The Production of Housing Services and the Derived Demand for Residential Energy

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The production of housing services and the derived demand for residential energy

John M. Quigley*

Most studies of residential energy usage treat energy as a final consumer good. This study explicitly considers the production of housing service flows from stocks of real estate and flows of operating inputs, and considers the demand for residential energy as a factor input. The empirical results, based upon analysis of a sample of newly constructed dwellings and their occupants, are used to evaluate the effects of energy price changes on the price of housing services and on the demand for housing and real estate—thus indicating the extent of residential energy “conservation” in response to higher prices. Finally, the results are used to analyze federal and state tax subsidies for residential energy conservation.

1. Introduction

Almost 40% of the energy consumed in the United States is used to service commercial, industrial, or residential structures; in turn, half of this energy is consumed in residential buildings. In commercial and industrial usage, energy is clearly an input into the production of intermediate output or final consumption goods. Similarly, in residential usage, energy is an input into the production of the housing services enjoyed by households in final consumption. Landlords or homeowners combine service flows from existing stocks of real estate with purchased inputs of energy and other utilities to produce the housing services demanded by residents. But virtually all studies of residential energy usage view it as a final consumption good and estimate the demand for final output subject only to the rather weak Slutsky restrictions of consumer demand theory. In contrast, there are a number of high quality economic and engineering studies of the substitutability of energy for other inputs in the manufacturing sector. (See Bohi (1981) for a recent review.) The premise of this article is that a better understanding of the demand for residential energy and an assessment of public subsidies directed at that market require explicit recognition of the derived demand character of residential energy consumption.

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In this article, residential energy usage is viewed as an input to the production of housing services, a final consumption good, and production theory is used to estimate the derived demand for this factor. Section 2 presents a simple model of housing services production. The model is used to estimate the substitutability of inputs in the production of service flows and the parameters of household demands for final output. In Section 3 these results are used to analyze the effect of higher energy prices on the price of housing services and the consumption of housing, real estate, and residential energy. These results are used to investigate the effects of conservation subsidies and mandatory “energy standards” for new buildings. Section 4 contains concluding remarks.

2. The model

- The production relationship. Most economic models of the residential energy sector treat energy as an object of final demand by consumers. (See Hartman (1979) for an extensive review.) Although there is an extensive literature on the production function for new housing (see McDonald (1981) for a recent review), these analyses concentrate on the substitution between capital and land in the production of real estate. There are, apparently, only four studies that explicitly consider energy and utilities as operating inputs in supplying housing services to consumers (Muth, 1973; Neels, 1981; Ingram and Oron, 1979; Rydell, 1977). Of these, only one considers single-family or owner-occupied housing at all. For various reasons, these studies provide a limited basis for making inferences.¹

In the present analysis, the production process is specified as a nested constant elasticity of substitution (CES) production function (Sato, 1967) relating housing output (or annual flows of housing services) to land, capital, and operating inputs. The analysis is organized so that it is possible to replicate previous work investigating the elasticity of substitution between capital and land and then to extend this work to include current operating inputs.

The assumed production function is nested in the following sense. First, following most of the literature on housing production, assume that land \((L)\) and capital \((K)\) are combined to produce residential dwellings. Call the output real estate \((R)\). Following Muth (1973) and Ingram and Oron (1979), assume further that real estate and operating inputs \((V)\) are combined to produce the flows of housing services \((H)\) demanded by final consumers.

Specifically, the assumed production relationship is of the form:

\[
R = \omega \{(\beta R^{\mu} + \alpha L^{-\rho})^{-1/\mu}
\]

\[
H = \omega'\{(\beta' jR)^{-\mu'} + \alpha' (V^{-\rho'})^{-1/\mu'}
\]

(1a)

(1b)

where \(\alpha, \beta, \omega, \rho,\) and their primes are parameters, where \(j\) is the rate of flow of services provided by stocks, and where the elasticities of substitution between pairs of inputs, \(\sigma, \sigma',\) are: \(\sigma = 1/(1 + \rho); \sigma' = 1/(1 + \rho').\)

Capital, land, operating inputs, real estate, and housing are measured in physical units. For a given distribution ratio \((\beta/\alpha)\), the choice of physical units or a normalization for relative prices affects only the arbitrary normalization factor \(\omega\).

