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UNOBSERVABLES IN CONSUMER CHOICE: RESIDENTIAL ENERGY AND THE DEMAND FOR COMFORT

BY

JOHN M. QUIGLEY

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UNOBSERVABLES IN CONSUMER CHOICE: RESIDENTIAL ENERGY AND THE DEMAND FOR COMFORT*

by
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ABSTRACT

This paper describes a model of the consumption of residential energy in dwellings. The model distinguishes between attributes of housing that provide direct benefits to consumers and attributes that serve as inputs in the production of final goods, for example the thermal comfort of dwellings. A number of consumption and production relationships are estimated jointly using data from the Annual Housing Survey, and then used to calculate the effects of changes in energy prices on the consumption of housing, residential energy and other goods. The analysis suggests that the adjustment process within the housing market permits a great deal of substitution in response to energy price changes.

I. INTRODUCTION

The commodities purchased by households include some goods which provide direct and immediate satisfaction and other goods which are best viewed as inputs into the production of household satisfaction. Residential housing includes commodities which fall into both categories. The size and arrangement of rooms, bathrooms, and yard space, for example, provide direct consumer satisfaction. In contrast, furnaces, air conditioners and insulation are inputs which, when combined with fuel and energy inputs (and local climatic conditions) produce the thermal comfort enjoyed in final consumption. Of course, some attributes of housing may be included in both categories; for example, the vintage of a dwelling may proxy the obsolescence (or charm) of a residence as well as the thermal properties of the structure.

In transactions in the housing market, both kinds of commodities are jointly purchased and are jointly priced. The decision to purchase a particular dwelling involves the selection of a vector of attributes -- some objects of final consumption and some inputs into "home production" -- at a composite price. The "hedonic" character of attribute prices thus provides signals affecting both the selection of final consumption commodities and the substitution of input commodities in home production. This paper models the role of these joint prices in affecting the consumption and production activities of households.[1]

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[1] A number of studies have examined the demand for residential energy viewing energy as a final consumption good. See, for example, Khazzoom (1986) and the literature cited therein. See, also Fujii and Mak (1984). Other recent work, e.g., Quigley (1984, 1985) has considered the derived demand for residential energy as an input to the production of housing services. None of this prior work has considered the dual role of energy in terms of its

The methodological innovation in this paper is the exploitation of the nonlinear hedonic prices observed in the housing market to estimate the parameters of a simple model of home production and utility maximization.[2] Nonlinear hedonic prices have been exploited primarily in the context of demand estimation, so that the production side of our model marks a different application of the hedonic approach.[3] Besides its methodological interest, the paper describes a complete model of the consumption of residential energy in dwellings. It provides estimates of the effect of changes in energy prices on the consumption of housing, residential energy and other goods. The model is estimated using a rich cross-sectional sample of some 5,900 owner occupied dwelling units in the United States available for 1980 through the Annual Housing Survey.

The paper is organized as follows. Section II presents the theoretical description of the model. Section III considers empirical issues, and the results are summarized in Section IV and V. In Section VI we exercise the complete model and draw some implications.

II: THE MODEL

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direct impact on consumption and its indirect impact through the production of housing services.

[2] The use of hedonic methods to evaluate the attributes of housing has become widespread, especially after the publication of Rosen (1974). Some examples include Harrison and Rubinfeld (1975) Milon, et al. (1979), and reviews by Freeman (1979) and Follain and Jimenez (1985).

[3] For a general discussion of the problems of demand estimation when budget constraints are nonlinear, see Hausman (1985). One particularly interesting application in the context of housing markets is given by Venti and Wise (1984).

When a household makes a transaction in the housing market, it jointly purchases a wide collection of attributes H at a single price -- a monthly rent or a purchase price. Without loss of generality, we can partition the vector of attributes into several groups: those providing direct consumer satisfaction, h_{1i}; those that are inputs into the production of the comfort enjoyed in dwellings, h_{2j}; and, locational and spatial or climatic variables, W_k. From observations on the market value of single family housing, or its annual rental value,[4] a hedonic price function V can be estimated:

(1) $V = \nu(H) = \nu(h_{1i}, h_{2j}, W_k)$,

and the marginal prices of housing attributes,

(2) $P_{mn} = \partial\nu/\partial h_{mn}$

can be inferred. Consumers may choose housing attributes at different marginal prices because their incomes or tastes vary. Households of identical tastes and incomes, however, will consume different components of the housing commodity only if they are fully compensated for differences in housing consumption by differences in housing prices.

