A Monthly Model of Residential Electricity Demand in the District of Columbia

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1 Introduction

The purpose of this paper is to suggest a model for residential electricity demand and then to implement it using monthly data on electric energy usage in the District of Columbia for the period May, 1982 through July, 1989.[1]

The model is formulated in such a way that autocorrelation and herteroscedasticity of the disturbance terms are accounted for.[2] Given the monthly nature of the model, autocorrelation of the disturbance terms is reasonable, and our results strongly suggest its presence. Given the considerable seasonable variation of the demand for electricity due to, among other things, weather conditions, heteroscedasticity of the disturbance terms is reasonable.

We subject our model to a variety of tests. These include the consideration of additional variables, as well as tests relating to the basic structure of the model itself. In all cases considered, the model held up well: the additional variables were not significant and the coefficients of the basic model were reasonably stable for all the variations considered.

Elasticities with respect to the components of the price schedule are given. These include the end points defining the blocks of the marginal rates.

Section 2 presents the general form of the model. Section 3 presents details of the District of Columbia model specification and discusses corresponding data issues. Empirical results are given in Section 4.

2 The General Form for the Electricity Demand Model

The empirical model we consider has the general form

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[1] Because, among other things, regulatory issues relate to the electric utility industry, there is substantial interest concerning the demand for electricity. See, for example, Betancourt[**2**], Hausman and Trimble[**9**], Kohler and Mitchell[**12**], Howrey and Varian[**10**], Goett[**5**], Mayberry[**13**], and Anderson[**1**]. Moffitt[**14**]describes some related econometric issues.

[2] Essentially, we account for an AR(1) process by expressing the model in a nonlinear way with respect to its parameters; we account for herteroscedasticity via Hansen's GMM approach[**8**,**15**,**16**]. Greene [**6**,pp 370-381] provides an intuitive presentation of the GMM approach.

Table 1: District of Columbia Residential Rate Classes

Rate Class	Defining Characteristics	Proportion of Total Residential kilo-Watt-hour(kwh) Sales in DC in 1990
R0	Residential Basic Service	68%
R2	Residential Service with Electric Water Heating Only	3%
R3	Residential Service with Electric Space Heating Only	5%
R5	Residential Service with Electric Space and Water Heating	24%

of electricity in terms of the extent of usage. The rate schedule a particular residential customer faces depends upon the heating equipment the customer has. Table 1 describes the defining characteristics of the four residential rate classes and presents a measure of their relative importance in the District of Columbia residential electricity market.

Our empirical model corresponds to the R0 class. Over the period of our sample, the essential features of the rate schedule for this class are outlined in Figure 1.

In reference to Figure 1, the marginal price to a R0 class customer consuming less than B_1 kilo-Watt-hours(kwh) per month is P_1; the marginal price is P_2 if that usage is between B_1 and B_2, and it is P_3 if that usage exceeds B_2. For our entire sample period, May, 1982 to July, 1989, the lower breakpoint, B_1 was equal to 30 kwh/month. From May, 1982 through December 1982 the upper breakpoint, B_2, was equal to 450 kwh/month; since January, 1983 B_2 has been 400 kwh/month. At every point in our sample period, $P_1 < P_2 < P_3$. Finally, for our entire sample period, all R0 class customers had to pay a fixed monthly customer charge.

As a point of interest, the electric utility in the DC area, (PEPCO),[5]

[5]The Potomac Electric Power Company, commonly referred to as PEPCO, is the electric utility in the Washington, DC area.

as

$$BILL_t = \begin{cases} BC_t + P_{1,t}S_t, & when \quad S_t \leq 30 \\ BC_t + P_{1,t}B_{1,t} + & \\ \quad P_{2,t}(S_t - B_{1,t})(1 - D_t) + & \\ \quad P_{2,t}(B_{2,t} - B_{1,t})D_t + & \\ \quad P_{3,t}(S_t - B_{2,t})D_t, & when \quad S_t > 30 \end{cases} \tag{4}$$

where, at time t, BC_t is the customer charge, $P_{1,t}, P_{2,t}$, and $P_{3,t}$ are the marginal rates, $B_{1,t}$ and $B_{2,t}$ are the breakpoints, and

$$D_t = \begin{cases} 1 \ \ if & S_t > B_{2,t} \\ 0 \ \ otherwise & \end{cases}$$

3.2 The Empirical Model

In formulating an empirical demand model for electricity we assume that most DC residential R0 class customers do not know the components of the rate schedule facing them and so respond to the latest electric bill they receive. Thus in a sense the most recent electric bill received is viewed as the relevant price variable in the demand model. These assumptions concerning the role of the latest bill are tested in Section 4.1.

