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ECONOMETRIC ANALYSES of HOUSEHOLD FUEL DEMANDS

Steve Cohn
Eric Hirst
Jerry Jackson

OAK RIDGE NATIONAL LABORATORY

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Abstract

This study develops econometric models of residential demands for electricity, natural gas, and petroleum products. Fuel demands per household are estimated as functions of fuel prices, per capita income, heating degree days, and mean July temperature. Both cross-sectional and dynamic models are developed using a large data base containing observations for each state and year from 1951 through 1974.

Long-run own-price elasticities for all three fuels are greater than unity with natural gas showing the greatest sensitivity to own-price changes. Cross-price elasticities are all less than unity except for the elasticity of demand for oil with respect to the price of gas (which is even larger than the own-price elasticity of demand for oil).

The cross-sectional models show considerable stability with respect to own-price elasticities but much instability with respect to the cross-price and income elasticities. Agreement between the cross-section and dynamic models is good for the own-price elasticities but inconclusive for the other coefficients.

1. Introduction

This study analyzes residential demands for fuels — electricity, gas, oil — as functions of fuel prices, incomes, and climatic variables. The econometric models constructed use a large data base containing variables for each state and each year from 1951 through 1974. These data are used to develop both cross-sectional models and dynamic (pooled time series and cross-section) models of residential fuel uses.

Results of this study are being used in the development and improvement of a detailed engineering-economic model to simulate residential energy uses from 1970 through 2000.[1] The original version of the residential simulation model used fuel price and income elasticities from econometric analyses of the combined household/commercial sector using only a few years of data.[2,3,4] The present study was conducted primarily to provide improved estimates of these elasticities for the residential simulation model.

The key features of this study are:

1. The models deal explicitly with residential energy demands (not the combined residential/commercial sector).

2. Improved definitions of residential fuel uses are developed to account for some residential fuel use that is generally allocated to the commercial sector.

3. Three different fuel oil price series are constructed. Models are estimated with each one to evaluate their relative strengths and weaknesses.

4. Models developed here are based on a large data base that contains variables for 47 states* and 24 years, a total of 1128 observations.

5. Both cross-section and dynamic models are developed. Cross-section models for 1951, 1955, 1960, 1965, 1970, 1971, 1972, 1973, and 1974 are estimated to evaluate the stability of coefficients over time. Similarly, dynamic models are estimated for the following time periods: 1951-1974, 1960-1974, 1965-1974, 1969-1974. Four different estimation techniques are used with these dynamic models.

6. Fuel use per household (rather than fuel use per capita) is chosen as the dependent variable because residential energy uses are related more closely to number of households than to number of people.

7. Models are developed for the three major household fuels - electricity, gas, and oil. During the past ten years, these fuels accounted for more than 90% of total residential energy use. Coal and liquefied natural gases account for only a small and declining portion of the total (5% during the 1970's).

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*The states of North Carolina and South Carolina are combined, as are Washington, D.C. and Maryland.

Although the work described here represents a useful contribution to our understanding of household fuel demands, there are important deficiencies in both the data used and the models specified. These problems are discussed in Section 5. Because of these problems, the present study should not be considered final; additional work in this area is definitely needed.

A review of historical fuel use data reveals some interesting trends. Table 1 shows national residential fuel use from 1950 through 1975 for electricity, gas, petroleum products (kerosene and fuel oil), and other fuels (coal, liquefied gases).[1] The overall annual growth rate in energy use during this period was 3.4%, nearly double the growth rate in household formation (2.0%). However, during recent years, growth in fuel use has been negative: -0.8% per year between 1972 and 1975.

Table 1. Household Consumption of Fuels: 1950–1975[a]

	Electricity	Gas	Oil[b]	Other[c]	Total
			(10^{18} joules)		
1950	1.3	1.6	1.8	2.5	7.2
1955	1.8	2.5	2.6	1.5	8.4
1960	2.5	3.6	3.1	1.3	10.5
1965	3.5	4.5	3.4	1.1	12.5
1970	5.7	5.7	3.7	1.0	16.1
1971	6.1	5.8	3.6	0.9	16.4
1972	6.5	6.0	3.8	0.8	17.1
1973	6.9	5.8	3.7	1.0	17.0
1974	7.0	5.7	3.3	1.0	17.0
1975p	7.4	5.8	3.2	0.3	16.7

[a]Electricity use figures are in terms of primary energy; i.e., they include losses in generation, transmission, and distribution. Figures for other fuels do not include losses associated with refining and transportation.

[b]Oil includes kerosine and Nos. 1, 2, and 4 distillate fuel oils; these figures do not include LPG.

[c]Other includes coal and LPG, and statistical discrepancies among data sources (about 2% of totals).

Sources: ref. 1

The distribution of fuels among the total changed sharply during these 25 years. In 1950, coal accounted for more than one-third of household fuel use, while in 1975 coal accounted for only 2% of the total. Petroleum's share of the total also declined, from 26 to 18%. Electricity, on the other hand, increased its share from 18 to 43%. The share accounted for by gas increased from 22 to 24% during this period.

