RESIDENTIAL ELECTRICITY DEMAND
IN OKLAHOMA

By

SHAHDAD NAGHSHPOUR

Bachelor of Science
Tehran University
Tehran, Iran
1976

Master of Arts
Western Michigan University
Kalamazoo, Michigan
1977

Master of Science
Oklahoma State University
Stillwater, Oklahoma
1981

Submitted to the Faculty of the
Graduate College of the
Oklahoma State University
in partial fulfillment of
the requirements for
the Degree of
DOCTOR OF PHILOSOPHY
May 1988

RESIDENTIAL ELECTRICITY DEMAND

IN OKLAHOMA

Thesis Approved:

Keith D. Willett

Thesis Advisor

Kent W. Olson

Jim C. Ireland

Dean of the Graduate College

PREFACE

The factors effecting electricity demand are so numerous and complex that they hinder a general study of electricity demand. The statewide study of one electricity sector is more realistic, and requires less assumptions to be valid. The present study incorporates theoretical contributions of Muth in the household production area into the residential market for electricity. Empirically the study utilizes Taylor's residential electricity formulation.

I wish to express my sincere gratitude to all the people who have helped me in this work, especially my committee members, Dr. Kent W. Olson, Dr. Tim C. Ireland, Dr. Edward O. Price, III and finally Dr. Keith D. Willett, who has supported me both intellectually and morally.

I am thankful to Dr. Ed Coker of the University of Southern Mississippi for reading the original drafts and Mr. Robert Gilmore for editing the final copy. I also would like to thank Mrs. Denice Clark for her patience and for the great job she has done in typing sometimes challenging notations.

I would also like to thank my parents for their guidance and encouragement. My greatest debt and my deepest appreciation is for my wife, Zohreh, who was understanding and supportive, and also for all the sacrifices that she had to make for this job to be completed. But I owe even more to my daughter, Parisa, who was so forgiving and so loving in spite of all that she had to give up, without even knowing why.

TABLE OF CONTENTS

LISTT OF TABLES

CHAPTER I

INTRODUCTION

The energy crises of 1973-74 and 1979 reemphasized the importance of energy sources. Suddenly, energy economics studies became important at the national level, but state-level studies did not seem to receive the same attention. This inquiry focuses on the problem at the state level.

The terms energy and energy demand are very broad and diversified. Energy sources in general are substitutes, and the estimation of demand for energy in general does not specify the mix of different energy sources. The present study therefore will concentrate on electricity demand. Furthermore, since different categories of customers behave differently, they need to be studied separately. Of the three general electricity consumers (residential, commercial, and industrial) the residential demand in Oklahoma is the subject of the present study. The supply of electricity will be assumed to be elastic due to the various peculiarities of electricity demand as well as the fact that electricity is regulated.

The goal of this study is to identify the relevant exogenous variables in electricity demand, collect data on these variables and estimate residential demand for electricity in Oklahoma. Location and selection of data proved to be the most demanding task. Data on rate schedules, level adjustments, kilowatt-hour consumption, and the corresponding expenditures had to be collected one by one from separate files for each variable for each month for each of 35 different companies. Other data collection problems proved to be less formidable.

The concentration on residential demand for electricity is because the state of Oklahoma has several unique characteristics. Choosing a specific energy type makes it precise and well defined, rather than being general. The isolation of the customer type results in more homogenous data with less diversified motives for consumption than if all customer types were included. The choice of scale, namely state-wide versus national or regional, is based on empirical considerations. Only when states have the same behavior with respect to exogenous shocks is the aggregation of state data proper. In addition economic and environmental factors are more homogeneous within a state than nationally. The choice of the state as the basis of the study allows policy makers to make economic decisions based on that state's own environment and economic conditions rather than relying on national averages.

Chapter two will review the existing literature on residential electricity demand, the majority of which is at the national level. In chapter three, after examining the theoretical framework pertaining to the specific nature of electricity demand, a demand model for residential customers for the state of Oklahoma will be developed. Then the data and its sources will be discussed and the statistical tests of hypothesis will be explained. Chapter four will present the statistical analysis of the model and several mutations of the original model. The hypotheses will then be tested to determine which variables play a significant role in determining residential electricity demand. Chapter five will summarize the results and conclusion and will address future research possibilities.

CHAPTER II

RELEVANT THEORETICAL AND EMPIRICAL LITERATURE

The studies of electricity demand, like other demand studies can be divided into empirical and theoretical. While the empirical studies of the subject are abundant, the theoretical studies are scarce. The first part of this chapter will be devoted to the empirical studies and their methodology. While the majority of these studies are econometrically defendable and are valuable assets to scholars, they do not address the relevant demand theories. Thus one has to accept or reject them on their statistical and practical merits. It is not clear why a particular model is used or what justifies the inclusion or exclusion of the apparently endless number of possible variables. Economic theory states that the demand for a particular good depends on total expenditure and the price of all other goods. However, the majority of these studies, instead of starting from the economic theory and developing their models, use a variety of "seemingly sound" models and variables. Halvorsen states that "a large number of mathematical forms of the demand and price equations were estimated and the log-linear form was chosen on the basis of goodness of fit" (Halvorsen, 1975; p. 12 footnote). Since these studies provide conflicting results, it seems that one can pick the method or specific formulation which provides the desired results; namely one can find a model which will provide a predetermined value of the price and income elasticities of demand.

To avoid this selectibility problem one needs to apply economic reasoning and theory to the analysis. The second part of this chapter will review this literature. It will then concentrate on L. D. Taylor and his followers' contributions to the study of electricity demand.

The studies of electricity demand reveal a variety of econometric methods. The general practice in the study of energy markets in general and electricity in particular is that supply and demand are studied separately. There are two reasons for this practice. One is that utilities must provide electricity at all times to meet the demand. This means that the electricity must be available even at the moment of peak demand, which is usually determined by the maximum temperature during the "hottest" day of the year. This creates a safety margin which results in excess capacity during off-peak periods, providing further justification for the assumption of an infinitely elastic supply.

The second reason for separating supply and demand is practical. A simultaneous model for electricity is extremely difficult to manage. No study of the simultaneous type has been cited by any of the studies being reviewed, and only five studies are known to use structural models. Four of these studies use a demand model and a stock of appliances model, and the last one uses a price equation in addition to a demand equation. More common, however, is the use of reduced form models. These models and examples of studies using them and their shortcomings will be discussed shortly.

This chapter will also point out several problems shared by all macro studies, such as the aggregation problem. It will also address problems which are specific to the studies of electricity demand, most notably those of declining block-rate tariffs and the nature of closely-related substitutes.

Disaggregated Data

Studies utilizing disaggregated data are less common than those using aggregate data. There are eleven studies which use the reduced form model and only three studies which employ disaggregated data in a structural form model, and all are static models. Three of the reduced form models and one of the structural models use the marginal price of electricity; the rest use the average price.

Lyman (1973) uses nonlinear demand functions employing maximum likelihood methods for classes of customers from 1959 to 1968 on sixty-seven investor-owned electric utilities and allows for variations in price and income elasticities. Using the variable-transformation functional form, a linear semilogarithmic function is derived. The price elasticities of demand are typically elastic for each of the customer classes. Taylor (1975) has summarized Lyman's price elasticity as -.90 and income elasticity as -.20, the sign of the latter being opposite of what was expected.

Acton, Mitchell and Mowill (1976) used meter read books for 260 customers in Los Angeles County for July 1972 to June 1974. This study included the marginal prices of electricity and natural gas, incomes, demographic variables, residential characteristics, weather data, and appliance stocks as explanatory variables. The data was obtained from the 1970 United States Census. The weather data were used as weights for heating and cooling appliances. In addition, other appliances were weighted according to their saturation level, allowing consumption responses to vary with the stock of appliances. The appliance saturation level is the percentage of the households that own one or more of a particular appliance. The pooled data provided long-run price elasticities from -.4 to -1.0 with seasonal changes, and stable long-run income elasticity estimates of 0.4. The cross-price elasticity of natural gas was estimated to be 0.5.

Hewlett (1977) uses the survey conducted by the Washington Center for Metropolitan Studies of 1973 and 1975. The survey provides saturation levels, but it fails to provide individual rate structures. Hewlett regresses electricity expenditures on quantity consumed, and uses the slope of the estimated line as the marginal price of each household group, while the estimated intercept is interpreted as the intramarginal price. The implicit assumption is that all households served by a utility fall into the same marginal block.

The study utilizes three types of variables: economic and climatic; demographic; and physical/thermal. The main demographic variable influencing electricity consumption is the number of persons living in a household. The coefficient of this variable is inelastic, implying that the change in electricity consumption will not be proportional to the change in household size. The number of rooms, bathrooms, and doors are the major spatial characteristics of a house that influence residential electricity consumption. The short-run price elasticities were -.135, -.137 and -.092, for the 1973, 1975 and pooled data, respectively. The corresponding short-run income elasticities were .058, .068, and .081, respectively. The income elasticities are low, but statistically significant. One reason for these low values might be the inclusion of numerous explanatory variables. Hewlett reports 17 variables which are significant.

Barnes, Gillingham, and Hagemann (1981) base their study on the concept of income the effect in terms of Nordin's (1976) argument. The point is that falling marginal rates lower both marginal and average prices:

> To the extent that a lower average price per unit is charged up to, but exclusive of, the block in which the user's consumption level falls, he effectively pays a negative premium over what he would pay if marginal and average price were equal (p. 542).

This amount is called the rate structure premium (RSP). Theoretically, the effect of RSP on electricity consumption should be equal to, but opposite in sign from, the effect of income changes. Barnes, et. al. subtract RSP from income, thus making the remainder a function of marginal price with no intramarginal premium impact.

The household data were obtained from <u>1972-1973 Consumer Expenditure Survey</u> (Carlson, 1974), which consists of 10,000 interviewed households. The households in each region were matched with the corresponding utility company. The residential rate schedules were obtained from the Federal Energy Regulatory Commission. Demographic profiles and stocks of electric appliances were also used to estimate residential demand for electricity using instrumental variable techniques, allowing for variable rates of utilization for each appliance. The reported price elasticity is -.55 and that of the income elasticity is 0.2. The corresponding results, when ordinary least squares and actual prices are used, are -.88 and .21, a substantial change in the estimate price elasticity. The authors believe the results of the instrumental variable technique are superior. This claim is supported by the theoretical arguments of Taylor (1975) and Nordin (1976).

Hartman and Werth (1981) provide a disaggregated analysis which gives estimates for end uses. This study estimates three demand functions: One for space heating, one for central air conditioning and room air conditioning, and the last for freezing, cooking, water heating, clothes washing, clothes drying, and all other categories. The study provides ordinary least squares results as well as the results of the weighted least squares (WLS) technique. To overcome the problems inherent in pooled data, random- and fixed-effects models were applied and all results compared. Heating degree days and cooling degree days used in space heating and air conditioning equations are both positive and significant.

Hartman and Werth acknowledge that the estimated income elasticities are very low. The results of fixed- and random-effects model are not very favorable, except for particular end-uses. Even though the techniques are theoretically superior, the results are unsatisfactory and sometimes have the wrong sign, for which no explanation was offered.

Hewlett's (1977) dynamic version uses marginal price, and is basically the same as his static version. The short- and long-run price elasticities are -.16 and -.45 respectively, while neither the short- nor the long-run income elasticities are statistically significant. The insignificance of income creates doubt about the validity of the model. The insignificance of the income elasticities means that the demand for electricity does not depend on income. This implies that people with high incomes and large homes demand only as much electricity as lower income people with smaller homes and fewer electrical appliances. Also, insignificant variables must be removed from the model which will change the coefficients of the remaining variables. This can result in changes in the signs of other coefficients and may invalidate the entire model. Freund and Minton (1979; pp.35-39) provide an example of such drastic changes.

The literature review to this point suggests a wide range of models and statistical procedures. However, the differences in the statistical methods are minimal. Depending on the nature of the data, some statistical procedure is used. The general pattern, however, is that most of the variables included in the models do not appear in the textbook presentation of demand. In particular, the models include the variables which affect the electricity consumption: total area of the household, number of rooms, number of people at the residence, and cooling degree days. However, some of the important factors which affect electricity consumption such as space and water heaters, and space coolers, are missing from most models. Home insulation and the efficiency of the appliances are completely ignored, whereas the efficiency of appliances, and the amount of insulation, together with climatic factors, would seem to be of great importance with regard to total electricity consumption and hence its demand.

The micro approach to electricity demand can include provisions to incorporate the electricity specific variables in the demand model. One of the best examples is Anderson (1973). The only feasible way to obtain detailed data required for micro studies is sampling.