Consider those attributes of housing which are inputs to the production of comfort in dwellings. Differences in the relative prices of these commodities will lead to substitution among the vector of inputs and to substitution between

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[4] The use of rental values simplifies the notation without loss of generality. However, implicit in our discussion is the assumption that capitalization rates do not vary among locations.

energy and structural attributes in producing comfort in a dwelling. Comfort is, however, unobservable. Nevertheless, if we observe the physical quantities of these structural inputs, and their marginal prices and household expenditures on energy, it may be possible to estimate the parameters of the production function for comfort.

For example, assume that "purchased comfort" (C) is produced by combining energy inputs (E, in BTU's at unit price P_E) with structural characteristics of housing in a constant-returns-to-scale (CRS) technology.[5]

(3) $C = f(h_{2i}, E)$

Minimizing household costs, subject to the production constraint yields

(4) $$\frac{\partial f/\partial h_{mn}}{\partial f/\partial E} = \frac{P_{mn}}{P_E}$$

If the parameters of the function f can be estimated from (4), the quantity of C and its competitive price P_c can then be calculated.

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[5] Purchased comfort will be a function of expenditures that individuals make on items such as heating systems, insulation, and weatherproofing as well as expenditures on energy itself.

This amalgam of structural and energy inputs is, in turn, combined with attributes of the climate (using a CRS technology) to produce the comfort (D) that is enjoyed directly by consumers inside their dwellings:[6]

(5) $D = g(C,W_k)$

This production relationship may also be estimated without observing dwelling unit comfort directly. From the first-order conditions,

(6) $$\frac{\partial g/\partial C}{\partial g/\partial W_k} = \frac{P_c}{P_k}$$

where P_k is the marginal price of the climate variables.

If the parameters of g can be estimated from Equation 6, the quantity of dwelling unit comfort consumed by each household D and its competitive price P_D, a function of P_C and P_W, can be computed. Thus the consumers' problem can be described as maximizing utility from those housing commodities that provide direct satisfaction, dwelling unit comfort, and other goods (X, at a price of one):

(7) $U = U\ (h_{1i},\ D,\ X)$

subject to the budget constraint,

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[6] One would expect, for example, that homes located in a mild climate year-round would generate more comfort than homes located in a highly variable climate.

(8) $y = X + P_E E + \nu(H)$,

where y is income.

Again, the first-order conditions for this utility maximization problem involve the marginal prices from the hedonic function. In particular, since the marginal prices vary for each individual in the sample, it may be possible to estimate the first-order conditions in Equation (9) directly.

$$(9) \quad \frac{\partial U/\partial h_{1i}}{\partial U/\partial X} = P_{1i} \qquad i = 1,2,\ldots,I$$

$$\frac{\partial U/\partial D}{\partial U/\partial X} = P_D$$

The hedonic relationship, exogeneous to the individual, serves two roles in this model. First, it signals how producers may combine housing attributes, climate conditions and energy inputs optimally to produce the comfort enjoyed in dwelling units. Second, it signals how consumers may substitute across housing commodities, comfort and other goods in the process of utility maximization. The nonlinearity of the budget constraint implies that unit prices are functions of the level of consumption of all commodities.

Except in special cases, the hedonic price relationship by itself provides no information about the production or utility functions. In this analysis we take the price function and the unit price of residential energy to be exogeneous, and we assume specific functional forms for the utility and production relationships. Together this structure is sufficient to identify the parameters governing substitution in production and consumption.

III. THE DATA AND THE HEDONIC FUNCTION

The model of production and consumption is estimated sequentially using information available through the Annual Housing Survey. Our sampling frame includes the 1980 national cross-sectional sample of single detached owner-occupied non-farm dwellings. From this sample of 18,000 units, we selected most of the units located in 25 of the 28 SMSA's included in the Bureau of Labor Statistics (BLS) survey of prices and living costs in 1980.[7] From unpublished BLS data we were able to obtain the unit prices of energy (P_E, in dollars per BTU) for 1980.[8] From the National Weather Service, we obtained two measures of the climatic conditions in each metropolitan area: the number of heating degree days in 1980 (W_1) and the number of cooling degree days (W_2).

