A Critical Analysis of Studies of Demand for Residential Electricity

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A CRITICAL ANALYSIS OF STUDIES
OF DEMAND FOR RESIDENTIAL ELECTRICITY

BY

LUIS ENRIQUE ACOSTA
B.S.B.A., Florida Technological University, 1972

THESIS

Submitted in partial fulfillment of requirements
for the degree of Master of Arts in Economics
in the Graduate Studies Program of
Florida Technological University

Orlando, Florida
1977
ACKNOWLEDGEMENTS

To my professors Dr. Robert E. Hicks, Dr. J. M. David and Dr. Donald A. Fuller whose guidance made this work possible.
To Margarita my dear and understanding wife.
To Linda for the outstanding typing job.
TABLE OF CONTENTS

ACKNOWLEDGEMENTS ....................................................... iii

CHAPTER I. INTRODUCTION ............................................... 1

CHAPTER II. THE STUDIES ARE DISCUSSED ................................. 9

Houthakker and Taylor (1970) (10) --
Duane Chapman, Timothy Tyrrell, and Timothy
Mount, (1973) (17) -- H.S. Houthakker, Philip
K. Verleger, Jr., and Dennis P. Sheeham
(1974) (20)

CHAPTER III. PROBLEMS OF RESEARCH ....................................... 23

CHAPTER IV. CONCLUSIONS AND RECOMMENDATIONS .......................... 42

BIBLIOGRAPHY ............................................................. 50
# LIST OF TABLES

<table>
<thead>
<tr>
<th>Table</th>
<th>Description</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Electric Light and Power Industry--Energy Generated, Sales, Residential Consumption</td>
<td>3</td>
</tr>
<tr>
<td>2</td>
<td>Annual Growth Rate of Electricity Use for the Period 1964 to 1972</td>
<td>5</td>
</tr>
<tr>
<td>3</td>
<td>Percentage Shares of Sources in U.S. Electric Energy Generation</td>
<td>6</td>
</tr>
<tr>
<td>4</td>
<td>Aggregated Household Demand for Electricity</td>
<td>14</td>
</tr>
</tbody>
</table>
CHAPTER I

INTRODUCTION

The purpose of this thesis is to analyze a selected group of recent studies of residential demand for electricity. Several reasons have led to an increase in the number of studies for residential demand for electricity.

1. Residential consumption of electricity is a major component of total demand for the output of electricity generated.

2. The demand for electricity by the residential sector has exhibited a fast and steady rate of growth over the years.

3. Electricity is not a primary source of energy but depends on the availability of adequate supplies of fuels for its generation.

4. The development of new uses of electricity by the household sector.

The peculiar characteristics of electricity as a form of energy make it essentially irreplaceable to the homeowner. Electric power generating plants can use water, coal, gas, oil or nuclear power in producing their output which is then distributed to residential, industrial, commercial and government users.

The residential sector is a major consumer of electricity. For analytical purposes residential demand for electricity is
better understood if defined in terms of household consumption rather than per capita consumption. Two reasons are given to support this distinction: (1) Electricity consumption is more sensitive to the number of households than to population, i.e., the effects of changes in the number of households, holding population constant, would have a much larger effect on energy consumption than altering the population while maintaining the number of households constant; and (2) residential demand is the sum of all electricity used by household appliances for specific purposes, i.e., space heating, water heating, lighting, etc.¹

Table 1, page 3, shows the output and sales of residential electricity for selected years from 1950 to 1973. Total electricity generated increased from 329 billion kilowatt hours in 1950 to 1,849 billion kilowatt hours in 1973, a sixfold increase. Residential sales grew from 67 billion kilowatt hours to 554 billion kilowatt hours during the same period, nearly one-third of the total or a household average of 8,100 kilowatt hours per year. This was 6,100 kilowatt hours more than the average household consumption in 1950. The average annual bill for residential customers rose from $57 in 1950 to $192 in 1973, a 236 percent increase in twenty-three years.

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>1950</td>
<td>329</td>
<td>281</td>
<td>67</td>
<td>23.8</td>
<td>2,000</td>
<td>57</td>
</tr>
<tr>
<td>1955</td>
<td>547</td>
<td>481</td>
<td>125</td>
<td>26.0</td>
<td>2,800</td>
<td>73</td>
</tr>
<tr>
<td>1960</td>
<td>755</td>
<td>683</td>
<td>196</td>
<td>28.7</td>
<td>3,900</td>
<td>95</td>
</tr>
<tr>
<td>1965</td>
<td>1,055</td>
<td>953</td>
<td>281</td>
<td>29.5</td>
<td>4,900</td>
<td>111</td>
</tr>
<tr>
<td>1969</td>
<td>1,442</td>
<td>1,307</td>
<td>408</td>
<td>31.2</td>
<td>6,600</td>
<td>137</td>
</tr>
<tr>
<td>1970</td>
<td>1,532</td>
<td>1,391</td>
<td>448</td>
<td>32.2</td>
<td>7,100</td>
<td>148</td>
</tr>
<tr>
<td>1971</td>
<td>1,614</td>
<td>1,466</td>
<td>479</td>
<td>32.7</td>
<td>7,400</td>
<td>162</td>
</tr>
<tr>
<td>1972</td>
<td>1,747</td>
<td>1,578</td>
<td>511</td>
<td>32.4</td>
<td>7,700</td>
<td>176</td>
</tr>
<tr>
<td>1973</td>
<td>1,849</td>
<td>1,703</td>
<td>554</td>
<td>32.5</td>
<td>8,100</td>
<td>192</td>
</tr>
</tbody>
</table>

Table 2, page 5, shows the annual growth rate for total electricity use from 1964 through 1972. The rates of growth experienced during this period will nearly double the consumption of electricity every ten years. To maintain such growth rates is questionable from the point of view of the environmental impact. Environmentalists in every area of the country have been warning the public about the potential damage to the environment posed by the building of power plants. On the other hand, the absence of an adequate rate of growth of electricity generation may impair economic growth and increase unemployment.