All of the above studies, except two, use data obtained through sampling. Lyman's (1973) study uses firm data. The study by Acton, Mitchell and Mowill (1976) covers the entire Los Angeles County, and thus is a limited census and not a sample. However, none of the samples were taken specifically for electricity demand analysis; therefore, they do not provide all of the necessary details mentioned above.

The review of the disaggregated data studies indicates that, since the samplings were not conducted to obtain data for the electricity demand study, different statistical methods had to be utilized. Also, several simplifying assumptions had to be made in order to use the data. No sampling survey exists for Oklahoma, making it impossible to conduct an electricity demand study at disaggregated level without first conducting a sampling survey.

According to their authors, most of these studies give unsatisfactory results. Usually they take a longer time and are more expensive than studies using aggregated data because of the necessity of sampling or surveying to obtain data.

Aggregated Data

Studies which use aggregated data are reviewed in the same manner as studies using disaggregated data. There are seven static studies which use the average price of electricity as variables. The study by Fisher and Kaysen (1962) is the first study to distinguish between short-run and long-run residential demand for electricity. The short-run demand is expressed in terms of appliance stocks and uses intensity while the long-run demand is a function of the capital stock.

Let:

$$D_t = \sum_{i}^{n} K_{it} W_{it} \qquad 2.1$$

where

D_t = total metered use of electricity in kilowatt-hours by all households in community during period t,

n = number of white goods,

W_{it}= average stock during period of the ith white good measured in kilowatt-hours of electricity consumed during an hour of normal use,

K_{it}= average intensity of use of ith white good during period t (measured in units of kilowatt-hours per time period per unit of white good),

$$K_{it} = B_i P_t^{\alpha} Y_t^{\beta} \tag{2.2}$$

P_t = average price of electricity per kilowatt-hour to households in the community,

Y_t = community personal income per capita

Price and income are in real terms.

Substituting equation 2.2 in equation 2.1 results in:

$$D_t = \Sigma B_i P_i^{\alpha} Y_i^{\beta} W_{it} \tag{2.3}$$

Let

$$C = B_i \overline{P}^{\alpha_i} \overline{Y}^{\beta_i} \tag{2.4}$$

where $\overline{P}$ and $\overline{Y}$ are arithmetic means of T time periods in the analysis.

$$D_t = \sum_i^n C_i (P_t/\overline{P})^{\alpha_i} (Y_t/\overline{Y})^{\beta_i} W_{it} \tag{2.5}$$

Assume equation 2.5 can be approximated as:

$$D_t = C\ (P_t/\overline{P})^{\alpha_i} (Y_t/\overline{Y})^{\beta_i} \sum_i^n W_{it} \tag{2.6}$$

where c, α and β are constants independent of i and t

Let

$$W_t^* = \sum_i^n W_{it} \qquad 2.7$$

$$C_t = C / (\overline{P}^{\alpha}\ \overline{Y}^{\beta}) \qquad 2.8$$

Hence

$$D_t = \hat{C}\ P_t^{\alpha}\ Y_t^{\beta}\ W_t^* \qquad 2.9$$

$$LnD_t = Ln\hat{C} + \alpha LnP_t + \beta LnY_t + LnW_t^* \qquad 2.10$$

However

$$C^* = Ln\hat{C} = LnC - \alpha Ln\overline{P} - \beta Ln\overline{Y} \qquad 2.11$$

Finally substitute equation 2.11 in 2.10 to get:

$$LnD_t - LnW_t^* = C^* + \alpha LnP_t + \beta LnY_t + \varepsilon \qquad 2.12$$

$$W_t^* = W_0^* e^{\delta t} \qquad 2.13$$

$$lnD_t = C^* + \alpha lnP_t + \beta lnY_t + lnW_0^* + \delta t \qquad 2.14$$

Taking the first differences of 2.14:

$$\Delta LnD_t = \delta + \alpha \Delta LnP_t + \beta \Delta lnY_t \qquad 2.15$$

The data covers the period of 1946 to 1957 for 47 states. The price variable is ex post data since total revenue is divided by total kilowatt-hours per period to determine the average price. The estimated model for the State of Oklahoma is:

$$\Delta LnD_t = \delta - 0.23LnP_t + 0.043LnY_t \qquad 2.16$$

Thus, the price elasticity is -.23 and income elasticity is .04, with neither being significant at the five percent level. The coefficient of determination (R^2) was 0.2329. Fisher and Kaysen try to explain these unsatisfactory results through the degree of urbanization. They argue that the lower the urbanization, the lower the income elasticity, and the higher the price elasticity in absolute value. However, this argument fails to explain the low price elasticity observed for Oklahoma.

When states are grouped in more homogenous blocks (in terms of urbanization) the regional results show some improvement. No estimates for the United States as a whole is provided. An evaluation of the study is presented by Wilson (1971).

Moore (1970) acknowledges that the demand for electricity changes over time, but concentrates on a single-period demand and states that "the demand function for any particular period should be a function of the price of electricity, of income, the price of substitutes such as gas, and of climatic conditions" (p. 366). To overcome the lack of data for each block rate, Moore uses a weighted average price $\Sigma P_i \overline{Q}_i$ where $\overline{Q}$ is the number of kilowatt-hours per month in each of the three "typical electric bill" brackets, namely 100 kilowatt-hours, 250 kilowatt-hours, and 500 kilowatt-hours.

Moore views $\Sigma P_i\overline{Q}_i$ as the total expenditure on 250 kwh per month: "Dividing $\Sigma P_i\overline{Q}_i$ by $\Sigma \overline{Q}_i = 250$ kilowatt-hours per month would give the average price per kilowatt-hour for electricity" (Moore, 1970, p. 367). The demand model is:

$$Q = \beta_0+\beta_i\Sigma P_i Q_i+\beta_g P_g+\beta_y Y+\beta_a A+\varepsilon \qquad 2.17$$

where

$\Sigma P_i\overline{Q}_i$ is the price measure explained above,

P_g is the price of natural gas,

Y is income,

A is the area of the country where the consumer lives, and,

ε is a normally distributed error term.

The model is estimated using cross-sectional data from 417 companies. The income variable was deleted later because of difficulties in data gathering and justified on the basis of insignificant results for a small sample of utility companies (37 companies were included).

Four models representing different groupings of the regions were estimated. The long-run electricity elasticities ranged from -1.02 to -1.487. The two estimated cross-elasticities of natural gas were .146 and -.485 which are contradictory.

Wilson (1971) uses a cross-section of 77 cities for 1960 representing a long-run equilibrium. The estimated model is:

$$\text{Log}Q = 10.25 - 1.33\text{Log}P + 0.31\text{Log}G - 0.46\text{Log}Y + 0.49\text{Log}R + 0.04\text{Log}C \quad 2.18$$

where

Q is the electricity demand,

P is the average price of electricity

G is the average price of natural gas,

Y is the median family income,

R is the average size of housing units, and

C is the climatic conditions

(logs are in base 10)

While all the variables are statistically significant, the income elasticity has the wrong sign. Wilson, relying on beta coefficients, concludes that the primary determinant of residential electricity demand is price.

The model with income explains 52 percent of changes in electricity demand. The order of importance of the variables in explaining demand for electricity is: electricity price, income, and the price of natural gas. Unfortunately, beta coefficients for the average size of housing units (R = rooms per unit) and climatic conditions (C = cooling degree-days) are not provided. Also no explantions of the negative coefficient of income is offered.

It is likely that median family income used by Wilson is an inappropriate variable because Anderson (1973) uses annual income per household for 1960 and 1970 instead, and in both cases the income elasticities are positive (see below).

Anderson (1973) is concerned with the interdependencies between energy types and the exclusion of relevant prices of substitutes and complements of the energy type under consideration. Anderson has 33 explanatory variables which include appliance stocks and their prices, prices of different types of energy, household size, and climatic information. Data is cross-sectional for 1960 and 1970, which enables a static comparison of the two dates for a stability check. Most of the results, however, are statistically insignificant. The model is:

$$\begin{aligned} LnX = {} & \alpha_0 + \alpha_1 LnPelec + \alpha_2 LnPgas + \alpha_3 LnPoil + \alpha_4 LnPcoal \\ & + \alpha_5 LnPbgas + \alpha_6 LnYph + \alpha_7 LnHS + \alpha_8 LnSHU + \alpha_9 NUHU \\ & + \alpha_{10} Wtemp + \alpha_{11} Stemp + U \end{aligned} \tag{2.19}$$

where

X is the (unspecified) dependent variable,

Plec is the electricity price,

Pgas is the price of natural gas,

Poil is the price of heating oil,

Pcoal is the price of coal,

Pbgas is the price of bottled gas,

YPH is the annual income per household,

HS is the household size,

SHU stands for single detached housing units,

NUHU stands for nonurban housing units,

Wtemp represents the mean December temperature,

Stemp is mean July temperature, and

U is random error.

Charles River Associates (1976) reestimated Anderson's model with a pooled-time series of statewide observations during 1966-72. All coefficients in this study were statistically significant. The important result is that the long-run price elasticity of -1.2 is very close to that of cross-sectional studies mentioned before but the estimated income elasticity is .48, which is at the lower range of long-run income elasticities. It seems that the choice of variables made a difference with Anderson's study.

Charles River Associates use several measures of average price based on typical electric bills (TEB) and several average revenues from residential electricity sales, all of which provide stable price elasticities. The results of using marginal prices that were derived from TEB's were substantially different.

Halvorsen (1975), to overcome the "identification" problem caused by declining block rate, utilizes two equations: a demand equation and a price equation. The demand equation is a function of the marginal price of electricity, the prices of all other goods and a random disturbance variable. The price equation is a function of quantity, a set of exogenous variables determining the shape and location of the rate schedule, and a random disturbance variable. To overcome the lack of data, which makes the estimation of this two-stage least squares equation impossible, Halvorsen proposes the use of average price.

Halvorsen uses a two-stage regression. In the first stage, a demand price equation is used to estimate the (average) price. In the second stage, those estimates are substituted in the demand equation. Halvorsen does not elaborate on model specification. Instead he states that "a large number of mathematical forms of the demand and price equations were estimated and the log-linear form was chosen on the basis of goodness of fit" (Halvorsen, 1975 footnote 1 p. 12).

The value of the income elasticity is .51 and the price elasticity is -1.15. For comparison, Halvorsen provides the results of some dynamic models which do not differ substantially from his static model. All of the models estimate the income elasticity to be close to .5 and all price elasticities exceed unity in absolute value. The main conclusion of this study is that the price elasticity is greater than one.

Halvorsen (1978) uses pooled state data for 1961-69 to estimate a static demand function and reports highly significant estimates for the long-run price elasticity equal to -1.14 and the long-run income elasticity of .52. The results are similar to other studies. Observing these results, Bohi (1981) concludes that:

> evidently there is insufficient variation in income and other variables, over time or across geographic units, to generate separate estimates of income and price elasticities (p. 62).

In his 1978 book, Halvorsen reports that the short-run, own-price elasticity of electricity demand in Oklahoma is -.836, and the income elasticity is estimated to be .012. These results are significant at .10. The model is:

$$LnQ_t = \alpha_0 + \alpha_1 LnQ_{t-1} + \alpha_2 LnP_t + \alpha_3 LnP_{t-1} + \alpha_4 LnY + \alpha_5 LnY_{t-1} + \mu \qquad 2.20$$

where

Q_t = Quantity of electricity used,

P = Price of electricity

Y = income

t-1 represents lagged values.

The price elasticity of Oklahoma definitely contradicts the conclusion of Halvorsen's 1975 study. The difference, however, can be the result of higher price elasticities for other states, in which case Bohi's statement is invalidated.

Halvorsen also used the model in his book:

$$LnQ_t = \alpha_0 + \alpha_1 LnQ_{t-1} + \alpha_2 LnP_t + \alpha_3 LnY_t + \mu \qquad 2.21$$

which estimates price elasticity at -1.39 and income elasticity at .5, both significant at the 5 percent level. Time series data from 1961-1975 is used so that short-run elasticities could be obtained.

Halvorsen (1978) also uses the marginal price as the relevant variable instead of the average price. Without changing other variables, the estimated long-run price and income elasticity became −1.53 and .72, respectively. The magnitude of these elasticities is different from the one obtained using the average price of electricity. Halvorsen also tries different models such as ordinary least squares, simple lagged explanatory variable models, several distributed lag models and log-linear regressions, each of which provide different results. However, own-price elasticities are consistently greater than one in absolute value, and income elasticities are consistently less than one.

