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Hedonic Prices, Demands for Urban Housing Amenities, and Benefit Estimates[1]

GLENN BLOMQUIST

Department of Economics, University of Kentucky, Lexington, Kentucky 40506

AND

LAWRENCE WORLEY

Department of Economics, Texas A & M University, College Station, Texas 77843

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This paper uses a Rosen, two-step, hedonic price-trait demand approach to estimate demand functions for a vector of urban amenities. To ascertain whether this theoretically preferred approach yields benefit estimates which differ from the oft-used Ridker–Henning, one-step, hedonic approach we conduct a sensitivity analysis. We find that the two-step approach does yield different benefit estimates and that the differences are large for some amenities. The estimates are sensitive to the functional form of the hedonic equation when the forms are significantly different according to modified Box–Cox results, but are not particularly sensitive to specification of the amenity demand equation.

1. HEDONIC PRICES AND TRAIT DEMAND

Housing markets potentially can yield useful information about the demand for such goods as clean air and pure water which are not traded in explicit markets. The change in the area under the estimated demand curve measures the benefits of providing more of the non-marketed goods. This paper shows how recent theoretical innovation affects measurement of the benefits and explores the sensitivity of benefit estimates to: (1) the one-step hedonic approach and the two-step hedonic price-trait demand approach, (2) different functional forms of the hedonic equation in the hedonic price-trait demand approach and (3) different specifications of the demand

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equations in the hedonic price-trait demand approach. Of concern are the benefits and costs of the theoretically preferred, but more time consuming hedonic price-trait demand approach.

Since Ridker and Henning's [14] study of residential property values and air pollution considerable doubt has arisen as to exactly what information a single equation regression of property values on housing traits contains. Freeman [4, 5] argues that it is necessary that households be identical with respect to income and tastes for the trait coefficient to be the infinitely elastic demand curve for the trait. Rosen [15], who develops the conceptual framework for analysis of hedonic prices and implicit markets, shows that even these conditions are not sufficient for the trait coefficient to be trait demand. Prices estimated through a hedonic regression merely connect equilibrium prices and traits and do not reveal anything about the underlying supply and demand functions except under special conditions. If consumers are identical and producers differ (Freeman's case), then the hedonic regression yields something resembling the demand function, i.e., willingness to pay for marginal changes in the trait. If producers are identical and consumers differ, then the hedonic regression yields something resembling the supply function. If there are distributions of producers and consumers, then the hedonic regression is simply the market clearing function which need not resemble either a demand or supply function. Under any of the above conditions we fail to get estimates of the demand or supply functions from the single equation hedonic regression. The hedonic regression yields only estimated marginal trait prices which then can be used to estimate the demand function using appropriate variables.

2. THE HOUSING MARKET AND TRAIT DEMAND

Applying Rosen's insight to the housing market several works have appeared including Linneman [11, 12], Diamond [3], Nelson [13] and Harrison and Rubinfeld [8, 9]. While the works differ in important ways each employs a two-step procedure for estimating the demand for housing traits wherein marginal hedonic trait prices are estimated and then used to estimate the willingness to pay or demand for certain housing traits.

Housing is a package of traits consisting of not only structural characteristics, but neighborhood amenities as well. Households respond to the configuration of traits as well as the traits themselves if they cannot rearrange or repackage them to suit their tastes. Following Bradbury *et. al.* [2], Linneman [11], and others we view households as choosing a housing package located at a particular site and having only incidental dealings in the land market, i.e., households demand housing, not land.[2] We assume each household maximizes a utility function separable in Z, a vector of housing traits, and X, a bundle of market goods subject to available income. Letting X be the numeraire good, the valuation function, $P(Z{:}\, I, U, T)$, may be derived which depicts the willingness of the household to trade units of market goods, X, for additions of any housing trait, Z, given income, utility and tastes. Let $\bar{P} = \bar{P}(Z)$ define the market price function of housing traits. Assuming households have zero market weights and letting $\bar{P}$ be exogenous to households, at equilibrium $P = \bar{P}$. Hence we can refer to $P_i(\equiv d\bar{P}/dZ_i)$ as the equilibrium marginal price, or alternatively, the hedonic or implicit price of housing trait Z_i.

