The Estimation of Demand Parameters in Hedonic Price Models

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This paper shows that the econometric problem of estimating hedonic demand parameters is not a standard identification problem caused by demand-supply interaction, as has been often assumed. Estimation procedures based on this assumption lead to biased results. The hedonic estimation problem is instead caused by the endogeneity of both prices and quantities when households face a nonlinear budget constraint. An instrumental variables solution to this problem is suggested using instruments that exogenously shift the budget constraint.

This paper argues that standard procedures for estimating demand parameters in hedonic price models lead to biased results.[1] A solution to this estimation problem is developed and illustrated.

I. The Rosen-Freeman Approach to Estimating Hedonic Demand Parameters

The first formal contributions to hedonic price theory were made by Court (1941) and Tinbergen (1951, 1956). Tinbergen demonstrated the dependence of hedonic wage functions on the distributions of worker and firm characteristics and the parameters of utility and

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[1] Epple (this issue) presents a similar critique.

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production functions. Given distributional and functional form assumptions, he showed that utility and production function parameters may be recovered from estimated hedonic parameters. Rosen (1974) developed an empirical methodology for estimating demand and supply parameters if no explicit solution for the hedonic price function is available.

Rosen examined how to estimate a consumer marginal bid function for characteristics of a commodity given estimates of the commodity's hedonic price function.[2] This function gives information about consumers because in equilibrium a consumer's marginal bid for a characteristic equals the marginal price of the characteristic at the consumer's chosen commodity type.

Both Rosen (1974) and Freeman (1979) analyzed the estimation problem as a standard identification problem caused by demand and supply interaction. For any vector of observed characteristics $\mathbf{Z}_i$, the hedonic marginal price for a characteristic z_j is an estimate of both the marginal bid for z_j of the household purchasing $\mathbf{Z}_i$ and the marginal offer for z_j of the firm producing $\mathbf{Z}_i$.[3] Linear versions of these marginal bid and marginal offer functions are

$$\frac{\hat{\partial p}}{\partial z_j}(\mathbf{Z}_i) = W_{ij} = B_0 + \mathbf{B}_1'\mathbf{Z}_i + B_2X_i + \mathbf{B}_3'\mathbf{D}_{oi} + e_{ij}, \tag{1}$$

$$\frac{\hat{\partial p}}{\partial z_j}(\mathbf{Z}_i) = G_{ij} = A_0 + \mathbf{A}_1'\mathbf{Z}_i + \mathbf{A}_2'\mathbf{S}_{oi} + u_{ij}, \tag{2}$$

where $(\hat{\partial p}/\partial z_j)(\mathbf{Z}_i)$ is the estimated hedonic marginal price of characteristic z_j; W_{ij} is consumer i's marginal bid for z_j; X_i is consumer expenditure on commodities other than $\mathbf{Z}$; $\mathbf{D}_{oi}$ is a vector of observed demander traits affecting the marginal bid; G_{ij} is firm i's marginal offer price for z_j; $\mathbf{S}_{oi}$ is a vector of observed supplier traits affecting the marginal offer; and e_{ij} and u_{ij} are disturbance terms.[4]

Rosen suggested that this equation system presents a "garden variety identification problem" that can be solved by simultaneous estimation methods, such as two-stage least squares (2SLS). Applying 2SLS to the marginal bid function requires the assumption that individual supplier traits ($\mathbf{S}_{oi}$) are appropriate instruments for the endogenous variables in the marginal bid function ($\mathbf{Z}_i$ and X_i).

Using Rosen's framework, Freeman (1979) suggested that two spe-

[2] Hedonic models assume that only one unit of the commodity is purchased.

[3] The subscript i indexes the household or firm choosing a particular bundle, and j indexes a component of a bundle. In addition, a small z is used for a component of the vector $\mathbf{Z}$.