Table 1 reports summary measures of the information on the 5,900 dwelling units in the sample. Nine measures of the size and quality of dwellings are available. The number of rooms, bathrooms and garages is available, together with the vintage (year built) of each dwelling. The average dwelling in the sample is 30 years old, has about six and a half rooms, one and a half bathrooms and a garage. The neighborhood surrounding each dwelling is evaluated on a scale of one ("poor") to four ("excellent"). The average neighborhood quality is 3.5. In addition, three dummy variables report the presence of adequate

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[7] The three excluded SMSA's were Honolulu, Anchorage, and Northeast Pennsylvania. From observations in the remaining 25 SMSA's, a total of 1,047 dwellings and households were excluded, due to missing or incomplete data.

[8] The BLS provided unpublished monthly prices for electricity, gas, and fuel oil. We averaged these for 1980, converted them to dollars per thousand BTU, and weighted them by SMSA fuel usage to estimate the unit price, P_E.

TABLE 1

Summary Information
Single Detached Owner Occupied Housing
(Annual Housing Survey, 1980)

Variable	Mean Value	Standard Deviation
Size and Quality Measures: h_{1i}		
h_{11}: Vintage (year built)	1955.380	12.567
h_{12}: Baths (number)	1.513	0.439
h_{13}: Rooms (number)	6.429	1.565
Garages (1=yes)	0.826	--
Privacy (1=no)	0.034	--
Vermin (1=no)	0.922	--
Neighborhood (4=excellent)	3.465	0.622
Abandonment (1=no)	0.980	--
Heating, Cooling and Structural Measures: h_{2j}		
h_{21}: Basement (1=yes)	0.646	--
h_{22}: Central Air Conditioner (1=yes)	0.316	--
h_{23}: Room Air Conditioner (1=yes)	0.299	--
h_{24}: Warm Air Furnace (1=yes)	0.731	--
h_{25}: Steam/Hot Water Furnace (1=yes)	0.162	--
h_{26}: Floor/Wall Furnace (1=yes)	0.075	--
h_{27}: Radiators in All Rooms (1=yes)	0.865	--
h_{28}: Cracks (1=no)	0.976	--
Climate Measures: W_k		
Hot Weather: W_1 (1000/degree days)	0.001	0.949
Cold Weather: W_2 (1000/degree days)	0.003	4.796
Housing Value ($ thousands)	77.790	50.429

5880 observations on dwellings

privacy, vermin or a public health menace, and abandoned or boarded-up buildings nearby.

Eight dummy variables describe the thermal properties of these dwellings. Two dummy variables signify central or room air conditioning, while four other dummy variables describe the heating system; h_{24} has a value of one for dwellings served by a central warm air furnace with room ducts, and h_{25} has a value of one for dwellings with a steam or hot water system; h_{26} signifies heating systems with a floor, wall or pipeless furnace in one or more rooms; and h_{28} has a value of one if all rooms are served by hot air ducts, registers, radiators, or room heaters. Finally, a dummy variable describes the presence of a basement; another signifies the presence of cracked walls, ceilings or floors. The table also reports the average market value (self reported) of the sampled dwellings, about $78,000.

The hedonic function is estimated using an extension of the Box-Cox method.[9] We assume that the market price relationship is of the form

$$(1') \quad V^{(\lambda)} = \Sigma\, \alpha_i\, h_{1i}^{(\lambda)} + \Sigma\, \alpha_j\, h_{2j}^{(\lambda)} + \Sigma\, \alpha_k\, W_k^{(\lambda)} + \xi,$$

where the α's are parameters, (λ) is defined as the transformation

$$(1'') \quad V^{(\lambda)} = \begin{cases} (V^{\lambda} - 1)/\lambda & \lambda \neq 0 \\ \log V & \lambda = 0 \end{cases}$$

and ξ is a random disturbance.

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[9] See Box and Cox (1964) or, for a more recent discussion, Spitzer (1982).

Table 2 reports the parameters of the hedonic price relationship estimated by the maximum-likelihood method. The coefficients of eight of the nine size and quality measures are significant, as are those of seven of the eight heating, cooling, and structural measures. In addition, the coefficients on the variables measuring the severity of climate are highly significant. The estimated value of the "Box-Cox parameter" λ is rather small, -0.1, but is significantly different from zero ($x^2 = 3.2$) and one ($x^2 = 6.1$).

