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Project Summary

Inferring Willingness to Pay for Housing Amenities from Residential Property Values

Joel L. Horowitz

The standard hedonic model of consumers' choices in housing markets, which forms the basis of much environmental benefits analysis, fails to take into account three important characteristics of the bidding process through which houses are sold. First, the prices of houses are established through sequential bidding, so sellers do not necessarily accept the highest bids that might be made for their houses. Second, ignorance of the market may lead potential buyers to make bids that are either higher or lower than the ones they would make if they had complete information. Finally, the distribution of bids for a house is truncated at the seller's asking price. These characteristics of housing markets imply that buyers cannot choose houses so as to maximize a deterministic utility function subject to a deterministic budget constraint as required by the standard model. This report describes a new model of consumers' choices in housing markets that incorporates the foregoing market characteristics. The new model has been tested econometrically against the standard model, and the standard model has been strongly rejected. The new model gives estimates of buyers' willingness to pay for housing amenities that are significantly different from the estimates produced by the standard model.

This Project Summary was developed by EPA's Air and Energy Engineering Research Laboratory, Research Triangle Park, NC, to announce key findings of the research project that is fully documented in a separate report of the same title (see Project Report ordering information at back).

Introduction

Econometric estimation of households' willingness to pay for environmental and other residential amenities often is based on observations of the effects of environmental and other factors on residential property values. The standard estimation procedure is based on the hypothesis that each household occupies a house that maximized its utility subject to a budget constraint. It can be shown that, subject to regularity conditions, utility maximization occurs when the household's marginal willingness to pay for each housing attribute (e.g., house size, air quality at the residential location) equals the marginal price of that attribute.

In the standard procedure, willingness-to-pay estimation takes place in two steps. First, a hedonic price function describing the relation between the observed market prices of houses and attributes such as size and air quality is estimated. The first partial derivative of the hedonic price function with respect to an attribute level yields the marginal price function of this attribute. The numerical marginal prices pertaining to a particular household can be obtained by substituting the values of the attributes of that household's house into the estimated price function. The resulting marginal price of the attribute is then treated as an observation of that household's marginal willingness-to-pay for the attribute. In the second estimation stage, the relation between marginal willingness-to-pay and relevant explanatory variables is specified up to a finite set of constant parameters. The parameter values are inferred from the "observed" marginal willingness-to-pay values (i.e., the estimated marginal prices) using suitable econometric methods.

This hedonic pricing approach has been used in a variety of studies of willingness-to-pay for environmental improvements. However, the method has some serious difficulties. Three that are particularly relevant to the research described in this report are:

1. The assumptions underlying the standard hedonic model imply that houses are sold to the households that are willing to pay the highest prices for them (i.e., houses are sold to the highest bidders). However, it is unlikely that houses are sold to the highest bidders in real housing markets. In real markets, houses normally are sold through sequential bidding processes. Bids must be accepted or rejected as they are received, and a seller is not able to assemble all bids that might be made before deciding which one to accept. Therefore, the seller does not necessarily accept the highest bid that might be made. Substantial transactions costs tend to prevent the rectification of erroneous decisions regarding the rejection and acceptance of bids.
2. Potential buyers bid for houses with little or no knowledge of the bids made by others. Therefore, buyers do not know the price at which a house will be sold in advance of the sale, and buyers have incomplete information about the house price components of their budget constraints. This makes it impossible for buyers to choose houses by maximizing utility subject to deterministic budget constraints. Transactions costs tend to prevent buyers from rectifying any resulting errors in bidding or in choosing houses.
3. The sale price of a house rarely exceeds the seller's asking price. Thus, the asking price effectively truncates the distribution of bids. If ignorance of the market or other factors cause sellers to establish asking prices that are below the prices buyers are willing to pay, then truncation of the distribution of bids at the asking prices will prevent identification of the buyers willing to make the highest bids. Therefore, houses will not necessarily be sold to these buyers. Moreover, a process in which buyers choose houses by maximizing utility subject to budget constraints will not assign unique buyers to houses.