[4] Rosen's theoretical marginal bid function includes utility. He substitutes income for utility for empirical purposes. But indirect utility also depends on the hedonic. Utility can be eliminated by substituting in the arguments of direct utility: $\mathbf{Z}$, X, and $\mathbf{D}_o$.

cial cases will simplify estimation of marginal bid functions. First, assume that the quantities available of each **Z** are fixed. Freeman argued that the **Z** will then be exogenous, and the marginal bid function is consistently estimated by ordinary least squares (OLS). Second, assume that as many **Z** as desired can be obtained at the same prices. Assume further that the marginal bid functions can be inverted to express quantities $\mathbf{Z}_i$ as functions of marginal prices. Freeman argued that perfectly elastic supply implies that marginal prices are exogenous and therefore that inverse marginal bid functions are consistently estimated by OLS.

II. A Critique of the Rosen-Freeman Approach

The problem with Rosen's approach is that the hedonic estimation problem is not due to demand-supply interaction. An individual consumer's decision cannot affect suppliers in the hedonic model because an individual consumer does not affect the hedonic price function.

There is a hedonic estimation problem but from another source. The nonlinearity of the hedonic price function allows the consumer to endogenously choose both quantities and marginal prices. The resulting econometric problem can be seen by decomposing the disturbance term in the marginal bid equation into an unobserved "tastes" component (D_{ui}) and a purely random component (r_{ij}).[5] Equation (1) becomes

$$W_{ij} = B_0 + \mathbf{B}_1'\mathbf{Z}_i + B_2X_i + \mathbf{B}_3'\mathbf{D}_{oi} + D_{ui} + r_{ij}. \tag{3}$$

Ordinary least squares estimation of (3) will be biased because the household's choice of **Z** and X is correlated with the unobserved tastes in the residual. For example, a household with greater tastes for a characteristic will choose greater quantities of the characteristic. This endogeneity remains in Freeman's first special case. Even if firms cannot change supply, households can still choose among the **Z**.

The estimation problem does not arise because the household's chosen **Z** are on the right-hand side. Suppose equation (3) could be inverted to express quantities as a function of marginal prices. With a nonlinear hedonic, the household's choice of **Z** implies the simultaneous choice of marginal prices. Because marginal prices are endogenous, they are correlated with unobserved tastes in the disturbance. Ordinary least squares estimates of an inverse marginal bid function will be biased. Even with perfectly elastic supply, households can choose marginal prices, and the econometric problem remains.

[5] This purely random component might consist of errors in measuring the marginal price or household optimization errors.

The endogeneity problem emphasized here causes Rosen's suggested instruments for the marginal bid function, individual supplier traits ($\mathbf{S}_o$), to produce biased results because of their correlation with unobserved tastes in the marginal bid function residual. Even if households do not care about individual supplier traits, different suppliers may offer different $\mathbf{Z}$. The household's choice of a $\mathbf{Z}_i$ thus also implies a choice of $\mathbf{S}_{oi}$. The correlation between unobserved tastes and $\mathbf{Z}$ results in a correlation between unobserved tastes and $\mathbf{S}_o$.

For instance, suppose that housing units owned by landlords who are carpenters are better maintained. Households that have greater tastes for maintenance will choose carpenter landlords, even without knowing their landlord's occupation.

The biases in the Freeman-Rosen approach are illustrated in figure 1. Consider two households identical in all observed variables ($\mathbf{Z}$ and $\mathbf{D}_o$) except their chosen z_j. Household 2 has a greater taste for z_j (D_{u2}) than household 1 (D_{u1}) and thus a marginal bid function for z_j that is