Let $BILL_t^a$ be the bill that the "average" DC R0 class customer receives in period t+1 for the kwh's consumed in period t. Define the "average" R0 class customer at t as the one who consumes $\frac{SALES_t}{N_t}$ where $SALES_t$ is total kwh sales by PEPCO at t, and N_t is the corresponding number of R0 class customers. Then, $BILL_t^a$ is determined from (4) by replacing S_t by $\frac{SALES_t}{N_t}$.

Let S_t^a be the per customer demand for electricity at time t by DC R0 class customers. Let $M_{i,t} = 1$ if t corresponds to the ith calendar month, and $M_{i,t} = 0$ otherwise, $i = 2, \ldots, 12$. Then, taking $S_t^a = \frac{SALES_t}{N_t}$, we assume that S_t^a is determined by an empirical counterpart to (3):

Table 2: Variable Definitions

Variable	Definition[a]
S^a_t	Per customer demand in month t: $\frac{SALES_t}{N_t}$ (kwh/customer).
CD_t	Cooling degree days in month t.
HD_t	Heating degree days in month t.
INC_t	Average monthly real disposable income for DC in month t. (1968 $/month)
$BILL^a_t$	The monthly bill in 1982 dollars for a R0 Class customer corresponding to S^a_t.
$TREND_t$	Time trend variable equal to one in May, 1982.
F_t	Inefficiency index in month t relating to electric durables.
$M_{i,t}, k = 2, \ldots, 12$	Monthly dummy variables indicating the months February to December:$i = 2, \ldots, 12$.

[a]See Section 3.3 for details concerning the data relating to these variables.

$\rho > 0$ and $a > 0$ because most variables are positively autocorrelated over time. Finally, we have no prior expectation concerning the signs of b_0, b_5, or the coefficients of the monthly dummies $c_2, \ldots, c_{12}$. Thus, to summarize, our sign expectations are

$$b_1 > 0, b_2 > 0, b_3 > 0, b_4 < 0, b_6 > 0, \rho > 0, a > 0 \tag{6}$$

3.3 Rate Schedule Data

PEPCO provided us with data describing the R0 class rate schedule. Table 3 presents the basic variable definitions. In the District of Columbia, residential customers pay an ad-valorem tax on their electric energy purchases. The marginal price variables we used to construct the typical bill incorporate these ad-valorem charges. These marginal prices also include a per kwh fuel adjustment. During years when energy prices rose, the fuel adjustment increased the per kwh charge. During years when energy prices fell, the fuel adjustment decreased the per kwh charge. Thus, summing up, the nominal marginal price variables incorporate the per kwh charge, DC sales

Table 4: Regression Results

Parameter	Value	Standard Error	t-Ratio
ρ	0.368835	0.118011	3.12542
a	−11176.7	5178.31	−2.15837
b_0	0.225978	0.01517	14.8966
b_1	0.069325	0.012001	5.77674
b_2	0.1009	0.146615	0.688195
b_3	−3.07104	1.54049	−1.99354
b_4	0.287702	0.127814	2.25094
b_5	12.5061	5.24073	2.38633
b_6	1.19891	0.536801	2.23344
c_2	−39.4196	5.68638	−6.9323
c_3	−67.0883	9.43733	−7.10882
c_4	−62.0494	15.2737	−4.06249
c_5	−53.6044	20.6243	−2.59909
c_6	40.3703	27.9301	1.4454
c_7	126.149	28.7923	4.38135
c_8	137.428	33.7963	4.06636
c_9	117.754	35.7393	3.29481
c_{10}	34.9404	30.0314	1.16346
c_{11}	−13.4414	22.8511	−0.588216
c_{12}	−6.54337	13.572	−0.482122

first describe the tests relating to the additional variables, and then the test relating to the specification of the bill variable.