Since the generation of electricity depends on adequate fuel supplies, attention has recently turned to the long term availability of such supplies. Table 3, page 6, displays the percentage shares of fuel sources used in the generation of electricity for selected years from 1950 through 1973. The importance of coal has been declining since the late sixties, mainly as a result of environmental regulation and the availability of cheaper and cleaner fuels like oil and gas. Oil has been rising in importance, mainly because it is environmentally a much cleaner fuel than coal, which makes it more acceptable. It was also available during the sixties at a very low cost. The role of natural gas has been declining during the seventies mainly because of shortages brought about by Federal price controls on interstate sales of this desirable fuel. Hydroelectric power has been declining steadily during
TABLE 2

ANNUAL GROWTH RATE OF ELECTRICITY USE FOR THE PERIOD 1964 TO 1972

<table>
<thead>
<tr>
<th>Year</th>
<th>Percentage Increase</th>
</tr>
</thead>
<tbody>
<tr>
<td>1964</td>
<td>7.4</td>
</tr>
<tr>
<td>1965</td>
<td>7.1</td>
</tr>
<tr>
<td>1966</td>
<td>8.5</td>
</tr>
<tr>
<td>1967</td>
<td>6.6</td>
</tr>
<tr>
<td>1968</td>
<td>9.3</td>
</tr>
<tr>
<td>1969</td>
<td>7.4</td>
</tr>
<tr>
<td>1970</td>
<td>7.2</td>
</tr>
<tr>
<td>1971</td>
<td>5.4</td>
</tr>
<tr>
<td>1972</td>
<td>8.5</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Year</th>
<th>Coal*</th>
<th>Oil</th>
<th>Natural Gas</th>
<th>Hydroelectric</th>
<th>Nuclear</th>
</tr>
</thead>
<tbody>
<tr>
<td>1973</td>
<td>45.9</td>
<td>16.8</td>
<td>18.2</td>
<td>14.6</td>
<td>4.5</td>
</tr>
<tr>
<td>1972</td>
<td>44.1</td>
<td>15.6</td>
<td>21.5</td>
<td>15.6</td>
<td>3.2</td>
</tr>
<tr>
<td>1971</td>
<td>44.3</td>
<td>13.5</td>
<td>23.3</td>
<td>16.5</td>
<td>2.3</td>
</tr>
<tr>
<td>1970</td>
<td>46.2</td>
<td>11.9</td>
<td>24.3</td>
<td>16.2</td>
<td>1.4</td>
</tr>
<tr>
<td>1969</td>
<td>49.0</td>
<td>9.6</td>
<td>23.1</td>
<td>17.3</td>
<td>1.0</td>
</tr>
<tr>
<td>1968</td>
<td>52.5</td>
<td>7.8</td>
<td>23.1</td>
<td>16.7</td>
<td>a/</td>
</tr>
<tr>
<td>1965</td>
<td>54.5</td>
<td>6.1</td>
<td>21.0</td>
<td>18.4</td>
<td>Neg1</td>
</tr>
<tr>
<td>1960</td>
<td>53.6</td>
<td>6.1</td>
<td>21.0</td>
<td>19.3</td>
<td>-</td>
</tr>
<tr>
<td>1955</td>
<td>55.1</td>
<td>6.8</td>
<td>17.4</td>
<td>20.7</td>
<td>-</td>
</tr>
<tr>
<td>1950</td>
<td>47.1</td>
<td>10.3</td>
<td>13.5</td>
<td>29.2</td>
<td>-</td>
</tr>
</tbody>
</table>


a/ Less than 1 percent, included in coal.

*Includes small percentages from wood and waste and geothermal sources.
the period, mainly because of the environmentalist opposition to the building of new dams. The role of nuclear power for electricity generation has been increasing steadily since its appearance in the late sixties.

Relative prices and availability of the resources used to produce electricity play a major role in the kind of fuel used. Some existing electricity generating plants have substantial flexibility for fuel substitution which allows for the use of the more abundant domestic fuels. For example, oil fired plants can be converted to the cheapest domestic coal resources. Hydroelectric and nuclear power generating plants do not allow for inter-fuel substitution.

The quantity of electricity demanded for residential purposes has grown at a faster rate during the period from 1950 through 1970 than the quantity of electricity demanded for other purposes by the other consuming sectors. The average rate of growth of residential demand for electricity over the period was 9.7 percent per year.\(^2\)

The reasons for this rapid growth in the quantity demanded of electricity by the household sector may be found in the increasing affluence of the American people; the development of electricity consuming appliances such as television,

\(^2\)Ibid., p. 3.
space heating, air conditioning, electric ranges, water heaters, refrigerators, etc., and the trend towards the new all electric residence.

In the following chapter the reader will find an analysis and discussion of several selected studies found in the most recent econometric literature dealing with the topic of residential demand for electricity.
CHAPTER II

THE STUDIES ARE DISCUSSED

Empirical studies of the demand for specific commodities of interest have followed the development of demand theory. The demand for electricity has been the subject of several such studies following the pioneering work started by the Tennessee Valley Authority during the late nineteen thirties. Various approaches have been followed. Some authors analyzed the aggregate demand for electricity, while others made only sectoral analyses. This thesis discusses five studies dealing with the demand for electricity by the residential sector. The studies selected are those by Houthakker and Taylor (1970); John Wilson (1971); Kent P. Anderson (1972); Mount, Chapman and Tyrrell (1973); and Houthakker, Verleger and Sheeham (1974).

These studies were selected because they represented the most recent period, employed the most sophisticated techniques, represented diverse sections of the country, and were conducted by leading authorities on the subject. The five studies are discussed below in chronological order.
Houthakker and Taylor (1970)\(^3\)

This lengthy monograph is an econometric demand study designed to project all items of United States private consumption expenditures (PCE) to 1975. It consists initially of a conventional analysis of demand. The parameters of the demand functions are then estimated by the method of least squares on time series analysis covering the period 1947 through 1966.

The monograph develops a dynamic model ("state adjustment"), based on the idea that current decisions are affected by past behavior. The basic relationship is expressed in the following equation:

\[
q(t) = \alpha + \beta s(t) + \gamma x(t) + \lambda p(t)
\]

which specifies total consumption \(q\) as a function of stocks or inventories of electricity consuming appliances \(s\), income \(x\) and relative prices \(p\). The authors also used an approximation to denote the rate of change in stocks or inventories. This approximation is expressed by the following relationship:

\[
s(t) = q(t) - w(t)
\]

where \(s(t)\) denotes the rate of change in the stock at time \(t\), \(w(t)\) represents the average "using up" or "depreciation" of appliances. Stocks are considered to be of two kinds. They may be physical inventories of, for example, durable goods, or of

a psychological nature such as the force of habit. The stock coefficient $\beta$, when relating to physical inventories, is expected to be negative. This arises from the fundamental psychological law of diminishing marginal utility. In this instance $q$ is subject to stock adjustment. When stocks are of a psychological nature, the value of the $\beta$ coefficient is expected to take a positive sign. Electricity is a service, the use of which is determined by the stock of consuming appliances and the accumulated habits of the population.