Column 4 presents the mean marginal price of each of these attributes, i.e., the average value of the derivative of the estimated hedonic function evaluated at the values of the other variables for each observation. Column 5 lists the standard deviation of these estimated prices. The estimates imply that an additional room is worth \$5,500, and a bathroom is worth \$17,000. Ceteris paribus, a house ten years newer would sell for \$3,900 more. The estimated values of the heating and cooling characteristics of the dwelling are plausible. Compared to an unheated dwelling, one with a warm air furnace is worth an additional \$9,800. A steam/hot water or pipeless heating system is worth an additional \$8,600 to \$9,300. Finally, the results imply that dwellings located in milder climates are substantially more expensive than those located in warm or cold climates, other things being equal.

IV. THE HOUSEHOLD PRODUCTION RELATIONS

The prices reported in Table 2 provide signals to households in their roles as producers, combining housing attributes and energy to produce "purchased comfort" C, and combining "purchased comfort" and climatic attributes to produce the interior comfort of dwellings, D. We assume that purchased comfort can be produced by substituting among the eight structural conditions, the vintage of

TABLE 2

Hedonic Price Relationship and
Unit Prices of Housing Attributes
(Annual Housing Survey, 1980)

$$V^{(\lambda)} = [\Sigma\alpha_i h_i^{(\lambda)} + \alpha_k W_k^{(\lambda)}]$$

Variable	Coefficient	t-ratio	Mean Marginal Price, $\partial V/\partial h$	Standard Deviation of Marginal Price
Size and Quality Measures: h_{1i}				
h_{11}:Vintage (year built-1900)/10	0.115	10.14	$ 3875/decade	$1701
h_{12}:Baths (number)	0.124	15.76	17206/bath	6160
h_{13}:Rooms (number)	0.194	19.08	5505/room	2330
Garages (1=yes)	0.047	9.22		
Privacy (1=no)	0.001	0.10		
Vermin (1=no)	0.028	4.07		
Neighborhood (4=excellent)	0.058	18.16		
Abandonment (1=no)	0.136	10.25		
Heating, Cooling and Structural Measures: h_{2j}				
h_{21}:Basement (1=yes)	0.027	5.3	5915/house	2820
h_{22}:Central AC (1=yes)	0.059	10.91	12800/house	6102
h_{23}:Room AC (1=yes)	0.009	1.79	1891/house	901

TABLE 2 Continued...

Hedonic Price Relationship and
Unit Prices of Housing Attributes
(Annual Housing Survey, 1980)

$$V^{(\lambda)} = [\Sigma\alpha_i h_i^{(\lambda)} + \alpha_k w_k^{(\lambda)}]$$

Variable	Coefficient	t-ratio	Mean Marginal Price, ∂V/∂h	Standard Deviation of Marginal Price
h_{24}:Furnace: Warm Air (1=yes)	0.045	4.13	9780/house	4662
h_{25}:Steam/Hot Water (1=yes)	0.084	7.12	18393/house	8768
h_{26}:Floor/Wall (1=yes)	0.087	6.73	19056/house	9084
h_{27}:Radiators in All Rooms (1=yes)	0.019	2.71	4160/house	1983
h_{28}:Cracks (1=no)	0.008	.68	1809/house	862
Climate Measures:W_k				
Hot Weather:W_1 (1000/degree days)	0.048	27.43	5046/st dev	2886
Cold Weather:W_2 (1000/degree days)	0.042	27.59	5476/st dev	5112
Intercept	6.007	93.69		
λ	-0.10			
R^2	.48			
R^2 in original space	.65			

5880 observations on dwelling units

the dwelling, and units of purchased energy. Specifically, we assume a production relationship with a constant elasticity of substitution between the vintage of dwellings and the quantity of energy in the production of purchased comfort, but where the distribution ratio varies with the heating, cooling, and structural characteristics of dwellings, i.e.,

$$(3') \quad C = [\beta_o \, (\pi \, \beta_i^{\,h_{2i}}) \, h_{11}^{\,-\delta} + E^{-\delta}]^{-1/\delta}$$

Under these assumptions, the first-order conditions for output maximization, subject to a budget constraint are, after slight rearrangement:

$$(4') \quad \log \frac{P_{11} \, h_{11}}{P_E \, E} = \frac{\log \beta_o}{\delta+1} + \Sigma \, \frac{h_{2i} \, \log \beta_i}{\delta+1} + \frac{\delta}{\delta+1} \, \frac{P_{11}}{P_E}$$

Table 3 presents regression estimates of the parameters of equation (4') based upon the 5,880 households and dwellings in the sample.[10] The coefficients of all variables are highly significant. The elasticity of substitution is rather low, 0.143, suggesting that it is quite difficult to substitute energy inputs for vintage in the production of comfort. The results in Table 3 yield the production function for comfort (C) and its competitive marginal cost (P_c):

[10] This equation was estimated using ordinary least-squares, and assumes an additive normal disturbance term.