The production function is assumed to be homogeneous of the first degree, implying that the value of the output service flow equals the inputs consumed; that is,

\[
jrR = (j + d)kK + jlL
\]

(2a)

¹ Muth estimated factor demand equations for real estate on the basis of 32 observations. Ingram and Oron estimated the production function for housing using 29 observations. Rydell’s and Neels’ analyses assumed, among other things, that the unit prices of capital vary with the characteristics of dwellings.
\[ pH = jrR + vV, \]

where

\[ pH = \text{expenditures on housing services at price } p; \]
\[ rR = \text{expenditures on real estate at price } r; \]
\[ vV = \text{expenditures on operating inputs at price } v; \]
\[ kK = \text{expenditures on capital at price } k; \]
\[ lL = \text{expenditures on land at price } l; \]
\[ d = \text{the rate of depreciation of capital}. \]

The parameters of this production relationship are estimated by using information obtained from the sales of newly constructed owner-occupied housing insured under the Federal Housing Administration (FHA) Section 203 mortgage program. The data consist of 7378 observations on home sales and the associated FHA insurance approvals recorded in 16 counties in 5 metropolitan areas (SMSAs) from 1974 through 1978, a period during which real energy prices rose by 39%. Besides reporting the selling price of real estate \((rR)\) and the closing costs of each transaction, the FHA records indicate the parcel area of the property \((L)\) and an appraisal of the market value of an equivalent site \((lL)\). The latter two elements permit the unit price of the land input to be estimated.

Depreciation \((dkK)\), alternatively, the current expenditures required to prevent depreciation, is measured by the FHA “estimated cost of maintaining the physical elements of the property to prevent acceleration of depreciation and to assure safe and comfortable living conditions” (U.S. Department of Housing and Urban Development, 1977, iii). Operating input expenditures \((vV)\), also calculated by FHA appraisers, include “the cost of heating, electricity, gas, water, and other items generally known as utilities, excluding those services which are provided under the lien of nonprepayable special assessment which continues indefinitely for supplying water, sewage disposal, removal of garbage or other services necessary for the occupancy of the premises” (U.S. Department of Housing and Urban Development, 1977, iv). Note that by classifying, appropriately, maintenance expenditures as part of the annual cost of residential capital, operating input expenditures are essentially energy costs (plus minor charges for water, and occasionally sewer and garbage).

The rental costs of the services provided by stocks of real estate, land, and capital are estimated in two variants. The first variant combines information on taxes and mortgage terms. Annual property tax liabilities and the selling price of each property permit the calculation of the effective property tax rate \((t)\). This tax rate, together with the marginal federal tax rate \((\Gamma)\) of the purchaser (inferred from household income), the interest rate \((i^*)\) associated with the mortgage, the market interest rate \((i)\), and the loan-to-value ratio of the mortgage \((M)\), permits the annual cost of service flows, net of tax advantages, to be estimated:

\[ u = [i^*M + i(1 - M) + t](1 - \Gamma). \]  

Together with \(j = u\), this information permits annual capital expenditures to be computed from (2a) and (2b). For comparison, we also report the results by using a second variant, namely, the more conventional measure \((i + t)\) as the rental cost. In the subsequent discussion, Model 1 refers to analysis using \(j = u\) as the service cost and Model 2 refers to analysis using \(j = (i + t)\).

Table 1 summarizes the raw data on expenditures and unit prices. The directly observed variables include: the selling prices of houses, which average about $40,000; the expenditures on land, which average $10,700; annual operating expenses, averaging about $600; and a number of price indices. From these, using \(u\) as the user cost, annual costs
of capital and land, $1,800 and $800 on average, are computed as well as the net annual cost of housing services, about $3,600. The table also reports the summary data when \((i + t)\) is used.

The price of capital \((k)\) is measured by the Boeckh index of the cost of a new standardized frame residential structure exclusive of land, and is compiled from bimonthly information reported by county.\(^2\) The price of operating inputs \((v)\) is estimated by the price index of “fuel and other utilities” compiled by the Bureau of Labor Statistics and reported quarterly, or in some cases monthly, by SMSA.\(^3\)

Competitive equilibrium requires that the ratio of relative input prices equal the ratio of marginal products,

\[
\frac{\partial R/\partial K}{\partial R/\partial L} = (\beta/\alpha)(K/L)^{-\sigma-1} = (k/l) \quad (4a)
\]

or equivalently,

\[
\log (kK/IL) = \sigma \log (\beta/\alpha) + (1 - \sigma) \log (k/l) \quad (5a)
\]

\[
\log (jrR/vV) = \sigma' \log (\beta'/\alpha') + (1 - \sigma') \log (jr/v). \quad (5b)
\]

\(^2\) E.H. Boeckh Company, Boeckh Building Cost Index Numbers, Milwaukee, Wi., various years.

and \((\beta / \alpha)\) from equation (5a) without reference to \(r\). With these results, competition implies that \(r\) can be computed directly as the marginal cost of real estate output:
\[
\begin{align*}
    r &= \left[ (\beta / \alpha)^{\sigma k l^{-\sigma}} + l^{1-\sigma} \right]^{1/(1-\sigma)}.
\end{align*}
\]
(6) Given \(r\), we can then estimate equation (5b).