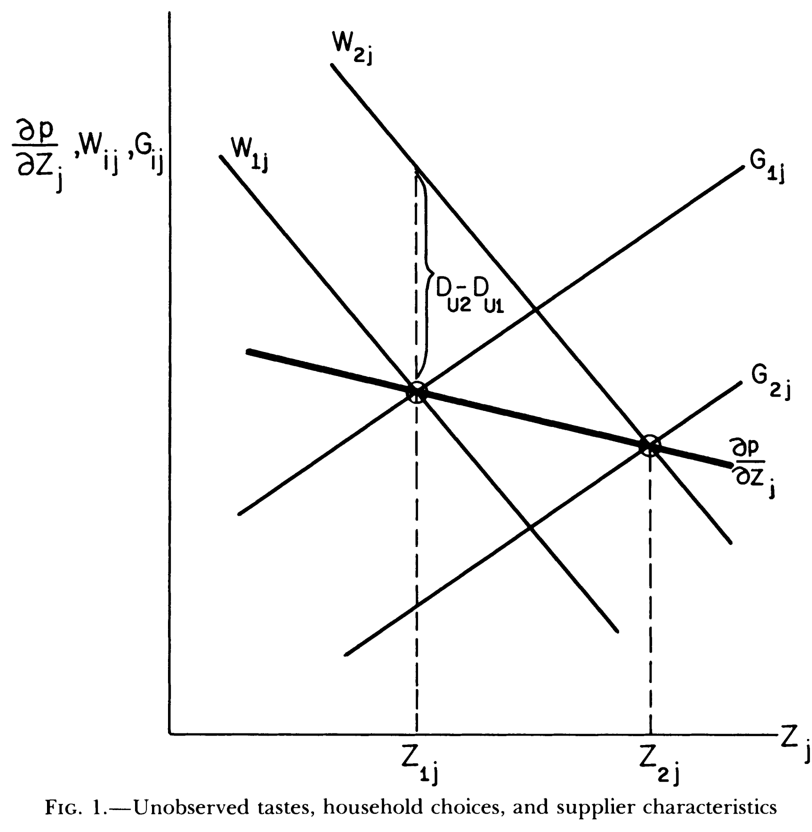

FIG. 1.—Unobserved tastes, household choices, and supplier characteristics

greater by $D_{u2} - D_{u1}$. Because of its greater tastes for z_j, household 2 chooses a higher level of z_j. Hence, unobserved tastes are positively correlated with z_j in this sample of two.

This positive correlation should lead to positive bias in OLS estimates of the common slope of these two consumers' marginal bid functions.[6] In fact, a regression of marginal bids on z_j will result in a straight line through the two observation points. The slope of this line is more positive than the true marginal bid slope. If we estimate the inverse marginal bid function, regressing z_j on the marginal price, the result is the same biased least-squares line.

Finally, consider Rosen's suggested instruments. Figure 1 shows the marginal offer curves of the two suppliers to the households. Suppose the difference between the marginal offer curves was due to a different level of a supplier trait. It is apparent in the figure that this supplier trait will be correlated with unobserved tastes. If Rosen's procedure was applied, z_j could be expressed as a perfect function of supplier traits. The second-stage regression of marginal bids on "fitted values" would again result in the biased line through the observation points.[7]

III. An Alternative Instrumental Variable Approach

Despite the problems with Rosen's instruments, the marginal bid function can be consistently estimated with correct instruments. If the estimation problem is due to unobserved tastes, any variable that exogenously shifts the household budget constraint will be an appropriate instrument because the budget constraint shift is correlated with the household's choices of **Z** and X yet uncorrelated with unobserved tastes. The budget constraint will be exogenously shifted by changes in income[8] and by variables shifting the hedonic function if average tastes do not vary across these shifts.

Consider the following example: estimation of the marginal bid function for "physical condition" of the neighborhood near a house.[9] The data come from the Demand Experiment of the Experimental

[6] This positive bias necessarily holds only if there is just one characteristic; the multiple-characteristic case is more complex.

[7] In this example, the biased estimates approximate the marginal price function. Brown and Rosen (1982) show this result if the data come from one hedonic and no functional restrictions are assumed. The present paper shows that Rosen's approach yields bias under more general conditions.

[8] In a sense, income is in the marginal bid equation in X_i, equal to income minus hedonic expenditure. The constraint relating the income and expenditure coefficients allows income to be an instrument.