TABLE 3

Purchased Comfort (C) Produced from Housing Vintage (h_{11}),
Structural Characteristics (h_{2i}) Energy (E) Inputs

$$C = [\beta_o (\pi \beta_i^{h_{2i}}) h_{11}^{-\delta} + E^{-\delta}]^{-1/\delta}$$

First order condition:

$$\log \frac{P_{11} h_{11}}{P_E E} = \frac{\log \beta_o}{\delta+1} + \Sigma \frac{h_{2i} \log \beta_i}{\delta+1} + \frac{\delta}{\delta+1} \frac{P_{11}}{P_E}$$

Parameter	Estimated Value	t-ratio
Intercept: $\log \beta_o/(\delta+1)$	0.544	5.81
Dummies: $\log \beta_i/(\delta+1)$		
h_{21}:Basement	-0.233	17.11
h_{22}:Central Air Conditioning	-0.149	9.84
h_{23}:Room Air Conditioning	-0.166	11.04
h_{24}:Warm Air Furnace	-0.152	4.30
h_{25}:Steam/Warm Air	-0.397	10.46
h_{26}:Floor/Wall	0.245	5.88
h_{27}:Radiators in All Rooms	0.088	3.92
h_{28}:No Cracks	0.252	6.44
$\delta/(\delta+1)$	0.857	63.31
R^2	0.526	

5880 Observations on first-order conditions

$$(10)\ C = [\{45.44(.195^{h21})(.353^{h22})(.311^{h23})(.345^{h24})(.062^{h25})(55.70^{h26})(1.852^{h27})(5.846^{h28})\}h_{11}^{-6.01} + E^{-6.01}]^{-1/6.01}$$

$$= [\{\sigma\}\ h_{11}^{-6.01} + E^{-6.01}]^{-1/6.01}$$

$$(11)\ P_c = [\{\sigma\}^{0.143} P_{11}^{0.857} + P_E^{0.857}]^{1.166}$$

Equations (10) and (11) permit us to compute the quantity of purchased comfort and its price to be computed for each observation in the sample.

This purchased comfort, C, is combined with local climatic conditions to produce the interior comfort (D) enjoyed by residents in their dwellings. Again, we assume the production relationship is CES, i.e.,

$$(5')\ D = [\gamma_1\ W_1^{-\varepsilon} + \gamma_2\ W_2^{-\varepsilon} + C^{-\varepsilon}]^{-1/\varepsilon}.$$

Efficient household production implies two first-order conditions which can be transformed to

$$(6')\ \log \frac{P_k W_k}{P_c C} = \frac{\log \gamma_k}{\varepsilon+1} + \frac{\varepsilon}{\varepsilon+1} \log \frac{P_k}{P_c} \qquad k=1,2$$

Table 4 presents regression estimates of these parameters. The parameters of both equations were estimated jointly subject to one cross-equation constraint. Again, the coefficients are statistically significant; in this case the elasticity of substitution parameter, 0.898, is quite large. The results in Table 4 yield a production function for dwelling comfort

$$(12)\ D = [0.410\ W_1^{-.114} + 0.365\ W_2^{-.114} + C^{-.114}]^{-1/.114}$$

and a marginal cost function

TABLE 4

Dwelling Unit Comfort (D) Produced from Climatic (W) and Purchased Inputs (C)

$$D = [\gamma_1 W_1^{-\varepsilon} + \gamma_2 W_2^{-\varepsilon} + C^{-\varepsilon}]^{-1/\varepsilon}$$

Two first-order conditions:

$$\log \frac{P_k W_k}{P_c C} = \frac{\log \gamma_k}{\varepsilon+1} + \frac{\varepsilon}{\varepsilon+1} \log \frac{P_k}{P_c} \qquad k=1,2$$

Parameter	Estimated Value	t-ratio
$\log \gamma_1/(\varepsilon+1)$	-0.801	48.42
$\log \gamma_2/(\varepsilon+1)$	-0.905	21.60
$\varepsilon/(\varepsilon+1)$	0.102	55.83
R^2	0.430	