\(\square\) The demand relationship. As is well known, housing market transactions provide observations on real estate expenditures, not on the unit prices of housing services or real estate. The unobservability of unit prices has led to great uncertainty about the responsiveness of housing demand to variations in relative prices. The production analysis, however, permits the unit price of housing service output to be computed from observations on factor input prices. Thus, since price equals marginal cost, 
\[
    p = \left[ (\beta'/\alpha')^{\sigma' (j l)^{1-\sigma'} + u^{1-\sigma'}} \right]^{1/(1-\sigma')},
\]
(7) where \(r\), in turn, is computed from capital and land prices by using equation (6). This insight permits direct estimation of the parameters of the household demand curve for single detached housing.

This is, of course, an extension of the work of Polinsky and Ellwood (1979), who regressed the sale price of newly constructed dwellings upon household income and a price variable computed by inverting the production function for dwellings. In our terminology they estimated household expenditures on the factor real estate \((rR)\) as a function of income and real estate prices \((r)\). Variation in real estate prices was derived from individual variation in land prices \((l)\) and metropolitan-wide variation in capital costs \((k)\). In contrast, this analysis investigates household demands for housing services as a function of income \((Y)\) and the price of housing services \((p)\); variation in the price of housing services is derived from individual variation in interest costs \((j)\), land prices \((l)\), and real estate prices \((r)\), and metropolitan-wide variation in the prices of capital \((k)\) and operating inputs \((u)\).

Assume a log-linear demand curve for the stock of owner-occupied housing (deLeeuw, 1971) of the form:
\[
    \log \left( \frac{H}{j} \right) = \gamma_0 + \gamma_1 \log \left( \frac{Y}{p_o} \right) + \gamma_2 \log \left( \frac{p}{p_o} \right).
\]
(8) The dependent variable is the logarithm of the capitalized flow of housing services \((H/j)\), \(Y\) is household income, and \(p_o\) is the price of other (nonhousing) goods. Household income is measured by "net effective income" as reported by the FHA. This figure, a transformation of gross household income to reflect "earning capacity (net of federal income tax) likely to prevail during the first third of the mortgage term," is only a crude measure of permanent income (see Muth (1971) or Polinsky and Ellwood (1979) for a discussion). The price of nonhousing goods is taken from the BLS consumer price index compiled annually by SMSA. The mean values of these variables are reported in Table 1.

\(\square\) Results. Table 2 presents the results of estimating the two production relationships, equations (5a) and (5b), and the demand function, equation (8), by ordinary least squares. The top panel presents the results for the production function for real estate. The elasticity of substitution between capital and land, derived from the regression of expenditure shares on relative prices, is about .72 for Model 1 and about .75 for Model 2.\(^4\) The distribution factor is estimated to be 1.90 to 2.11.\(^5\)

\(^4\) McDonald (1981) has recently reviewed the results of some 13 analyses of the elasticity of substitution between residential capital and land in the production of dwelling units—analyses based upon rather different production models, estimation techniques, and sources of data. His survey does not indicate any consensus on the magnitude of the substitution parameter, other than general agreement that \(\sigma\) is significantly less than 1. The estimate of .72–.75 reported in Table 2 is in the middle of the range reported by McDonald.

\(^5\) In these regressions, the ratio of price indices is scaled to an average sample value of about one. This
TABLE 2  Ordinary Least Squares Estimates of Housing Services  
Production and Demand Relationships  
(Computed t-Ratios in Parentheses)  

<table>
<thead>
<tr>
<th>Production of Real Estate</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Model 1 ( \log (kK/IL) = .911 + .279 \log (k/l) )</td>
<td>( R^2 = .227 )</td>
</tr>
<tr>
<td>(241.36) (46.53)</td>
<td></td>
</tr>
<tr>
<td>Model 2 ( \log (kK/IL) = .966 + .252 \log (k/l) )</td>
<td>( R^2 = .197 )</td>
</tr>
<tr>
<td>(492.25) (42.56)</td>
<td></td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th>Production of Housing</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Model 1 ( \log (jR/vV) = 1.616 + .685 \log (j/r) )</td>
<td>( R^2 = .144 )</td>
</tr>
<tr>
<td>(408.48) (35.25)</td>
<td></td>
</tr>
<tr>
<td>Model 2 ( \log (jR/vV) = 1.967 + .776 \log (j/r) )</td>
<td>( R^2 = .160 )</td>
</tr>
<tr>
<td>(492.25) (37.44)</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Demand for Housing Services</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Model 1 ( \log (H/jj) = 3.773 + .340 \log (Y/p_a) - .716 \log (p/p_o) )</td>
<td>( R^2 = .340 )</td>
</tr>
<tr>
<td>(23.25) (38.40) (52.70)</td>
<td></td>
</tr>
<tr>
<td>Model 2 ( \log (H/jj) = 3.696 + .342 \log (Y/p_a) - .711 \log (p/p_o) )</td>
<td>( R^2 = .341 )</td>
</tr>
<tr>
<td>(22.34) (38.71) (51.78)</td>
<td></td>
</tr>
</tbody>
</table>