McFadden and Puig (1975) also use an instrumental variables model. The difference from Halvorsen (1978) is in the price equation. McFadden and Puig use a three-parameter function of Typical Electricity Bill (TEB) at different consumption levels in order to allow the average price to vary in proportion to the marginal price. The estimated marginal prices are then used in the consumption equation. The price elasticity is reported at −.48, and the income elasticity is .99. The two almost identical studies provide opposite results. Halvorsen's price elasticity is large and greater than one in absolute value, while his income elasticity is very small. McFadden and Puig, on the other hand, estimate low price elasticity and high income elasticity.

In an attempt to include the appliance stock, Halvorsen included the wholesale price index for household appliances. There are two reasons for this approach. One is that there are no data on retail sales of appliances. Second, the study is using aggregate data. However, no significant relationship existed between electricity and the wholesale price index for household appliances. Wills (1977) in a similar attempt, adds saturation rates for different appliances to a standard consumption model, but the regression yielded results that were of the wrong sign. Wills then uses a cross-section of utilities in Massachusetts for 1975 and reports a short-run price elasticity of -.08 and a short-run income elasticity of -.32, implying that as income increases, the demand for electricity decreases.

Another study of electricity demand, which is rather limited in scope, is that of Lacy and Street (1975). They conducted a time-series study for the 1967-74 period for an Alabama power company. Using the marginal price, the estimates of short-run price and income elasticities are -.45 and 1.87, respectively.

Hartman (1983) develops a short-run energy model based on an error component model which uses aggregate data to measure household demand. The use of an error component enables Hartman to gain the extra information provided by the covariances of error terms.

Hartman's study incorporates the stock of electricity by including appliances and their list price, household income, and climatic variables to build the demand model.

Hartman then argues that the stock variable for each appliance in general is either zero or one. Thus for each appliance, Hartman presents an electricity demand function whose variables are the marginal price of electricity, the household's income and a weather factor.

Hartman's (1983) results of fixed effects and random effects are inconclusive and at times contradictory. For example, in the case of space heating, price elasticity of the fixed effects model is more than four times that of the random effects model. Income elasticity of space heating is negative and greater than one in absolute value but the random effects model gives a positive income elasticity and is less than one. In addition to space heating models, air conditioning models are the only models with relatively large elasticities for price, income, and climatic variables.

Dynamic Consumption Models

Houthakker (1951) deals with residential demand for electricity under two-part tariff, and points out the economic and statistical problems of such a pricing system. Houthakker argues that at equilibrium, consumers equate marginal cost and marginal utility. Therefore, the appropriate price variable is the marginal price. To overcome the identification problem, the prices are lagged two periods. The estimated equation is:

$$\mathrm{Ln}X = \beta_0 + 1.66\mathrm{Ln}M - .893\mathrm{Ln}P_{-2} + .211\mathrm{Ln}G_{-2} + .178\mathrm{Ln}H \qquad 2.22$$

where

X = average annual consumption.

M = average price of electricity.

P = marginal price of electricity.

G = marginal price of gas.

H = average holdings of heavy domestic equipment per customer.

The price elasticity of electricity is -.89, income elasticity is 1.17; the cross-price elasticity of natural gas is .21, and the cross-price elasticity of complementary goods is .18. Variable H is used to represent a proxy of past and present prices of complementary goods. Therefore, the above result represents short-run elasticities.

In 1980, another study of residential demand was published by Houthakker. The only common denominator between Houthakker's two studies is the use of marginal price and disaggregated data. Houthakker (1980) is much closer in approach to a study conducted by Houthakker, Verleger, and Sheehan (1974). Both studies share:

1. The logarithmic flow adjustment model with lagged consumption price and income as variables.

2. The pooling of annual time series of 48 states using the error component approach of Balestra and Nerlove (1966).

3. The use of the marginal price of electricity.

The 1980 study uses a new approach to calculate the marginal price. Houthakker uses the Typical Electric Bill, which is published by the Federal Energy Regulatory Commission for 100, 250, 500, 750 and 1,000 kwh, by regressing the average bill on the corresponding quantities to get a single marginal price for each year. This implies that marginal prices are constant over the covered range. The marginal rate, however, falls in the lower half and then rises again.

The estimated model for the United States is:

$$\text{LogQ} = .111 + .922\text{LogQ}_{-1} + .139\text{LogY} - .111\text{LogP} + .082\text{LogH} + .058\text{LogC} + .057\text{LogZ} \qquad 2.23$$

where annual per capita consumption Q is expressed as a linear function of last period's consumption, disposable income, marginal price of electricity, change in heating degree days, change in cooling degree days, and the average price of natural gas.

The corresponding equation for the west south central region (census division) is:

$$\text{LogQ} = .256 + .942\text{LogQ}_{-1} + .027\text{LogY} - .069\text{LogP} + .133\text{LogH} + .328\text{LogC}_{it} + .021\text{LogZ}_{it} \qquad 2.24$$

Substantial differences are seen in all elasticities except with respect to the last period's consumption. The long-run price elasticity, income elasticity and cross-price elasticities are −1.48, 1.78, and .73, respectively. The corresponding elasticities for the west south central region are −1.19, .47, and .34.

Houthakker provides a static version of the model with the following results:

$$\begin{aligned} \mathrm{Log}Q_{it} =& .586+1.388\mathrm{Log}Y_{it}-1.18\mathrm{Log}P_{it}+.199\mathrm{Log}H_{it} \\ &+.483\mathrm{Log}C_{it}+.566\mathrm{Log}Z_{it} \end{aligned} \qquad 2.25$$

This model provides substantially different results, particularly with respect to price elasticity and cross-price elasticity.

The 1978 study by Houthakker and Taylor is an extensive study of consumer behavior in general and provides estimates of price and income elasticities for several consumer goods, including electricity and natural gas. The elasticities for electricity consumption are calculated for the period 1946−1964. The model is:

$$Q_t = 3.7+.87Q_{t-1}+.003X_t-.05P_t \qquad 2.26$$

where

Q_t is the per capita personal consumption

X_t is total per capita personal consumption expenditures,

P_t is the relative price of electricity (1958 = 100) calculated as the implicit deflator for electricity divided by private consumption expenditures.

The technique used is ordinary least squares. The short-run price and income elasticities are −.13 and .132, respectively, and their long-run counterparts are −1.89 and 1.93, respectively.

Mount, Chapman, and Tyrell (1973) point out that cross-section or time series analysis of electricity demand using state data are valid only if the price elasticity of demand is the same in each state and over time. Since this is not the case, Mount, et al, utilize a variable electricity model of the form:

$$\mathrm{Ln}Q_{it} = \alpha + \delta_0/D_{it} + \lambda \mathrm{Ln}Q_{i(t-1)} + \sum_j^N \beta_j \mathrm{Ln}\, V_{ijt} + \sum_j^N \delta_i \mathrm{Ln}\, V_{ijt}/D_{it} + \sum_j^N \gamma_j / V_{ijt} + \varepsilon_{it} \qquad 2.27$$

where

Q_{it} = electricity consumed in state i during time t.

D_{it} = value of a "shift" variable for state i during time t.

V_{ijt} = value of the jth independent variable for state i during time t.

N = number of independent variables.

ε_{it} = random error term.

Furthermore, Mount, et al., point out that economic phenomena are not instantaneous and use a geometric lag. With regard to the choice of price variable and structure of the model they say:

> . . .there is no empirical evidence that either the use of marginal prices or the consideration of simultaneity gives results that conflict with those obtained with average prices and

> single-equation models. In addition, rate adjustments tend to stabilize average prices to maintain a balance with average costs; consequently, it is not unreasonable to consider that consumers are aware of average prices and consider supply to be elastic in the short run (p. 6).

Cohn, Hirst, and Jackson (1977) derive the residential demand for energy, including electricity, natural gas and fuel oil. For each energy type, a static as well as a dynamic model is presented each using average prices. This study uses state data for price of electricity, prices of substitutes, per capita income, number of households, heating degree days, and average July temperature to estimate the national demand for electricity.

To compensate for the exclusion of multi-family electricity metering, they add 4 percent to the residential sales of electricity. In order to compensate for multifamily natural gas metering, they add 22 percent of the commercial gas sales to the residential gas sales. Data from several cities in each state are weighted by population to develop state estimates for mean July temperature. These adjustments in data are ad hoc, and the authors provide no empirical justification for their actions.

The cross-section analysis suggests steady own-price elasticities for electricity, with a long-run average of -1.0. The cross-price elasticity of gas has generally increased in absolute value over time, signifying a greater awareness of relative prices on the part of household members. The average value of the coefficients for mean July temperature was -.34 for the 1970 to 1974 period, which reflects the effect of air conditioning use on demand for electricity, but has the wrong sign.

The literature on aggregate studies of electricity demand reveals very elaborate econometric methods, but almost no economic theory. None of the studies presented here tries to explain or justify the inclusion or exclusion of variables used in their models. It seems as if the wide selection of variables is based upon the performance of the models and variables according to some statistical criterion such as "goodness of fit" or "beta coefficients." The same approach has been followed in the selection of the models themselves. Even the improper sign for coefficients does not seem to matter as long as the "fit" is "good." Almost all the studies cited have disregarded the problem without addressing the subject.

Most of the variables, such as income, price, or the size of the residency, are legitimate and can be defended on the basis of economic theory. There are variables, however, that cannot conceivably explain the total electricity demand. For example, why should the mean July temperature explain the annual electricity demand, or why should median family income--a stock variable--should explain the demand for electricity--a flow variable? It is easy to conceive of cases such as incomes changes without a change in median income, hence changing demand without changing median income. Mode and average are less susceptible to these kinds of changes in variables.

The selection of model and procedure is *ad hoc*, except that models can be selected based on econometric theory requirements. However it seems that simple methods such as ordinary least squares give results similar to more complex methods. This is expected because of the lack of accurate data that is generally needed with more elaborate methods.

The main problems facing the majority of the electricity demand studies are that they either ignore difficulties imbedded in the electricity demand question or they confine themselves to a brief acknowledgment of the problems and then ignore them.

Fisher and Kaysen pointed out the problem of the declining block rate schedule as early as 1962. No one, including Fisher and Kaysen, was able to propose a satisfactory solution until 1975. Until 1975, some measure of average or marginal price was used to estimate electricity demand.

Macro studies also further face the aggregation problem. Many researchers have acknowledged this problem, but they have persistently undertaken their studies with unrealistic assumptions and proceeded with aggregated data. Aggregation will consistently result in biased estimates if the individuals are not alike in their response to changes in factors affecting electricity demand. The bias will exist anytime non-homogenous factors are aggregated.

Macro studies should be based on data that is as homogeneous as possible but should not be so narrowly defined that they lose their generality. One method of dealing with nonhomogenous data, with certain assumptions and conditions, is the error components model, which exploits the correlation among the error terms. The restrictions on data and the assumptions of the method make it less desirable in the study of electricity demand, and very few studies have used this method (Hartman, 1983).

In summary, the dominant model in the literature is the logarithmic form. This type of modeling has been used widely since the introduction of the Cobb-Douglas equation. The usefulness of this format has been proven in all aspects of economic and business studies.

In aggregate and disaggregate studies, attempts to incorporate stocks of appliances or its proxies, such as saturation rates, fail to provide reasonable results. As before, the main problems are lack of data and lack of knowledge concerning the functional relation between the existence of an appliance and total household electricity consumption.

Derivation of the Price Variables

The price variable proved to be troublesome and researchers have had to justify the use of average or marginal price. The latter, being more difficult to calculate, is used less often. Sometimes, as with Halvorsen (1975,1978), after an author establishes the practicality or superiority of one price variable, he later switches to the other one. The difficulty surrounding price variables will be dealt with in detail below.

The most important variable in the study of electricity is the price of electricity. In economics, the price of commodities is assumed to be well defined, known, and independent of the individual quantity consumed. In electricity, none of these criteria hold. Instead of a single price, there is a rate schedule with price per kilowatt-hour dependent upon consumption. In addition, no consumer, no matter how well informed or knowledgeable about electricity, can determine the exact price per kilowatt hour. Too many factors are involved for the consumer to deal with effectively. The price depends on the rate schedule and its adjustment coefficients. The latter depend upon total consumption or measures such as pollution factors, or both. These factors depend on the location of the utility company and its plant type, as well as the consumption behavior of the population. Total consumption is affected by factors such as the stock of appliances, insulation, climate and other factors.

Multi-rate tariff schedules were introduced and used as early as 1882. A two-part tariff was adopted due to the unique nature of electricity production. A utility company provides two types of services: the actual energy provided as measured in kilowatt-hours, and the availability of electricity whenever it is demanded, twenty-four hours a day. Provision of these services justifies two types of charges: a variable cost and a fixed cost.