Given that households maximize utility in a way similar to that when they face a linear budget constraint, the first-order conditions yield demand functions for housing site traits

$$Z_i^d = Z_i^d(P_1, \ldots, P_i, \ldots, P_n, I, T), \qquad (1)$$

where the quantity demanded of trait i depends on its marginal price, P_i, marginal prices of complementary and substitute traits, P_j for $j = 1, \ldots, n$ and $j \neq i$, household income, I, and tastes, T. To estimate the demand for any trait we first estimate trait prices. These prices are implicit in the hedonic regression, housing prices regressed on housing traits, in that they are the partial derivatives of housing price with respect to the housing trait. If the functional form of the hedonic regression is linear, then the hedonic price of trait i is the coefficient of trait i. However, if households cannot repackage traits or arbitrage across areas or producers experience economies of scale or produce traits jointly, then marginal trait prices vary across sites and the functional form is nonlinear, which means that the trait coefficients no longer represent trait prices in the market.

Once the appropriate functional form of the hedonic equation is found and estimated, we are able to generate the implicit trait prices by evaluating $\partial P/\partial Z_i$ at the trait values for each household. Using a linear functional form for the demand equation these prices are used as independent variables in estimating trait demand along with income and taste variables. While this specification yields a conventional demand function which is readily interpreted, the appropriate specification depends on one's view of the implicit market for housing traits. We assume that each household

[2] As a generalization of the Alonso–Muth CBD location models, Diamond [3] and Henderson [10] make utility a function of market goods, housing amenities, and land. While such a formulation is superior to ignoring amenities it has the implication that the composition of the package of housing traits does not affect consumption of land (lot size) since only the price of land (and income) matter. Smith [17] investigates the implications of the approach for estimating trait (amenity) prices.

faces exogenous prices for each trait and can purchase all he wants at that price. Other assumptions may be more appropriate for other traits and markets.[3]

3. THE DEMANDS FOR HOUSING TRAITS—RESULTS

We are interested in the demands for housing amenities in order to estimate the benefits of improved housing by measuring changes in the area under the demand curve for an amenity, i.e., by changes in consumer surplus. We are interested in the effect of alternative specifications of the hedonic and demand equations on estimates of the benefits of providing more of certain neighborhood amenities. A base case will be estimated, it being the benefits using a modified Box–Cox [1] procedure to choose the best functional form of the hedonic equation from which implicit prices are generated. Amenity demand is estimated using those prices. Estimated benefits are then compared to various alternative functional forms of the hedonic equations and various linear specifications of the demand equation.

The data are block and block group data from the 1970 U.S. Census for owner occupied housing in southeastern Springfield, Illinois. For the hedonic equation we follow the statistical model of Box and Cox which

[3]Estimating trait demand by regressing the housing trait quantity on trait price, the prices of complementary and substitute traits, income and other demand shifters is appropriate if trait prices are exogenous. Such is the case for the individual if supply adjusts quickly. He can buy different quantities at a particular price by locating in different areas, but prices need not be the same due to incomplete arbitrage or joint production. This specification yields a typical demand function with the price and income coefficients having their usual interpretations. Harrison and Rubinfeld [9] assume that the supply of traits adjusts slowly and that an individual bids for fixed quantity of a trait where the quantity is exogenous. Given that this assumption is appropriate, they regress the trait price as a function of its quantity, the quantity of other traits, income, and other demand shifters. The result resembles an inverse demand function except that the quantities of other traits are included. Harrison and Rubinfeld include only the trait whose demand is estimated—clean air. Nelson [13] and Witte *et al.* [18] assume that the traits and prices are both endogenous and estimate the demand and supply of traits simultaneously. However, these studies have their own drawbacks. Witte *et. al.* use factor analysis which limits benefit estimation for individual traits. See Freeman [6] concerning Nelson.

In our study we assume for the rapidly growing region studied that trait prices are exogenous to the individual though he may face different prices. This does have the minor advantage of an implied specification yielding the usual own-price, cross-price, and income effects, but this is somewhat incidental to its choice. The assumption may be important since it is fairly obvious that regressing quantity as a function of price is not econometrically equivalent to regressing price as a function of quantity. We do not choose 2SLS because of the lack of suitable instruments and hence, its use may introduce simultaneous equation bias. As Freeman [6] relates in his review each of the above assumptions is consistent with Rosen and the matter of which is most appropriate is essentially empirical. Resolution awaits future work.

permits investigation of the functional specification through search for the best fit as measured by the log likelihood function. To simplify a complex, costly search we limit the search to the forms where the power transformations of all variables are the same and find: the 0.1 power transformation is best, 0.1 is significantly different from the linear form of 1.0, and 0.1 is not significantly different from the natural logarithmic of 0.0. Linneman [12] and Goodman [7] also find the best transformation to be different from the linear form. (A statistical appendix available from the authors describes the data and Box–Cox findings in greater detail and reports the estimated hedonic equations for the linear, logarithmic, and 0.1 form as well as the calculated trait prices.)

