ESTIMATING RESIDENTIAL ELECTRICITY DEMAND UNDER DECLINING-BLOCK TARIFFS: AN ECONOMETRIC STUDY USING MICRO-DATA

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I. INTRODUCTION

Measurement of residential demand for electricity has taken on increased importance with the rapid increase in real energy prices and the identification of the electricity sector as a central focus of energy policymaking. Reliable analysis of proposals to revise electricity rate structures and projections of future supply needs must be based on quantitative judgments about price and income elasticities as well as the effects of other major variables.[1] To date, virtually all econometric studies of household demand have used aggregate time-series or cross-section data and some measure of the average residential price per kilowatt-hour of electricity. Because the marginal price per unit of electricity is not constant under the declining-block rates used by utilities, such studies may contain biases that can be especially serious when analyzing the effect of any change in rate structure.

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[1] Although peak-load pricing is the most far-reaching of the proposed changes in U.S. electricity rate structures, its desirability for residential, as opposed to industrial and large commercial, customers is still an open question. See Mitchell et al. (1978).

The empirical research reported here is based on micro-level data for 3825 geographic areas throughout the county of Los Angeles, California. By adopting this disaggregated approach to estimating demand equations, we are able to measure the marginal price faced by households, control for eight major appliances, and include the important influence of weather.

Section II outlines a general demand model for household energy and analyzes the theory of demand under declining-block rate structures. Section III summarizes the principal types of bias that have plagued earlier demand studies relying on an average price measure and analyzes the question of estimator bias when marginal price is used. Section IV describes the data and presents in detail the estimated model, and in Section V the principal empirical results are reported.

II. THE DEMAND FOR ENERGY

The household demand for energy is fundamentally influenced by its role as an intermediate service and by the nonlinear pricing structure under which electricity is sold.

THE CONSUMER'S DECISION

The household's demand for energy is derived from the demand for services that electricity, natural gas, fuel oil, or coal can perform rather than from any direct benefits from consuming those fuels. We can envisage a three-stage process that determines the consumption of energy during a particular time period:

1. The household decides whether or not to acquire an energy-using appliance capable of providing certain services, such as cooking.
2. Given the decision to have an appliance, it selects the type of fuel for that appliance (e.g., an electric or gas stove).
3. Having acquired an appliance of a given fuel type, the household determines the frequency or intensity of its use.

Although these economic decisions are logically interdependent, it is useful to model the choices separately because of the widely different time periods within which they can be modified. Due to their cost and durability, appliance stocks will generally be adjusted only over a long period of time, whereas the intensity of utilization of a given stock of appliances is subject to short-run adjustment.

The first two decisions--appliance choice and fuel selection--depend on the purchase price of different appliances and their expected operating costs.[2] Moreover, the consumer's current inventory of appliances influences the decision to keep, convert, or retire a particular appliance. Income, assets, and expected prices of other goods and services determine the budget constraint within which the consumer can maximize its utility.

The intensity with which a given stock of appliances is used depends on current values of energy prices, income, and noneconomic factors. For a given type of appliance (say, cooking or water heating), a household will normally use only one fuel, although the same household may employ another fuel for a different function. Consequently, for each source of energy, the short-run effect of its own price will be relatively more important than will the effect of prices of substitute fuels.

To represent these relationships, assume for simplicity that only two fuels are available to the household--electricity and gas. Let E_t and G_t be the quantities of electricity and gas consumed by the household at time t and A_{et} and A_{gt} be the corresponding stocks of appliances held in time period t.[3] Then

$$E_t = U_e(p_{et}, p_{gt}, Y_t, Z_t, A_{gt}) \cdot A_{et}, \tag{1a}$$

$$A_{et} = F_1(p_{e\tau}, p_{g\tau}, Y_\tau, Z_\tau'), \tag{1b}$$

[2]The consumer may also be concerned about the future availability of some fuels, due to possible curtailment of their supply, but we assume this uncertainty is included in expectations about operating costs.

[3]Construction of the appliance indices, A_i, is described in Section IV.

where p_e is price of electricity, p_g is price of natural gas, Y is income, Z are other relevant variables (such as household characteristics and weather) that influence the consumption of energy, and Z′ are variables that influence the purchase of appliances. The subscripts t and τ refer, respectively, to the current time period, and to one or more earlier time periods in which relevant explanatory variables were observed. Similar equations apply for gas consumption g_t and gas appliance A_{gt}.

Variations in the intensity of utilization of appliance i are captured in the functions $U_i(\cdot)$, while long-run adjustments in the stocks of appliances are reflected in the A_i's. The adjustment process with respect to the price of electricity is given by

$$\frac{\partial E_t}{\partial p_{e\tau}} = \frac{\partial U_e(X_t)}{\partial p_{e\tau}} \cdot A_t + \frac{\partial A_t}{\partial p_{e\tau}} \cdot U_e(X_t), \qquad (2)$$

where X_t is the vector of explanatory variables in period t. If $t = \tau$ and no appliance adjustment takes place due to price changes in that period, then the second term in Eq. (2) is zero, and all changes in E are due to changes in the intensity of utilization of the available stock. However, if a given price change persists for several periods, earlier price changes will reflect themselves in non-zero stock adjustment effects. In this case $(\partial A_t/\partial p_{e\tau}) \neq 0$ so that for over a period of time there is a larger (in absolute value) effect of price changes.[4]

THEORY OF DEMAND UNDER DECLINING-BLOCK RATE SCHEDULES

In the markets for most goods, consumers face a single price; to study consumer demand, it suffices to examine the relationship between this single (marginal) price and the quantity of the good consumed,

[4]When $t - \tau$ is very large, the impact on appliance choice will disappear because most people will have replaced appliances at least once in the interim.