The variable cost covers the actual energy supplied (in kilowatt hours). The fixed cost covers the costs of having the supply always available. The logic behind two-part tariffs also rests on the principle that the ultimate customer should pay the total cost of the commodity. Hopkinson in 1882 suggested that:

> the variable exponent of costs, which consisted mainly of fuel consumed in the thermal plants and a share of the plant repairs and maintenance costs, was to be assessed in terms of kilowatt-hours, while the fixed component was to be assessed in terms of kilowatt demand (United Nations, 1972, p. 8).

Two-part pricing was refined such that the consumer not only paid for actual consumption, but also paid additional fees to cover a share of the fixed costs of maintaining supply depending on his maximum demand.

Multi-rate pricing would not be possible except under a monopoly that is granted by a regulatory commission. While multi-rate pricing is justified for economic equity, it provides a vehicle for maximizing profit by extracting the consumer surplus. Gabor (1955-56) argues that:

> It is generally recognized that the maximum gain in total revenue which can be obtained from a consumer by departing from single pricing while inducing him to buy the same quantity as before is the money equivalent of his consumer's surplus, and the multi-pricing,. . . can extract the whole of this amount. . .same money amount can also be extracted by a block tariff, even if it consists of two prices only (p. 33).

That is, only a point, and not a schedule, exists for demand; therefore an equilibrium point, in the sense of the intersection point of supply-and-demand, does not exist. This point has also been noted by Houthakker (1951); Halvorsen (1975); and Taylor, Blattenberger, and Rennhack (1982). Buchanan (1952-53) argues that the supply curve under a declining price scheme is downward sloping. In addition he states that:

> It makes no difference. . .whether all units or only the marginal ones are offered at lower prices as greater amounts are purchased. A lowered price on additional units is equivalent to a lowered average price on all units. . .if rational, the buyer will consider the marginal supply price, whether stated directly or as a lowered average price (p. 199).

He then proceeds with a downward sloping supply curve based on average supply prices at which various quantities may be purchased from a monopolistic seller. The elasticity of such a downward sloping supply curve has to be greater than one for all cases in which the marginal cost is non-negative. If the quantity discount is stopped, and a uniform price equal to the average prevailing supply price is charged, the consumer will purchase less of the commodity and move to a higher indifference curve as demonstrated by Buchanan (p. 201). Buchanan continues:

> . . .the effect of this type of market offer is clearly that of forcing the buyer to purchase the commodity at a price in excess of the marginal contribution to his "satisfaction" provided by a unit of the commodity (p. 204).

Finally, Buchanan argues that the quantity discounts of this nature are ". . . equivalent to a reduction in the real income of the buyers and an increase in the real income of the sellers" (p. 204). This is what Taylor (1975, p. 102) has termed the income effect of the intramarginal price; and Taylor, Blattenburger, and Rennhack (1982) try to approximate it with the "fixed charge premium" to be discussed in detail below. Houthakker (1981) subtracts this amount from the household's real income and calls it the adjusted real income.

After Buchanan (1952-1953) no major contribution has occurred in the area of electricity demand. One explanation might be that the real price of electricity and other energy prices have declined and were not a major policy concern to many.

Taylor (1975) changes this picture. In The Demand for Electricity: A Survey, Taylor raises a legitimate question. He argues that the consequences of declining block rates are that average price is declining as marginal price falls. To avoid the bias due to the exclusion of relevant variables, Taylor argues that both marginal and average prices should be included.

Taylor defined the marginal and average prices as follows:

> the marginal price should refer to the last block consumed in, while the average price should refer to the average price per kwh of the electricity consumed up to, but not including the final block (Taylor, 1975, p. 80).

Taylor suggests that, in aggregate studies, the last block of the "typical" household should be used as the marginal price. Taylor proposes the use of total expenditure on electricity up to the final block instead of the average price. He also points out that:

> whichever variable is used, the variable will measure the income effect arising from intramarginal price changes, thus leaving the price effect to be measured by the marginal price (Taylor, 1975, p. 80).

This income effect was elaborately shown by Buchanan (1952-53) as mentioned before.

Nordin (1976) proposes replacement of the average price (or total expenditure for that matter) with a different price related variable. This measure is most aptly explained by Barnes, Gillingham, and Hagemann (1981, p. 542):

> To the extent that a lower average price per unit is charged up to, but exclusive of, the block in which the user's consumption level falls, he effectively pays a negative premium over what he would pay if marginal and average price were equal.

This measure is adopted in other studies and is termed "intramarginal premium," or "fixed cost".

Nordin demonstrated that the use of Taylor's average price or total expenditure may result in identical output production in two times or places. Terza and Welsh (1982) agree with Nordin, and through a two-block system show the bias of using the ordinary least squares (OLS) estimation procedure, and use a probate model to express household demand as a random variable. The contributions by Taylor (1975) and Nordin (1975) have sparked additional study in the area of electricity demand. Blattenberger (1977) contributed heavily to the theoretical development of the nature of demand under multi-tariff pricing. Taylor, Blattenburger, and Rennhack (1982) utilize Blattenberger's contributions as well as the contributions of others, especially that of Nordin, in a report to the Electric Power Research Institute (EPRI) titled Residential Demand for Energy, Volume I: Residential Energy Demand in the United States. This study will be examined more closely, and its contributions and innovations will be used extensively in the model utilized in the next chapter.

Taylor, Blattenberger, and Rennhack (1982), following Taylor (1975), partition each electricity rate schedule into the component rates and draw the kinked budget restraint. They then examine several alternatives such as changes in intramarginal price(s), marginal price, income, and other variables. Taylor, et al., show that in response to a change in the marginal rate, the possibility of shifting from one tariff rate to another does exist.

There are four direct consequences of a kinked budget line. First is the inability to derive the equilibrium, using calculus; "While the demand function and Engel curves still exist, they cannot be derived analytically through solution of the first order conditions for utility maximization" (Taylor, Blattenberger, and Rennhack, 1982, p. 25). Second, anytime that a price change causes a shift from one rate to another, the demand curve will be discontinuous. Third, switches due to change in income cause discontinuity in the Engle curve. Lastly, the possibility of multi-value demand functions exists.

Blattenberger (1977) shows that the aggregate demand function will become continuous at the limit as the number of consumers increases. The requirement is that the tastes and income of customers must be different. Rassenti (1979) demonstrates that even with aggregation over 12 customers, the continuity might be achieved. Therefore, the discontinuity of the aggregate demand can be ruled out, for all practical purposes. In practice it is assumed that budget constraints and indifference curves do not become tangent at more than one point, thus ruling out the multi-valued demand functions.

Taylor, Blattenberger, and Rennhack (1982) propose three methods to overcome the problems caused by decreasing block rates. First is the marginal-intramarginal premium approach based on the two-part theory discussed by Gabor (1955-56). The second approach is the use of the simultaneous equation method proposed by Halvorsen (1975) and others. Taylor, Blattenberger, and Rennhack define an average price function to accompany the demand function, but unlike the others, their average price model is based on the actual rate schedule. In the third approach, the average prices are estimated from the rate schedule and then used in a reduced form demand function. In the empirical work, the second method is ignored and the third method is tried in limited scope for the sake of comparison. The first approach is dealt with in detail.

In the first approach, Taylor, et al., define a revenue function:

$$R(q) = \Sigma r_i (K_{i+1} - K_i) + r_j (q - K_j) \qquad 2.28$$

where

K_i, K_{i+1} denotes the kilowatt-hour demarcations for the ith block.

r_i denotes the rate in this block, $q > K_{j-1}$ and consumption occurs at the jth tariff rate schedule.

They propose:

> parameterizing the rate schedule in terms of total revenue as a function of quantity and thus defining the marginal price as the slope of this function and the fixed charge as its intercept . . .a linear function provides a good approximation of the total-revenue function, so that marginal price is independent of quantity and is thus unambiguously defined (Taylor, et al., 1982, p. 42).

After each rate schedule is established, the state rate schedule is obtained by weighting each company's rate schedule by its number of customers. The state total revenue function is written as:

$$R(q) = \sum_{i}^{m} W_i R_i(q) \qquad 2.29$$

where

m is the number of rate schedules in the state,

$R_i(q)$ is the total-revenue function, and

W_i is the ratio of the customers in schedule i to total customers.

If more than one rate prevails during a given year, the company total rate is obtained by weighting each of the prevailing rates by the number of days that it was in effect.

To obtain the coefficients, the values of the q are varied at increments of 5 kilowatt hours from 50 to 1500 kilowatt-hours and the corresponding average revenues as specified by the rate schedule are regressed on the q's. The results are estimates of marginal price and intramarginal premiums.

Then R(q) is approximated by a linear function:

$$R(q) = a+bq+u \qquad 2.30$$

where a and b are parameters and u is the approximation error. The parameters a and b are estimated by the least squares regression of R(q) on q, using values of R(q) as calculated by equation 2.29, using U.S. data. This has been done for 290 values of q between 50 and 1500 kilowatt-hours. Thus, the estimate of the marginal price (b) is independent of electricity that is consumed, and no simultaneity bias exists.

In the second approach, Taylor, et al. (1982) approximate the total revenue function by:

$$R(q) = r_0 + r_1 q \qquad 2.31$$

where r_0 is the intramarginal premium, and r_1 is the marginal price. In the final approach, the average revenue is defined as:

$$\bar{r}(q) = R(q)/q \qquad 2.32$$

and it is assumed that average revenue can be approximated by a double logarithmic function:

$$Ln\bar{r}(q) = \alpha_0 + \alpha_1 Lnq + \varepsilon \qquad 2.33$$

As in the first approach, α_0 and α_1 are estimated by regressing $\bar{r}(q)$ on q using 290 points on equation 2.29 calculated at values of q between 50 and 1500 kilowatt-hours in increments of 5 kilowatt-hours.

The main shortcoming of Taylor, et al. is that they do not elaborate on the model selection. This study uses a Cobb-Douglas model with as many as 25 explanatory variables. Only the two electricity price variables and the availability of the natural gas are addressed in detail, while the other variables are treated as if their inclusion or the form in which they are presented are self-evident. Furthermore, while aggregate data are used, the aggregation problems, and the necessary assumptions to avoid those problems, are not clearly stated.

The marginal prices and the intramarginal premium are estimated for individuals for a single rate schedule. However, the macro studies aggregate over individuals and rate schedules. One method of dealing with this problem is to identify the "typical" customer and use the marginal rate for this individual as the applicable rate for actual consumption. The intramarginal premium is then calculated based on this marginal rate. An alternative approach would be the use of the rate of the most frequently used block or the mode rate as the marginal price.

One other factor incorporated in Taylor, et al. is the incorporation of the availability of natural gas. In most of the studies cited above, the price of natural gas, or the quantity, or both, are included to capture the substitution effect. However, as Taylor, et al. point out, natural gas was not available in some regions and still is not. Therefore, natural gas should be considered a substitute good only in those areas where it is readily available. In a study of natural gas availability, Blattenburger, Taylor, and Rennhack (1983) use the logarithmic Koyck version of the Houthakker-Taylor flow adjustment to estimate the gas availability for each state from 1960-75.

In summary, the focus of this section has been the price. On one hand, Taylor (1975), and Taylor, et al. (1982) demonstrate the necessity of two price variables, namely "intramarginal premium" and "marginal price," where the intramarginal premium has been modified according to the comments of Nordin (1976). Nordin treated intramarginal premium as the amount that the consumer has to pay in order to purchase electricity at a lower marginal rate.

In addition, theoretical support for two-part tariffs presented by Buchanan (1952-53) and Gabor (1955-56) was summarized. Finally the steps in derivation of intramarginal premium and marginal price was explained.

In the next chapter the theoretical model of residential electricity use will be developed according to the household production function approach of Muth (1962). However, before ending this chapter, it should be noted that Muth's approach does not require any particular functional form. In this study, following common practice, the model is written in a Cobb-Douglas type functional form.

The Cobb-Douglas function, in addition to being the most widely used form, serves other purposes, as well. First the model can be simply linearized by taking the natural logarithm. This also results in constant elasticities which are the regression estimates of the coefficients as well.

Finally, as will be seen in the next chapter, Muth's (1962) derivation involved the natural logarithm of the price.

CHAPTER III

CONCEPTUAL AND STATISTICAL FRAMEWORK

This chapter will develop the theoretical basis for establishing the demand for electricity model. Then the validity tests and hypotheses will be discussed. Finally, the nature and the sources of the data will be addressed.

The literature reviewed in chapter two revealed the long-standing economic justification for multi-rate tariffs It established that multi-rate pricing is a valid way of charging the "economically equitable" price. However, at the same time the review might suggest that at least until Taylor's 1975 study, no other study had recognized the need for two sets of price variables to account for "demand charge" and "usage charge." There are at least two reasons for this: one is the lack of powerful computers prior to the 1970's. The second is that, while utility companies have been charging both "fixed charge" and declining rate price schedules, no historical data are kept. The only data available are monthly data of kilowatt-hour consumption, revenue and the total number of customers for the residential sector.