The time period selected was 1947 through 1966 and observations were made on annual values. Data were obtained from publications of the U.S. Department of Commerce and the U.S. Bureau of Labor.

The short and long run price and income elasticities are reported below.

<table>
<thead>
<tr>
<th>Elasticities</th>
<th>Income</th>
<th>Price</th>
</tr>
</thead>
<tbody>
<tr>
<td>Short run</td>
<td>0.13</td>
<td>-0.13</td>
</tr>
<tr>
<td>Long run</td>
<td>1.93</td>
<td>-1.89</td>
</tr>
</tbody>
</table>

The magnitude of both elasticities appear to be relative small in the short run, but are relatively large in the long run.
Wilson (1971)\(^4\)

In the spring of 1971 John Wilson published an article entitled "Residential Demand for Electricity (1)." He states that the major objective of the study is centered on the long run estimation and evaluation of the inter-market variation in the quantity of electricity consumed by households that arises from inter-market price variations in electric power rates.

The study is based on a cross section analysis of electric power consumption by urban households. The city was employed as the unit of observation. A cross section of seventy-seven cities based on 1966 data was used. The data used came from the Federal Power Commission statistical publications and the U.S. Department of Commerce Bureau of Census. Five variables were considered in the analysis. The method of least squares was used to estimate the parameters of the demand function. The model is based on the traditional demand hypothesis which assumes that the demand for consumer goods is a function of the price of the commodity, the price of substitutes, income, taste and preferences. The model is described by the following equation.

\[ Q = K + b_1P + b_2G + b_3Y + b_4R + b_5C \]

where the dependent variable \( Q \) = average electricity consumption

per household measured in kwh per year. The independent variables are defined as follows:

\[ K = \text{constant quantity intercept} \]
\[ P = \text{average price} \]
\[ G = \text{average price of natural gas (cents per therm)} \]
\[ Y = \text{median family income (dollars per year)} \]
\[ R = \text{average size of housing units (rooms per unit)} \]
\[ C = \text{climate conditions (degree days)} \].

Linear and log linear estimation functions were fitted to the data. Table 4 on page 14 summarizes the results of the study. The log linear form gives the respective elasticities of the variables under consideration.

The basic assumption under consideration is:

... whether there is a predictable relationship between the quantity of electric power demanded by households and the price of electricity, and, if so, whether it is elastic or inelastic.\(^5\)

The basic conclusions of the study, which relate the long run, are as follows:

1. The price of electricity is the primary determinant of the volume of electric power consumed by residential buyers.
2. Residential demand for electricity is price elastic.
3. Cross elasticity of residential demand for electricity with respect to the price of gas is substantial.\(^6\)

\(^5\)Ibid., p. 11.

\(^6\)Ibid., p. 2.
### Table 4

**Aggregated Household Demand for Electricity**

<table>
<thead>
<tr>
<th>Equation</th>
<th>Variable</th>
<th>Partial $r^2$</th>
<th>Beta</th>
</tr>
</thead>
<tbody>
<tr>
<td>$Q = 21,737 - 1,178P^* + 144G^{**}$</td>
<td>$P$</td>
<td>.463</td>
<td>-.659</td>
</tr>
<tr>
<td>$-1,370Y^* + 47.9R^{****}$</td>
<td>$G$</td>
<td>.098</td>
<td>+.238</td>
</tr>
<tr>
<td>$+.069C^{***}$</td>
<td>$Y$</td>
<td>.180</td>
<td>-.349</td>
</tr>
</tbody>
</table>

$R^2 = .524$

\[
\begin{align*}
\log Q &= 10.25 - 1.33\ln p^* \\
\frac{\log Q}{10} &= 10.25 - 1.33\ln p^* \\
\frac{\log p}{10} &= .470 \\
\frac{\log G}{10} &= .127 \\
\frac{\log Y}{10} &= .223 \\
\end{align*}
\]


* Statistically significant at the .001 confidence limit.
** Statistically significant at the .01 confidence limit.
*** Statistically significant at the .10 confidence limit.
**** Statistically insignificant at the .10 confidence limit.
The two main objectives of this study as stated by the author are: (1) To obtain better predictive equations for residential demand for electricity. This includes the identification and measurement of the effects of important explanatory variables; (2) To consider whether it would be feasible to formulate and administer policies aimed at affecting the demand for electricity and to estimate the extent of the possible effects of such policies on electricity demand growth.

Like Wilson's analysis, this study relies on cross-sectional observations based on 1969 data. Sources of data were the Statistical Year Book of the Edison Electric Institute; Typical Electric Bills, 1969, published by the Federal Power Commission; Gas Facts published by the American Gas Association; Survey of Current Business; and the 1970 Census of Housing.

The method of estimation of the parameters used was the ordinary least squares. This is the standard tool used in econometric research.

The basic assumptions were formulated according to the conventional economic analysis of demand. It follows that household demand for electricity is a function of the cost of electricity and electricity using equipment, as well as

the cost of competing energy sources and related equipment, and the taste and preferences of the consumers.

A dynamic formulation was employed to distinguish between customers who choose to remain "locked" into specific patterns of energy consumption, because of the cost of changing or acquiring appliances; and those who are willing to make major alterations in their appliances. The model assumes that "locked in" customers are unresponsive to changes in energy cost and income at least in the short run.

The demand equation used for estimation purposes was of the form:

\[ \ln D = a_0 + a_1 \ln DCE + a_2 \ln PG + a_3 \ln RYPH + a_4 \ln SOH + a_5 NMP + a_6 WTEMP + a_7 STEMP + u \]

where

- \( D \) = total quantity of electricity consumed annually by residential customers.
- \( DCE \) = average real cost of electricity to residential customers
- \( PG \) = average real cost of gas to residential customers
- \( RYPH \) = average real personal income per household
- \( SOH \) = average size of household, persons/household
- \( NMP \) = fraction of population living in non-metropolitan areas
- \( WTEMP \) = average January temperature
STEMP = average July temperature

u = random error term.

