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Simultaneous Estimation of Hedonic Equations with Unbalanced Data

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INSTITUTE FOR SOCIAL AND ECONOMIC RESEARCH AND POLICY
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Abstract

Hedonic non-market valuation often requires estimating housing and labor market regressions. We show how to accomodate unbalanced data in hedonic regressions. In addition to efficiency gains, the method allows consistent estimation of confidence intervals for amenity values. We illustrate by estimating the implicit price of a temperature increase in urban Brazil.

Key words: hedonic, unbalanced data, seemingly unrelated regression, non-market valuation

JEL Classification: C31, Q51

1 Introduction

Hedonic techniques are commonly used to estimate the implicit price of non-market amenities such as local environmental conditions. The basic model posits that workers are attracted to cities with greater amenities. The influx of workers depresses wages and increases housing rents. To obtain an implicit price, studies typically estimate cross-sectional variations in urban wages or rents attributable to differences in amenities (see Bartik and Smith (1987) and Palmquist (1991) for reviews of this literature). Where migration is possible, it is important to calculate amenities' effects on both rents and wages. Estimates obtained from hedonic wage models alone can overstate the compensation required for living in areas with less desirable amenities, since firms also adjust wages to account for differences in housing prices (Cropper, 1981).

In spite of this potential bias, relatively few studies estimate effects of amenities in both labor and housing markets (Roback, 1982; Blomquist et al., 1988; Srinivasan and Stewart, 2004). Even these, however, estimate labor and housing market equations individually, in what we call separate equation estimation (SEE). Although consistent, SEE is generally less efficient than Zellner's (1962) seemingly unrelated regression (SUR).[1] Moreover, inference on the amenity value drawn from SEE standard errors is not valid, except under the assumption that cross-equation error correlation is zero. Since data from the same observational unit are used in both equations, this assumption is especially restrictive.

A challenge to using SUR in this setting is that standard software routines are designed for balanced data (i.e., an identical number of observations in each equation). In practice, data may be missing variables appearing in one equation. Schmidt (1977) examines several methodologies for estimating a SUR model with unbalanced data. These methods use consistent estimators for the covariance matrix that, while asymptotically equivalent, generate different values in finite samples. Monte Carlo experiments by Schmidt (1977), Baltagi et al. (1989), Hwang (1990), and Im (1994) suggest that the Hocking and Smith (1968) estimator (HS) has efficiency advantages in finite samples. To our knowledge, however, this method has not yet been applied using real data. Thus, there has been no research indicating the practical importance of these issues in an actual problem, hedonic or otherwise.

The main contributions of this paper are i) to show how the HS framework can be adapted for estimation of hedonic models, and ii) indicate practical implications of using SUR versus SEE methods. Building a data set that matches household surveys with local climate characteristics, we estimate the implicit price of a temperature change in urban Brazil. In our application, SUR generates a noticeable, yet modest, reduction in standard errors; point estimates differ between the two methods, but not significantly; and SEE generates a confidence interval for the implicit price of the amenity that is too narrow in the presence of cross-equation correlation.

[1] SEE and SUR are equivalent if cross-equation disturbances are uncorrelated or all explanatory variables are identical in both equations.

2 Theoretical Model

We adapt the standard inter-urban location equilibrium model (Roback, 1982; Blomquist et al., 1988). Cities differ by exogenous endowments of amenity a. A representative individual earns income from selling one unit of labor. Let h and q respectively indicate the quantity consumed of housing and a composite numeraire good. Being freely traded, the price of q is the same everywhere, but prices of labor w and housing p vary by location, depending on a.

The individual chooses a consumption bundle and location to maximize utility $U(q, h; a)$ subject to budget constraint $w(a) - p(a) \cdot h - q$. The indirect utility function $V(w, p; a)$ is then a function of wages, housing prices, and amenities. With costless migration, equilibrium utility is equal across all cities, $V(w(a_j), p(a_j); a_j) = \bar{u}$ for each city j. This condition, combined with Roy's identity, allows derivation of the amount of wealth necessary to compensate the individual (the implicit price) for a small change in the amenity:

$$\frac{\partial V/\partial a}{\partial V/\partial w} = h \cdot \frac{dp(a)}{da} - \frac{dw(a)}{da}. \tag{1}$$

From the demand side alone, one would expect $dp/da > 0$ and $dw/da < 0$. In general equilibrium, however, the amenity may also affect production. As noted by Roback (1982), if the amenity reduces production costs, the equilibrium effect of its marginal increase would be to increase the cost of real estate, while its overall effect on wages would be ambiguous. Conversely, an amenity that increases costs reduces wages and has an ambiguous effect on property values.