Demands are estimated for six housing traits: number of rooms (*ROOM*), distance from the electric power plant (*DPP*), proximity to Lake Springfield (*NLAK*), proximity to park area (*NPK*), distance from Highway 66 (*DSS*), and distance from Interstate 55 (*DFF*). The price variables are designated as PZ_i, e.g., *PROOM* for the price of *ROOM*. *INC* is the income per adult in the block group. *FAMSZ* is the average family size. *AGE* is the average age of the population. *GSPER* is the percentage of the population in grade school, while *HSPER* is the percentage in high school. *PROF* is the percentage in professional occupations. *SMHOS* is the percentage living in the same house five years ago. The estimated demands are reported in Table 1, which shows that the results are for the most part consistent with expectations. Of the six trait demands estimated, four (*ROOM*, *DPP*, *NLAK*, and *DSS*) have negative signs for own price with all being significant at the 5% level. *DFF* and *NPK* have positive signs. The positive sign on own price indicates *DFF* should have been specified as a net amenity where access outweighs noise and air pollution. *NPK* is subject to a large amount of measurement error. Four of the trait demands have the expected positive signs for income except for *NPK* which has a low t value. For cross-price effects, where a positive sign indicates substitutability and a negative sign indicates complementarity, of the 13 comparisons of cross-price effects six are consistent and only two are inconsistent with each coefficient significantly positive or negative at a 5% level or a 1-tail test.

If we limit inspection to the demand for traits with significant coefficients in the hedonic equation the results are more reasonable yet. *ROOM*, *NLAK* and *DSS* each have own-price coefficients which are significantly negative at the 5% level with elasticities (evaluated at the means) of −0.26, − 0.06, and −0.29, respectively. Each has a positive coefficient on income, although only *DSS* is significantly positive at the 5% level. No cross-price effects are inconsistent and significant.

TABLE 1
Demand Equations for Housing Traits

Variable/statistic	Coefficient (absolute *t* value)			Coefficient (absolute *t* value)		
	ROOM	*DPP*	*NLAK*	*NPK*	*DSS*	*DFF*
PROOM	− 0.01644	1.639	0.4522	− 1.087	1.366	0.2561
	(2.10)	(6.47)	(1.35)	(2.84)	(3.09)	(0.76)
PHBAS	0.01406	—	—	—	—	—
	(0.96)					
PHPLB	6.402	—	—	—	—	—
	(4.63)					
PDPP	49.19	− 21476	6428	10377	− 4850	− 1900
	(1.97)	(8.74)	(1.98)	(2.79)	(1.13)	(0.58)
PNLAK	0.0005512	1.965	− 6.312	2.018	− 3.233	1.163
	(0.02)	(1.05)	(2.56)	(0.71)	(0.99)	(0.47)
PNPK	—	− 29.50	− 17.13	30.03	− 43.40	14.30
		(2.97)	(1.30)	(2.00)	(2.50)	(1.08)
PDSS	—	− 8.282	4.558	5.838	− 30.86	− 20.68
		(1.69)	(0.70)	(0.79)	(3.60)	(3.15)
PDFF	—	44.27	− 78.12	171.4	99.65	223.1
		(1.33)	(1.78)	(3.41)	(1.72)	(5.02)
PWHOS	− 0.03872	5.846	2.028	0.06599	− 0.3258	− 0.1130
	(0.64)	(1.29)	(0.34)	(0.01)	(0.04)	(0.02)
INC	0.00001649	0.3183	0.1776	− 0.09751	0.4868	0.2584
	(0.01)	(3.58)	(1.51)	(0.72)	(3.14)	(2.17)
FAMSZ	− 0.1939	18.20	3.994	− 17.19	45.48	36.22
	(1.34)	(1.65)	(0.27)	(1.03)	(2.36)	(2.45)
AGE	− 0.01826	0.6286	− 0.7916	0.1566	1.248	2.283
	(1.74)	(0.79)	(0.75)	(0.13)	(0.89)	(2.14)
GSPER	− 0.02172	− 6.913	− 1.286	8.301	− 8.282	− 5.669
	(0.37)	(1.53)	(0.22)	(1.21)	(1.05)	(0.94)
HSPER	0.04054	3.955	− 4.400	1.980	− 15.43	− 10.77
	(0.84)	(1.07)	(0.90)	(0.35)	(2.39)	(2.17)
PROF	0.004671	− 0.4764	0.07301	0.1439	0.02033	0.01455
	(0.99)	(1.33)	(0.15)	(0.27)	(0.03)	(0.03)
SMHOS	− 0.00001540	0.004408	0.0002479	0.01417	− 0.02033	0.002821
	(0.12)	(0.44)	(0.02)	(0.93)	(1.16)	(0.21)
CONSTANT	5.251	− 27.22	− 1.420	327.8	197.1	− 96.53
R^2	0.9223	0.9375	0.8518	0.7484	0.8813	0.8509
F	21.90	24.66	9.44	4.89	12.20	9.37
SEE	0.1929	14.56	19.25	22.03	25.41	19.46
n	38	38	38	38	38	38