The implication, then, is that while the total revenue from residential sales is known, the fixed charge and the marginal price of each individual customer is not known.

While Taylor, Blattenberger, and Rennehak (1982) satisfies a major shortcoming of applied research in electricity demand, they do not concern themselves with the specification of the model. They simply include variables deemed to be relevant and the statistical significance indiscriminately determines the entries. This does not undermine their invaluable contributions in the area of price variables or their ingenius approach to the availability of natural gas.

Several studies have recognized that the demand for electricity (and other energy sources for that matter) is a derived demand. That is, it is not demanded for its own sake, but is demanded for use with electricity-using appliances. Electrical appliances are not demanded and consumed for their own sake either. The reason for using electricity and appliances is to acquire the service they jointly produce. In other words, the consumer uses energy in conjunction with appliances to "produce" some ultimate commodities which are used within the household. According to Friedman (1962, p. 153), "the demand for final products reflects directly the 'utility' attached to them; the demand for factors of production does so indirectly, being derived from the demand for the final product."

The idea of considering the commodities purchased on the market by consumers as inputs in the production of goods within the household was first suggested by Muth (1962). Muth (1962) assumes weakly separable utility functions, which are continuous, twice differentiable and concave. The production function is assumed to be homogenous of degree one, and the household produces goods $X_1, X_2, \ldots, X_g$ such that:

$$X_g = X_g(Y_{g1}, Y_{g2}, \ldots, Y_{gng})$$

where Y_g's are inputs. Then Muth shows that

$$(\partial U/\partial Y_i)/(\partial U/\partial Y_j) = (\partial X_g/\partial Y_j)/(\partial X_g/\partial Y_j) \qquad 3.1$$

and

$$(\partial U/\partial Y_i)/(\partial U/\partial Y_j) = (\partial U/\partial X_g)/(\partial U/\partial X_{nj}) \cdot (\partial X_g/\partial Y_i)/(\partial X_{nj}/\partial Y_j) \qquad 3.2$$

Using theorem 5 of Goldman and Uzawa(1) (1964), Muth develops the cross-partial demand elasticities, which for a weakly separable, quasi-concave utility function are:

$$(\partial Y_{i,g})/(\partial P_j) = K^{gh}\{(\partial Y_i)/(\partial I)\cdot(\partial Y_j)/(\partial I)\} \qquad 3.3$$

---

(1) S. M. Goldman and H. Uzawa, "A Note on Separability in Demand Analysis," Econometrica 32, 3 (July, 1964). "Theorem 5: A strictly concave utility function u(x) is weakly separable with respect to a partition $\{N_1, N_2, N_3 \ldots, N_e\}$ if, and only if, the Slutsky terms $K_{fj}(X)$ are of the form

$$K_{fj}(x) = K^{et}(x)(\partial x_f/\partial I)(\partial x_j/\partial I), \text{ for all } i \varepsilon N_e, j \varepsilon N_t$$

(s not equal to t), and for all x, with some functions $K^{et}(X)$ defined for s not equal to t."

Where I is income, K is defined for all g not equal to h and is a function of the quantities of the various commodities constituting the initial position. In elasticity form:

$$H_{ij}=S_jE_iE_j(K^{gh}/I) = S_jE_gE_h(K^{gh}/I) \tag{3.4}$$

since $E_i=E_j=E_g$ for all inputs i and j used in g.

Muth then gives the following relation for the demand for a commodity i used in the production of good g:

$$\partial LnY_i= E_g\partial LnI + \Sigma H_{ij}\partial LnP_j \tag{3.5}$$

by considering the contribution of prices of commodities used in producing good g. Muth writes

$$\Sigma H_{ij}\partial LnP_j = \Sigma S_{g,j}(S_{g,ij}+H_{gg})\partial LnP_j$$

$$= H_{gg}\partial LnP_g+\Sigma S_{gj}S_{g,i}\partial LnP_j \tag{3.6}$$

Using 3.5 and 3.6 Muth derives the demand function for commodity i as

$$\partial LnY_i= E_g\partial LnP_i+\Sigma H_{gh}\partial LnP_g+\Sigma S_{g,j}S_{g,ij}\partial LnP_{g,j} \tag{3.7}$$

According to Muth (1964, P. 703):

> The demand function for commodity i therefore depends upon real income, the relative prices of all commodities used to produce good g and the price of good g.

Thus Muth establishes the minimum theoretical requirement for the demand as a function of the input.

Now the task is to establish the specific demand function for residential electricity. The demand function for electricity will be derived using a generalized

Cobb-Douglas production function by assuming profit maximization by the household-producer. For simplicity the production function will only include the energy inputs electricity (E), natural gas (G), and liquid propane gas (B); and non-energy inputs $Y_1, Y_2, Y_3, \ldots, Y_n$ will be represented by a general input Y, which is used to produce the general non-energy related good z. All factors affecting the production of the energy-related good X_{en}, such as climate, housing characteristics, and population, are represented by D_t which is assumed to be constant. The constant stock of appliances is represented by K_t. The price of the energy related and non-energy related products is represented by a weighted average price P.

The production function of the household is:

$$X = AE^{\sigma 1} G^{\sigma 2} B^{\sigma 3} Z^{\sigma 4} D_t^{\sigma 5} K_t^{\sigma 6} \tag{3.8}$$

where $\sigma 1+\sigma 2+\sigma 3+\sigma 4+\sigma 5+\sigma 6=1$

and the profit function is

$$\Pi = PAE^{\sigma 1} G^{\sigma 2} B^{\sigma 3} Z^{\sigma 4} D_t^{\sigma 5} K_t^{\sigma 6} - EW_e - GW_g - BW_b - ZW_z \tag{3.9}$$

where W_i, i=e,g,b,z are the prices of the inputs

$$\text{Let } \Phi = PAE^{\sigma_1} G^{\sigma_2} B^{\sigma_3} Z^{\sigma_4} D_t^{\sigma_5} K_t^{\sigma_6} \tag{3.10}$$

$$\Pi = \Phi - EW_e - GW_g - BW_b - ZW_z \tag{3.11}$$

$$\partial \Pi / \partial E = \sigma_1 \Phi / E - W_e = 0 \tag{3.12}$$

$$\partial\Pi/\partial G = \sigma_2 \Phi / G - W_g = 0 \qquad 3.13$$

$$\partial\Pi/\partial B = \sigma_3 \Phi / B - W_b = 0 \qquad 3.14$$

$$\partial\Pi/\partial Z = \sigma_4 \Phi / Z - W_z = 0 \qquad 3.15$$

$$\partial\Pi/\partial D_t = 0 \qquad 3.16$$

$$\partial\Pi/\partial K_t = 0 \qquad 3.17$$

Equations 3.12 - 3.17 result in:

$$\Phi = EW_e/\sigma_1 = GW_g/\sigma_2 = BW_b/\sigma_3 = ZW_z/\sigma_4 \qquad 3.18$$

From 3.18, the values of G, B, and Z can be written as:

$$G = E(W_e/\sigma_1)(\sigma_2/W_g) \qquad 3.19$$

$$B = E(W_e/\sigma_1)(\sigma_3/W_b) \qquad 3.20$$

$$Z = E(W_e/\sigma_1)(\sigma_4/W_z) \qquad 3.21$$

Substituting for Φ from equation 3.10 in 3.11 results in:

$$\sigma_1 E^{-1}\{PAE^{\sigma_1} G^{\sigma_2} B^{\sigma_3} Z^{\sigma_4} D_t^{\sigma_5} K_t^{\sigma_6}\} = W_e \qquad 3.22$$

Substituting for G, B, and Z in 3.22 gives:

$$\sigma_1 PAE^{\sigma_1 - 1}(EW_e\sigma_2/\sigma_1 W_g)^{\sigma_2}(EW_e\sigma_3/\sigma_1 W_b)^{\sigma_3}$$

$$(EW_e\sigma_4/\sigma_1 W_z)^{\sigma_4} D_t^{\sigma_5} K_t^{\sigma_6} = W_e \qquad 3.23$$

$$\sigma_1 PAE^{\sigma_1+\sigma_2+\sigma_3+\sigma_4-1}(W_e/\sigma_1)^{\sigma_2+\sigma_3+\sigma_4}(\sigma_2/W_g)^{\sigma_2}$$

$$(\sigma_3/W_b)^{\sigma_3}(\sigma_4/W_z)^{\sigma_4}D_t^{\sigma_5}K_t^{\sigma_6} = W_e \tag{3.24}$$

Solving for E:

$$E^{\sigma_1+\sigma_2+\sigma_3+\sigma_4-1} = W_e(\sigma_1 PA)^{-1}(W_e/\sigma_1)^{-\sigma_2-\sigma_3-\sigma_4}$$

$$(W_g/\sigma_2)^{\sigma_2}(W_b/\sigma_3)^{\sigma_3}(W_z/\sigma_4)^{\sigma_4}D_t^{-\sigma_5}K_t^{-\sigma_6} \tag{3.25}$$

Let $\sigma_1+\sigma_2+\sigma_3+\sigma_4-1=\alpha$ 3.26

$$E=(\sigma_1 PA)^{-1/\alpha}(\sigma_1)^{(\sigma_2+\sigma_3+\sigma_4)/\alpha}(W_e)^{(1-\sigma_2-\sigma_3-\sigma_4)/\alpha}$$

$$(W_g/\sigma_2)^{\sigma_2/\alpha}(W_b/\sigma_3)^{\sigma_3/\alpha}(W_z/\sigma_4)^{\sigma_4/\alpha}D_t^{-\sigma_5/\alpha}K_t^{-\sigma_6/\alpha} \tag{3.27}$$

$$E = \gamma_0 W_e^{\gamma_1} W_g^{\gamma_2} W_b^{\gamma_3} W_z^{\gamma_4} \tag{3.28}$$

where

$$\gamma_0 = (\sigma_1 PA)^{-1/\alpha}\sigma_1^{(\sigma_2+\sigma_3+\sigma_4)/\alpha}\sigma_2^{-\sigma_2/\alpha}\sigma_3^{-\sigma_3/\alpha}$$

$$\sigma_4^{-\sigma_4/\alpha}D_t^{-\sigma_5/\alpha}K_t^{-\sigma_6/\alpha}$$

$$\gamma_1 = (1-\sigma_2-\sigma_3-\sigma_4)/\alpha$$

$$\gamma_2 = \sigma_2/\alpha$$

$$\gamma_3 = \sigma_3/\alpha$$

$$\gamma_4 = \sigma_4/\alpha$$

Thus the quantity of electricity can be expressed in terms of the price of relevant energy resources used by the households. The results can be generalized for other energy sources.

As mentioned previously, the data on D_t, the variables which represents the climate, housing characteristics, population, and K_t, stock of electricity using appliances are scarce and inconsistent. In addition, there is no developed theory on the functional format that these variables should take in the electricity model. As documented in Chapter Two, models incorporating the stock of appliances were unsuccessful.

D_t can be broken up into two components. In particular the climate variables will be introduced in the same multiplicative form as the other variables. The commonly used climatic variables are heating degree days (HDD) and cooling degrees days (CDD). The cooling degree day is the sum of the days for which cooling is required, and is defined to be the total degree days over 75 degrees Fahrenheit. Similarly, heating degree days are the total degree days under 65 degrees Fahrenheit. These measures are *ad hoc*, and their form in the equation are not known a priori. The values of HDD and CDD could be used, as could their logarithmic values, their first differences, or the logarithm of the ratio of the first differences to the normal HDD and normal CDD, respectively. Each of these forms have been used in previous studies.

The relationships stated above are valid under pure competition, but when a household is selling factors of production to itself, a monopolistic seller is confronted by a monopolistic buyer. This theoretical problem is alleviated by noting that no barriers to vertical integration exist, and the householder resembles a firm which operates on more than one level of production. In general, the primary problem of such a market is the division of the gains, which is of little importance when dealing with the householder. It does not matter how much is gained from each act of selling and buying; the only requirement of the theory which must be met is that the householder must be a price taker with regard to purchase of the energy sources, which will be assumed to hold.

The demand function derived above does not include real income and other variables affecting the demand for electricity. These variables complicate the model without helping either understanding or affecting the procedure. Therefore, all other relevant variables not directly related to the production function approach were left out. However, once the model is derived, it can be generalized to include all the variables called for by theory. Their inclusion will result in additional terms which will follow the same Cobb-Douglas format as the other variables. In particular the price variables will be those proposed by Taylor, Blattenberger, and Rennhack (1982).