$Q = D(p)$, holding other things constant. However, the pricing of electricity (or natural gas) is nonlinear.[5] Each customer faces a *price schedule* under which the price per unit of additional consumption depends on his total quantity of consumption in the time period and declines in a series of blocks. Moreover, for residential customers, the price schedule usually has two components--a monthly (or bimonthly) customer charge, which does not depend on the level of consumption, and a per-unit schedule of charges.

Under a "declining-block" tariff the consumer pays a fixed customer charge C plus a series of per-unit charges $p_1, \ldots, p_m$ for kilowatt-hours (x) consumed in the intervals $[0, x_1), [x_1, x_2), \ldots, [x_{m-1}, \infty)$. His bill is

$$\begin{aligned} B &= C + p_1 x, && \text{if } 0 \leq x < x_1, \\ &= C + p_1 x_1 + p_2(x - x_1), && \text{if } x_1 \leq x < x_2, \\ &\ldots && \ldots \\ &= C + \sum_{i=1}^{m-1} p_i x_i + p_m(x - x_{m-1}), && \text{if } x_{m-1} \leq x < \infty. \end{aligned} \tag{3}$$

The three-block schedule shown in Fig. 1 illustrates how a declining-block tariff generates the nonconvex, piecewise linear budget line in commodity space that is shown in Fig. 2 as the solid line DEFG. The fixed charge $C = Y - D$ is the difference between income, Y, and the intersection of the budget line with the vertical axis, a point that represents expenditure on other goods. The slopes of the segments DE, EF, and FG correspond to the marginal prices, p_1, p_2, and p_3.

[5]Other household fuels--such as fuel oil, bottled gas, and coal--do not generally exhibit such an unusual pricing structure.

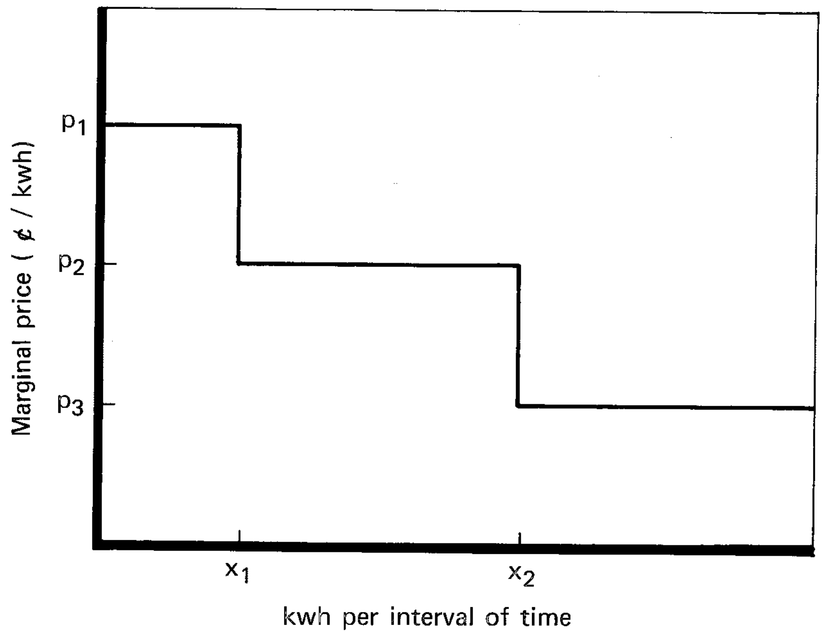

Fig. 1 — Declining block tariff
(C = fixed customer charge)