4. BENEFITS

A cogent question is whether or not the additional effort to estimate trait demand from generated implicit prices is worthwhile. Despite the theoretical superiority of the two-step approach, do estimates of the benefit derived from a change in the quantity of an amenity differ in the one-step and two-step approaches? Additionally, given the approach, how sensitive is it to different functional forms of the hedonic equation and different specifications of the demand equation? In this section we compare benefit estimates from alternative procedures and specifications.

From the estimated demand, we estimate the benefits per household, B, for the ith housing trait by finding the area under the demand curve of

$$B_i = \int_{Q_a}^{Q_b} D^{-1}(Q_i)\, dQ_i, \tag{2}$$

where D^{-1} is the inverse demand for Q_i, i.e., $P_i = D^{-1}(Q_i)$, Q_a is the initial quantity and Q_b is the new quantity. Total benefits for an area would be given by nB_i, where n is the number of households. These benefits are estimated for three specifications of demand: (1) following Linneman [11], $Q_i = f_i(P_i, P_{c+s}; I, T)$, (2) following Harrison and Rubinfeld [9], $P_i = g_i(Q_i, Q_{c+s}; I, T)$ and (3) following Nelson [13], but where P_i is exogenous, $Q_i = h_i(P_i; I, T)$, $c + s$ stands for complements and substitutes. For each of the three forms, benefits are estimated for the best fit version of the hedonic regression (transformation), $\lambda = \gamma_i = 0.1$.

We limit ourselves to a simple linear functional form of the demand equations to keep the number of comparisons manageable. Its importance is explored in Harrison and Rubinfeld [9] and for at least one data set found to be negligible. From the hedonic equations we estimate benefits as $B_i = (\partial P/\partial Q_i)\Delta Q_i$, where $\partial P/\partial Q_i = b_i P^{(1-\lambda)} Q_i^{(\gamma_i - 1)}$, where b_i is the estimated coefficient from the hedonic equation. For a linear hedonic, $B_i = b_i \Delta Q_i$, which exactly follows the traditional manner used by Ridker and Henning. The benefit estimates are given in Table 2 from *ROOM*, *NLAK* and *DSS*, each of which has a significant coefficient in the hedonic equation. The demand for *DPP* which is not significant in the hedonic is reported for comparison, but those for other insignificant amenities are not. The benefit estimates for these variables changed tremendously with the estimation method. The benefit estimates for *ROOM*, *NLAK*, and *DSS* are stable by comparison. The percentage given below each benefit estimate compares the estimate to that obtained from the demand equation with prices of other housing traits where those prices are calculated from the "best" functional form of the hedonic equation, i.e., two-step, Blomquist–Worley.

For *ROOM*, each of the one-step hedonic methods overestimates the benefits relative to our base case. When income is included in the hedonic

TABLE 2
Benefits of Providing Additional Housing[a]

Estimation method	Housing trait[b] ROOM $/Room	NLAK $/hundred ft.	DSS $/hundred ft.	DPP $/hundred ft.
Ridker–Henning, One-Step				
Linear hedonic with	2996	1.382	0.907	3.423
income	+ 56%	+ 29%	− 43%	+ 18015%
Linear hedonic	2212	2.070	0.904	1.512
$\lambda = \gamma_i = 1.0$	+ 15%	+ 93%	− 43%	+ 7958%
Log–log hedonic	2282	0.504	0.634	0.157
$\lambda = \gamma_i = 0.0$	+ 19%	− 53%	− 60%	+ 726%
Hedonic	2185	0.6391	0.791	0.016
$\lambda = \gamma_i = 0.1$	+ 14%	− 40%	− 50%	− 16%
Two-step				
Blomquist–Worley	1922	1.072	1.593	0.019
$\lambda = \gamma_i = 0.1$				
Blomquist–Worley	1988	0.827	1.452	0.196
$\lambda = \gamma_i = 0.0$	+ 3%	− 23%	− 9%	+ 932%
Nelson	—[c]	1.337	1.622	0.019
$\lambda = \gamma_i = 0.1$	—	+ 25%	+ 2%	+ 0%
Harrison–Rubenfeld	—[c]	1.723	1.660	0.019
$\lambda = \gamma_i = 0.1$	—	+ 61%	+ 4%	+ 0%

[a]The benefit for a trait is calculated for a 5% increase of that housing trait from its mean value with the other traits held constant at their means. The benefits shown are per household.