The partial elasticities of the explanatory variables reported by Anderson are as follows:

<table>
<thead>
<tr>
<th>Variable</th>
<th>Partial</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cost of Electricity</td>
<td>-0.91</td>
</tr>
<tr>
<td>Cost of Gas</td>
<td>+0.13</td>
</tr>
<tr>
<td>Household Income</td>
<td>+1.13</td>
</tr>
<tr>
<td>Size of Household</td>
<td>-0.85</td>
</tr>
<tr>
<td>Winter Temperature</td>
<td>+0.18</td>
</tr>
<tr>
<td>Summer Temperature</td>
<td>+0.83</td>
</tr>
<tr>
<td>Non-metropolitan Index</td>
<td>+0.34</td>
</tr>
</tbody>
</table>

The results are in accordance with a priori expectations. The price elasticity is small but the income elasticity is rather substantial.

Duane Chapman, Timothy Tyrrell, and Timothy Mount (1973)

This study analyzes the problems associated with the demand for electricity in both the short run and long run. It expresses the belief that many of the factors influencing the demand for electricity are themselves departing from long established patterns. They point out that "increasing cost

---

involved in environmental protection and decreasing fuel supplies will cause cost and prices to increase." For example, in 1971 the deflated average electricity price experienced its first increase since 1946. The figures show that the price rose from 1.66 to 1.69 cents per kilowatt hour in 1971 prices.\(^9\)

The authors study both the short run and long run demand for electricity for residential, commercial and industrial consumers. It is assumed that the demand for electricity is determined by five explanatory factors: population, income, the prices of electricity, substitute fuels such as gas and complementary products such as household appliances. Their estimates are based on data prepared by the Bureau of Economic Analysis of the Department of Commerce and by the Federal Power Commission, and assume the cost of electricity will increase in the future.

Their model uses cross section and time series data consisting of observations on forty-seven states from 1947 to 1970. The method of estimation is least squares. The model used is of the following form:

\[
Q_{ijt} = A_{ij}(Q_{ijt-1})^{\theta_1(P_{Eijt})} a_1(N_{jt}) \beta_1(Y_{jt}) \gamma_1(P_{Gijt-1}) \beta_1
\]

where

\[
i = \text{consumer class}
\]

\( j = \text{region} \)
\( t = \text{year} \)
\( Q = \text{electricity consumed} \)
\( A = \text{constant} \)
\( \beta = \text{time response parameter} \)
\( PE = \text{average price of electricity} \)
\( N = \text{population} \)
\( Y = \text{per capita income} \)
\( PG = \text{average price of gas} \)
\( \alpha, \beta, \text{and } \rho = \text{short run elasticities for electricity price} \).

Two alternative cost and population projections are used.

The elasticities reported are summarized as follows:

<table>
<thead>
<tr>
<th>Elasticity</th>
<th>Population</th>
<th>Income</th>
<th>Price of Electricity</th>
<th>Price of Gas</th>
</tr>
</thead>
<tbody>
<tr>
<td>Short run</td>
<td>0.12</td>
<td>0.02</td>
<td>-0.14</td>
<td>0.02</td>
</tr>
<tr>
<td>Long run</td>
<td>0.99</td>
<td>0.20</td>
<td>-1.20</td>
<td>0.19</td>
</tr>
</tbody>
</table>

Their major conclusions are:

1. There will not be much effect in the near future.
2. Supply problems are not going to be eased by rate increases and population trends.
3. The population assumption is an important determinant for growth in the next twenty or thirty years.
4. Long run demand for electricity appears to be price elastic.
5. Demand is generally inelastic with respect to income.
The above authors' paper presents the results of a study on the demand for gasoline and residential electricity, which also happens to be the top two items in the consumer's budget for energy resources. Pooled time series data from forty-eight different states and the District of Columbia were used to estimate the demand functions. The data were fitted to dynamic demand functions to reveal the importance of dynamic elements, especially the role of habit formation. Generally consumers react over time to changes in income and prices; fuel adjustment is most likely going to take several years. Thus, it is useful to distinguish between short run and long run elasticities. It has been found that habit formation prevails in the large majority of non-durable goods and services and as such the short run elasticities are smaller than the long run elasticities. Energy resources are non-durable but the stock of energy consuming equipment is relevant to the analysis of demand for energy.

The data used in the study were compiled from standard sources. Information on prices was obtained from the Typical Electric Bills, published annually by the Federal Power Commission. Electricity sales were obtained from the Statistical Year Book.

---

published by the Edison Electric Institute. Per capita personal income figures were gathered from data published by the Regional Economics Division of the Bureau of Economic Analysis. Population data were obtained from the U.S. Census Bureau. Information on gasoline consumption was provided by the American Petroleum Institute.

The authors assume that in the short run the stock of energy consuming equipment is fixed and the use of it is a function of the operation of economic forces. It is assumed there exists a desired demand $q_{it}^*$ for energy by individuals in state $i$ at time $t$. The log linear form of the demand equation as a function of income and prices was used, and it is expressed as follows:

$$\ln q_{it}^* = \alpha + \gamma \ln p_{it} + \beta \ln y_{it}$$

where:

$q^* = \text{desired demand for energy}$

$p = \text{price of energy}$

$y = \text{income}$

$i = \text{state}$

$t = \text{time}$

$\alpha = \text{y intercept}$

$\gamma$ and $\beta = \text{elasticity coefficients}$. The method of estimation chosen was the error component technique developed by Balestra and Nerlove.\footnote{P. Balestra and M. Nerlove, "Pooling Cross Section and Time Series Data in the Estimation of a Dynamic Model: The Demand for Natural Gas," \textit{Econometrica} 34 (July 1966): 585-612.} This kind of...
technique was necessary to deal adequately with the lagged dependent variable contained in the flow model. The ordinary least squares technique was found to produce biased estimates of the parameters.

The results of three marginal prices computed for electricity are reported below. The marginal price is the additional cost consumers must bear when they increase their consumption by one unit. Electricity is typically priced according to declining block rate schedules.