The second panel of the table presents estimates of the relationship between real estate and operating inputs in the production of flows of housing services. As expected, the elasticity of substitution, which is estimated as .22 and .32 in the two models, is much smaller than the capital-land substitution parameter. The intercept, and hence the distribution parameter, is substantially higher. This, too, is to be expected, since carrying costs are typically substantially higher than operating costs.6

The third panel of Table 2 presents estimates of the demand function. The price elasticity of demand is estimated to be \(-.72 \pm .02\) and \(-.71 \pm .02\) with 95% confidence for Models 1 and 2, respectively. These results compare rather closely to those of Polinsky and Ellwood \((-67 \pm .02\) for homeowners, on the basis of a single cross section of FHA data, and with the less precise results reported by Hanushek and Quigley (1980, normalization affects only the intercept of the regression, and a different arbitrary choice of physical units or relative prices affects only the units in which the distribution ratio is reported. See the original ACMS paper for an extensive discussion (Arrow et al., 1961).

6 Again, the ratio of relative prices is scaled to an average sample value of about one. The higher value of the distribution ratio may also reflect market expectations of continued increases in energy and other operating costs over the planning horizon. This follows from the putty-clay nature of the investment. Once constructed, residential structures are quite expensive to modify. Thus, if prices are expected to vary over time, marginal products will be equilibrated to some average of expected future prices over the lifetime of the structure \(T\). For example, if prices are expected to increase exponentially \(i.e., k(r) = k \exp[g_r r]; l(r) = l \exp[g_r r]\), then the right-hand side of (4a) is

\[
\frac{(1/T) \int_0^T \exp[g_r t] dt}{(1/T) \int_0^T \exp[g_r t] dt} = \frac{(k/l) \left[ \frac{g_r}{g_r} \left( \frac{\exp[g_r T] - 1}{\exp[g_r T] - 1} \right) \right]}{1}. 
\]

Since the term in the square brackets is a constant, this also affects only the intercept in equation (5a). For example, if the relative price of capital were expected to increase by 10% per year, then if buildings were expected to last 40 years, the term in the square brackets would be about .07. The estimate of \(\sigma\) derived from (5a) by ignoring these expectations would be identical, and the expectations would be reflected in the regression estimate of \((\beta/\alpha)\).
on the basis of observations on renters generated in the Housing Allowance Demand Experiment (HADE) in the Pittsburgh (−.64 ± .30) and Phoenix (−.45 ± .25) metropolitan areas. The income elasticity of housing demand is estimated to be .34. Polinsky and Ellwood report a figure of .38 based upon the same definition of income. Friedman and Weinberg (1981) use the HADE data and report income elasticities of .25 (Phoenix) and .26 (Pittsburgh) based on a somewhat different income measure for renters.

In general, there are only small differences in the results for Models 1 and 2. The results reported in Table 2 are, however, based upon the sequential estimation of parameters. The coefficients of the real estate production function are used to compute \( r \), which then permits estimation of the production function for housing. These results, in turn, permit the price of output to be computed and the price sensitivity of demand to be investigated. Although this methodology does permit a direct comparison of results with previous analyses, it is subject to well-known statistical limitations. Since the right-hand sides of the housing production and demand equations include variables that are estimated from other variables, it follows that the standard errors computed by ordinary least squares will underestimate the true errors. Moreover, the errors-in-variables problem will, in general, lead to biased coefficient estimates.