This report describes a model of consumers' choices in housing markets that incorporates the market characteristics just discussed. The new model and the standard model have been estimated and tested econometrically to determine which provides a better description of the operation of these markets. The formulation and testing of the new model and the implications of this model for willingness-to-pay estimation are summarized in report Chapter 1. The remaining chapters are more detailed discussions: Chapter 2 gives detailed mathematical formulations of the new and standard models; Chapter 3 presents econometric tests of the models; and Chapter 4 presents the willingness-to-pay analysis.

Formulation of the Models

In this research, the new and standard models have been formulated as bidding models. Bidding models are housing market models in which the dependent variable is the sale price of a house, modeled as a function of attributes of the house and the buyer. It is assumed in these models that sales occur as results of a bidding process.

The standard model used in this research is the well-known bid rent model of housing markets. Roughly speaking, this model assumes that houses are sold to the buyers who bid the most for them, and a house's sale price is the amount the highest bidder is willing to pay for that house. Under the customary assumptions of hedonic analysis, the bid rent model is equivalent to the model in which buyers choose houses to maximize utility subject to a budget constraint. Moreover, under the same assumptions, willingness-to-pay analysis based on the bid rent model is equivalent to analysis based on a utility maximization approach. Thus, the standard market model can be tested using either the bid rent or the utility maximization form. The bid rent form is more convenient in the research discussed here.

In the version of the bid rent model used here, the probability density that a house with observed attributes X has sale price p_s is:

$$\text{Density}\,(p_s) = f[p_s|W(X)], \tag{1}$$

where W(X) denotes the buyer's willingness to pay for a house with observed attributes X, and f is the function giving the probability density that p_s is the highest bid made for the house.

In the new model, the probability density that a house with observed attributes X and asking price P_a has sale price p_s is:

$$\text{Density}\,(p_s) = Q(p_s|P_a)g[p_s|W(X)]|P(\text{sale}) \tag{2}$$

if $p_s < P_a$, where g is the probability density that the buyer makes a bid of p_s, $Q(p_s|P_a)$ is the probability that the seller accepts a bid of size p_s, and P(sale) is the probability that the house is sold at any price. The probability that $p_s = P_a$ is:

$$\text{Prob}(P_a) = \{1 - G[P_a|W(X)]\}/P(\text{sale}), \tag{3}$$

where G is the cumulative probability distribution function corresponding to g. The probability that $p_s > P_a$ is zero. P(sale) is given mathematically by:

$$P(\text{sale}) = \int_{\infty}^{P_a} \text{Density}(p)dp + \{1 - G[P_a|W(X)]\}. \tag{4}$$

Equations (2-4) constitute a bidding model of consumers' choices in housing markets that is analogous to the standard model but that is based on different assumptions concerning the bidding process that operates in housing markets. In particular, Equations (2-4) incorporate the hypotheses that sellers process bids sequentially, buyers do not have certain knowledge of the bids made by other buyers, and the distribution of bids for a house is truncated at the sellers' asking price. These hypotheses are inconsistent with the standard model's assumption that houses always are sold to the buyers willing to pay the most for them. As a consequence, it is possible to distinguish empirically between the new model [i.e., the model of Equations (2-4)] and the standard model and to test each against the other empirically to determine which better explains the available data.

Data

The new and standard models were tested and compared empirically using data describing a sample of 1196 houses sold in Baltimore City and County, Maryland, during 1978. The data were assembled from records of the Central Maryland Multiple Listing Service, Baltimore City and County tax records, the U.S. Census Bureau, the Maryland Bureau of Air Quality, and the results of previous investigations of school quality and crime levels in the Baltimore area. The data include the sale price, asking price, and annual property tax liability of each sampled house as well as 49 attributes of the house and its neighborhood. Environmental quality is characterized in these data by three air pollution variables: annual geometric mean particulate concentration, annual average NO_2 concentration, and annual maximum hourly O_3 concentration.