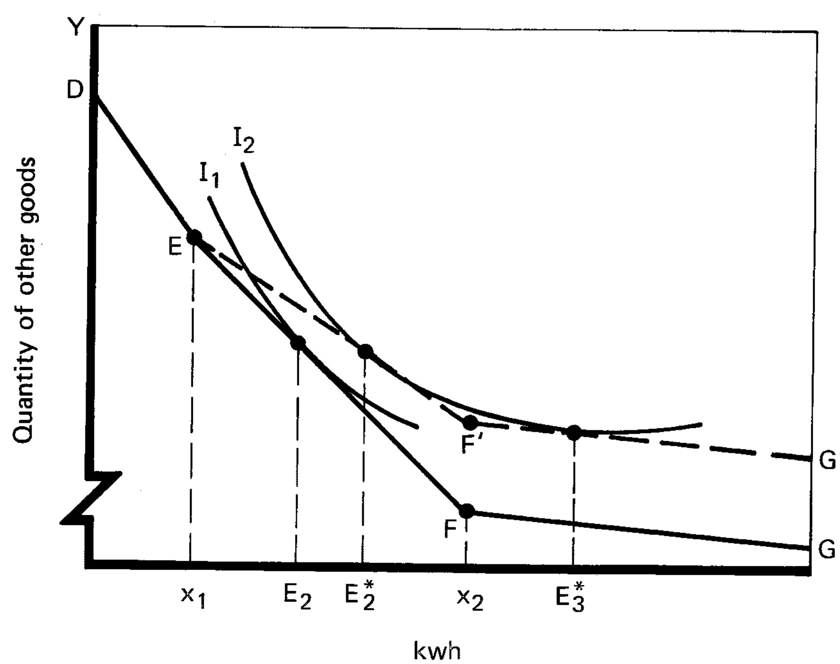

Fig. 2 — Nonconvex budget line and possibility of multiple equilibria

The behavior of the utility-maximizing consumer can be deduced by systematically varying each of the prices and locating the tangencies of his indifference curves with successive budget constraint. Here we briefly summarize the key results of this analysis.[6] At certain prices, illustrated by the dashed line DEF'G' in Fig. 2, the consumer will be in equilibrium at more than one quantity (e.g., E_2^* and E_3^*). Thus, the general relationship is a demand correspondence between quantities demanded and the levels of the rate-structure prices. However, the relationship between quantity demanded and the *marginal price* is single-valued. As shown in Fig. 3 it resembles an ordinary demand curve except for gaps in the neighborhood of the x_i quantities at which the block-structure prices change.[7]

The consumer who faces a different declining block rate structure in which the blocks occur at different quantities will have the same demand curve shown in Fig. 3 (with the same values of other explanatory variables) but with the gaps S-T, U-V, etc. located at different points on the curve. Consequently, in cross-sectional data covering several service areas with different values of the x_i's we will estimate the full relationship between quantity and marginal price.

III. THE PRICE VARIABLE AND ESTIMATION BIAS

The theory of consumer demand under a declining-block rate structure requires that the marginal price be used in the estimated demand function. To date, however, studies of electricity demand have almost always been based on some measure of the average price per kwh.[8] The

[6] See Acton, et al. (1976) for details.

[7] The empirical results in Section IV confirm that the income effect of the customer charge and inframarginal prices result in only negligible differences in quantity demanded, $D(p_m)$, if electricity were sold at a constant price p_m for all units consumed.

[8] Houthakker (1951) is an exception. Several recent studies have adopted a mixed approach, either by aggregating rate structures to a state level or by computing average rates for different levels (typical electric bills) of monthly consumption. See Anderson (1973), Halvorsen (1975), Houthakker et al. (1974), McFadden et al. (1977), Ruffell (1977, 1978), and Taylor et al. (1976).

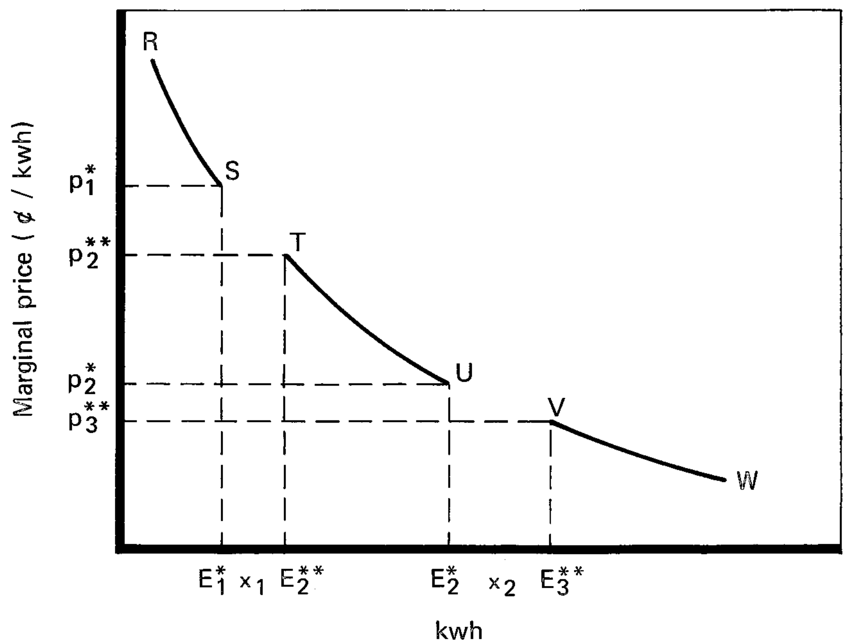

Fig. 3 — Observed relationship $D(p_m)$ between quantity demanded and marginal price under a declining-block rate structure

use of average price necessarily leads to biased coefficient estimates, although estimates based on marginal price are not without their own difficulties.

AVERAGE PRICE BIASES

Under a declining-block rate schedule, the average price per kwh approaches the marginal price as the quantity consumed increases. Thus the distortion between marginal and average price is not uniform, and causes the estimated demand curve to follow the locus of the average-price and quantity points and to have a greater (absolute slope) than the true demand curve.

A second bias is introduced when the average price is measured by revenue per kilowatt-hour sold. Differences in observed values of average price can result from variations in both customer changes and infra-marginal prices across the sample. Moreover, use of an average per-unit revenue measure introduces a classic errors-in-variables problem by including total consumption in the equation as both the dependent variable and the divisor of one of the independent variables. Stochastic variation in electricity demand will affect both sides of the equation and thus bias the estimated price coefficient away from zero.