According to Muth's methodology, the price of electricity, as well as the price of other commodities used in the production of energy goods, and income must be included in the demand model. The problem, as evidenced by the literature review, is that there are no data on the price of the stocks of the appliances. The attempts to use the stock of appliances as an explanatory variable have failed to provide statistically significant results. The only exception is Anderson's model (1973), which is based on disaggregated sampling data. The magnitude of a state-wide census of appliances stocks makes state-wide studies of demand based on stock variables impractical, particularly when it is noted that stock data are valuable only if continued over a period of time. Otherwise, as soon as the stock changes the model becomes obsolete. These problems lead to the exclusion of stock variables from the model.

Climate factors will be included in the model in the same format as the other variables, i.e., in multiplicative form. As has been mentioned, the availability of the data in the Heating Degree Days (HDD) and Cooling Degree Days (CDD) format is the determining factor in using HDD and CDD instead of actual temperature. However, HDD should not have great explanatory power since Oklahoma is located in warmer quarters of the country, reducing the need for heating. In addition, since Oklahoma is the second largest producer of natural gas, homeowners traditionally rely on the gas furnace for household and water heating.

Oklahoma's position as the second largest producer of natural gas in the nation has a great impact on the study of electricity demand in the state. Blattenberger, Taylor, and Rennhack (1983) try to define the availability of natural gas using:

$$\begin{aligned} Lnq_t = {} & A_0+A_1Lnq_{t-1}+A_2LnX_t+A_3LnMPE_t+A_4Ln\,FCE_t \\ & +A_5Ln\,FCNG_t+A6LnMPNG_t+A7LnPO_t+A8LnDDH_t \\ & +A9LnDDC_t+U_t \end{aligned} \qquad 3.29$$

where

q_t = consumption of the natural gas in a given state at time t.

x = total personal income

MPE = marginal price of electricity

FCE = fixed charge for electricity

MPNG = marginal price for natural gas

FCNG = fixed charge for natural gas

PO = price of fuel oil

DDH = heating degree days

DDC = cooling degree days

U = random error term

The inclusion of natural gas availability was necessary since it cannot be a substitute for electricity if it is not available.

Blattenberger, Taylor and Rennhack (1983; p. 24) argue that:

> Natural gas pipelines . . . involve major investments in both time and money and are also regulated. Consequently, the supply of natural gas does not adjust instantaneously to changes in demand, and hence must be taken into account if biased estimates of demand elasticities are to be avoided.

However, the investment by individual households in natural gas pipe lines becomes a factor only when and if the individual decides to undertake the project after the house already exists. This is relevant under two conditions: older homes in the area where natural gas pipelines exist; when there was no pipeline previously but now has become available. The investment decision for new homes is in the hands of the builder, and no price differential exists for the house based on the choice of the fuel.

Regulation has proven to be detrimental to the availability of natural gas. There are no regulations limiting the construction of natural gas pipelines or the supply of natural gas to residential customers. On the contrary there are severe penalties for disrupting the supply to residential users even when they are delinquent. However, until 1978 the price of interstate natural gas was kept at less than competitive levels; while the intrastate sale was not regulated, which means it could compete with electricity. No major problem existed in regard to the availability of natural gas in a natural gas producing state. Therefore, unlike in Taylor, et al., no natural gas availability variable will be included in the model.

In summary the proposed model is:

$$LnQ = \beta_0 + \beta_1 LnMP + \beta_2 LnFC + \beta_3 LnPNG + \beta_4 LnY + \beta_5 LnCDD + \beta_6 LnHDD + \varepsilon \quad 3.30$$

where MP and FC are marginal price, and fixed cost or intramarginal premium as derived before,

PNG = price of natural gas

CDD = cooling degree days

HDD = heating degree days

Y = per capita income

ε = a random error term

All the price and income variables are measured in real dollars. The price of liquid propane is not included since no consistent and reliable data could be acquired for the entire period under consideration. The preliminary analysis proved that the residential consumption of liquid propane gas is not a significant factor in explaining the electricity demand. Since the data are based on utility data the exclusion of the liquid propane gas variable is justified. The parts of the state without electricity and natural gas--the likely candidates for use of liquid propane gas--are not even included.

Hypothesis and Methodology

The primary object of the study is to develop a model capable of explaining the residential demand for electricity. Hence the primary hypothesis to be tested is the overall explanatory power of the model which will be conducted using an F-distribution function.

After the validity of the model is established the main hypothesis to be tested is the magnitude of the price elasticity of demand. The literature review of chapter two revealed two equally important hypotheses concerning the price coefficient; first, whether the coefficient is zero, second, whether it is less than one, greater than one or equal to one. Two hypotheses will be tested: First $H_0{:}\beta_p=-1$ versus H_1 $\beta_p<-1$. If the hypothesis is rejected, then the second test will be obsolete. However, if the hypotheses is not rejected, the second test will be necessary to find out whether the own price of electricity does help to explain consumption. Thus, H_0: $\beta_p=0$ versus H_1: $\beta_p<0$ will be tested.

The sign of the coefficients for the price of natural gas and liquid propane can be either positive or negative, implying substitute or complementary goods respectively. In micro economic theory, the manipulation of Slutsky's equation for the case of three goods allows one to prove that not all three can be complimentary goods, and at least one must be a substitute. This relation is shown by:

$$P_1X_{11}+P_2X_{12}+P_3X_{13} = 0 \qquad 3.31$$

where X_{1i} i = 1, 2, 3 are the partial derivatives with respect to good one and P_i i = 1, 2, 3 are the prices. X_{11} or the own-price substitution effect is always negative, and since $P_i>0$ for every i = 1, 2, 3, therefore, at least one of the remaining two factors must be positive in order to satisfy the equation. Therefore, the two goods can not both be complements of the first good. It is, however, possible for both goods to be substituted for the first good which means

$$X_{1i}> 0 \text{ for every } i = 2,3$$

As revealed in the literature review, most studies assume that electricity and other energy sources are substitutes. This presumption is more or less valid, especially in the case of natural gas. The hypothesis to be tested following the literature will be one sided T-test at the right tail, i.e.:

$$H_0: \beta_{e,ng}=0 \qquad H_0: \beta_{e,bg}=0$$

and

$$H_1: \beta_{e,ng}>0 \qquad H_1: \beta_{e,bg}>0$$

However, one should not forget the special cases mentioned in the literature review in which it was pointed out that the cross-price elasticities of electricity and natural gas, for example, can be negative.

From 3.31 it follows that if only two goods are included, then they must be substitutes. The fact that only a small number of Oklahoma households uses liquid propane gas should result in statistically insignificant coefficients for liquid propane gas. In that case, the coefficient of natural gas has to be positive.

The coefficient of income β_y is believed to be positive since electricity does not present any characteristics of inferior goods. Therefore, a one sided T-test is the reasonable choice:

H_0: $\beta_y=0$

H_1: $\beta_y>0$

However, since the two major arguments about the nature of electricity as a good have been presented, another hypothesis test is in order. The first argument describes electricity as a necessity favoring protective measures such as an imposition of rate schedules by some governmental authority. The second arguement is that, except for very limited amounts and for specific uses such as refrigerations, the consumption of electricity is very responsive to changes in income. Since other phenomena such as the size of the house and the power of the cooling and heating units do change considerably due to changes in income, the income elasticity is greater than one:

H_0: $\beta_y=1$

H_1: $\beta_y>1$

This hypothesis should be tested before the previous one because the rejection of the null hypothesis will render the previous test unnecessary.

The sign of the marginal price is expected to be negative, and the sign of the intramarginal premium as pointed out by Taylor, Blattenberger, and Rennhack (1982) is believed to be negative. However, it should be noted that all the studies, including Taylor, et al., that have used intramarginal premium have resulted in positive coefficients for intramarginal coefficients. The cooling and heating degree days are expected to have a direct effect on electricity consumption. The impact of heating degree days is expected to be minimal due to the climate of Oklahoma and the dominance of natural gas as the primary heating source.

Data

The study by Taylor, Blattenberger, and Rennhack (1982) uses the rate schedules published in _National Rate Schedule_ book. This data set is deficient in that it was discontinued since 1979, and it lacks "fuel adjustment" data.

Fuel adjustments were introduced in the early 1970's to avoid substantial losses by power companies during times of rapidly rising prices of fuel, specifically crude oil, while their applications for rate increases are being reviewed by the Corporation Commission. By 1976, two-thirds of utility companies had fuel adjustment clauses. The only study to adjust prices using fuel adjustments is Taylor, Blattenberger, and Rennhack (1982). The studies which use ex post data do not have provisions to include fuel adjustments. Such studies use the revenues or typical electric bills after the consumption has taken place, and they use these and similar aggregate variables to obtain the price variable. Fuel adjustment is added to each and every kilowatt-hour, and thus it is usually called "the adder."

While the rate schedule is the basis of utility revenue, it is the fuel adjustment that determines the actual monthly bill. The lack of data on fuel adjustments becomes crucial when one realizes that some companies, such as "Cimmaron Rural Electric Cooperative," have not had a rate schedule change since January of 1973. The actual utility bills have been rising through the fuel adjustment factor and is comparable to other utility companies in the state.

The only sources of fuel adjustment factor data are the Corporation Commission and the companies themselves, providing they keep the data over extended periods of time. The source of the actual rate schedule is the Corporation

Commission of Oklahoma, the companies themselves, prior to 1979 the annual utility companies <u>Rate Schedule Book</u>, and for 1955-1975, Energy Power Research Institute's unpublished data. The present study uses the EPRI data from 1960-1974. The 1975-1985 data are extracted from the forms 1, 19, 7 7a, 7b, and 13a, required by the Corporation Commission from the companies and filed monthly.

For each company, the actual bill for consumption of 50 to 1500 kilowatt-hours at 5 kilowatt-hour intervals is calculated. This gives 290 base bills for each company for each month. Then the "adder" for each month is multiplied by each of the 290 points between 50 to 1500 kilowatt-hours and added to the base bills to get the fuel-adjusted rate schedule. The result is aggregated to obtain the annual fuel adjusted rate schedule for the company. These values are multiplied by the "weight" assigned to each company in the state. The weights are the ratios of the number of the company's customers to the total number of the customers in the state. The total number of utility customers is obtained directly by adding the customers of all the companies operating in the state. By adding these weighted fuel adjusted rate schedules, one obtains the average state fuel adjusted rate schedules.

Therefore, there are 290 observations each year by the state. By regressing these values on the 290 kilowatt-hours between 50 to 1500 kilowatt-hours, the marginal price (MP) and the intramarginal premiums (FC) are obtained. These are the slopes and intercepts of the corresponding regression lines for each year.

Overall there are 31 electric cooperatives which either produce or purchase their electricity from major producing companies. The rate schedule of each of the 31 companies is used to create a monthly revenue function as proposed by Taylor, Blattenberger, and Rennhack (1982) and explained in chapter two and earlier in this chapter. The data extends from January 1975 to April 1986 for a total of 136 months. Each company's fuel adjustment rate is used to find the actual cost of kilowatt hours consumed by the customer. Next the state's revenue function is derived by weighing each company's monthly revenue function by the ratio of its number of customers to total customers in the state at that month.

The final result is a matrix with 295 rows and 136 columns, each column representing a month. Each column is regressed on 295 quantities between 50 - 1500 kilowatt-hours, to establish a single fixed-cost premium and a single marginal price for each of 136 months.

The data on the number of residential electric customers, their consumption, and expenditure were also collected directly from the files of Corporation Commission at Oklahoma City. The data on heating degree days and cooling degree days are obtained from Historical Climatology Series 5-1 and 5-2 published by the National Oceanic and Atmosphere Administration, 1986. The use of monthly data is an attempt to achieve more accuracy than annual data would provide in showing the relationship between weather conditions and electricity consumption.

The data on natural gas price, consumption, and number of customers, as well as per capita income, comes from Gas Facts. The price of liquid propane gas is extracted from the Energy Power Administration data bank.

CHAPTER IV

EMPIRICAL ANALYSIS AND TESTS OF HYPOTHESES

This chapter will adopt the model of the previous chapter in an empirical study of the residential demand for electricity in the state of Oklahoma.

The suggested model is:

$$LnQ = \beta_0+\beta_1 LnMP+\beta_2 LnFC+\beta_3 LnY+\beta_4 LnPNG+\beta_5 LnCDD +\beta_6 LnHDD+\varepsilon \qquad 4.1$$

where

MP = marginal price of electricity

FC = fixed cost or intramarginal premium

Y = per capita income for the state

PNG = price of natural gas

CDD = cooling degree days

HDD = heating degree days

ε = random disturbance

All the variables are in natural logarithmic form. The income and prices are in real dollars.