Results

The new and standard models were both estimated (i.e., fit to the data) using standard econometric methods. These methods make it possible to test the models against one another by comparing how well each model fits the data. If the fit of one model is significantly worse than the fit of the other, then it is possible to conclude with a high degree of confidence that the worse fitting model is incorrect.

Figures 1 and 2 show the results of this comparison process. In Figure 1, the observed sale prices of 50 randomly selected houses are plotted against the predicted sale prices obtained from the new model. In Figure 2, the observed sale prices of the same 50 houses are plotted against the predicted sale prices obtained from the standard model. The predicted sale prices were computed as expected values conditional on attribute levels and, in the case of the new model, asking prices. Figure 1 shows that the new model fits the observations well: there is no indication of serious errors in the model. Figure 2 shows that the standard model fits the observations much more poorly than does the new model.

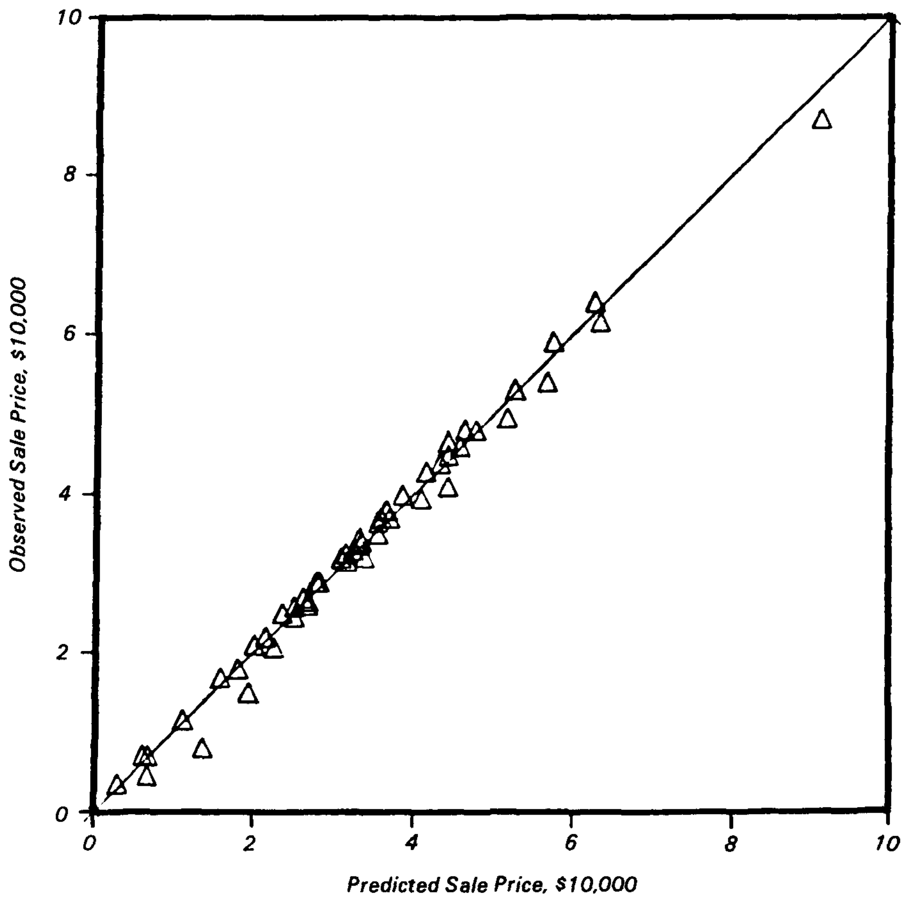

Figure 1. *Comparison of observed sale prices and sale prices predicted by the new model.*

The differences in fit shown in Figures 1 and 2 are reflected in the root-mean-square (RMS) errors of the two models' predictions of houses' sale prices. For the 1196 houses in the full data set, the new model has a RMS prediction error of $2,830; whereas, the standard model has a RMS prediction error of $11,360.