Finally, if the average price is used in the estimation equation, then differences in consumption between consumers in the same rate block that are due to unmeasured non-price factors, such as weather or appliance stocks, will be falsely ascribed to a price effect.[9]

MARGINAL PRICE

For this study we use data aggregated over several hundred consumers in small geographic areas within which households face the same

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[9]This criticism also extends to studies (e.g., Halvorsen, 1975; Wilder and Willenborg, 1975) which estimate a relationship between price and quantity and enter a predicted value of price (either average or marginal) in the equation explaining quantity of energy. The auxiliary regression will provide a monotone-decreasing relation between price and quantity, despite the fact that for a given observation, the marginal price is constant, not declining.

rate structure. The estimated demand function

$$E = f(p_m, Z, \varepsilon) \quad (4)$$

is an approximation to the demand correspondences of individual consumers. Pooling across service areas in which the size of the blocks differ allows us to estimate a continuous demand function. In each area we have calculated mean values per household of electricity consumption (E), appliance stocks, and exogenous variables such as weather (Z) and marginal prices (p_m). The supply price schedule facing the individual consumers consists of the unique rate structure given by $p = S(E) = p_i$, where p_i is the price in the i^{th} rate block. Although the marginal supply price is a function of the quality consumed, the supply schedule is a known, determinate function; there is no need to estimate its parameters or the marginal prices.[10]

We now consider econometric difficulties that may bias the estimated price coefficient in an equation using marginal price. First, suppose the true demand curves are shown as $D_1, \ldots, D_6$ in Fig. 4, and the appliances and exogenous variables Z are not observed. In this case in different geographic areas the mean electricity consumption (E_1 and E_2) will be negatively correlated with the mean marginal price simply because of the declining block structure of the tariff. A regression of quantity on price in a cross-section will yield an approximation $\hat{D}$ to the downward slope of the supply schedule, S(E), rather than an estimate of the demand curve. The estimated price coefficient will be biased away from zero.

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[10] In more aggregative studies, such as those based on statewide data, a composite supply schedule must be constructed from several different rate schedules. In these circumstances, the most statisfactory procedure would be to aggregate directly the rate structures of individual utilities within each state. However, if rate structure data for the individual utilities are unavailable, then it may be useful to treat the composite schedule as a function with unknown parameters to be estimated (Halvorsen, 1975) or to fit the composite schedule by combining data on the distribution of consumption over rate blocks at a point in time with a time series of mean price (Ruffell, 1978).

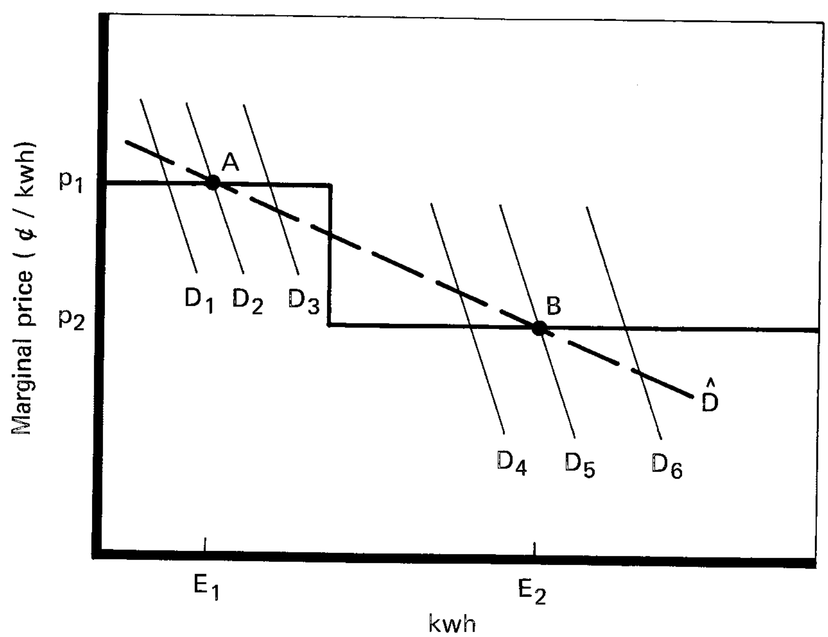

Fig. 4 — Regression of quantity on marginal price when only mean consumption is observed in each block

Suppose instead, that all of the major predetermined variables Z that account for the differences in consumption between geographic areas are included in the regression equation; in this case a major portion of the cross-sectional variation in consumption will be attributed to a shift of the demand curves, for example, from D_1 to D_2 in Fig. 5. If all variation in electricity use is due either to measured variation in the Z's or to difference in marginal prices, households in area 2 with exogenous factors Z_2 would consume $\tilde{E}_2$ units of electricity at a uniform price of p_1. But because of the lower second block price p_2, they are induced to use somewhat more electricity and consume E_2 units. In this case, with no random errors or unmeasured explanatory variables, knowledge of the mean consumption, exogenous variables Z in each block, and price are sufficient to determine exactly and without bias the unknown price and stock coefficients in Eq. (4). The true demand curves D_1 and D_2 are correctly estimated.[11]

The realistic third case represents a combination of Fig. 4 and Fig. 5 and occurs when some variations in individual consumption levels are due to unobserved factors such as individual tastes and habits and to imperfect measurement of the effects of weather and the stock of appliances. Thus, in practice the use of marginal price will not totally eliminate the bias in single-equation estimates of Eq. (1). The bias in the price coefficient away from zero will be greatest in cross-section regressions in which much of the observed variation in marginal prices is due to observing customers in different blocks of the same rate structure. But over time, this factor is of less importance because general rate increases and changes in the automatic fuel-adjustment clause will shift the price levels of all blocks. In our samples, when pooled time series and cross-sectional data are used, the standard deviation of price is about 0.34 cent per kwh, whereas the standard deviation of prices across blocks of a single rate structure is about 0.1 cent per kwh.