Table 3 presents some evidence on these possible complications. The first two columns present the point estimates of the economic parameters obtained from the sequential, ordinary least squares regression approach. Also presented are the \( r \)-ratios computed by ignoring the sequential aspect of the estimation. Columns 3 and 4 present maximum likelihood estimates of the elasticities of substitution and price and income elasticities of demand. These coefficients were obtained by estimation of equation (8) subject to the restrictions imposed by (6) and (7). Coefficients of the resulting expression, highly nonlinear in the parameters, were obtained by steepest descent methods. The

<table>
<thead>
<tr>
<th>TABLE 3 Estimated Parameters of Production and Demand Models (( r )-ratios in parentheses)</th>
</tr>
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<tbody>
<tr>
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<tr>
<td></td>
</tr>
<tr>
<td><strong>Real Estate Production</strong></td>
</tr>
<tr>
<td>( \sigma ) \hspace{1cm} .721 \hspace{1cm} .748 \hspace{1cm} .756 \hspace{1cm} .758</td>
</tr>
<tr>
<td>( (120.17) \hspace{1cm} (126.46) \hspace{1cm} (4.44) \hspace{1cm} (5.47) ) \hspace{1cm}</td>
</tr>
<tr>
<td>( (\beta/\alpha) ) \hspace{1cm} .539 \hspace{1cm} 3.639 \hspace{1cm} — \hspace{1cm} —</td>
</tr>
<tr>
<td>( (77.72) \hspace{1cm} (80.35) \hspace{1cm} — \hspace{1cm} — ) \hspace{1cm}</td>
</tr>
<tr>
<td><strong>Housing Production</strong></td>
</tr>
<tr>
<td>( \sigma' ) \hspace{1cm} .315 \hspace{1cm} .224 \hspace{1cm} .400 \hspace{1cm} .252</td>
</tr>
<tr>
<td>( (16.21) \hspace{1cm} (10.81) \hspace{1cm} (3.21) \hspace{1cm} (4.44) ) \hspace{1cm}</td>
</tr>
<tr>
<td>( (\beta/\alpha') ) \hspace{1cm} 168.240 \hspace{1cm} 6536.814 \hspace{1cm} — \hspace{1cm} —</td>
</tr>
<tr>
<td>( (105.69) \hspace{1cm} (56.34) \hspace{1cm} — \hspace{1cm} — ) \hspace{1cm}</td>
</tr>
<tr>
<td><strong>Housing Demand</strong></td>
</tr>
<tr>
<td>( \gamma_0 ) \hspace{1cm} 3.773 \hspace{1cm} 3.696 \hspace{1cm} — \hspace{1cm} —</td>
</tr>
<tr>
<td>( (23.25) \hspace{1cm} (22.34) \hspace{1cm} — \hspace{1cm} — ) \hspace{1cm}</td>
</tr>
<tr>
<td>( \gamma_1 ) \hspace{1cm} .340 \hspace{1cm} .342 \hspace{1cm} .280 \hspace{1cm} .298</td>
</tr>
<tr>
<td>( (38.40) \hspace{1cm} (38.71) \hspace{1cm} (3.57) \hspace{1cm} (6.89) ) \hspace{1cm}</td>
</tr>
<tr>
<td>( \gamma_2 ) \hspace{1cm} −.716 \hspace{1cm} −.711 \hspace{1cm} −.904 \hspace{1cm} −.864</td>
</tr>
<tr>
<td>( (52.70) \hspace{1cm} (51.78) \hspace{1cm} (5.21) \hspace{1cm} (10.81) ) \hspace{1cm}</td>
</tr>
</tbody>
</table>

Notes:

\( ^a \) Computed by imposing nonlinear coefficient restrictions on OLS model.

\( ^b \) Asymptotic \( r \)-ratios computed by inverting matrix of cross partials at point of maximum likelihood.

— Coefficient not estimated. For maximum likelihood estimation these coefficients were set equal to their OLS estimated values.
asymptotic t-ratios for the coefficients are substantially smaller when the parameters are estimated by maximum likelihood techniques. They are, however, clearly "significant" by conventional criteria, and the 95% confidence intervals for these coefficients include the OLS estimates. 7

3. Implications

Market responses. The empirical analysis of production and demand during a period of rising energy costs can be used to trace the effects of exogenous changes in energy price and availability upon the operation of the housing market. In particular, estimates of the production function indicate the extent to which higher input prices increase the cost of housing services to consumers. The demand curve indicates the extent to which these prices decrease the demand for real estate and induce "conservation" by reducing residential energy consumption. Inferences drawn from this production function are, of course, long-run and static. Presumably the ease of substitution of real estate for operating inputs is greater in new construction than in existing dwellings, where "retrofits" may be quite expensive. Thus, the effect of energy price changes on housing service costs based on new dwellings will underestimate the cost increases observed in the existing stock.

Point estimates of the elasticity of demand with respect to the prices of operating inputs are 8:

\[
\left( \frac{\partial V}{\partial v} \right) \cdot \left( \frac{v}{V} \right) \approx -0.28
\]

\[
\left( \frac{\partial R}{\partial v} \right) \cdot \left( \frac{v}{R} \right) \approx -0.06
\]

\[
\left( \frac{\partial H}{\partial v} \right) \cdot \left( \frac{v}{H} \right) \approx -0.09.
\]

A 10% increase in energy prices is associated with a 9% decline in the demand for housing services, a 6% decline in the demand for real estate, and a 2.8% decline in the demand for residential energy.