4.1.1 Additional Regressors

The variables that were considered to be potentially significant are described in Table 5. The price of gas was considered because it is an alternative fuel, and as such, its coefficient might be positive in an expanded form of (5). The saturation variable was considered for evident reasons, and if significant, its coefficient should also be positive. The renter variable was considered because it relates to the population being considered, and could proxy for a variety of distributional changes in that population. The alternative bill variable $\overline{BILL^a_{t-1}}$ was considered because consumers may respond to an average of

Table 6: Results Related to Additional Variables

Added Variable	t-ratio of Added Variable	$BILL^a_{t-1}$ coefficient	t-ratio
Basic Equation	na	-3.07	-1.99
G_t	-0.817	-3.97	-2.25
S_t	-0.470	-2.92	-1.81
R_t	-0.760	-3.08	-2.03
$BILLL^a_{t-1}$	0.350	-3.35	-1.30
$BILL_{t-12}$	1.04	-3.03	-2.35
$BILL_{t-13}$	0.94	-3.68	-1.94

for all of the elements of the rate schedule. One test of this specification is to disaggregate the bill variable into its additive components via (4) and then test the hypothesis that the coefficients of these components are equal.

In our sample, $S^a_t > 30$ for all t so that we consider the second form of the bill variable described in (4). To simplify notation, let:

$$\begin{aligned} q_{1,t} &= BC_t \\ q_{2,t} &= P_{1,t}B_{1,t} \\ q_{3,t} &= P_{2,t}(S^a_t - B_{1,t})(1 - D^a_t) \\ q_{4,t} &= P_{2,t}(B_{2,t} - B_{1,t})D^a_t \\ q_{5,t} &= P_{3,t}(S^a_t - B_{2,t})D^a_t \end{aligned} \tag{7}$$

where $D^a_t = 1$ if $S^a_t > B_{2t}$ and $D^a_t = 0$ otherwise.

Given the notation in (7):

$$\begin{aligned} b_4(BILL^a_{t-1} - \rho BILL^a_{t-2}) &= d_1(q_{1,t-1} - \rho q_{1,t-2}) + \\ &\vdots \\ &d_5(q_{5,t-1} - \rho q_{5,t-2}) \end{aligned} \tag{8}$$

where $d_i = b_4, i = 1, \ldots, 5$.

Table 7: Short Run Elasticity At Last 12 Data Points In Sample

Month	BILL	P1[a]	P2	P3	B1	B2	BC
August	−0.1547	0.0001	−0.0478	−0.1012	0.0040	0.0462	−0.0059
September	−0.2637	0.0001	−0.0624	−0.1938	0.0052	0.0593	−0.0076
October	−0.3094	0.0001	−0.1010	−0.1963	0.0083	0.0952	−0.0121
November	−0.1552	0.0008	−0.0981	−0.0451	0.0087	0.1005	−0.0128
December	−0.1084	0.0013	−0.0781	−0.0205	0.0076	0.0523	−0.0111
January	−0.1151	0.0011	−0.0685	−0.0379	0.0067	0.0457	−0.0097
February	−0.1507	0.0011	−0.0757	−0.0656	0.0072	0.0495	−0.0106
March	−0.1445	0.0007	−0.0817	−0.0527	0.0074	0.0506	−0.0108
April	−0.1501	0.0003	−0.0887	−0.0508	0.0075	0.0513	−0.0110
May	−0.1349	0.0006	−0.0950	−0.0284	0.0083	0.0567	−0.0121
June	−0.0873	0.0004	−0.0713	−0.0073	0.0062	0.0425	−0.0091
July	−0.1087	0.0002	−0.0551	−0.0469	0.0047	0.0541	−0.0069

[a]The value of the rate element P_1 was negative during the last 12 months of our sample. Because the slope of P_1 in the demand model is negative, a straight application of an elasticity formula results in a positive value for the elasticity.

As a final point of interest, we note that Mitchell, Mowill, Halvorsen and Hewlett[**7**]report price elasticities which are, in absolute value, greater than the ones we report for the bill variable. Possible reasons for this are that the models considered by these researchers as well as their estimation techniques are different than what has been considered in this paper.

15. B. M. Pötscher and I. R. Prucha, *Basic Structure of Asymptotic Theory in Dynamic Nonlinear Models, I. Consistency and Approximation Concepts*, Econometric Reviews (1991).

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