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[11]We are indebted to Ed Park for clarifying this point.

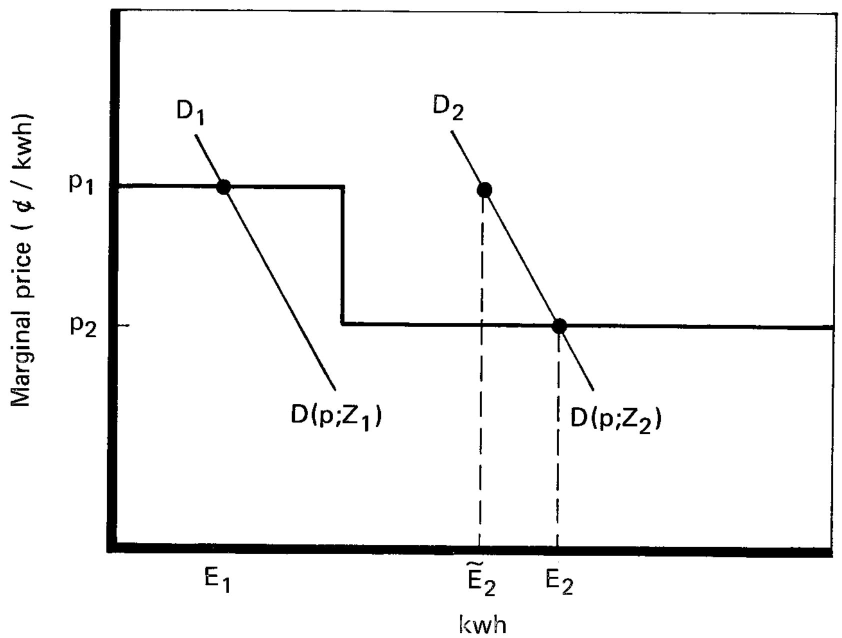

Fig. 5 — Regression of quantity on marginal price when mean consumption and predetermined variables Z are observed in each block

IV. SPECIFICATION OF THE ESTIMATED MODEL

This study employs micro-level data that permit us to measure the marginal price of electricity (as well as the inframarginal changes of declining-block rate structures) and the principal variables affecting residential electricity usage--the stocks of appliances and weather conditions--in more detailed and accurate form than in previous econometric investigations.

DATA[12]

Bimonthly electricity consumption and price data from July 1972 through June 1974 were constructed from records of the two utilities that supply Los Angeles County--the municipal Los Angeles Department of Water and Power (DWP) and the Southern California Edison Company (SCE). Other explanatory variables were developed from U.S. Census and weather service data.

In the DWP area the unit of observation is the meter readbook--a geographic area covered by a meter reader in one day. There are about 260 customers per readbook and 3610 readbooks in the entire area. The (weighted-average) marginal price is computed from the four-block DWP rate structure using the observed consumption levels of the individual households. In the SCE areas of the county we use the 215 SCE geographic areas as observations. SCE has six rate schedules, with five blocks and a different customer charge for each schedule. The marginal price for each observation is computed from mean consumption per customer in each geographic area.

The 1970 Census, fourth count, provided census-tract level data for income, family size, housing tenure, and ownership of eight major household appliances classified by fuel used. The 1970 income levels were updated, on a city-by-city basis, to 1972, and subsequent monthly observations were adjusted upward by the rate of increase in real

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[12] A complete description of these data and the merging of different micro-files is found in Mowill (1976).

earned income for the SMSA. Census tracts are not co-terminus with utility readbook or geographic areas and therefore variables were aggregated to our level of observation using address-matching algorithms.

Monthly measurements of heating degree-days and cooling degree-days were obtained for six weather stations located in the county.[13] Each observation was assigned the measurements from the closest weather station.

SPECIFICATION

We now develop the equations used to estimate Eq. (1a). Let E_t represent mean consumption of electricity per household in an observation at time t; $U(X_t)$ the intensity of utilization as a function of a vector of explanatory variables X_t; and AE_t the stock of electrical appliances. Then our basic estimating equation is

$$E_t = a_0 + U_1(X_t) + U_2(X_t) \cdot AE_t + \varepsilon_t, \tag{7}$$

where ε_t is the error term, and functions U_1 and U_2 allow for different responses in the intensity of utilization of a composite stock of measured appliances (AE) and in uses of electricity (such as illumination) for which we have no stock measure. For linear utilization functions this becomes

Specification I:

$$E_t = a_0 + \Sigma_i a_i X_{it} + \Sigma_i b_i X_{it} AE_t + \varepsilon_t. \tag{8}$$

To measure AE_t we have aggregated the eight major electrical appliances in the household, weighting by the average monthly con-

[13]A heating degree-day is a measure intended to capture the fuel used for heating. One heating degree-day is recorded for each degree that the mean daily temperature is below the base level of 65°F. A cooling degree-day is recorded for each day that the mean daily temperature is one degree above 65°F.