11,760 Observations on first order conditions

$$(13)\ P_D = [0.449\ P_{W_1}^{0.102} + 0.404\ P_{W_2}^{0.102} + P_C^{0.102}]^{9.764}$$

V. HOUSEHOLD UTILITY

Finally, we consider the effects of the hedonic price structure on households' choices among goods in final consumption. We assume households have direct preferences for three aspects of housing: vintage (h_{11}), the number of bathrooms (h_{12}) and the number of rooms (h_{13}), as well as the level of dwelling comfort enjoyed (D) and other goods (X).

We also assume the utility function is generalized CES, i.e.,

$$(7')\ U = [\Sigma\theta_i\ h_{1i}^{\phi_i} + \theta_4\ D^{\phi_4} + X^{\upsilon}]^{\eta}$$

where θ_i and ϕ_i, $i=1,2,\ldots,4$ and υ are parameters and η is arbitrary. Maximization of (7'), subject to the budget constraint (8) yields four first-order conditions, which after slight rearrangement, can be expressed as

$$\begin{aligned}(9')\ \log P_{12} &= \log \phi_2\ \theta_2/\upsilon + (\phi_2-1) \log h_{12} - (\upsilon-1) \log X\\ \log P_{13} &= \log \phi_3\ \theta_3/\upsilon + (\phi_3-1) \log h_{13} - (\upsilon-1) \log X\\ \log P_D &= \log \phi_4\ \theta_4/\upsilon + (\phi_4-1) \log D - (\upsilon-1) \log X\end{aligned}$$

and

$$\begin{aligned}&\log [P_{11} - (\phi_4\ \theta_4/\upsilon)(D^{\phi_4-1}/X^{\upsilon-1})(\partial D/\partial h_{11})]\\ &\quad = \log \phi_1\ \theta_1/\upsilon + (\phi_1-1) \log h_{11} - (\upsilon-1) \log X\end{aligned}$$

Table 5 presents estimates of the parameters of the utility function. All four first-order conditions are estimated jointly, subject to the concavity

TABLE 5

Utility Function Relating Housing Vintage (h_{11}), Baths (h_{12}), Rooms (h_{13}), Dwelling Comfort (D) and Other Goods (X)

$$U = [\Sigma\ \theta_i\ h_{1i}^{\phi_i} + \theta_4\ D^{\phi_4} + X^{\upsilon}]^{\eta}$$

Four first-order conditions:

$$P_{1i} = \partial U/\partial h_{1i} \qquad i=1,2,3$$
$$P_D = \partial U/\partial D$$

estimated jointly, subject to the constraints $\phi_i \leq 1$, $\nu \leq 1$.

Parameter	Estimated Value	asymptotic t-ratio
ϕ_1	1	
ϕ_2	0.832	13.33
ϕ_3	0.769	8.81
ϕ_4	1	
ν	0.892	58.56
θ_1	1.251×10^2	63.80
θ_2	6.845×10^3	202.75
θ_3	3.403×10^3	99.76
θ_4	8.379×10^7	482.90

restrictions,[11] $\phi_i \leq 1$, $\nu \leq 1$. This system of equations was estimated by non-linear two stage least squares using SAS.[12]

The results in Table 5 imply that the utility function may be expressed as:

$$(14)\ U = [1.251(10^2)h_{11} + 6.845(10^3)h_{12}{}^{0.832} + 3.403(10^3)h_{13}{}^{0.769} + 8.379(10^7)D + X^{0.892}]^{\eta}$$

VI. SOME IMPLICATIONS

These econometric results indicate a rich pattern of substitution in production and consumption in response to variations in relative prices. As producers, households combine housing attributes, energy inputs and local climatic conditions to obtain the dwelling unit comfort that they enjoy in final consumption. The production process is characterized by an elasticity of substitution of about 0.14 between the vintage of dwellings and the quantity of energy used to produce "purchased comfort" and an elasticity of substitution of about 0.90 between "purchased comfort" and climate conditions (i.e., degree

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[11] Given the form of the production functions (3') and (4'), $\phi_i \leq 1$, $\nu \leq 1$ are necessary, but not sufficient restrictions to ensure global concavity of the utility function.

[12] The estimation results were identical using either the Gauss or Marquardt methods.

days) in the production of dwelling comfort. As consumers, households substitute among housing attributes, comfort, and other goods in maximizing their well being.