[9] See Bartik (1986) for details on the empirical work.

Housing Allowance Program, which involved 3,601 low-income renters in Pittsburgh and Phoenix from 1973 to 1976.

Because the data come from an experiment, excellent instruments are available. Experimental households were randomly assigned to treatment groups. Some groups received subsidies for various percentages of rent, while others received income transfers. Dummy variables for treatment groups are good instruments because they are correlated with household choice of **Z** and X but uncorrelated with tastes.[10]

Plausible instruments are also provided by the city and time period of the observation in housing studies, assuming that the hedonic function varies across cities and time but that unobserved tastes do not. If the city is believed to be a good instrument, then interaction terms between city dummies and demand shifters will also be appropriate instruments. With a nonlinear hedonic function, the marginal price of a characteristic may be greater in city A than in other cities at lower quantities of the characteristics but lower at high quantities. Households with high demand for the characteristic will choose greater quantities in city A than in other cities, and households with low demands will choose lower quantities in city A. City/demand shifter interaction terms will be correlated with **Z** and X but uncorrelated with unobserved tastes. Thus the assumption that the city is uncorrelated with unobserved tastes provides more instruments than one might suppose.

In this example, a semilog functional form was used to estimate hedonic price functions. A separate hedonic price function was estimated for each city, and a time trend was included as a regressor. For treatment group households that received a percentage-of-rent subsidy, the marginal price paid is equal to the hedonic marginal price times (1 − percentage subsidy). Each household's marginal bid for neighborhood physical condition equals the marginal price paid.

The marginal bid for neighborhood physical condition is assumed to depend on the quantity of physical condition, nonhousing expenditure (including any transfers), and demand shifters. The functional form of the marginal bid equation is based on the direct addilog utility function (Quigley 1982). The instruments used for physical condition and nonhousing expenditure include those discussed above: income, treatment group dummies, a time trend, a dummy variable for city, and interaction terms between the city variable and demand shifters.

Table 1 reports estimates of this marginal bid function. The func-

[10] Treatment group assignment is an argument of the marginal bid function if price and income subsidies are ignored in calculating marginal bids and X_i. The appropriate adjustments were made here.

TABLE 1

ESTIMATES OF THE MARGINAL BID FUNCTION FOR PHYSICAL CONDITION OF A NEIGHBORHOOD

Independent Variable	OLS Estimated Coefficients	2SLS Estimated Coefficients
Physical condition of neighborhood	−.001	−1.65
	(−.05)	(−9.05)
Ln(nonhousing expenditure)	.05	.69
	(1.62)	(7.23)
Household size	.034	−.116
	(2.88)	(−3.50)
Age of household head	.015	.020
	(2.17)	(1.19)
$(\text{Age})^2$	-2.1×10^{-4}	-1.3×10^{-4}
	(−2.75)	(−.68)
Black head of household	.061	−1.16
	(1.13)	(−6.09)
Hispanic head of household	−.70	−.97
	(−14.46)	(−7.68)
Female head of household	.17	.28
	(4.58)	(2.95)

NOTE.—The dependent variable is ln(marginal bid). Number of observations is 1,519. *t*-statistics are in parentheses below coefficient estimates.

tion is estimated using both OLS, as proposed by Freeman, and the instrumental variable approach proposed in this paper. The results are substantially different. In particular, the OLS estimate for the coefficient on neighborhood physical condition is greater than the instrumental estimate, consistent with the argument above that OLS estimates are positively biased.

IV. Conclusion

The main point of this paper is that the problem of estimating hedonic demand parameters is caused not by demand-supply interaction but by the endogeneity of both marginal prices and quantities when households face a nonlinear budget constraint. Appropriate instrumental variables for this problem should exogenously shift the hedonic price function; previously proposed instruments do not do so. The practical problem for empirical hedonic research is finding instruments whose exogeneity can be defended with some plausibility.

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[Footnotes]

[7] **On the Estimation of Structural Hedonic Price Models**
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