These results suggest strongly that the standard model is erroneous. It is possible to perform a formal statistical comparison of the new and standard models. This comparison leads to the conclusion that, if the standard model is correct, the observed goodness-of-fit results are events whose probabilities of occurrence are less than 0.0001. Thus, it is virtually certain that the standard model is erroneous and that the new model provides a better explanation of the operation of the Baltimore housing market than does the standard model. Since the bid rent model is equivalent to the utility maximization model (in either the utility maximization or random utility formulation, depending on whether housing is a continuous or discrete good), the latter model also is rejected.

The new and standard models give substantially different estimates of buyers' willingness to pay for changes in houses' attributes. Table 1 shows willingness-to-pay estimates for the following arbitrarily selected attribute changes: add a room, add 1000 ft² (92.9 m²) to the lot, add a fireplace to a house that does not already have one, and add a garage to a house that does not already have one. The table also shows 95 percent confidence intervals for the willingness-to-pay estimates obtained from the new model. The contrast between the willingness-to-pay estimates obtained from the new and standard models is striking. Whereas the estimates obtained from the new model all are statistically significantly positive, as intuition suggests should be the case, all of the estimates obtained from the standard model are negative. Thus, the estimates obtained from the standard model are unreasonable as well as statistically distinct from the estimates obtained from the new model. The willingness-to-pay estimates illustrate the practical differences between the new and standard models and the practical consequences of attempting to estimate willingness to pay with the incorrect standard model.

The willingness-to-pay estimates given in Table 1 do not include willingness to pay for air quality improvement. This is because no statistically meaningful association was found between the air pollution variables and either the prices of houses in the Baltimore area or the willingness of buyers to pay for these houses. In estimates of the hedonic price function of houses in the Baltimore area, none of the air pollution variables was found to have a statistically significant association with sale price. Moreover, the coefficients of the particulate matter and O_3 variables have signs indicating, unreasonably, that more air pollution is preferred to less. Similarly, none of the air pollution variables has a statistically

