then, the comparisons illustrate the potential sensitivity of estimates to local conditions and the need to incorporate not simply differences in air pollution conditions in each location, but also economic variables important to the MWTPs transferred to individual cities. A comparison of estimates based on the mean MWTP (col. 3) versus the meta model's predictions (col. 4) illustrates that there are large differences in the estimates that depend on the characteristics of each city's residents in relation to the composite represented through the use of an overall mean estimate for MWTP. This would suggest a clear potential for using meta-analysis to improve transfers of benefit estimates likely to be sensitive to the level of environmental quality and the demographic characteristics of the population.

IV. Implications

The increased recognition of the difficulties in estimating willingness to pay functions (from hedonic data) has caused analysts to reevaluate Freeman's (1974) early proposal to use point estimates of the MWTP together with linearized MWTP functions to measure the value of air quality improvements (see Bartik 1988; Kanemoto 1988). However, little attention has been given to the process of developing point estimates of the marginal willingness to pay for reducing air pollution. Current practice usually involves selecting a "best" judgmental point estimate, sometimes combined with low and high values for the estimated MWTP, and applying each *uniformly* to all the areas expected to realize the reduction in air pollution. Our findings suggest that this can lead to serious mistakes. The differences in figure 1's display of the estimated MWTPs across the cities in our sample suggest that the variation due to local conditions can be substantial. Moreover, the estimated conditional median function indicates that implementation decisions in modeling can matter.

Metasummaries offer the prospect for ex post adjustments to estimates to account for specification and variable measurement decisions found later to be desirable (or undesirable) as part of a benefits transfer. Equally important, to the extent local economic and air quality conditions are found important to these summaries of the market results, they can be reflected in extrapolations using the research synthesis. Our application to nonattainment cities illustrated the wide range of estimates possible beginning from a common theme—the original hedonic estimates. Metasummaries reduce sensitivity to extreme results and were found comparable and uniformly lower than those based on damage functions using the value of statistical life's approach to monetize the mortality impacts of particulate matter. Because they offer a systematic method to adjust for the local conditions found important to the benefit measures, these models may serve a role complementary to that of research synthesis: improving the adjustment practices applied to empirical estimates in policy analyses that must rely on results not directly relevant to the questions or geographic locations involved.

Appendix

Studies Reviewed in the Sample

Anderson, Robert J., Jr., and Crocker, Thomas D. "Air Pollution and Residential Property Values." *Urban Studies* 8 (October 1971): 171–80. (6)[10]

Appel, David. "Estimating the Benefits of Air Quality Improvement: An Hedonic Price Index Approach Applied to the New York Metropolitan Area." Ph.D. dissertation, Rutgers Univ., UMI Order no. 8022540, 1980. (31)

Atkinson, Scott E., and Crocker, Thomas D. "A Bayesian Approach to Assessing the Robustness of Hedonic Property Value Studies." Manuscript. Laramie: Univ. Wyoming, Dept. Econ., 1982. (22)

Bender, Bruce; Gronberg, Timothy J.; and Hwang, Hae-Shin. "Choice of Functional Form and the Demand for Air Quality." *Rev. Econ. and Statis.* 62 (November 1980): 638–43. (3)

Bender, Bruce, and Hwang, Hae-Shin. "Hedonic Housing Price Indices and Secondary Employment Centers." *J. Urban Econ.* 17 (January 1985): 90–107. (25)

Berry, Brian J. L. "Ghetto Expansion and Single-Family Housing Prices: Chicago, 1968–1972." *J. Urban Econ.* 3 (October 1976): 397–423. (28)

Blomquist, Glenn C.; Berger, Mark C.; and Hoehn, John P. "New Estimates of Quality of Life in Urban Areas." *A.E.R.* 78 (March 1988): 89–107. (18)

Bresnock, Anne E. "Housing Prices, Income and Environmental Quality in Denver." Ph.D. dissertation, Univ. Colorado, 1981. (23)

Brookshire, David S.; d'Arge, Ralph C.; Schulze, William D.; and Thayer, Mark A. *Experiments in Valuing Non-market Goods: A Case Study of Alternative Benefit Measures of Air Pollution Control in the South Coast Air Basin of Southern California.* Vol. 2 of *Methods of Development for Assessing Air Pollution Costs and Benefits.* Washington: Environmental Protection Agency, 1979. (16)

[10] The number in parentheses following the reference refers to the ID number of the study listed in table 1.

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Egan, Francis Joseph. "Air Pollution and Property Values in the Hartford Metropolitan Region." Ph.D. dissertation, Fordham Univ., UMI Order no. 74-2777, 1973. (33)

Goodwin, Susan Ann. "Measuring the Value of Housing Quality—a Note." *J. Regional Sci.* 17 (April 1977): 107–15. (14)

Graves, Phil; Murdoch, James C.; Thayer, Mark A.; and Waldman, Don. "The Robustness of Hedonic Price Estimation: Urban Air Quality." *Land Econ.* 64 (August 1988): 220–33. (34)

Harrison, David, Jr., and Rubinfeld, Daniel L. "Hedonic Housing Prices and the Demand for Clean Air." *J. Environmental Econ. and Management* 5 (March 1978): 81–102. (1)

Hoehn, John P.; Berger, Mark C.; and Blomquist, Glenn C. "A Hedonic Model of Interregional Wages, Rents, and Amenity Values." *J. Regional Sci.* 27 (November 1987): 605–20. (35)

Jackson, Jerry R. "Intraurban Variation in the Price of Housing." *J. Urban Econ.* 6 (October 1979): 464–79. (29)

Krumm, Ronald J. "Neighborhood Amenities: An Economic Analysis." *J. Urban Econ.* 7 (March 1980): 208–24. (8)

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McDonald, John F. "The Use of Proxy Variables in Housing Price Analysis." *J. Urban Econ.* 7 (January 1980): 75–83. (27)

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