<table>
<thead>
<tr>
<th>Elasticity</th>
<th>Price</th>
<th>Income</th>
</tr>
</thead>
<tbody>
<tr>
<td>Short run</td>
<td>-0.089</td>
<td>+0.143</td>
</tr>
<tr>
<td>Long run</td>
<td>-1.0</td>
<td>+1.6</td>
</tr>
</tbody>
</table>

**Marginal price between 100 and 250 kwh**

<table>
<thead>
<tr>
<th>Elasticity</th>
<th>Price</th>
<th>Income</th>
</tr>
</thead>
<tbody>
<tr>
<td>Short run</td>
<td>-0.094</td>
<td>+0.127</td>
</tr>
<tr>
<td>Long run</td>
<td>-1.2</td>
<td>+1.6</td>
</tr>
</tbody>
</table>

**Marginal price between 250 and 500 kwh**

<table>
<thead>
<tr>
<th>Elasticity</th>
<th>Price</th>
<th>Income</th>
</tr>
</thead>
<tbody>
<tr>
<td>Short run</td>
<td>-0.029</td>
<td>+0.145</td>
</tr>
<tr>
<td>Long run</td>
<td>-0.45</td>
<td>+2.2</td>
</tr>
</tbody>
</table>

Elasticities are smaller in the short run than in the long run. The reason for the disparities in the price elasticities may be found in the fact that the marginal prices as calculated include some of the fixed charge to customers.
Analysis of Study by Houthakker and Taylor

The empirical study of residential demand for electricity by Houthakker and Taylor is based on statistics compiled by the United States Department of Commerce and the Bureau of Labor Statistics. The U.S. Department of Commerce collects data on all major items of personal consumption expenditures (P.C.E.). The data available through this source is thought to be of the quality and reliability required for this type of studies based on estimation. The authors do not report any manipulations with the data that may suggest reasons to question the value of the results. However, they indicate that all variables have been reduced to constant 1958 dollars. This had to be done because most data are published in current dollars as constant dollar figures are not available with the degree of detail desirable to the investigators. The authors also had accessibility to unpublished data giving them the opportunity to enhance the accuracy of the analysis.

Houthakker and Taylor report the results of their study of residential demand for electricity based on data covering the post World War II period. The years 1946 to 1964 were included. This set of time series data gives a sample size of nineteen observations and may be considered adequate for studies dealing with time series analysis. This is a period of normal economic activity characterized by full employment and relatively stable prices. The economy did not suffer any major disruptions and there was a period of general prosperity and stability with minor ups and downs like the Korean War period during the early 1950s; a mild recession during the last years of the Eisenhower administration around the late 1950s and the beginning of the expansionary period dominated by the Vietnamese War during the 1960s.

Three independent variables were selected to explain the behavior of the dependent variable: per capita personal consumption expenditure of electricity. In the first place, the lagged values of the dependent variable were entered in the regression as an explanatory variable. The other two variables used were total per capita personal consumption expenditure and the relative price of electricity. According to the authors, the use of total per capita consumption expenditure is supported by the argument that it appears that at least in the short run, consumers have more control over their expenditures than upon their receipts of income, thus making total expenditure a better measure of the true income of the consumer. This kind of
reasoning is very close to the permanent income hypothesis developed by Professor Milton Friedman of the University of Chicago. This appears to be a plausible approach to demand analysis. The introduction of the relative price of electricity as an explanatory variable is in accordance with that used in the theoretical formulation of demand.

The use of the lagged values of the dependent variable as an independent variable makes the model autoregressive. Lagged values of the dependent variable are entered in the regression as a means of introducing a dynamic element into the model. Adoption of lagged variables in econometric studies is based on the assumption that the dependent variable responds to their past own value. This means for example that in the case of electricity consumption, it depends not only on current income and total per capita personal consumption expenditure, but also on past consumption. This helps to account for the role of human behavior which in many cases is influenced by habit formation.

The method of estimating the parameters for the demand equation used by Houthakker and Taylor is based on least squares regression analysis. The linear form was selected since it yielded the best fit to the observations. The least squares regression techniques appear to be the most appropriate method

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13 Ibid., pp. 58-59.
of estimation of demand equations and are the most widely used and accepted by investigators of economic phenomena.

The least squares method of estimation has some desirable properties that make it so useful to the investigators. Specifically, the parameters calculated by this method are unbiased, most efficient and consistent estimators. This is so providing that the theoretical assumptions concerning the probability distribution of the error term are met.\textsuperscript{14}

Autoregressive models like the one under consideration tend to violate one or more of the assumptions concerning the error term. The presence of lagged values of the dependent variable in the regression model result in serial correlation of the error term and correlation between the lagged dependent variable and the error term. As a result, the classical least squares estimators are biased given that the assumption that the values of the error term are independently distributed is violated.\textsuperscript{15}

However, it should be pointed out that if the other assumptions concerning the probability distribution of the error term are satisfied the estimators are consistent.

The use of linear regression equation models to estimate the parameters gives rise to problems of multicollinearity. This


\textsuperscript{15}Ibid., pp. 90-93.
problem is caused when there are more than one independent variable in the model and the variables tend to move together in the same pattern. The presence of multicollinearity will produce large variance in the sampling of the population parameters. The authors point out that the post war data appear to be dominated by trends which produce multicollinearity.

Models based on time series analysis are most likely to be autocorrelated. Autocorrelation is present when the residuals are correlated with each other. It may be present also when the model is misspecified, or when certain explanatory variables are left out from the model. It leads to underestimation of the variance in the error term. Autocorrelation can be detected by the use of the Durbin-Watson statistic.

The estimated value of the Durbin-Watson statistic reported by Houthakker and Taylor is 2.32. By using this result to test the hypothesis of no first order autocorrelation, it was found that there is no significant autocorrelation.

The multiple coefficient of determination $F^2 = .999$. This means that an estimated 99.9 percent of the variation in the dependent variable may be explained by knowledge of the regression plane and the values of the independent variables.

16 Ibid., pp. 73-77.
The standard error of the estimate \( Se = .16 \) indicates the degree of scatter in the data. Errors in making predictions from the regression line are smaller when the scatter of the data is less pronounced. The standard error of the estimate appears to be small which enhances the confidence in the results.

It can be concluded on the basis of the above considerations, and of the Durbin-Watson statistic, the multiple coefficient of determination, and the standard error of the estimate that the results of the study under consideration may be reliable. As such, it may be added, the study by Houthakker and Taylor can be a valuable source of information to decision makers. This is so given that the study provides, in broad terms, a close approximation of the behavior consumers will most likely exhibit in the future.

**Analysis of the Study by Wilson**

Wilson's empirical study of residential demand for electricity is based on data collected and published by U.S. government agencies. Specifically, he used data collected by the Federal Power Commission published in the National Power Survey, the Statistics of Privately Owned Electric Utilities in the U.S., and the Typical Electric Bills, 1966. Data on population were taken from the U.S. Department of Commerce found in the 1950 and

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1960 Census of Housing, and the County and City Data Book. Wilson does not report any manipulations with the data that may provide grounds to question the value of the results.