Table 4 presents estimates of the effects of energy price changes on the output price of housing services and the demand for housing and for factor inputs. As compared with a base case, a 50% increase in the price of energy leads to a 6–8% increase in the price of housing service flows. 9 A tripling of energy prices will result in an increase in housing prices of 22–28%. A 50% increase in energy prices reduces demand and hence housing consumption by 4–5%. Because demand is price inelastic, however, expenditures on housing are increased by 2%. 10 A tripling of energy prices similarly leads to a reduction in housing consumption of 13–17% and an increase in expenditures of 6–7%. These estimates are, of course, along the compensated demand curve. They measure the direct

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7 It should be noted, however, that these consistent estimates of parameters are not fully efficient, since the distribution ratios and the intercept are constrained to their OLS values. One (expensive) attempt was made to estimate all seven parameters simultaneously. The iterative routine failed because of high covariance between two estimated coefficients, \( \phi \) and \( \gamma \). As noted previously, however, \( \gamma, (\beta/\alpha) \), and (\( \beta'/\alpha' \)) are merely scaling factors for the units of prices and incomes.

8 These elasticities are based on the estimates reported for Model 1 and the expressions in footnotes 10, 11, and 12.

9 From equation (7) at \( vr = 1 \), using the coefficients for Model 1, \( p_1 = [168.315 + 1.685]^{1.460} \), at \( v = 1.5, p_1 = [168.315 + 1.5685]^{1.460} \) an increase of 8%.

10 From equation (8) initial housing consumption is \( H_0 = Z(p_i)^{2.716} \) and expenditures are \( E_1 = Z(p_i)^{2.84} \). At \( v = 1.5, \) expenditures increase by 2% to \( E_2 = Z(p_2)^{2.716} \) and consumption declines by 5% to \( H_2 = Z(p_2)^{2.716} \).
TABLE 4  Energy Price Increases and the Markets for Residential Housing, Energy, and Real Estate

<table>
<thead>
<tr>
<th></th>
<th>Base 100%</th>
<th>150%</th>
<th>200%</th>
<th>250%</th>
<th>300%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Effect on Market for Housing Output</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Price of Housing Services, ( p )</td>
<td>100</td>
<td>106–108</td>
<td>111–115</td>
<td>117–122</td>
<td>122–128</td>
</tr>
<tr>
<td>Demand for Housing Services, ( H )</td>
<td>100</td>
<td>95–96</td>
<td>90–93</td>
<td>87–90</td>
<td>84–87</td>
</tr>
<tr>
<td>Expenditures on Housing Services, ( pH )</td>
<td>100</td>
<td>102–102</td>
<td>103–104</td>
<td>105–106</td>
<td>106–107</td>
</tr>
<tr>
<td>Effect on Demand for Factor Inputs</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Demand for Real Estate, ( R )</td>
<td>100</td>
<td>97–97</td>
<td>95–95</td>
<td>92–93</td>
<td>91–91</td>
</tr>
<tr>
<td>Demand for Residential Energy, ( V )</td>
<td>100</td>
<td>85–89</td>
<td>76–81</td>
<td>69–76</td>
<td>64–71</td>
</tr>
<tr>
<td>Changes Sufficient to Restore Initial Level of Housing Consumption</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Household Income, ( Y )</td>
<td>100</td>
<td>113–117</td>
<td>125–134</td>
<td>138–152</td>
<td>151–169</td>
</tr>
<tr>
<td>Price of Land, ( l )</td>
<td>100</td>
<td>71–78</td>
<td>50–60</td>
<td>34–46</td>
<td>22–34</td>
</tr>
<tr>
<td>Price of Capital, ( k )</td>
<td>100</td>
<td>87–91</td>
<td>77–83</td>
<td>67–75</td>
<td>59–69</td>
</tr>
<tr>
<td>Price of Real Estate, ( j )</td>
<td>100</td>
<td>91–93</td>
<td>83–87</td>
<td>76–82</td>
<td>69–76</td>
</tr>
</tbody>
</table>

Note: Entries are computed from parameters presented in Table 3. Ranges represent results using coefficients for Model 1 and Model 2. Numerical results using OLS and MLE estimates are virtually identical.

effects of energy prices on the housing sector and neglect the indirect effects of energy prices through lower real incomes.

The table also indicates the effect of energy price increases on the derived demand for inputs into the production of housing services. A 50% increase in energy prices causes a decline in the derived demand for real estate, new owner-occupied housing, of 3%, while a tripling of energy prices causes demand to decline by about 9%.