3 Empirical Model

Using the common semi-log specification, we formulate a reduced-form system of housing and wage equations:

$$\mathbf{y} = \mathbf{X}\boldsymbol{\beta} + \boldsymbol{\varepsilon}, \text{ where}$$

$$\mathbf{y} = \begin{bmatrix} \mathbf{y}_1 \\ \mathbf{y}_2 \end{bmatrix}, \qquad \mathbf{X} = \begin{bmatrix} \mathbf{A}_1 & \mathbf{B} & \mathbf{0} & \mathbf{0} \\ \mathbf{0} & \mathbf{0} & \mathbf{A}_2 & \mathbf{D} \end{bmatrix},$$

$$\boldsymbol{\beta} = \begin{bmatrix} \boldsymbol{\beta}_1 \\ \boldsymbol{\beta}_2 \end{bmatrix}, \text{ and} \qquad \boldsymbol{\varepsilon} = \begin{bmatrix} \boldsymbol{\varepsilon}_1 \\ \boldsymbol{\varepsilon}_2 \end{bmatrix}.$$

Each row corresponds to an observation. Here, $\mathbf{y}_1$ is a vector of log housing expenditures, $\mathbf{y}_2$ is a vector of log wages, $\mathbf{A}_1$ and $\mathbf{A}_2$ are matrices of L city amenities, $\mathbf{B}$ is a matrix of M residential characteristics, $\mathbf{D}$ is a matrix of N worker demographic characteristics, $\boldsymbol{\beta}_1$ and $\boldsymbol{\beta}_2$ are parameter vectors of dimensions $L + M$ and $L + N$, respectively, and $\boldsymbol{\varepsilon}_1$ and $\boldsymbol{\varepsilon}_2$ are idiosyncratic error vectors. A data point in $\mathbf{y}_1$, $\mathbf{y}_2$, $\mathbf{A}_1$, $\mathbf{A}_2$, $\mathbf{B}$, and $\mathbf{D}$ corresponds to each individual survey respondent. Due to missing housing expenditure responses, in our sample, there are unequal observations in the two equations. Accordingly, T denotes the number of observations in the housing equation ($\mathbf{y}_1$, $\mathbf{A}_1$, $\mathbf{B}$ and $\boldsymbol{\varepsilon}_1$), and $T+E$ denotes the number in the wage equation ($\mathbf{y}_2$, $\mathbf{A}_2$, $\mathbf{D}$ and $\boldsymbol{\varepsilon}_2$).

We assume $\boldsymbol{\varepsilon}$ is i.i.d. and uncorrelated with the regressors. Its covariance matrix is

$$\operatorname{cov}[\boldsymbol{\varepsilon}] = \boldsymbol{\Omega} = \begin{bmatrix} \boldsymbol{\Sigma} \otimes \mathbf{I}_T & \mathbf{0} \\ \mathbf{0} & \sigma_{22}\mathbf{I}_E \end{bmatrix}, \text{ where}$$

$$\boldsymbol{\Sigma} = \begin{bmatrix} \sigma_{11} & \sigma_{12} \\ \sigma_{12} & \sigma_{22} \end{bmatrix},$$

and $\mathbf{I}$ is the identity matrix with dimensions indicated by the subscript. The SEE estimator for $\hat{\boldsymbol{\beta}}_{SEE}$, is then equivalent to the system ordinary least squares (OLS) estimator:

$$\hat{\boldsymbol{\beta}}_{SEE} = \hat{\boldsymbol{\beta}}_{OLS} = (\mathbf{X}'\mathbf{X})^{-1}(\mathbf{X}'\mathbf{y}).$$

A consistent estimator for the asymptotic variance of $\hat{\boldsymbol{\beta}}_{OLS}$ is

$$\text{Av}\hat{\text{a}}\text{r}\left(\hat{\boldsymbol{\beta}}_{OLS}\right) = (\mathbf{X}'\mathbf{X})^{-1}\left(\mathbf{X}'\hat{\boldsymbol{\Omega}}\mathbf{X}\right)(\mathbf{X}'\mathbf{X})^{-1},$$

where $\hat{\boldsymbol{\Omega}}$ consistently estimates $\boldsymbol{\Omega}$ (see, e.g., Wooldridge, 2002). Let $\mathbf{e}_i$ denote the OLS residuals from equation $i = 1, 2$. SEE implicitly calculates $\text{Av}\hat{\text{a}}\text{r}\left(\hat{\boldsymbol{\beta}}_{OLS}\right)$ using