A cross section data sample of 77 cities was used as a base to estimate the unknown parameters of his model of residential demand for electricity. The year under consideration was 1966. A cross section data sample consisted of observations of economic events from activities of families, firms, industries, cities, etc., for a given time period. Cross section data surveys usually provide larger samples than time series data. The sample size with cross sectional data can be extended, with a minimum financial effort.

The year 1966 may be characterized as a year of booming economic activity. It came during the early period of the Vietnam conflict. During this period inflation became a major concern for the American public, though at the time it was relatively minimal compared to the inflation rate for 1975. It may be added that it was a year of full employment. As a matter of fact, the unemployment rate was substantially below four percent of the labor force. It was a year of expansion and growth for the economy as a whole.

Five independent variables were used as explanatory variables of the dependent variable, which was the average electricity consumption per household. The selection of the average electricity consumption per household appears to be the appropriate dependent
variable for the purposes of the study. The average price for 6000 kilowatt hours per year is entered as the main explanatory variable. The selection of this variable seems to be a better choice than the alternative of a simple average price which may be insufficient. The average price of natural gas was selected as the second explanatory variable. This is also a good choice given that natural gas is a major competing energy source used directly by households. The price variables are included in the standard assumption to demand analysis. The median family income was included as another explanatory variable. Given that the population exhibits a few small and large income values, the selection of the median income over the mean income is a better estimator as a measure of central tendency. The average size of the housing units expressed as the number of rooms per unit was the fourth independent variable chosen. The number of persons per household could have been the alternative unit used. The former was selected by Wilson on the assumption that larger homes should consume greater quantities of electricity. The question of which of those two variables may be the most appropriate gives room for a separate discussion and is not the subject of this analysis.

The final variable used by Wilson in his study was climate conditions expressed in degree days. This can be a very important factor in

explaining the demand for electricity in conjunction with the use of specific appliances such as air conditioners, water heaters, and space heating equipment.

The generalized least squares regression analysis was the method of estimation of the unknown parameters of the demand equation. The model has been expressed as a linear relationship. The elasticities were calculated by converting the linear form to the log linear form. This approach to the estimation of the demand equation is the most widely used by investigators.

The model developed by Wilson is a static model. There are some potential problems associated with this type of model. One of the potential problems that may arise with models like this is the problem of multicollinearity. Multicollinearity occurs when two independent variables are highly correlated with each other. When two independent variables are perfectly correlated, the solution for the coefficient of the parameters under consideration is indeterminate. The problem of multicollinearity is more likely to be present with samples based on time series analysis as most economic data tend to move together over the business cycle; however, cross section data samples are not free from it. When multicollinearity is present the standard errors of the regression coefficients are biased upward, thus reducing the reliability of the sample coefficient as an estimate of the population parameter. One way of eliminating the problem is by increasing the sample size.
The value of the multiple coefficient of determination \( R^2 = .524 \) reported by Wilson suggests there are no problems of multicollinearity in the model. Even the reported values of the partial coefficients of determination suggest that there are no problems of multicollinearity. The multiple coefficient of determination serves as an index to measure the variation in the dependent variable that may be explained by the independent variables. In this case, 52.4 percent of the variation in the dependent variable can be explained by the independent variables. Based on the above considerations, it may be concluded that the model developed by Wilson provides reliable estimators of the parameters.

Analysis of the Study by Anderson\(^2\)

The empirical estimates of the study of residential demand for electricity by K. P. Anderson are based on statistics collected and published by standard sources. He constructed his samples from data found in the Statistical Year Book published by the Edison Electrical Institute. From the Federal Power Commission, he obtained data published in its Typical Electric Bills, 1969. From Gas Facts, published by the American Gas Association, he

obtained data on value of sales and quantity of gas sold. The Survey of Current Business published by the U.S. Department of Commerce provided data on per capita personal income per household. The 1970 Census of housing provided figures on the average size of households. The author used the cost of living index to convert gas and electricity cost from money terms to real terms. The indexes used were those published by the U.S. Bureau of Labor Statistics in the Spring of 1969 for several metropolitan and non metropolitan areas. This is the only manipulation reported in the data. The indexes are a device used to measure the changes occurring over time as a result of rising prices.

The study by Anderson is based on a cross section data sample of 50 states. The year 1969 was the period under consideration. The early part of the year shows a very high level of economic activity. As a matter of fact, it was the peak year of the Vietnam era. It was a year of full employment, but the rate of inflation was accelerating. The end of the year was characterized by a decline in economic activity, and it may be added that it marks the beginning of the recession experienced during the year 1970.

Anderson used seven explanatory variables with the dependent variable expressed as the average quantity of electricity consumed annually per residential customer. The first explanatory variable is the average cost of electricity to residential customers for 1000 kilowatt hours per month. The average cost of gas
to residential customers is the second variable considered in the study. This is in agreement with the standard economic approach to demand analysis. The third variable considered is the average real personal income per household. This is a very important assumption used on the theoretical approach to demand analysis. The fourth variable selected was the average size of households expressed as persons per household. The residential demand for electricity is made up from the aggregate household consumption for this service. Thus the choice of this variable seems appropriate. The other three variables included in the study are the fraction of population living in non-metropolitan areas, the average January temperature and the average July temperature. The inclusion of the above three variables appears to add strength to the study. The fraction of population may help to explain changes in consumption as a result of demographic shifts. The use of average January and July temperatures may be justified on grounds of changes in electricity consumption that may occur as a result of climatic variations.

The generalized least squares regression analysis was the method of estimation of the unknown parameters of the demand equation. The log-linear form of the equation was the functional form selected from a number tested. It was mentioned above in conjunction with the study by Houthakker and Taylor that this appears to be the most appropriate approach to demand analysis.
A dynamic formulation is built into the model to account for changes in consumption of electricity. This was accomplished by the use of a special formulation that differentiates between customers who alter their consumption patterns over time and those who decide not to alter their consumption.

It appears that some of the potential problems that may arise in the process of estimation by the use of ordinary least squares, like multicollinearity and autocorrelation, have been overcome in this study by Anderson. At least there is no immediate basis to indicate that the analysis is obscured by such problems.

The value of the multiple coefficient of determination reported by Anderson is $R^2 = .758$. This indicates that 75.8 percent of the variation in the dependent variable is explained by the independent variables. On the basis of the above considerations, it may be concluded that the results of the study by Anderson are reliable.