Table 6 summarizes the average values of the unobserved "produced comfort" and "dwelling comfort" implied by the model. The table presents the average standardized normal deviate of each quantity in each of the 25 SMSA's represented in the sample. The largest quantities of this comfort input are purchased in those cities with extreme climates: Washington, Kansas City, Chicago, Minneapolis, and Milwaukee. The smallest quantities of purchased comfort are produced in coastal cities with mild climates: Seattle, Portland, San Diego, San Francisco, and Los Angeles. In contrast, the cities enjoying the highest levels of dwelling comfort -- the amalgam of housing attributes, energy inputs and climatic conditions -- are those same coastal cities, especially San Francisco, San Diego, and Seattle. The cities which, on average, have the least dwelling comfort are those of the interior: Dallas, Cincinatti, Philadelphia, Kansas City and St. Louis.

The empirical results can also be used to simulate the direct and indirect effects of energy price changes upon household consumption and well being. For example, household choice of three housing attributes (vintage, rooms, and bathrooms), dwelling comfort, energy inputs and other goods can be estimated by maximizing the utility function (equation 14, reported in table 5), subject to the non-linear budget constraint (equation 8, using the hedonic function reported in table 1), and the production relationships (reported in tables 3 and 4). This system can be solved to reveal the pattern of consumption in response to variations in energy prices, P_E.

TABLE 6

Average Values of Purchased Comfort (C) and Dwelling Unit Comfort (D) by SMSA*

Rank	SMSA	Produced Comfort (C)	Rank	SMSA	Dwelling Comfort (D)
1	Washington, D.C.	1.33	1	San Francisco	2.45
2	Kansas City	1.29	2	San Diego	2.20
3	Chicago	1.12	3	Seattle	2.12
4	Minneapolis	0.99	4	Miami	1.41
5	Milwaukee	0.93	5	Los Angeles	1.15
6	St. Louis	0.85	6	Portland	0.77
7	Atlanta	0.85	7	Milwaukee	-0.20
8	Baltimore	0.66	8	Houston	-0.22
9	Denver	0.55	9	Denver	-0.38
10	Cincinatti	0.49	10	Buffalo	-0.40
11	Detroit	0.48	11	Cleveland	-0.42
12	Pittsburgh	0.21	12	Atlanta	-0.49
13	Cleveland	0.15	13	Detroit	-0.50
14	Philadelphia	0.08	14	Washington	-0.52
15	Boston	-0.16	15	Pittsburgh	-0.53
16	Houston	-0.17	16	Chicago	-0.54
17	Buffalo	-0.17	17	Boston	-0.54
18	New York	-0.22	18	Baltimore	-0.56
19	Dallas	-0.25	19	Minneapolis	-0.56
20	Miami	-0.65	20	New York	-0.64
21	Seattle	-1.19	21	Dallas	-0.66
22	Portland	-1.22	22	Cincinatti	-0.68
23	San Diego	-1.65	23	Philadelphia	-0.69
24	San Francisco	-1.79	24	Kansas City	-0.77
25	Los Angeles	-2.51	25	St. Louis	-0.78

* Quantities of C and D are reported as standardized normal deviates with sample means of zero and standard deviations of one.

Estimates of household consumption responses to increases in energy prices are presented in Table 7. Panel A presents estimates of short run changes in the consumption of energy and other goods.[13] These estimates assume that housing capital is fixed (at the mean values observed in the sample), and that in response to energy price increases, households choose between reduced expenditures on energy (and hence less dwelling comfort) and reduced consumption of other goods.

The results suggest that the short run price elasticity of demand for residential energy is quite low, about -0.1, and that the arc elasticity is slightly smaller than the point elasticity.

Panel B of the table presents estimates of the long run response to changes in energy prices, after a sufficient time has elapsed so that household housing consumption (that is, consumption of vintage, baths and rooms) could be adjusted in response to energy price changes. Over this longer run, households would respond by choosing newer (presumably more energy efficient) dwellings, with more bathrooms (presumably of higher quality) and with fewer rooms (presumably requiring less purchased energy to produce dwelling comfort). Modest changes in the consumption of these housing attributes permits greater economy in energy consumption. The long run price elasticity is estimated to be about 7 times as large as the short run elasticity. Over the longer run, it appears that increases in residential energy prices have little effect on consumers' choices

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[13] These estimates were obtained using the non-linear maximization program GINO written for the micro computer. In all cases the observed average values of the variables were used as starting values for the search. In some cases the program required considerable time to converge upon the (local)maximum.