sumption (γ_i) of those appliances.[14] In addition, this variable incorporates the effect of weather in a novel manner. The percentage of households with air conditioning and the percentage with electric heating were weighted by cooling degree days (CDD) or heating degree days (HDD), respectively. Thus the effective stock of appliances is

$$AE_t = \gamma_1 AC \cdot CDD_t + \gamma_2 AH \cdot HDD_t + \sum_{i=3}^{8} \gamma_i A_i, \qquad (9)$$

where AC and AH are the percentages of households with air conditioning and electric heating, CDD_t and HDD_t are the heating and cooling degree days in month t relative to a four-year average, and the third term sums over all remaining appliances. Under this specification, the effective stock of appliances varies from month to month depending on the weather.[15] For instance, in the summer when electric heat is not used, HDD takes the value zero, and electricity consumption depends only on air conditioning and other electrical appliances that may be in use.

To allow for differential responses with respect to air conditioning, electric heating, and the other electrical appliances (AO), we also estimate

Specification II:

$$E_t = a_0' + \Sigma a_i' X_{it} + \Sigma c_i X_{it} AC \cdot CDD_t + \Sigma d_i X_{it} AH \cdot HDD_t + h_i X_{it} AO + \varepsilon_t' \qquad (10)$$

where

$$AO = \sum_{i=3}^{8} \gamma_i A_i .^{16}$$

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[14]These consumption weights (measured in kwh) are a more desirable measure of the relative "size" of appliances than is rated capacity (measured in kw). For instance, the average capacities of an electric toaster and a room air conditioner are 1100 and 1500 watts respectively, but the toaster is 39 kwh and the air conditioner 1389 kwh.

[15]In equations that include the stock of gas appliances (AG), gas heaters are analogously weighted by HDD and all gas appliance percentages multiplied by typical monthly usage.

[16]Since HDD is almost always zero during the four summer months of June-September, we excluded the terms involving AH_t from cross-sectional regressions over those months. Similarly, terms with AC_t were excluded during the months of December-March.

V. RESULTS

For reasons of space, we report only the central empirical findings here. Readers interested in greater detail may consult Acton et al. (1976).

PRELIMINARY REMARKS

Although we have incorporated measurements of the ownership of eight types of household appliances in the stock variable, no data are available about variations across households in rated capacity or operating efficiency of, say, air conditioners. For this reason care must be taken in the interpretation of the "intensity of utilization" coefficients $U_i(\cdot)$ in Eqs. 7, 8, and 9. These coefficients capture not only the proportion of time the appliances are in use and the "setting" at which they are used, but also differences in their size or rated capacity. In our data these three factors are operationally indistinguishable, so that rather than interpreting the term $U(\cdot)$ to mean "hours of use," we interpret it to mean "kilowatt-hours of use." Thus, in the short run, households will react to an increase in the price of electricity by adjusting their hours of use or the setting of the appliance, and in the longer term, they may adjust the "size" of the appliance as well.

In our data set there is relatively little cross-section variation in the price of gas that is independent of the price of electricity. Both gas and electricity prices are higher in areas of Los Angeles County where homes are more sparsely distributed. Furthermore, within the City of Los Angeles a single price schedule for gas applies. Consequently, we do not expect to detect a significant effect of the price of gas on the demand for electricity in cross-sectional analysis.

On the other hand, changes in the price of natural gas play a potentially important role in the time series estimates because our appliance stock measures are limited to a single-cross section of observations provided by the 1970 Census. As noted, changes in the size or rated capacity of these stocks over time will be captured in the utilization coefficients. However, changes in relative fuel prices will promote the conversion of specific appliances, so that electricity consumption will be altered despite the fact that our measure of appliance stocks is unchanged. The price of natural gas will therefore serve as a proxy variable for these types of stock adjustment and limit the specification bias that would otherwise result.

In addition to the appliance stock measures (AE), the other explanatory variables in our estimation equations include the marginal price of electricity (PE), the marginal price of natural gas (PG), average income per household (INC), average number of rooms per housing unit, average number of persons per housing unit, average monthly rent for rental units, average market value of owner-occupied housing, and percentage of renter-occupied units. In addition, some specifications employed the stock of gas appliances (AG) and the income effect of the customer charge and earlier blocks of the rate structure (YPE) to test their effect on electricity consumption.[17]

CROSS-SECTION RESULTS

The two alternative specifications, Eqs. 8 and 10, were estimated for each of the 12 bimonthly periods from July-August 1972 to May-June 1974. In general, the principal explanatory variables have the expected effects and are statistically significant at the .05 level or better. Coefficients of determination lie between .8 and .9. We report here only the principal results involving the effects of marginal price, the income effect of customer charges and infra-marginal prices, income, and the stock of gas appliances. Specification II, which allowed for differential response of the weather-sensitive

[17] All regressions were run on observations weighted by the square root of number of customers in the unit of observation to eliminate heteroskedasticity in observations due to differing number of households in a given geographic area. Explanatory variables used in the bimonthly regressions are taken from the two-month period over which the majority of consumption data are measured. For example, March-April electricity consumption depends on values of explanatory variables from February and March.

appliances, had only a minor effect on these primary variables, and all reported coefficients are from Specification I.[18]

Table 1 gives the elasticity of demand for electricity with respect to PE and INC and t-ratios for each of the 12 bimonthly observations. The equations reported exclude AG and PG. The marginal price of electricity showed a consistently negative effect on the quantity of electricity consumed, and ignoring the two-month observation at the height of the energy crises (billings for March-April 1974),[19] the elasticities have an average value of -0.70.[20] These results were not substantially changed by alternative equations that included stocks of gas appliances or the price of gas. As noted in Section III, incomplete measurement of variables that shift demand curves from one customer to another can bias the estimated marginal price elasticity away from zero, and smaller elasticity estimates should result when time series as well as cross-section variation in price is present.