According to Taylor (1975) and Nordin (1976), the coefficient of the marginal premium must be negative. The coefficient of marginal price, like the price of any other normal good must be negative. The coefficient of price of the natural gas variable should be positive since natural gas, the only product in the model other than electricity, must be a substitute for electricity as was established on page 57. Income and cooling degree days should have positive coefficients, implying that the higher the income or temperature, and thus the cooling degree days, the higher the electricity consumption of the household. Heating degree days, while a likely candidate, are unlikely to have a significant impact on residential electricity demand in Oklahoma. The primary reasons for this are the temperate climate and the lack of widespread all-electric homes in the state. In case of significant impact, it must have a positive coefficient.

The literature does not provide any guidelines on the magnitude of the price variables except for fixed cost.

> . . . if consumers view the intramarginal premium as a subtraction from income, the coefficient for [lnFC] should be the negative of the coefficient of [lnY]. (Taylor, Blattenberger, and Rennhack, 1984, p. 105)

Where fixed charge, following Howrey (1979) is defined as:

$$FCE = 1-(\Pi_0/Y) \qquad 4.2$$

where

FCE = fixed charge

Π_0 = intramarginal premium

Y = income

Since

$$Ln(y-\Pi_0) = LnY(1-\Pi_0/Y)$$
$$= LnY + Ln(1-\Pi_0/Y)$$

Empirically, however, Taylor, Blattenberger, and Rennhack (1983) reject the claim because the coefficient of fixed charge is more than 45 times larger than the coefficient of income. The use of $1-\Pi_0/y$ as the fixed charge proved to be unsatisfactory as equation 4.3 reveals.

$$\underset{}{LnQ} = -9.002 \underset{(2.603)}{-.659LnMP} \underset{(.192)}{-.036LnFC} \underset{(10.654)}{+2.088LnY} \underset{(.712)}{+.252LnPNG}$$

$$\underset{(1.49)}{+.195LnCDD} \qquad 4.3$$

t values are in parenthesis.

In addition to model 4.3, other models of the same format but different formulations of cooling degree days and heating degree days will be examined.

The logarithm of heating degree days proved to be statistically insignificant. Other formulations of heating degree days used in previous studies were tried, namely:

$$LnHDD_1 = Ln\ |HDD_t - HDD_{t-1}|$$

$$LnHDD_2 = Ln(HDD_1/\text{Normal HDD})$$

$$LnHDD_3 = Ln(HDD_t/HDD_{t-1})$$

None of these variations seemed to help: therefore, heating degree days is dropped from the model.

The estimated model is:

$$LnQ=-9.038-.791LnMP+.293LnFC+2.053LnY+.627LnPNG$$
$$\quad(5.09)\quad(5.87)\quad(2.03)\quad(11.55)\quad(2.81)$$

$$+.233LnCDD \qquad 4.4$$
$$(1.95)$$

The validity of the model is tested using the F-test. The model can be tested by assuming that all the coefficients of the exogenous variables are simultaneously zero. In other words, none of the variables are able to explain changes in electricity demand. The alternative hypothesis is that at least one of the variables is helpful in explaining demand. Notationally this is written as:

$H_0: \beta_1 = \beta_2 = \beta_3 = \beta_4 = \beta_5 = 0$

H_1 at least one of the betas is not zero.

The model proved to be highly significant and the hypothesis is strongly rejected.

The next step is to establish which, if any, of the variables helped to explain the residential demand. The test is performed using five t-tests, one for each variable. The hypothesis is that the ith variable is not important in explaining the demand. However, the alternative is not simply the opposite of the hypothesis.

For marginal price and intramarginal premium, the alternative is that the coefficient is negative. The necessity of the negative sign for marginal price does not require explanation. The reason for the negative alternative for intramarginal premium is based on the discussion of Taylor, et al. (1982) and Nordin (1976) as explained in the literature review.

As explained before (pp. 57-59), the alternative hypothesis for the coefficient of the remaining variables, namely the natural logarithm of income, price of natural gas and cooling degree days must be positive. Notationally:

$H_0: \beta_i = 0$ for $i = 1, 2$

$H_1: \beta_i < 0$ for $i = 1, 2$

and

$H_0: \beta_i = 0$ for $i = 3, 4, 5$

$H_1: \beta_i > 0$ for $i = 3, 4, 5$

All the coefficients are significantly different from zero at levels below 7 percent. To determine the contributions of each variable in explaining the residential demand, beta coefficients are calculated.

The order of importance is income, marginal price of electricity, average price of natural gas, intramarginal premium of electricity, and cooling degree days.

The adjusted R^2 is .99 and the Durbin-Watson statistic is 1.42 which falls between lower and upper bound-values of the tabulated values, making the test for serial correlation indeterminate.

Summary statistics are provided in Table I.

TABLE I Results of Model 4.3

coefficient for:	standard error	t-statistics	p-value	95% confidence interval		beta coefficients
lnMP	0.13468	-5.873	0.0	-1.072	-0.051	-0.325
lnFC	0.1442	2.03	0.056	-0.008	0.593	0.082
lnY	0.1776	11.555	0.0	1.682	2.42	0.675
lnPNG	0.2232	5.088	0.0	0.161	1.092	0.108
lnCDD	0.1195	1.952	0.065	-0.016	0.48	0.042

While all the coefficients are significant one can not reject:

H_0: β_1 is equal to −1

H_1: β_1 is not equal to −1

That is to say that while the coefficient of the logarithm of the marginal is more than zero in absolute value, one cannot reject the hypothesis that price elasticity of demand is unitary.

On the other hand, the income elasticity is definitely greater than one at the 95% confidence level. This is in sharp contrast with the majority of the existing literature that report very low income elasticities except for Lacy and Street (1975), which uses homogeneous data of a single company in Alabama and reports an income elasticity of 1.87. This might be explained by the fact that the state of Oklahoma is relatively less developed than most of the states of the union and by the fact that electricity is relatively inexpensive in Oklahoma when compared to more industrialized states.

According to Taylor (1975), Nordin (1976), Taylor, Blattenberger, and Rennhack (1984), p. 105, β_2 must be negative, but not a single study, including that of Taylor, Blattenberger, and Rennhack (1984), has ever reported a negative value for β_2 . On the other hand, by definition the lower the marginal price in a declining price schedule the higher the intramarginal premium. Since there is an inverse relation between marginal price and demand for electricity on the one hand and between marginal price and the intramarginal premium on the other, it might be reasonable to see a positive relationship between the intramarginal premium and the electricity demand. This does not imply that the higher the intramarginal charge the higher the demand. Considering all facts, the implication can be made that the lower the marginal price, the higher the consumption and the higher the intramarginal premium. It should be noted that the latter is defined as the amount that a customer must pay in order to be able to pay the marginal rate for all the KWH's he consumes up to and including the block to which the marginal rate is applied.

Natural gas is a significant substitute for electricity as might be expected. The cross-price elasticity of .63 indicates a strong substitute, and beta coefficients put the price of natural gas behind income and the price of electricity as determining factors in the residential demand for electricity.

Although chapter three provided the model and the choice of the variables, it left the specific form of the climatic variable undefined. While the natural logarithm of the cooling degree days behaved as expected, other formulations of the cooling degree days suggested in the literature are worth exploring further.

The suggested forms are:

$$CDD_1 = |CDD_t - CDD_{t-1}|$$

$$CDD_2 = (|CDD_t - CDD_{t-1}|)/\text{Normal CDD}$$

$$CDD_3 = CDD_t/\text{Normal CDD}$$

$$CDD_4 = CDD_t/CDD_{t-1}$$

The use of CDD_3 is not justified, since:

$$\text{Ln}(CDD_3) = \text{Ln}(CDD_t/\text{Normal CDD}) = \text{Ln}CDD_t - \text{Ln}(\text{Normal CDD})$$

Since the normal cooling degree days is defined as the 30 year average, then ln (Normal CDD) is just a constant and is absorbed by the constant term. Similarly CDD_2 can be reduced to CDD_1 . The use of CDD_1 however, proved to be inappropriate. Model one, after replacing CDD by CDD_4 resulted in:

$$LnQ = -7.288 - \underset{(-5.89)}{.778LnMP} + \underset{(1.64)}{.229LnFC} + \underset{(11.81)}{2.058LnY}$$

$$+ \underset{(2.71)}{.594LnPNG} + \underset{(2.19)}{.195LnCDD_4} \qquad 4.5$$

Adjusted R^2 = .99 and D-W = 1.50.

Coefficients of lnMP, and lnY have not changed with regard to statistical significance by remaining highly significant. The change in the lnPNG's p-value is considerable, but the coefficient is still very significant. The gain in p-value of $lnCDD_4$ over lnCDD is minor, while the loss of p-value of lnFC from .056 to .117 is very significant.

No other change is apparent. The results of tests of hypotheses are still the same. In light of this and the fact that no theoretical reason exists to pick one model over the other, model one will be retained, largely due to the performance of the coefficient of lnFC. The comparison between models 4.3 and 4.5 is summarized in Table II.

TABLE II

	coefficient		t-value		p-values	
	model 1	model 2	model 1	model 2	model 1	model 2
lnMP	-0.793	-0.778	-5.873	-5.889	0.0	0.0
lnFC	0.293	0.229	2.03	1.638	0.056	0.117
lnY	2.053	2.058	11.555	11.814	0.0	0.0
lnPNG	0.627	0.594	5.088	2.705	0.0	0.014
lnCDD	0.233	---	1.952	---	0.065	---
$lnCDD_4$	---	0.195	---	2.189	---	0.04

McFadden and Puig (1975) suggests the use of the Typical Electric Bill (TEB) to get marginal price and intramarginal premium by regressing the TEB for 250, 500, 750, and 1000 kilowatt-hours on the four respective bills. The slope of the regression line is considered the marginal price, and the intercept is the fixed charge. The justification for using TEB is the practicallity and ease of accessing data. The delay for filing company data with the corporation commission is often over six months, and there is another three to four-month lag before they can be accessed by the public. In addition the compilation and manipulation of the company data is very time consuming. By way of contrast, TEB is readily available, and the derivation of the marginal prices and fixed charge are very simple. The model is the same as before except for the marginal price and fixed charges. The result is:

$$\begin{aligned} \text{LnQ} = -3.077 - &\underset{(5.75)}{.925\text{LnMP}} - \underset{(17.18)}{.897\text{LnFC}} + \underset{(7.83)}{1.374\text{LnY}} \\ &+ \underset{(6.34)}{1.169\text{LnPNG}} + \underset{(2.09)}{.312\text{LnCDD}} \end{aligned} \qquad 4.6$$

Adjusted R^2 = .99 D-W = 1.76

The model performs well, is statistically significant, and all the variables are significant at the 5% level.

This estimation is slightly different than that of model one. The coefficient of marginal price is still too close to one to reject the hypothesis of unitary elasticity. The income elasticity of electricity is much smaller than model one but nevertheless greater than one. The coefficients of cooling degree days and cross-price elasticity of natural gas both have increased. The most striking change, however, is that of fixed cost. The first model resulted in a small elasticity with respect to fixed cost, which was positive, contrary to Nordin (1976) and Taylor, Blattenberger, and Rennhack (1984). The model based on Typical Electric Bill resulted in a negative coefficient. In addition, the confidence interval for the true coefficient of fixed cost (in absolute value) overlaps the confidence interval for the true income coefficient. This means that one cannot reject the hypothesis that the two coefficients are equal.

Both models have performed very well. However, the model with the Typical Electric Bill (equation 4.4) resulted in more powerful t-tests than the model with actual data from the companies (equation 4.1). Theoretically the latter is stronger since it uses the marginal price and fixed cost that are derived from more data points (290 for each company each year), whereas the former is based upon four typical bills for each year. The former is weighted by the population, while the latter is weighted by the number of customers for each company. Nevertheless the Typical Electric Bill model proved to be a very good substitute for the first model.

In summary, the electricity demand model performs well, and all the coefficients are statistically significant. In addition, all except the elasticity of fixed cost have the expected sign. The positive coefficient of fixed cost was defended on the basis of an inverse relation between marginal price and fixed cost on one hand, and the inverse relation of the marginal price with demand on the other resulting in the positive relation of the demand with the fixed cost. If this argument is valid, then elasticity of fixed cost in the model using the Typical Electric Bill is incorrect. The claim is supported by all other empirical studies as was documented.

CHAPTER V

CONCLUSION

The object of this chapter is to summarize the study and its contributions. The results of the study will be reviewed and the shortcomings will be pointed out. Finally possible areas of further research will be suggested.