Similarly, a 50% increase in energy prices reduces the derived demand for residential energy by 11–15%, and a tripling of prices reduces residential energy consumption by 29–36% in newly constructed dwellings.

The bottom part of the table indicates the substantial changes in real incomes, or in the prices of real estate or land or capital inputs that would be required to offset the changes in housing demand and housing consumption induced by energy price increases.

The magnitude of the induced effects on the markets for housing output and factor inputs can be appreciated by considering the pattern of energy price changes in the recent

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11 From equations (1b) and (4b) after some manipulation:

\[
\frac{R}{H} = (\beta' / \alpha')^{\nu/(1 - \nu)} [1 + (\beta' / \alpha')^{-\nu} (j/r/v)^{\nu/(1 - \nu)}].
\]

At initial prices \( R_1 = 10.559[1 + 168^{-31.5}]^{460}H_1 \), while at \( v = 1.5 \), \( R_2 = 10.559[1 + 168^{-31.5}(667)^{-685}]^{460}H_2 \), a decline of 3%.

12 Also from equations (1b) and (4b): \( V/H = [1 + (\beta' / \alpha')^{-\nu} (j/r/v)^{\nu/(1 - \nu)}]^{\nu/(1 - \nu)} \). At initial prices

\[
V_1 = [1 + 168^{-31.5}]^{460}H_1,
\]

while at \( v = 1.5 \), \( V_2 = [1 + 168^{-31.5}(667)^{-685}]^{460}H_2 \), a decline of 14%. 

past and the prospects for future increases. During the period 1970–1983, the price index for fuel and utilities increased by 134% in real terms; the index for household fuels increased by 169% relative to the consumer price index, and the real price index for oil, coal, and bottled gas increased by 222% (Council of Economic Advisors, 1984). Thus the overall effect of energy scarcity on housing consumption, real estate production, and expenditures on housing has been quite large. Similarly, market forces have led to a substantial conservation of residential energy resources, at least of those resources utilized to provide services in newly constructed dwellings.

Government policy. The importance of residential usage in overall energy consumption and the substantial increase in energy prices during the past decade have led to a series of regulatory and subsidy policies designed to induce builders and house purchasers to take specific energy conservation measures in the construction of real estate or in the “retrofit” of existing dwellings. These policies are presumably intended to increase the component of real estate in the production of housing services, to decrease the energy component per unit of housing services, and thereby to “save” energy.

For residential dwellings completed after April 20, 1977, the federal government has offered a tax credit of 15% on as much as $2,000 in additional expenditures on selected real estate components (for example, insulation). Final consumers (owners or renters) are thus offered a closed-ended matching grant of 15% for the purchase of certain real estate components. Some states have offered similar tax credits for the same expenditures, thereby reducing the price of real estate by an even larger fraction, up to 40% in the state of California.

Besides these subsidies, policies have been introduced to mandate the use of certain energy-saving real estate components in new residential construction as a precondition for insurance or as a part of the building permitting process. For example, the FHA minimum property standards are regularly updated to mandate minimum thermal and other attributes of dwellings to be financed or insured under federal programs. Several states (for example, California and Connecticut) and many localities (for example, Champaign, Illinois, and Port Arthur, Texas) have adopted regulatory codes mandating particular building components or building orientations to reduce energy usage.

There are at least two different rationales for these policies of market intervention. First, regulation may be invoked to protect house purchasers (and perhaps builders) from the consequences of their own ignorance of the cost-minimizing combination of factor inputs at given efficient prices. Second, regulation may be invoked because the administered prices in the market do not accurately represent scarcity—because residential energy prices are less than marginal private or social cost, correctly calculated.

While recognizing the first rationale of these public policies, though not evaluating its merits, it is possible to evaluate the second one, in a rough manner, using the results of this empirical analysis. Consider, for example, the federal subsidy for investment in energy-saving real estate. The average house in the sample sold for $39,913. Thus a 15% reduction in real estate prices for an additional $2,000 invested would reduce the output price of housing services by no more than about .6% (from equation (7)) and would thus affect housing consumption only trivially (by no more than .4%, from equation (8)). The subsidy would, however, increase real estate as a fraction of housing services and reduce the energy component of housing services. From the production function, equation (1b),

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13 It should be noted, however, that "labelling" the energy attributes of buildings may be a preferred solution to a problem of producer or consumer ignorance.
and the mean values of the variables (Table 1 with \( j = u \)), it appears that a $2,000 subsidized investment would save $111 in energy annually (or a capitalized energy saving of $1,480).\(^{14}\) Thus, neglecting the trivial effects of changes in output prices, society would have to value each dollar of energy saved at about $1.35 to justify the subsidized investment of $2,000.