$$\begin{aligned} \hat{\boldsymbol{\Omega}}_{SEE} &= \begin{bmatrix} \hat{\boldsymbol{\Sigma}}_{SEE} \otimes \mathbf{I}_T & \mathbf{0} \\ \mathbf{0} & \mathbf{e}_2'\mathbf{e}_2\mathbf{I}_E/(T+E) \end{bmatrix}, \text{ where} \\ \hat{\boldsymbol{\Sigma}}_{SEE} &= \begin{bmatrix} \mathbf{e}_1'\mathbf{e}_1/T & 0 \\ 0 & \mathbf{e}_2'\mathbf{e}_2/(T+E) \end{bmatrix}. \end{aligned}$$

This estimator is consistent if there is no cross-equation correlation ($\sigma_{12} = 0$).

Let us partition $\mathbf{e}_2$ as

$$\mathbf{e}_2 = \begin{bmatrix} \mathbf{e}_2^* \\ \mathbf{e}_2^0 \end{bmatrix},$$

where $\mathbf{e}_2^*$ contains the first T elements of $\mathbf{e}_2$ (i.e., residuals from individuals appearing in both equations) and $\mathbf{e}_2^0$ contains the remaining E residuals. The feasible generalized least squares procedure suggested by Schmidt (1977) calculates the SUR estimator, $\hat{\boldsymbol{\beta}}_{SUR}$, using the HS covariance estimator, $\hat{\mathbf{\Omega}}_{HS}$, as follows:

$$\begin{aligned}
\hat{\boldsymbol{\beta}}_{SUR} &= \left(\mathbf{X}'\hat{\mathbf{\Omega}}_{HS}^{-1}\mathbf{X}\right)^{-1}\left(\mathbf{X}'\hat{\mathbf{\Omega}}_{HS}^{-1}\mathbf{y}\right), \text{ where} \\
\hat{\mathbf{\Omega}}_{HS} &= \begin{bmatrix} \hat{\mathbf{\Sigma}}_{HS}\otimes\mathbf{I}_T & \mathbf{0} \\ \mathbf{0} & \mathbf{e}_2'\mathbf{e}_2\mathbf{I}_E/\left(T+E\right) \end{bmatrix}, \text{ and} \\
\hat{\mathbf{\Sigma}}_{HS} &= \begin{bmatrix} \frac{\mathbf{e}_1{}'\mathbf{e}_1}{T} - \frac{E\left(\left(\mathbf{e}_1{}'\mathbf{e}_2^*\right)/\left(\mathbf{e}_2^{*\prime}\mathbf{e}_2^*\right)\right)^2\left(\mathbf{e}_2^{*\prime}\mathbf{e}_2^*/T-\mathbf{e}_2^{0\prime}\mathbf{e}_2^0/E\right)}{T+E} & \frac{\left(\mathbf{e}_1'\mathbf{e}_2^*\right)\left(\mathbf{e}_2'\mathbf{e}_2\right)}{\mathbf{e}_2^{*\prime}\mathbf{e}_2^*(T+E)} \\ \frac{\left(\mathbf{e}_1'\mathbf{e}_2^*\right)\left(\mathbf{e}_2'\mathbf{e}_2\right)}{\mathbf{e}_2^{*\prime}\mathbf{e}_2^*(T+E)} & \mathbf{e}_2'\mathbf{e}_2/\left(T+E\right) \end{bmatrix}.
\end{aligned}$$

The asymptotic variance of $\hat{\boldsymbol{\beta}}_{SUR}$ is then consistently estimated by (Wooldridge, 2002)

$$\mathrm{Av\hat{a}r}\left(\hat{\boldsymbol{\beta}}_{SUR}\right) = \left(\mathbf{X}'\hat{\mathbf{\Omega}}_{HS}^{-1}\mathbf{X}\right)^{-1}.$$

Unlike the SEE model, this variance estimator is consistent under arbitrary cross-equation correlation.

In sum, regardless of the validity of the assumption of zero cross-equation correlation of errors, SEE consistently estimates wage and housing price differentials and, by Eq. (1), the amenity's implicit price. SEE does not allow consistent calculation of standard errors for the implicit price if the zero correlation assumption is violated.[2] This shortcoming is unfortunate for hedonic models since obtaining the implicit price is often the primary motivation for the analysis, and one would like to construct valid confidence intervals around its point estimate. SUR does not suffer from this problem and has the advantage of asymptotic efficiency (Wooldridge, 2002). Further, $\hat{\boldsymbol{\beta}}_{SUR}$ and $\mathrm{Av\hat{a}r}\left(\hat{\boldsymbol{\beta}}_{SUR}\right)$ are easy to calculate using the HS estimator, and straightforward to program in a matrix-based software such as GAUSS.