The main outcome of the literature review was the great diversity of the methods and results. While the majority of the studies presented were econometrically dependable and conceptually reasonable, all but the studies stemming from Taylor's (1975) study were deficient since they lacked the proper price variables. The other commonly encountered problem was the inclusion of variables with economically incorrect signs or variables that were insignificantly different from zero in a statistical sense.

The existence of economically incorrect coefficients for variables results in incorrect signalling and hence flawed policy and decision making. For instance, a negative income coefficient means that as per capita income increases, electricity consumption will decrease. In other words, the policy implication is that electricity is an inferior good. If per capita income increases--as is expected--the demand for electricity will decrease, thus utility companies should abandon expansion plans and adopt a policy of phasing out some plants and personnel.

The existence of one or more variables which fail the t-test means that the R^2 is possibly inflated. More importantly, the inclusion of these variables results in the distortion of the coefficients of the other variables. If there is a valid economic reason for inclusion of a variable, then either the theory is incorrect or the data is improper or ill-defined, which casts doubts upon the reliability of the other coefficients.

Chapter three demonstrated the need for two price variables, namely marginal price and fixed costs. That chapter also showed income, the price of natural gas, and a measure of climate, were required variables.

The statistical analysis of chapter four proved the selected model to be a viable one. The variations of the original model did not perform strikingly different. The use of the Typical Electric Bill to derive marginal price and fixed cost gave very close and satisfactory results except for the coefficient of the fixed cost changing from positive to negative. The coefficients were all significant. The highest p-value is .065, which corresponds to cooling degree days.

This might be compared with some of the results of the most comparable study, Taylor, Blattenberger and, Rennhack

(1983). Four of the twelve variables included by the above study have p-values greater than the highest p-value of the present study.

Own price elasticity is less than one in absolute value, but the hypothesis that the coefficient is equal to one cannot be rejected. Income elasticity is considerably greater than one and positive; this nullifies the implication of some of the studies that electricity is an inferior good, and as expected, natural gas is a substitute for electricity. Cooling degree days have a direct impact on residential demand for electricity. At first, heating degree days were expected to have similar impacts, but this was not supported empirically. One possible explanation is the use of annual data; while there are two major peaks and two troughs, peaks occur in August and January, while troughs come at six-month intervals. The fact that the winter peak occurs in January may justify the use of heating degree days in a monthly study. The monthly data for all the companies were from January 1982 to December 1985, which hindered the empirical test of usefulness of the heating degree days in explaining the residential demand.

Future studies can concentrate on major utilities, which usually have a better data base, to conduct study of monthly demand by incorporating all of the variables used in the present study plus the heating degree days. Another likely approach to the monthly demand is the use of autoregressive integrated moving average (ARIMA) methods of time series analysis. This method requires much data, which would force the researcher to limit his or her study to major utility companies rather than to an entire state.

BIBLIOGRAPHY

Acton, J. P., B. M. Mitchell and R. S. Mowill. 1976. "Residential Demand for Electricity in Los Angeles: An Econometric Study of Disaggregated Data." Santa Monica, California: Rand Corporation, Report R-1899-NSF.

Anderson, Kent P.. 1973 "Residential Energy Use: An Econometric Analysis." Santa Monica, California: Rand Corporation, Report R-129-NSF.

Balestra, P. and M. Nerlove. 1966 "Pooling Cross-Section and Time-Series Data in the Estimation of a Dynamic Model." Econometrica, 34 (July, 1966), pp. 585-612.

Barnes, R., R. Gillingham and Hagemann. 1981 "The Short-run Residential Demand for Electricity." The Review of Economics and Statistics, 63 (1981), pp. 541-552.

Battalio, Raymond C., John H. Kagel, Robin C. Winkler and Richard A. Winett. 1979 "Residential Electricity Demand: An Experimental Study." The Review of Economics and Statistics. (May), pp. 61:180-9.

Blattenberger, G. R.. 1977. "The Residential Demand for Electricity." (Unpublished Ph.D. dissertation, Department of Economics, University of Michigan, Ann Arbor, Michigan.)

Blatttenberger, G. R., L. D. Taylor and R. K. Rennhack. 1983. "Natural Gas Availability and the Residential Demand for Energy." The Energy Journal, 4, 1 (1983), pp. 23-45.

Bohi, Douglass R.. 1981. "Analyzing Demand Behavior: A Study of Energy Elasticities." Published for Resources for the Future: The John Hopkins University Press, Baltimore, Maryland.

Buchanan, J. M.. 1952-53. "The Theory of Monopolistic Quantity Discounts." Review of Economic Studies, 20 (1952-53), pp. 199-208.

Carlson, M. T.. 1974. "The 1972-73 Consumer Expenditure Survey." Monthly Labor Review, 97, 12 (December, 1974), pp. 16-23.

Charles River Associates, Inc. (CRA). 1976. Long-Range Forecasting Properties of State-of-the-Art Models of Demand for Electric Energy. Palo Alto, California: Electric Power Research Institute, Report EA-221.

Cohn, Steve, Eric Hirst and Jerry Jackson. 1977. Econometric Analyses of Household Fuel Demands. Oak Ridge, Tennessee: Oak Ridge National Laboratory, Report ORNL/CON-7.

Fisher, Franklin M. and Carl Kaysen. 1962. A Study in Econometrics: The Demand for Electricity in the United States. Amsterdam, North-Holland.

Freund, Rudolf J. and Paul D. Minton. 1979. Regression Methods: A Tool for Data Analysis. New York and Basel: Marcel Dekker, Inc.

Friedman, M.. 1962. Capitalism and Freedom. Chicago: University of Chicago Press.

Gabor, A.. 1955-56. "A Note on Block Tarriffs." Review of Economic Studies. 23 (1955-56), pp. 32-41.

Gill, G. S. and G. S. Maddala. 1976. "Residential Demand for Electricity in the TVA Area: An Analysis of Structural Change." 1976 Proceedings of the Business and Economic Statistics Section, pp. 315-319.

Goldman, S. M. and H. Uzawa. 1964. "A Note on Separability in Demand Analysis." Econometrica, 32, 3 (July, 1964), pp. 32:387-98.

Griffin, James M.. 1974. "The Effects of Higher Prices on Electricity Consumption." The Bell Journal of Economics and Management Science, 5, 2 (Autumn) pp. 515-539.

Halvorsen, R.. 1975. "Residential Demand for Electric Energy." Review of Economics and Statistics, 57, 1 (February), pp. 12-18.

Halvorsen, R.. 1978. Econometric Models of U. S. Energy Demand. Lexington, Mass.: D. C. Heath.

Hartman, Raymond S.. 1983. "The Estimation of Short-Run Household Electricity Demand Using Pooled Aggregate Data." Journal of Business and Economic Statistics, 1, 2 (April, 1983), pp. 127-135.

Hewlett, James G.. 1977. "Changing Patterns of Households' Consumption of Energy Commodities." 1977 Proceedings of the Business and Economic Statistics Section, Part 1 (1977), pp. 99-108.

Houthakker, H. S.. 1951. "Electricity Tariffs in Theory and Practice." The Economic Journal, 61, 241 (March), pp. 1-25.

Houthakker, H. S.. 1980. "Residential Electricity Revisited." Journal of Energy, 1, 1 (1980), pp. 29-41.

Houthakker, H. S. and L. D. Taylor. 1978. Consumer Demand in the United States. 2nd Ed. Cambridge: Harvard University Press.

Houthakker, H. S., Philip K. Verleger, Jr., and Dennis Sheehan. 1974. "Dynamic Demand Analyses for Gasoline and Residential Electricity." American Journal of Agricultural Economics, 56, 2 (May), pp. 412-418.

Howrey, E. P.. 1979. "The Demand for Electricity with Declining Block Rates." (Unpublished paper) Department of Economics, University of Michigan.

Lacy, A. W. and D. R. Street. 1975. "A Single Firm Analysis of the Residential Demand for Electricity." Auburn, Alabama: Department of Economics, University of Alabama.

Lyman, R. A.. 1973. "Price Elasticities in the Electric Power Industry." (Unpublished paper) Tuscon, Arizona: Department of Economics, University of Arizona.

McFadden, Daniel and Carlos Puig. 1975. "An Econometric Model of the Demand for Electricity." Economic Impact of Water Pollution Control on the Steam Electric Industry. Washington D. C.: Teknekron, Inc., Report EED-12.

McFadden, D., C. Puig and D. Kirshner. 1977. "Determinants of the Long-Run Demand for Electricity." 1977 Proceedings of the Business and Economic Statistics Section, Part 2 (1977), pp. 109-117.

Moore, Thomas G.. 1970. "The Effectiveness of Regulation of Electric Utility Prices." Southern Economic Journal, 36, 4 (April), pp. 365-375.

Mount, T. D., L. D. Chapman and T. J. Tyrell. 1973. Electricity Demand in the United States: An Econometric Analysis. Oak Ridge, Tennessee: Oak Ridge National Laboratory, Report ORNL-NSF-EP-49.

Muth, Richard F.. 1966. "Household Production and Consumer Demand Functions." Econometrica, 34, 3 (July) pp. 699-708.

National Oceanic and Atmospheric Administration. State, Regional and National Monthly and Seasonal Heating Degree Days: Weighted by Population (1980 Census). Asheville, North Carolina: National Climatic Data Center, July 1931-June 1986.

National Oceanic and Atmospheric Administration. State, Regional, and National Monthly and Seasonal Cooling Degree Days: Weighted by Population (1980 Census). Asheville, North Carolina: National Climatic Data Center, January 1931-December 1986.

Nordin, John A.. 1976. "A Proposed Modification of Taylor's Demand Analysis: Comment." The Bell Journal of Economics and Management Science, 7 (Autunm), pp. 719-721.

Rassenti, S.. 1979. "The Effect of Decreasing-Block Tariffs on Demand: An Experimental Study." (Unpublished Paper) Tucson, Arizona: Department of Systems Engineering, University of Arizona.

Taylor, L. D.. 1975. "The Demand for Electricity: A Survey." The Bell Journal of Economics and Management Science, 6, 1 (Spring), pp. 74-110.

Taylor, L. D., G. R. Blattenberger, and R. K. Rennhack. 1982. "Residual Demand for Energy, Volume 1." Palo Alto, California: Electric Power Research Institute. Report EA-1572, April.

Taylor, L. D., G. R. Blattenberger and R. Rennhack. 1984. "Residential Energy Demand in the United States: Empirical Results for Electricity." Advances in the Economics of Energy and Resources, 5 (1984), pp. 103-127.

Uri, Noel D.. 1976. "Short-Run Variations in the Demand for Electrical Energy." 1976 Proceedings of the Business and Economic Statistics Section, pp. 618-621.

Wilder and Willenborg. 1975. "Residential Demand for Electricity: A Consumer Panel Approach." Southern Economic Journal, (1975), pp. 212-217.

Wills, J.. 1977. Residential Demand for Electricity in Massachusetts. Cambridge, Massachusetts: Massachusetts Institute of Technology, Working Paper No. MIT-EL-77-016WP.

Wilson, John W.. 1971. "Residential Demand for Electricity." <u>The Quarterly Review of Economics and Business</u>, 11, 1 (Spring), pp. 7-19.

VITA

Shahdad Naghshpour

Candidate for the Degree of

Doctor of Philosophy

Thesis: RESIDENTIAL ELECTRICITY DEMAND IN OKLAHOMA

Major Field: Economics

Biographical:

Personal Data: Born in Tabriz, Iran, August 24, 1954 the son of Ali and Fatemeh Naghshpour. Married to Zohreh Zoofan on August 25, 1976.

Education: Graduated from Kharazmi High School, Tehran, Iran, in May, 1972; received Bachelor of Science in Economics from Tehran University in January, 1976; received Master of Art in Economics from Western Michigan University in December, 1977; received Master of Science in statistics from Oklahoma State University in May, 1981; completed requirements for the Doctor of Philosophy degree at Oklahoma State University in May, 1988.

Professional Experience: Research Assistant, Iran Planning Center, Tehran, Iran, January, 1975 to July, 1976; Mathematics Instructor, Department of Mathematics, Oklahoma State University, August, 1979, to January, 1980; Teaching Associate, Department of Statistics, Oklahoma State University, August, 1979, to May, 1981; Teaching Associate, Department of Economics, Oklahoma State University, August, 1981, to May 1982; Computer Programmer, Department of Sociology, Oklahoma State University, February, 1982, to May, 1982; Research Assistant, Department of Agricultural Economics, Oklahoma State University, June, 1982, to July, 1983; Instructor, Department of Economics, Oklahoma State University, August 1983, to July 1985; Assistant Professor, College of Business Administration, University of Southern Mississippi, August 1985, to present.