TABLE 7
Effects of Energy Price Variation on Consumption of Housing, Energy and other Goods

Percent Charge in	Energy Price Level, P_E 1.00	1.25	1.50	1.75	2.00
A. Short Run Response					
Energy, E	-	-2.6%	-5.4%	-8.1%	-12.3%
Other goods, X	-	-1.3%	-2.5%	-3.7%	-4.6%
B. Long Run Response					
Vintage, h_{11}	-	+10.4	+19.6	+25.2	+29.1
Baths, h_{12}	-	+0.7	+7.6	+13.4	+18.1
Rooms, h_{13}	-	-9.9	-26.1	-38.4	-45.2
Housing Expenditures, V	-	-0.5	-2.3	-4.6	-7.9
Energy, E	-	-17.4	-24.4	-26.7	-28.3
Other Goods, X	-	-0.0	-0.0	-0.1	-0.2

of other nonhousing goods. Households adjust by reconfiguring their consumption of housing attributes and their expenditures on housing.

Overall, these simulation results suggest that the adjustment process within the housing market permits a great deal of substitution in response to energy price changes. This substitution increases the price elasticity from -0.1 to -0.7 and leaves household consumption of non-housing goods relatively insensitive to increases in energy prices.

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APPENDIX TABLE 1

Hedonic Price Relationship
For Different Functional Forms
(Annual Housing Survey, 1980)

Variable	Linear	Box-Cox Dependent	Box-Cox Independent & Dependent
		Functional Form	
Size and Quality Measures: h_1			
Baths: h_{12} (number)	22545.02 (14.98)	79.07 (17.36)	.124 (15.76)
Rooms: h_{13} (number)	8998.45 (22.74)	27.42 (22.89)	.194 (19.08)
Vintage: h_{11} (year built-1900)/10	.732.24 (0.46)	6.747 (4.42)	0.115 (10.14)
Privacy (1=no)	3318.31 (1.13)	5.22 (.59)	.001 (.10)
Vermin (1=no)	-118.94 (.06)	7.11 (1.18)	.028 (4.07)
Neighborhood (4=excellent)	12056.99 (13.32)	43.46 (15.86)	.058 (18.16)
Abandonment (2=no)	20176.02 (5.35)	88.98 (7.79)	.136 (10.25)
Garages (number)	11179.10 (7.76)	42.77 (9.81)	.047 (9.22)
Heating, Cooling and Structural Measures: h_2			
Basement: h_{21} (1=yes)	-4349.82 (3.29)	-10.12 (2.53)	.027 (5.38)
Central AC: h_{22} (1=yes)	4156.94 (2.85)	16.58 (3.75)	.059 (10.91)
Room AC: h_{23} (1=yes)	-6925.72 (5.14)	-19.14 (4.69)	.009 (1.79)
Furnace: Warm Air: h_{24} (1=yes)	11952.82 (3.86)	38.18 (4.07)	.045 (4.13)

APPENDIX TABLE 1 Continued...

Hedonic Price Relationship
For Different Functional Forms
(Annual Housing Survey, 1980)

Variable	Linear	Box-Cox Dependent	Box-Cox Independent & Dependent
	Functional Form		
Steam/Hot Water: h_{25}	12692.96	47.49	.084
(1=yes)	(3.76)	(4.64)	(7.12)
Floor/Wall: h_{26}	24882.98	97.03	.087
(1=yes)	(6.81)	(8.78)	(6.73)
Radiator in All Rooms: h_{27}	4623.38	14.11	.019
(1=yes)	(2.30)	(2.32)	(2.71)
Cracks: h_{28}	-3930.15	-6.07	.008
(2=no)	(1.14)	(.58)	(.68)
Climate Measures: W			
Hot Weather: W_1	11154113.44	352.96	.048
	(16.71)	(17.47)	(27.43)
Cold Weather: W_2	1763961.04	6155.74	.042
	(14.75)	(17.00)	(27.59)
Intercept	-188947.81	-487.92	6.007
	(11.27)	(9.62)	(93.69)
λ		.50	-.10
R^2	.37	.42	.48
R^2 in original space:	.37	.61	.65

t ratios in parentheses