Analysis of the Study by T. D. Mount, L.D. Chapman and T. J. Tyrrell

These investigators based their study of residential demand for electricity on data published in the Statistical Abstract of

the U.S.; The Survey of Current Business of the U.S. Bureau of Economic Analysis; Gas Facts; and the Edison Electric Institute Yearbook. These sources are thought to contain the most reliable data required for this type of study. Investigators of economic phenomena accept them as standard sources. The authors do not report any manipulations with the data that may produce reasons to question the value of the results.

The pooling of both cross section and time series data was the technique used to build the data sample. The sample contains annual observations for all variables in the model. Data were obtained for 47 contiguous states from 1947 to 1970. The data collection technique used by the author was first employed by Balestra and Nerlove in 1966. Interest in this approach has been growing among econometricians in recent years. It appears that the pooling of both time series and cross section data leads to more satisfactory results.

The dependent variable, quantity of electricity demanded, is assumed to be subject to the influences of five explanatory variables. The explanatory variables used were the relative price of electricity, the relative price of gas and the relative price of household appliances. The other variables included were population and income. This approach follows the standard theoretical assumptions to demand analysis.

22 Ibid., p. 4.
The method of estimation of the parameters of the demand equation was based on the generalized least squares regression techniques. The model includes a dynamic formulation expressed by the use of lagged values of the dependent variables in the regressor. The dynamic formulation helps to explain the changes in the demand for electricity over time. The properties of the least squares estimators, as well as the potential problems with this method of estimation, were discussed previously in this paper in the sections on the study by Houthakker and Taylor, and in the Wilson paper.

The observed values of the explanatory variables, specifically population, income and the relative price of electricity, exhibit very strong trend components between 1946 and 1970. The existence of trend components creates problems of serial correlation. Under such circumstances estimation is likely to be complicated as a result of serial correlation. The problem of serial correlation arises when important related variables are omitted, or when the relationship is not properly specified.

Serial correlation can be detected by the use of the Durbin-Watson test. A more simple and faster procedure to determine the existence of autocorrelation is to observe the pattern of the residuals from a regression line. If a pattern is detected, then it may be assumed that the error term is autocorrelated. Serial correlation can be corrected by the "first difference"
method. In addition, since serial correlation results from missing explanatory variables, the problem can be corrected by adding explanatory variables to the regression equation. It should be pointed out that no serious problems of autocorrelation have been reported by the authors.

The regression results reported by the authors suggest that the data employed were very good. The multiple coefficient of determination (R^2) is 0.99. This indicates that 99 per cent of the variation in the dependent variable is explained by the regression plane. The high percentage may be an indication that multicollinearity exists. However, the authors have not made any comment about it.

On the basis of the above considerations, it may be concluded that the results of the study are reliable. As such, they can be a good source of information to policymakers and decision-makers, by providing guidelines to the decision-making process. Specifically, policy-makers will be guided by an empirical approximation explaining the behavior of consumers when confronted with electricity consumption.
Analysis of the Study by H.S. Houthakker, P.K. Verleger, and Dennis P. Sheehan

These investigators based their study of residential demand for electricity on data published by the Edison Electric Institute, the U.S. Census Bureau, the U.S. Department of Commerce, and the Federal Power Commission. Personal Income data were obtained from statistics published by the Bureau of Economic Analysis of the U.S. Department of Commerce; data on population were obtained from the U.S. Census Bureau; both the Federal Power Commission and the Edison Electric Institute provided the data on residential consumption of electricity. These are considered reliable and standard sources used by investigators of economic phenomena.

The data sample was developed by the pooling of both cross section and time series data. Observations were made over the twelve years from 1960 to 1971 for the 48 continental contiguous states. The data collection approach is based on the techniques developed by Balestra and Nerlove. The time period covered by the analysis may be thought of as typical. It encompasses the Vietnam war which can be described as a time of general prosperity for the U.S. economy.

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The model is based on the assumption that the desired demand for electricity is a function of household income and the price of electricity. The dependent variable is expressed as "desired" demand in order to explain the effects of economic influences upon the utilization of the stock of electricity consuming appliances. Like Houthakker and Taylor, these authors assume the stock of electricity consuming appliances to be fixed in the short run. Such a model appears to be very plausible given that economic forces influence the behavior of individuals. In turn, individuals tend to adjust their expenditures among the several commodities according to their budgets which are more or less fixed in the short run. Thus, utilization of the stock of electricity consuming appliances may be realistically considered as a function of the economic influences.

The parameters of the demand equation are estimated through the use of the generalized least squares regression techniques. A dynamic formulation is employed by these investigators. Such approach enables the researcher to account for changes in the demand for electricity over time. The characteristics and properties of the least squares estimators have been discussed in conjunction with the other studies reviewed above.

The authors indicate that the model fits the data adequately. This is an indication that problems of estimation like autocorrelation, multicollinearity and the presence of lagged values of the dependent variable in the regressor have been
overcome by the model. The multiple coefficient of determination $(R^2)$ equals .986. This result indicates that 98 percent of the variation in the dependent variable is explained by the regression plane.

The model is a realistic one and may be considered as a further step leading to the improvement of the forecasting techniques for residential demand for electricity. As such, it is a relevant model to the researchers interested in this particular field. At the same time, it is a valuable study for those engaged in policy making problems affecting the residential consumer of electricity. Given the state of the art, demand studies like this provide the best approximation available of the behavior of consumers faced with higher electric bills.
CHAPTER IV

CONCLUSIONS AND RECOMMENDATIONS

The studies analyzed and criticized in this paper represent a courageous effort to investigate and forecast the demand for electricity in the residential sector. The authors have followed the standard approach to demand analysis as prescribed by the theory of demand. At the same time they have used the most sophisticated statistical techniques and the most reliable sources of data available thought to be of the highest quality. Each study has developed demand models specifically suited to deal with this particular problem.

Although advances in statistics and econometrics have provided the foundations for the development of better forecasting techniques, their findings are not quite the same. Indeed, there is considerable variation among the results of the different studies. It is thought that such variation is the result of the existence of a combined set of peculiar problems faced by the investigators of residential demand for electricity. The most pervading problems can be classified as follows: (1) definitional problems; and (2) problems of aggregation.

42
1. Definitional Problems

Among the definitional problems that create some difficulties to the investigators of residential demand for electricity, the following deserve further investigation: (a) What is the proper price of electricity to enter the demand function? (b) What is the proper household size to enter the demand function? and (c) What is the proper income statistic to enter the demand function?

