Electricity Consumption in Rural vs. Urban Areas

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Average Winter electricity consumption for rural residents in Utah is significantly greater than for those living in urban areas. Based on data from a 1980 survey of Utah residents, this rural-urban consumption differential was investigated using multiple regression analysis. It was determined that the stock of electricity-using devices, climate, and demographic characteristics were the most important determinants of variations in household electricity consumption. The hypothesis that rural residents use electricity-consuming devices more intensively than their urban counterparts was rejected.

A 1980 survey of 2155 Utah residents determined that Winter electricity consumption was significantly greater in rural than in urban areas. Winter consumption for respondents living in rural areas and in cities with population of 2,500 or less averaged 1157 KWH per month, while the average for households in cities larger than 2,500 was only 875 KWH per month.

There are six possible explanations for the greater consumption reported by rural respondents. First, rural and urban households may have been billed under different tariffs. Second, rural dwellings may have more electricity-using devices (especially electric space and water heating). Third, the urban housing stock may be more energy efficient. Fourth, the rural locations may be colder than the urban areas. Fifth, rural and urban residents may have different demographic characteristics which are related to electricity usage. Finally, holding the other five factors constant, there may have been variations in the intensity of use of electricity-consuming devices.

The study reported here uses multiple regression techniques to investigate the determinants of variations in household electricity usage. Of particular interest is the observed difference in rural and urban consumption. A primary objective of the analysis is the identification of those factors which are primarily responsible for the greater use of electricity in rural areas. The findings have important implications for assessing the impact of electric utility rate structures.

The remainder of the paper is organized in the following sequence. Section I presents a theoretical model of household electricity demand. Section II describes data obtained from the 1980 survey of Utah residents. Section III specifies a regression model and reports the results of the empirical analysis. Finally, the conclusions and implications of the study are found in the final section.

Theoretical Model of Household Electricity Demand

In a pioneering study, Fisher and Kaysen noted that the demand for electricity is a function of the stock of electricity-using devices and the intensity of use of those devices. Their conceptual framework is the basis of the model developed in this section.

For analytical purposes it is useful to divide household electricity demand into two categories. The first is electricity used for space heating. The second is consumption for other purposes such as water heating, cooking, refrigeration, and lighting. The determi-

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nants of the two categories of demand are sufficiently different as to require that they be discussed separately.

Electricity Demand for Space Heating

Space heating demand is commonly modeled using the relationship

$$(1) \qquad E_t = U(T_r - T_t)$$

where E_t is energy demand at time t, U is a measure of the energy efficiency of the structure, T_r is a reference temperature indicating the desired degree of comfort, and T_t is the ambient temperature at time t.

Equation (1) suggests that electrical energy used for space heating is a function of the energy efficiency of the structure in which the respondents live, climate, and factors which affect the reference temperature. It is likely that the price of electricity and demographic characteristics of the household are the primary determinants of the reference temperature. Thus, the electric space heating demand (E_{SH}) is given by:

(2) E_{SH} = f(structure energy efficiency, climate, price of electricity, demographic characteristics)

Other Electricity Demand

The Fisher and Kaysen framework is especially useful in modeling household electricity demand for other purposes. Households which have electricity-using devices such as electric water heaters, freezers, electric ranges, and electric dryers will require more electricity than those with a smaller stock of such equipment.

Intensity of use of these electricity-consuming devices is likely to be determined by factors such as the price of electricity and the demographic characteristics of the household. Thus, demand for electricity for other purposes (E_0) is given by:

(3) E_0 = f(stock of electricity-using devices, price of electricity, demographic characteristics)

Total Electricity Demand

A primary purpose of this study is to determine if there are differences in rural-urban electricity consumption that cannot be accounted for by other factors. As such, the location of the household is considered as another variable which may affect electricity consumption. Hence, the total demand for electricity by a household (E_T) is given, in general terms, by Equation (4).

(4) $E_T = E_{SH} + E_0$ = f(structure energy efficiency, climate, stock of electricity-using devices, price of electricity, demographic characteristics, location)

Equation (4) is the theoretical model on which the empirical analysis is based.

Data

Data were obtained from a questionnaire sent to 2155 customers of Utah Power and Light in the Spring of 1980. The mailing list was developed from a stratified random sample designed to generate an approximately equal number of rural and urban respondents.

Those receiving the questionnaire were asked to answer questions relating to their energy conservation efforts, the nature of their dwelling, and personal characteristics such as age, education, and income. Using the basics of the *Total Design Method* proposed by Dillman, a response rate of 70.5% was achieved. This percentage is high for a mail questionnaire, but consistent with the response rate for other surveys conducted using the Total Design Method.

Electricity consumption of the respondents was obtained directly from Utah Power and Light (UP&L). In order to secure this information it was necessary to utilize a procedure that guaranteed the right to privacy of the respondents. This was accomplished by allowing UP&L to match the consumption and questionnaire data. At no time were the researchers aware of the electricity consumption of specific, named customers. The consumption data provided by the utility were the average number of kilowatt hours consumed during the first three months of 1980. Hence, the empirical analysis refers to Winter consumption patterns.