4 Data and Results

Data on individual demographic and residential characteristics come from the 1995 Brazilian National Household Sample Survey. Each observation corresponds to a single-family head of household, age 18 to 65, in eleven metropolitan areas.[3] Lack of information prevented imputation of rents for home owners. Our final sample is consequently unbalanced, with 18,943 workers and 4,199 rental residences. We use a Brazilian health ministry DATASUS database, and the Instituto Brasileiro de Geografia e Estatística (IBGE) Municipality Database to construct population density, distances from São Paulo and Brasilia, and metropolitan

[2]Since by Eq. (1) the implicit price is a function of housing and wage differentials, its standard error depends on their estimated covariance.

[3]These areas are Belem, Belo Horizonte, Brasilia, Curitiba, Fortaleza, Goiania, Porto Alegre, Recife, Rio de Janeiro, Salvador, and São Paulo.

fixed effects. Climate data come from the University of East Anglia Climate Research Unit Global 0.5° Monthly Time series, Version 2. We use the Data Library of the International Research Institute for Climate and Society (IRI) to construct thirty-year average monthly temperature and precipitation variables. GIS data provided by IBGE allow georeferencing of climate variables by municipality.

Table 1 presents results for average temperature, the amenity of interest. Monetary values are in 1995 Reais (R$). Consistent with Im (1994), estimates for the two models differ most in the equation with fewer observations, housing expenditure. Efficiency gains from SUR are also most pronounced in this equation. Implicit prices and differentials are calculated at the mean housing expenditure and wage. Although the SEE implicit price for a 1°C increase is about 10 percent higher than that calculated by SUR, the difference is not statistically significant. The same is true for the differences in wage and price differentials. For both models, the implicit price and wage and rent differentials suggest that preferences and production in urban Brazil are consistent with the hypothesis that a temperature increase is an amenity (implicit price is positive) that reduces productivity (wage differential is negative and housing differential is negative/indeterminate).

An important shortcoming of SEE is that, in the presence of cross-equation correlation (the HS estimate of the correlation coefficient between the two equations is 0.24), it provides a confidence interval for the implicit price that is too narrow. By assuming no correlation, SEE rejects the null hypothesis that the marginal amenity value is zero at less than 95 percent significance, while SUR rejects only at less than 90 percent.

5 Conclusion

Simultaneous estimation of hedonic equations results in efficiency gains and enables consistent estimation of confidence intervals for marginal amenity values compared with estimating each equation separately. We show that it is straightforward to estimate hedonic systems even with unbalanced data. In our application, cross-equation correlation is small, resulting in statistically similar point estimates. This correlation is large enough to affect inference, however. Using an inconsistent covariance matrix, estimating equations separately identifies a statistically significant (at 95 percent) positive welfare effect of a temperature increase for urban residents of Brazil, whereas the consistent SUR method does not.

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Table 1: Parameter estimates, housing and wage differentials, and full implicit price of a change in average annual temperature in urban Brazil

	SEE Model			SUR Model		
Estimate (unit)	Housing equation[a,b]	Wage equation[b,c]	Full implicit price[d]	Housing equation[a,b]	Wage equation[b,c]	Full implicit price[d]
Parameter	-0.0179	-0.0759***		-0.0397	-0.0776***	
(%/°C)	(0.0627)	(0.0286)		(0.0607)	(0.0286)	
Differential[e]	-34.51	-410.69	376.18**	-76.57	-419.71	343.14*
(R$/°C)	(120.87)	(154.75)	(196.36)[f]	(117.40)	(154.75)	(203.06)
R^2	0.48	0.52				
observations	4,199	18,943		4,199	18,943	

Notes: Standard errors in parentheses. *P-value < 0.10,**P-value < 0.05, ***P-value < 0.01. [a]Includes dummies for housing characteristics (flush toilet, filtered water, 1,2,3,3+ bedrooms, with apartment and house interactions). [b]Includes other amenities (population density, March and August precipitation, distances from São Paulo and Brasilia, and regional fixed effects). [c]Includes demographic variables (work experience, experience squared, and dummies for level of education, race, gender,and occupation). [d]Calculated from Eq. (1). [e]Calculated with means of annual rent (R$1,927.80) and wage (R$5,410.94). [f]Assumes zero cross-equation correlation.

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