The household income variable is consistently significant and positively related to electricity consumption, with an elasticity averaging 0.40. When a variable is included to measure inframarginal price effects--the customer charge plus blocks of the rate structure lying above the marginal price--its coefficient is very near zero, of the wrong sign about half the time, and frequently insignificant. Economic theory predicts that this coefficient should be equal in magnitude and opposite in sign to the income coefficient.

Consumers do not generally have both gas and electricity appliances to perform the same function (for instance, most residences do not have both an electric and a gas water heater). Nevertheless, some

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[18] See Acton et al. (1976) for full details of both specifications.

[19] Consumption within the City of Los Angeles was unusual at this time because residential customers served by the DWP were required to reduce their consumption 10 percent over the preceding year or face a significant surcharge on their bills. Because the ordinance was generally effective in achieving its goals, the consumption for billings in February through July 1974 is questionable for measuring a normal price response. Acton and Mowill (1976) provide a statistical analysis of the response to the curtailment ordinance.

[20] The price elasticities are calculated at the mean level of marginal price and the mean of appliance stocks.

Table 1

OWN-PRICE AND INCOME ELASTICITIES OF DEMAND FOR ELECTRICITY FROM CROSS-SECTION REGRESSIONS

Observation (month of billing)	Own-Price Elasticity	Own-Price t-value	Income Elasticity	Income t-value
1972				
July-August	-0.55	7.1	0.32	6.8
September-October	-1.03	11.7	0.37	8.7
November-December[a]	-0.77	9.0	0.37	9.1
1973				
January-February	-0.72	9.4	0.34	12.4
March-April	-1.03	13.5	0.43	12.4
May-June[a]	-0.53	10.3	0.34	7.6
July-August	-0.44	5.8	0.39	8.9
September-October	-0.67	7.4	0.39	7.5
November-December[a]	-0.66	7.9	0.42	9.6
1974				
January-February	-0.97	11.5	0.44	12.0
March-April	-0.06	0.89	0.42	11.0
May-June[a]	-0.36	5.2	0.43	10.3
Mean	-0.70[b]	-	0.40	-
Standard deviation of mean of coefficients	0.23	-	0.04	-

[a]May-June and November-December billings contain both AC and AH.

[b]Excluding March-April 1974 billings which cover the height of the energy crisis and the period in which the DWP curtailment ordinance was in effect.

Table 2

ELASTICITIES FROM TIME SERIES REGRESSIONS

Time Period	Electricity Price (PE)	Income (INC)	Gas Price (PG)
July 1972 - June 1973	-0.52	0.31	0.75
July 1973 - June 1974	-0.20	0.42	0.73
July 1972 - June 1974	-0.35	0.38	0.71

households may be able to achieve some short-run substitution between fuels by adjusting the intensity of utilization of a given stock. When the price of electricity rises, consumers with gas appliances may be able to perform more household functions using gas instead of electric appliances, and thereby reduce their consumption of electricity more easily than households without gas appliances. When an index for the stocks of gas appliances (AG) is included in the estimating equation in the same manner as AE or AO, the expected negative elasticity for gas appliances is obtained (averaging -0.16) with considerable variability and statistical significance at the .05 level in only about half the observations.

As previously noted, in our cross-sectional samples there is little variation in the price of gas which is independent of the price of electricity. If we include PG and limit our analysis to bills rendered between November and April (months when heating may be used, thus giving the maximum opportunity of any reasonable substitution to be observed), the cross-price effect of natural gas on consumption of electricity shows a rather high average elasticity of +0.53.

TIME SERIES RESULTS

By analyzing a time series of cross-sections we can measure the effects of changes in prices, weather, and appliance stocks from one billing period to the next on the intensity of utilization and demand for electricity. The pooled data yield estimates that are neither pure short-run nor pure long-run estimates. However, since the time series include the month-to-month variation of particular variables of interest, these pooled regressions capture more of the immediate, or short-run, adjustment in intensity of utilization than do the purely cross-sectional regressions. Consequently, we expect some elasticities to be smaller than the elasticities just discussed. Results for the income variable (whose variation is limited to a uniform increase for each geographic area) and other census variables that do not change during the 24-month period, should be similar to the results of individual cross-section regressions presented above.

For samples covering one- and two-year consumption periods, the elasticities with respect to PE, INC, and PG are presented in Table 2. The anticipated reduction in the price elasticity of electricity emerges. When PG is included, the own price elasticity of demand for electricity is -0.35 in the regression pooled over two years. It ranges from -0.20 to -0.52 in the one-year regressions. We argued above that it was most appropriate to concentrate on specifications that include the price of natural gas as a proxy variable for unobserved changes in the stock of appliances over time. In fact, the exclusion of PG has only a minor impact on the principal elasticities.