Of course, given the parameters of the production relationship, the average household would not choose to make the full $2,000 investment. Net of the subsidy, the household would, if it spent $2,000, incur about $127 in costs a year to save $110. Further analysis suggests that, given the estimated parameters of the production function, a typical household would make a gross investment of about $1,200 in energy-saving real estate. Net of the subsidy, the household would pay about $76 annually in capital costs and would have an equivalent saving in energy costs. To justify the subsidy for a $1,200 investment, society as a whole would have to value a dollar in energy savings at about $1.19.

In California,\(^ {15}\) where the average selling price of a house was about $89,000 in 1980 and where the residential utility costs for dwellings built according to "historic practice" averaged $1,156, state law permitted a combined federal-state tax credit of 40% of the cost of a $2,000 investment in selected components of real estate if they were installed before August 1983. If installed on or after this date, the credit is limited to 35% of the cost. The same calculations as those above for the federal subsidy applied to the average house in the entire sample suggest that the carrying costs of the full $2,000 real estate investment, net of these subsidies, was somewhat greater ($90) with a 40% tax credit than the private benefits of reduced energy consumption ($84), and the cost to society was about $1.78 per dollar of energy saved. At the optimal consumer response, which called for an investment of about $1,000, the cost to society was about $1.65 per dollar of energy saved. At the 35% subsidy rate society pays $1.62 for a dollar of energy saved.

The precision of these calculations of the value of energy implied by these subsidy policies may be illusory. Figure 1 presents some evidence on this point. It shows the additional amount of real estate investment that ought to be made if market transactions do not reflect the social cost of energy, and it is calculated from the parameters of the production function, Model 1, for the average dwelling. As the figure shows, if the social value of $1 of energy is $1.20, then the real estate component of housing should be increased by $1,300; if the social value of $1 of energy is $1.50, then real estate investment should be increased by $2,700. These responses can be induced from builders and homeowners by open-ended investment tax credit offers of 9% and 33%, respectively. The figure also displays 90% confidence intervals for these statements.\(^ {16}\) If the social value of $1 of energy is $1.20, then the optimal additional real estate investment is between $1,100 and $1,400 with 90% confidence. Stated another way, a 9% tax credit induces an additional real estate expenditure of between $1,100 and $1,400, with 90% confidence, implying that the 90% confidence interval for society's value of $1 of energy is $1.13 to $1.28.

\(^{14}\) \(H_1 = [168.24\{(.0746)(39913)\}^{2.1746} + (611)^{2.1746}]^{-4599} \simeq H_2\)

\[= [168.24\{(.0746)(41913)\}^{2.1746} + (62)^{2.1746}]^{-4599}.\]

\(^{15}\) These and other descriptive items rely on: California Energy Commission (1981a, 1981b).

\(^{16}\) The interval is computed by a Taylor series approximation to the nonlinear transformation of the production parameters.
4. Conclusions

This article uses estimates of the production and demand functions for housing services to analyze the tax expenditures made to induce conservation of residential energy by consumers.

The elasticity of substitution of capital and land in the production of real estate is estimated to be about .7, and the elasticity of substitution between operating inputs, largely energy, and real estate is much lower, about .3. The income and price elasticities of demand are estimated to be .3 and -.7, respectively.

Together, these parameter estimates support an analysis of the effects of energy price changes upon the housing and residential energy markets. According to the estimates, a doubling of energy prices is associated with an 11–15% increase in the price of housing services, a decline of 7–10% in the demand for housing, and a small increase in housing expenditures. In response to these price changes, the model suggests a 5% decline in the demand for real estate, and a 19–24% decline in the demand for energy inputs.

It should be noted that the model is estimated from data on newly constructed owner-occupied housing. Presumably, the scope for the substitution of energy-saving real estate for operating inputs is much more limited for existing dwellings, whether owner- or renter-occupied. In principle, the same approach, though not the numerical results, is applicable to the rental market, at least in the long run. Because of variation in rental contract terms, within and between markets, the analysis is, however, probably less compelling for the rental market than it is for the setting in which the investor supplies services to himself as final consumer.

Nevertheless, the results provide some evidence on a principal rationale for subsidy and regulation in the market for new construction—the underpricing of residential energy relative to its social cost. For example, the analysis suggests that the federal tax credit for
residential energy can be justified on efficiency grounds if a dollar of energy at private prices is worth more than $1.20. Although the calculations are less reliable outside the 1974–1978 range of sample values, results also indicate that it would require a far larger underpricing of energy to justify tax credits offered by the State of California.

Finally, it should be stressed that this analysis provides no evidence on the efficiency of market intervention that is motivated by consumer or producer ignorance.

References