The specific data used to satisfy the requirements of the theoretical model specified in Equation (4) are described below.

Household Electricity Consumption: Average monthly consumption for the first three months of 1980.

Structure Energy Efficiency: Inches of ceiling insulation as reported by the respondent.

Climate: Heating degree days below 65° F. However, an adjustment must be made to account for observations which do not use electric space heating and, hence, whose electricity consumption is not affected by climate. This is accomplished by multiplying the number of degree days by a dummy variable that takes on a value of one if the dwelling uses electricity for space heating and zero if another energy source is used. The result is a variable which equals zero for dwellings without electric space heating and the number of degree days otherwise.

Stock of Electricity-Using Devices: The stock of electricity-using devices in this study was measured by the presence or absence of particular equipment in a dwelling. Specifically, dummy variables denoting the presence of an electric water heater, freezer, dishwasher, and electric dryer are included. Electric ranges, refrigerators, and electric lights were excluded because they were present for virtually every observation in the sample. However, lighting, cooking, and refrigeration demand are proxied by inclusion of the number of people living in the dwelling.

Prices of Electricity: The data were obtained from an area served by a single electric utility, Utah Power and Light. Thus, all of the households were billed under the same set of tariffs. However, UP&L bills customers with electric space and water heating under different, preferential tariffs. Notwithstanding, no separate variable to capture the effects of price differences was included in the regression model. However, the estimated coefficients of the degree day and water heating variables can be interpreted as including price effects.

Demographic Characteristics: Age, family income, and number of people in the dwelling.

Location: Urban/rural. A dummy variable is used which equals unity for respondents living in a city of 2,500 or more and zero for those living in rural areas or cities with a population less than 2,500.

Empirical Results

The model of Section II suggests that differences in rural-urban consumption are, in part, the result of differences in the efficiency of the housing stock, climate, the stock of energy-using devices, and demographic characteristics. The mean values of the variables used to proxy these factors are reported in Table 1 for both rural and urban respondents. For the dummy variables, the means should be interpreted as the proportion of observations in the sub-sample having the device. The number of observations fluctuates because of missing data.

Table 1 shows that rural residents lived in colder locations and were more likely to have electric space and water heating, electric clothes dryers, and electric freezers. Urban dwellers had a higher proportion of dishwashers, were younger, had more people per household, reported higher family incomes,

TABLE 1. Mean Values of Independent Variables in Rural and Urban Areas.

	Rural		Urban	
Variable	Number	Mean	Number	Mean
Degree Days of Location	573	6663	676	6211
Electric Space Heating[a]	573	0.222	678	0.131
Electric Water Heating[a]	573	0.635	676	0.286
Electric Clothes Dryer[a]	573	0.743	678	0.720
Dishwasher[a]	573	0.424	678	0.529
Freezer[a]	573	0.805	678	0.655
Number in House	568	3.34	669	3.50
Family Income	548	16,163	654	19,354
Age of Respondent	567	50.7	674	43.6
Inches of Ceiling Insulation	496	6.7	554	6.9

[a]Means represent the proportion of respondents having an appliance or using electric space or water heating.

and lived in structures with slightly more ceiling insulation.

Regression Model

The regression model used to investigate variations in household electricity consumption is formally specified by Equation (5).

$$\text{(5)} \quad KWH = \sum_{i=0}^{10} (a_i + b_iU)X_i$$

where

KWH = KWH of electricity used per month

U = 1 if in an urban area, 0 otherwise

X_0 = Constant

X_1 = Heating degree days if electric space heating, 0 otherwise

X_2 = 1 if electric water heating, 0 otherwise

X_3 = 1 if electric clothes dryer, 0 otherwise

X_4 = 1 if dishwasher, 0 otherwise

X_5 = 1 if freezer, 0 otherwise

X_6 = Number of people living in dwelling

X_7 = Family income in dollars

X_8 = Age of respondent in years

X_9 = $(\text{Age})^2$

X_{10} = Inches of ceiling insulation

The a_i and b_i coefficients of Equation (5) are interpreted in the following way. If the observation is from a rural area, then $U = 0$ and $a_i + b_iU = a_i$. Thus, a_i is the change in KWH/month per one unit change in the ith independent variable. For urban areas $U = 1$ and the derivative of KWH with respect to the ith variable is $a_i + b_iU = a_i + b_i$. If b_i is significantly different from zero, this indicates that there is a difference in rural-urban consumption patterns. The sum $a_o + b_oU$ is the intercept of the equation. A value of b_0 significantly different from zero would indicate that the rural and urban equations have different intercepts.