The income elasticity of demand for electricity is quite similar to that obtained in the cross-section regressions. When PG is included, the elasticity ranges from 0.31 to 0.42.

The effect of an increase in the price of natural gas is to raise the consumption of electricity, with a cross-price elasticity of about 0.75. As we have noted, this elasticity is best interpreted as measuring both adjustments in stocks of electrical appliances and changes in the intensity of their use.

Entering the infra-marginal price effects in the pooled equations produces results similar to those found in the individual cross-section regressions. The elasticity with respect to this variable is of the wrong sign (positive) and very close to zero (from 0.01 to 0.14). The remaining coefficients are little affected by its exclusion from the estimating equations.

In addition to the elasticities for prices and income reported here, the coefficients of other variables included in the equations generally behaved as expected. Average rent per unit, rooms per unit, and persons per household are all positively related to per-household consumption of electricity, and percent renter-occupied housing is negatively related. The average value of housing proved to be an exception; it was negatively related to electricity consumption, perhaps reflecting the multicollinearity of housing value with included variables such as rooms, number of persons, and income.

RATE RESTRUCTURING

Almost all utilities in the United States, as well as those in some Western European countries, have a declining-block rate structure for residential customers. These tariffs are criticized for charging different marginal prices according to the total amount of consumption when, in many cases, the cost of supplying an extra kilowatt-hour of electricity is the same for different groups of customers. For instance, during most of 1976/77, the DWP rate structure in Los Angeles charged \$1.50 per month plus about 4.6¢/kwh for the first 150 kwh, 3.5¢/kwh for the next 250 kwh, 3.2¢/kwh for the next 600 kwh, and 2.9¢/kwh for all consumption in excess of 1000 kwh per month (see Table 3). A widely proposed reform in electricity rates is to "flatten" the rate structure.

To investigate the approximate effect of rate flattening on different sized customers we assume that the DWP rate is changed to a fixed monthly customer charge plus a uniform 2.92¢/kwh for all kwh.[21] We base our calculation on the equation estimated for the two-year pooled time-series of cross-sections. The demand response to lower marginal prices depends on consumers' stocks of appliances as well as the magnitude of change in their marginal prices.[22] Data are not readily available on appliance holdings by block of rate structure, so we assume that customers in block 1 have an appliance stock one-half a standard deviation below the mean of our DWP subsample, customers in block 2 hold the mean level of stocks, and that customers in block 3 have stocks one-half a standard deviation above the mean. As shown in Table 3, the estimated price elasticities for the first three blocks are -0.25, -0.35, and -0.44, and the effect of rate flattening is to increase consumption by 10 percent in block 1, 6 percent in block 2, and 4 percent in block 3. Given the distribution of DWP customers this amounts to an approximately 6 percent increase in total residential consumption.

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[21] To offset the loss of revenue, the customer charge could be revised.

[22] For instance, in Specification I, $\frac{\partial E}{\partial PE} = \hat{a}_i + \hat{b}_i AE$.

Table 3

CHANGES IN ELECTRICITY CONSUMPTION DUE
TO FLATTENING OF RESIDENTIAL TARIFF

Item	Block 1 (0-150)	Block 2 (151-400)	Block 3 (401-1000)	Block 4 (1000+)
Mean consumption (kwh per month)[a]	92	264	593	1533
Current charge (¢ per kwh)	4.64	3.46	3.15	2.92
New Flat rate	2.92	2.92	2.92	2.92
Percent change in price if rate flattened[b]	48	17	8	0
Estimated price elasticity	-0.25	-0.35	-0.44	-
Percent change in quantity	10	6	4	-

[a]Mean consumption for the system is 387 kwh per month for residential customers.

[b]Calculated as a percentage of the average of current and new rate levels.

VI. CONCLUSIONS

The presence of declining-block rates in the sale of electricity gives rise to potentially strong biases in empirical investigations of demand which are based on the average price of electricity. However, the theory of demand under declining-block rates establishes that the quantity demanded is correctly specified as a function of the marginal price and major exogenous variable.

This study has used micro-level data for geographic areas comprising several hundred households throughout the County of Los Angeles. For each area, marginal price, inframarginal price, stock of major appliances, and weather variables were constructed.

The elasticities, calculated at the mean levels of price and exogenous variables, represent short-run changes in the utilization of a fixed stock of appliances plus a degree of longer-term adjustment in the size or capacity of appliances that cannot be directly measured in this data set. In the long run, changes in major variables will alter the stock of appliances as well as utilization patterns and result in larger elasticities than estimated here.

Own-price elasticities of demand range from -.35 in two-year pooled samples of cross-sections to -.70 in cross-sections for a single billing period. The higher elasticity estimates reflect long-run adjustment of appliance stocks, and possibly some estimation bias that remains even when marginal, rather than average, price variables are used. The estimated effect of fixed and infra-marginal charges in the rate structure is quite small and insignificant.

Income elasticities of demand are found to be approximately .40. Natural gas, the principal competitor for household electricity in this region, is found to have a cross-price elasticity of .75 to .90. Some part of this rather large magnitude is undoubtedly due to the fact that the price of natural gas serves as a proxy variable for unmeasured changes in the appliance stock that are due to changes in the relative gas/electricity price over time.

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