[b]The percentage reported below each benefit estimate compares the estimate to that obtained using the two-step method we employ where all variables are raised to the 0.1 power.

[c]The benefits would be negative since the own-price coefficient is positive.

as a proxy for omitted neighborhood amenities the overestimate is the greatest, 56%, and when the 0.1 power transformation is used the overestimate is the least, 14%. For the two-step methods the estimates from the 0.1 and log transformations are virtually the same. The benefits are negative if other traits are omitted or the quantities of the traits are included instead of their prices.[4]

For *NLAK*, the one-step hedonic both overestimates and underestimates the benefits depending on the method with the linear hedonic yielding benefits which are 93% too high and the log hedonic yielding benefits 53% too low. Alternate forms of the two-step demand method also yield

[4]If one allows for interactions as well as power transformations, the Nelson and Harrison–Rubinfeld methods yield positive benefits. If an interaction term for ROOM and HPLB is included the former overestimates benefits (by 25%) while the latter gives virtually the same estimate as our base case.

overestimates and underestimates compared to our base case but by smaller amounts. The Harrison–Rubinfeld estimate is 61% more than ours and the log form is 23% less.[5]

For *DSS*, each of the one-step hedonic methods underestimates the benefits relative to our base case. The underestimate is the greatest for the log hedonic, 60% and least for the linear hedonics, 43%. The two-step demand methods all yield approximately the same estimate.[6]

5. CONCLUSIONS

Typically the benefits of urban housing amenities are estimated directly from a hedonic equation which includes the amenities as regressors. However, it is known that such a procedure does not necessarily yield information about consumers' values of the amenities. One estimation method which can reveal the values of the amenities involves two steps where a hedonic housing price equation is estimated and after generating the implicit prices of the amenities, the demand equations are estimated. Paying particular attention to the functional form of the hedonic equation the role of complementary and alternative housing traits in the demand equations we estimate the benefits of several housing traits.

Using a modified Box–Cox procedure we find that the widely used linear form of the housing price hedonic is inferior to the power transformation where all variables are raised to the 0.1 power. The 0.1 transformation is not significantly different from the log form of the hedonic. With implicit prices computed from the best hedonic, demands are estimated for each trait by regressing the quantity of each trait on its own price, prices of other traits, income and taste variables treating the price as exogenous. Benefit estimates from this base case are compared to others. We find that benefits are sensitive to whether the one-step hedonic or two-step demand methods are used, and that the direction of bias varies from trait to trait. For ROOM, the hedonic equation *over*estimates the benefits by 14–56%,

In other work, Harrison and Rubinfeld [8] find that the Ridker–Henning approach causes a 56.7% upward bias in the estimated benefits of clean air compared to their approach where, 33.2% is due to using a linear hedonic equation, 11.2% is due to intramarginal differences in willingness to pay because of income differences and 12.3% is due to intramarginal differences because of differences in clean air consumed. They do not estimate the willingness to pay for housing amenities other than clean air.

[5] For the log form, the demand curve crossed the abscissa at a quantity less than the new level of NLAK meaning that not all of the proximity to the lake has positive value. For smaller amounts of the amenity, the estimates are closer for the log and 0.1 transformation.

[6] An attractive attribute of the two-step estimation method is that it allows one to consider intramarginal valuation. For example, the benefits of a buffer form the bustle of traffic, DSS, varies with income. For those with average income benefits are 1.593 dollars per hundred feet, but the benefits for those with income one standard deviation above and below the mean are 1.869 and 1.317, respectively.

for distance from the bustle of a commercial thoroughfare the hedonic equation *under*estimates the benefits by 43–60%; and for proximity to the lake, the hedonic equation *over*estimates the benefits by 93% for the linear form and *under*estimates by 53% for the log form. We find that benefits do vary with changes in the specification of the demand equation, but the differences appear to be small compared to those between the one-step and two-step estimates. While we feel that these results are probably not peculiar to our particular data set, assumptions or methodology, future work with other housing market data which permit specific econometric tests for exogeniety, and less constrained search techniques for the best functional form of hedonic and demand functions will tell.

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