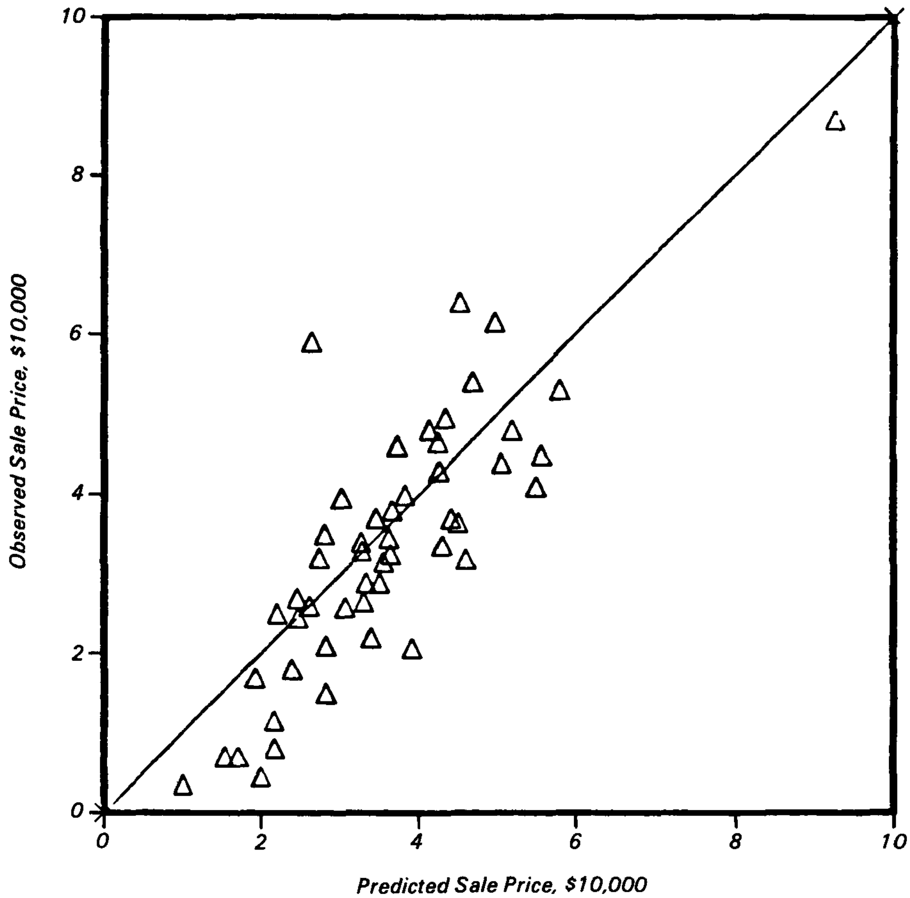

Figure 2. *Comparison of observed sale prices and sale prices predicted by the standard model.*

significant association with willingness to pay for houses as estimated from the new model, and the coefficient of the particulate variable has the incorrect sign. The coefficients of the air pollution variables all have correct signs in the willingness-to-pay function estimated from the standard model, and the association of the O_3 variable with willingness to pay is nominally statistically significant in this model. However, given the virtual certainty that the standard model is erroneous, little importance can be assigned to willingness-to-pay results obtained from this model. Thus, it is not possible on the basis of the research reported here to reach conclusions concerning the willingness of Baltimore area households to pay for improvements in air quality.

The causes of the poor performance of the air pollution variables in this research cannot be identified with certainty from the available data. However, one possible cause is error in the estimation of pollutant concentrations in the vicinities of houses. The concentration data reported by the Maryland Bureau of Air Quality pertain to concentrations at a set of fixed monitoring stations. The concentrations at individual houses had to be interpolated from the concentrations at the stations. Errors introduced in the interpolation could have caused the coefficients of the air pollution variables to be statistically nonsignificant and to have incorrect signs. Another possible cause of the poor performance of the pollution variables is that pollution concentrations in the Baltimore area during 1978 were relatively low and varied little among geographical areas. Most monitoring stations reported annual geometric mean particulate concentrations below the particulate ambient air quality standard. Although several stations reported O_3 concentrations above the O_3 standard, the range of variation of O_3 concentrations in the available data is only 67 $\mu g/m^3$, which is too small to be perceptible to most people.

Table 1. *Estimates of Buyers' Willingness to Pay for Changes in Houses' Attributes*

Attribute Change	*New Model* Estimate	*New Model* 95 Percent Confidence Interval	*Standard Model* Estimate
Add a room	*$2,540*	*$1,960-3,130*	*$ -470*
Add 1000 ft² to lot[a]	*270*	*222-318*	*-72*
Add fireplace	*1,350*	*290-2,410*	*-1,150*
Add garage	*737*	*47-1,430*	*-423*

[a]1000 ft² = 92.9 m²

Conclusions

The standard hedonic model of consumers' choices in housing markets, which forms the basis of much environmental benefits analysis, assumes a market mechanism that is considerably different from the one that casual observation suggests operates in real housing markets. This report describes a new model that incorporates the main characteristics of the market mechanism that appears to operate in real housing markets. The new model has been tested against the standard model econometrically, and the standard model has been rejected strongly. Thus, the econometric results strongly support the hypothesis that the new model provides a better description of the operation of housing markets and, therefore, a firmer basis for environmental benefits analysis than does the standard model. The new and standard models give considerably different estimates of buyers' willingness to pay for changes in houses' attributes. Moreover, the standard model gives willingness-to-pay estimates that are highly unreasonable. Thus, the new and standard models are clearly distinguishable in terms of their fundamental assumptions, empirical performance, and practical consequences.

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Joel L. Horowitz is with the University of Iowa, Iowa City, IA 52242.
***J. David Mobley** is the EPA Project Officer (see below).*
The complete report, entitled "Inferring Willingness to Pay for Housing Amenities from Residential Property Values," (Order No. PB 86-103 082/AS; Cost: $11.95, subject to change) will be available only from:
National Technical Information Service
5285 Port Royal Road
Springfield, VA 22161
Telephone: 703-487-4650
The EPA Project Officer can be contacted at:
Air and Energy Engineering Research Laboratory
U.S. Environmental Protection Agency
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