In addition to examining the individual b_i, it is possible to test the hypothesis that rural and urban consumption patterns are generally different. This is accomplished by testing the joint hypothesis that $b_0 = b_1 = \ldots\ldots = b_{10} = 0$ If this hypothesis cannot be rejected, the inference is that there is no difference in rural and urban consumption patterns that cannot be explained by the independent variables.

Although there are reasons to believe that rural electricity consumption patterns are dissimilar to urban patterns, no specific sign hypothesis with respect to the b_i are postulated. However, it is possible to formulate sign hypotheses for the a_i. The variables X_1 through X_7 should all have positive coefficients. The coefficient of X_{10} should be negative. Finally, the coefficients of X_8 and X_9 depict the relationship between consumption and age. It is likely that consumption increases with age to some maximum and then declines. This phenomenon may reflect changing consumption patterns of adults in the household and also the stage of the family. The age at which maximum electricity consumption occurs is given by:

$$AGE_{max} = -a_8/2a_9 \quad (6)$$

The second order conditions for a non-negative maximum require that a_8 be positive and a_9 be negative.

Regression Results

The initial regression model estimated was that of Equation (5). However, the hypothesis that $b_o = b_1 = \ldots\ldots = b_{10} = 0$ could not be rejected ($F = 1.12$ with 11 and 975 d.f.). That is, as a group, the coefficients involving the urban/rural dummy variable were not determined to be statistically significant. Hence, the model reported in Table 2 constrains all of the b_i to be zero.

Over 70 percent of the variation in electricity consumption is explained by the independent variables shown in Table 2. All of the coefficients are significant except X_3 and X_{10}. Although the coefficient of X_3 is not significant using a two-tailed test at 5 percent, it is significant based on a one-tailed test at the same level. Since the prior hypothesis was that the coefficient would be positive, a one-tailed test is appropriate.

The coefficient of X_{10}, Inches of Ceiling Insulation, has the wrong sign. However, as just noted, it is not significant. The problem is probably that the data were based on the estimate of insulation as indicated by the questionnaire respondents. It is likely that this information was not very accurate.

For the dummy variables indicating the presence of electricity-using devices (X_2,X_3,X_4,X_5), the coefficients all appear reasonable. For example, electric water heating is estimated to increase monthly electricity consumption by about 300 KWH. This is consistent with UP&L estimates which place water heating demand at 300-400 KWH per month.

The estimated coefficient for income implies that every additional thousand dollars of family income results in an increase in electricity consumption of about six KWH per

TABLE 2. Regression Results

Variable	Description	Estimated Coefficient	t-Statistic
X_0	Constant	−356.14	———
X_1	Degree Days	0.1984**	29.46
X_2	Electric Water Heater	321.08**	9.36
X_3	Electric Clothes Dryer	59.75	1.79
X_4	Dishwasher	62.54*	2.06
X_5	Freezer	106.87**	2.96
X_6	Number in House	71.35**	7.93
X_7	Family Income	0.0058**	3.66
X_8	Age of Respondent	20.28**	3.84
X_9	$(Age)^2$	−0.1958**	−3.71
X_{10}	Inches of Ceiling Insulation	14.28	1.33
$N = 985$			
$R^2 = 0.72$			

**Significant at 1%
*Significant at 5%
NOTE: Missing observations were omitted.

month. This seems low, but may be explained by the fact that high income families are more likely to have other electricity-consuming devices. Thus, the coefficient of X_7 represents additional consumption with other factors, such as the stock of electricity-using devices, held constant.

The linear and quadratic terms in age have the expected sign. They imply that electricity consumption increases to age 52 and then begins to decline. As expected, the number of people in the household is positively associated with electricity consumption. Each additional person is estimated to increase monthly usage by about 70 KWH.

Conclusions and Implications

Rural residents in Utah use significantly more electricity in the Winter than do those in urban areas. However, when variations in climate, structure energy efficiency, the stock of electricity-using devices, and demographic characteristics are held constant, the empirical analysis of this paper suggests that there is no difference in the intensity of use of electricity-consuming equipment.

Differences in rural and urban electricity consumption are primarily the result of differences in the stock of electricity-using devices. Rural residents are far more likely to have electric space and water heating and somewhat more likely to have electric clothes dryers and freezers. For space heating, water heating, and clothes dryers, the explanation is the lack of alternative energy sources available to perform these tasks in rural areas.

The findings have implications for assessing the impacts of utility rate structures. Because there is a higher proportion of electric space and water heating in rural areas, the use of tariffs that provide preferential rates for customers using electricity for these purposes is especially beneficial to rural customers. Conversely, utility tariffs that do not differentiate on the basis of end use will impose relatively greater burdens on rural residents.

References

Dillman, D. A., *Mail and Telephone Surveys: The Total Design Method*, John Wiley and Sons, New York, 1978.

Fisher, F. M. and Kaysen, C., *A Study in Econometrics: The Demand for Electricity in the United States*, North Holland, Amsterdam, 1962.