(a) The Price Variable

The issue related to the specification of the proper price of electricity to enter the demand function is perhaps the most crucial one. It arises from the fact that there is not a single price for electricity, but rather, electricity is sold in blocks priced according to a declining marginal tariff. Thus, the existence of a declining marginal price schedule produces a budget constraint that is non-linear, and creates multiple equilibria for the consumer. Taylor acknowledges that the existence of such price schedules have significant econometric implications. As a result there is a need to specify whether the average or the marginal is the proper price to be used with the demand model. A further complication arises because of the existence of several marginal prices. Thus, a decision has to be made as to whether the marginal or intra-marginal price is the more suitable price to be used. In addition, it should be
pointed out that several intramarginal prices can be calculated. Again, this circumstance creates the dilemma of which intramarginal price is the proper one to be entered if that is the case.

The use of marginal prices in the estimation of the demand function typically results in overestimates of the true price response. Conversely, when the average price is the one used in the estimation of the demand function, it is more likely that the result will lead to under-estimation of the true price response.

(b) The Household Size Variable

Investigators of residential demand for electricity are confronted by the issue created by the existence of two different sets of statistics measuring the household size; namely: the number of rooms per housing unit and the number of persons per household. As a result, it is necessary to specify whether the number of rooms per housing unit or the number of persons per household is the proper measure of household size to be entered in the demand model. The need to specify the proper household size arises from the fact that the results obtained will vary depending on the unit used. Since the residential demand for electricity is a derived demand depending on the stock of electricity consuming appliances, it seems plausible that larger homes have more and larger appliances, and as a result should consume larger quantities of electricity. In considering that
the dependent variable employed is consumption per household, and that the household size is used as an explanatory variable, it appears that the average number of rooms per unit and not the average number of persons per household is the proper unit that should be used in the demand equation.

It must be pointed out that when both household income and the number of rooms per household are entered in the demand equation, problems of collinearity may arise. For instance, household income and average number of rooms per unit seem to be highly correlated. This may be so given that it should be expected that families with higher income will tend to have larger homes with more electricity consumer appliances.

(c) Household Income

An additional definitional problem arises from the issue created by the necessity to specify whether the mean or the median household income should enter the demand function. The mean has desirable mathematical properties. Therefore, it lends itself to algebraic manipulation. Many statistical techniques have been developed as a result of its mathematical properties. The fact that the mean is influenced by extreme values to a larger degree than the median indicates that its use can produce misleading results.

The median is said to be more "democratic." That is, each unit has one vote in determining the location of the population center. Generally, the median gives a better measure of
central tendency provided the population has few extremely large or small values.

It appears that in the case of household income extremely large and small values exist. Thus, it is thought that the median household income, and not the mean household income, should be entered in the demand function.

2. Problems of Aggregation

The large size and geographical diversity of the U.S. territory gives rise to the existence of regional differences. In addition, there are also differences within regions. The existence of such differences creates some problems of aggregation to the investigator. It can be said, in general, that aggregation produces loss of information. In addition, misspecification of the variables will lead to aggregation problems.

In general, the price of electricity is different among regions, and even it changes within regions. Therefore, the use of a simple price average produces misleading results.

Recommendations

The remainder of this study will be devoted to the exposition of some recommendations. What follows does not necessarily imply to be the panacea to the problem. That would be too presumptious.

It was stated earlier that the most crucial problem encountered by the investigators of residential demand for electricity arises from the existence of multi-step block pricing. This
aspect deserves further investigation. There is a need to develop a plausible system to arrive at the most reliable results when forecasting residential demand for electricity. This is most urgent today when, as a result of the energy crisis, the traditional patterns of demand for electricity have been seriously disrupted. Consumers have to bear the higher cost of electricity and are forced to watch more carefully their budget for energy.

It is recommended that in order to arrive at the most reliable estimates of residential demand for electricity it is necessary to develop systems able to deal with the peculiarities of the pricing mechanism in this sector of the economy. It is necessary to investigate whether the consumers are fully aware of the discounts available for higher levels of consumption. Awareness of such discounts presupposes full information. If this is so, it is the marginal price that must enter the demand function. If consumers base their expenditure decision regardless of the existence of the discounts available, then the use of a simple average price can be justified.

The existence of both average number of rooms per housing unit and the average number of persons per household poses a dilemma to the researcher. It is recommended at this point that the average number of rooms per housing unit should be used in the demand equation. It appears to be the more proper of the two. In addition, it seems to be a more consistent determinant of residential demand for electricity.
As to the proper income variable to enter in the demand equation, it is recommended that the median family income should be used in the demand model. By the nature of its particular statistical properties it seems to lead to more consistent results. It should be remembered that it is more democratic.

Generally consumers always react to changes in prices. Thus a need exists to investigate both the short run and the long run demand for electricity. It is acknowledged that the studies analyzed here have done so. However, it is reiterated that this is a very important aspect that must be considered thoroughly by researchers of residential demand for electricity. The relative price of electricity decreased constantly during the years before the energy crisis. As a result of the energy crisis there have been large increases in the price of electricity and there will be more in the foreseeable future.

It has been acknowledged that in the short run consumers do not have enough time to adjust to changes in the price of electricity since their stock of electricity consuming appliances is more or less fixed. Consumers are committed to their existing stock since replacement costs are rather high. The most consumers can do in the short run is to adjust their expenditures by carefully monitoring the usage of certain appliances like water heaters, space heaters, and air conditioners.

In the long run consumers have more time to adjust to changes in the price of electricity. They can replace their old
appliances for new and more efficient ones. It is also possible to switch to other sources of energy, like solar energy for space heating, air conditioning and water heating. In addition, better houses can be designed which can use more efficiently the heat from the sun.

A final aspect, which has been largely ignored, is the issue of peak load pricing. Peak load pricing is the pricing of electricity usage according to the time of day. So far the issue has been restricted to the academic community. However, several utilities in scattered communities throughout the country have been experimenting in this area. For example, Boston Edison and Florida Power have been offering substantially lower rates on week days between midnight and eight in the morning to selected customers.

Of course a great deal of information, which at present is lacking, should be incorporated into the studies. However, as information becomes available it will be possible to estimate the effects of such pricing schemes.

Both utilities and consumers will benefit from the pricing of electricity by the time of day that is used. Utilities will be able to postpone additions to existing capacity because of more efficient utilization of their existing generating equipment. Customers will benefit from the availability of cheaper electricity rates at certain hours.
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