Several recent studies attempt to quantify the behavioral decisions underlying the fuel use trends shown in Table 1. Baughman and Joskow[2] developed a dynamic model of household/commercial energy use with state data for the 1968-1972 period. Their model contains two parts. The first equation estimates total energy demand in the combined sector. The second part consists of two fuel split equations that estimate shares of total energy use consumed by the three fuels. The three shares are constrained so that they sum to unity.

With respect to the residential simulation model, the Baughman and Joskow results are less than ideal because they deal only with the combined residential/commercial sector and the time period covered is only five years. They also assume that the cross-price coefficients with respect to a given price are the same in both fuel split equations.

Chern[3] developed a similar market share model of residential/ commercial energy demand with data for 1971 and 1972. Chern's model includes an equation that estimates aggregate demand for fuels in the combined sector and two fuel split equations. Because Chern's models are cross-sectional, his results yield estimates of long-run elasticities only. In addition, his use of data for the combined residential/ commercial sector makes it difficult to apply his results directly to our residential simulation model.

Anderson[4] developed cross-section models (using data for 1960 and 1970) of residential demands for electricity and gas. Although Anderson dealt explicitly with the residential sector, he did not develop an equation for residential petroleum, presumably because of difficulties in separating residential and commercial uses of petroleum products. Thus, Anderson's results cannot be directly used in our simulation model both because oil is not included and no dynamics are included.

The remainder of this report is organized as follows. Section 2 discusses the structure of the models used to analyze residential fuel demands. The data used in these models is described in Section 3. Section 4 contains empirical results obtained with the models of Section 2 and the data of Section 3. The results presented in Section 4 are evaluated in light of data problems and limitations in the model specification in Section 5. Finally, Section 6 synthesizes our fuel price and income elasticities for electricity, gas, and oil; and compares these results with those from other studies.

2. Model Specification

For household i the demand for the jth good can be represented as:

$$q_{ij} = f(p_{i1}, p_{i2}, \ldots, p_{iJ}; y_i; t_i)$$

where

q_{ij} is the amount of commodity j demanded by household i

p_{ij} is the price of each of the J commodities facing household i

y_i is the income of household i

t_i is a taste or preference variable for household i .

Because quantitative information on household tastes and preferences are not available and because it is impossible to include prices for all commodities, a simplified stochastic formulation of the above equation is usually written:

$$q_{ij} = g(\overline{p}_i, y_i, \varepsilon_i)$$

where

$\overline{p}_i$ is a vector of prices for the jth commodity and several substitute goods

ε_i is a stochastic disturbance term reflecting the random influence of excluded variables.

In this study, j represents one of the three major household fuels and $\overline{p}_i$ represents prices of these three fuels (electricity, gas, oil).

Because individual household fuel consumption data are not available on a national scale, average state fuel consumption per household was used as the dependent variable. State average fuel prices were used as independent variables. (Marginal fuel price would be the theoretically correct price variable to use, but it is arguable whether the typical consumer is more aware of the cost for additional fuel used or the monthly fuel bill.[4])

Two model formulations of fuel demands are used. The first is a cross-sectional model using data for all states in a single year; the second is a dynamic model using pooled state and time-series data.

2.1 Cross-Sectional Model

A constant elasticity model* of the form:

$$Q_{ij} = A_j P_{elec_i}^{\beta_{j1}} P_{gas_i}^{\beta_{j2}} P_{oil_i}^{\beta_{j3}} Y_i^{\beta_{j4}} C_{1i}^{\beta_{j5}} C_{2i}^{\beta_{j6}} \varepsilon_{ij}$$

was used as the demand function for the three fuels. Taking the natural log of both sides of the equation yields a log-linear formulation:

$$\ln Q_{ij} = \beta_{j0} + \beta_{j1} \ln P_{elec_i} + \beta_{j2} \ln P_{gas_i} + \beta_{j3} \ln P_{oil_i} + \beta_{j4} \ln Y_i + \beta_{j5} \ln C_{1i} + \beta_{j6} \ln C_{2i} + \ln \varepsilon_{ij} .$$

where

Q_{ij} is the average consumption per household of fuel j in state i

P_{ki} is the average price of fuel k in state i

Y_i is the per capita income in state i

C_{1i} is the number of heating degree days in state i

C_{2i} is the mean July temperature in state i

β_{jm} is an unknown parameter

ε_{ij} is a random disturbance term.

The electricity demand equation includes both C_{1i} and C_{2i} as explanatory variables that influence demands for electric space heating and electric air conditioning, respectively. Only C_{1i} is included in the gas and oil equations because almost all residential air conditioning systems use electricity as an energy source.

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*Demand elasticity is defined as the percentage change in the quantity demanded associated with a 1% increase in a particular independent variable, i.e., $(\partial Q_i/\partial P_j)(P_j/Q_i)$.

2.2 Dynamic Model

A partial adjustment formulation was used to capture temporal as well as cross-sectional effects in the estimation. The geometric lag model used is:*

$$\ln Q_{ij,t} = \beta_{j0} + \lambda_j \ln Q_{ij,t-1} + \sum_{k=1}^{6} \beta_{jk} \ln X_{ki,t} + \varepsilon_{i,t}$$

where

t refers to a particular year and t-1 refers to the preceding year

$X_{ki,t}$ are the same explanatory variables used in the cross-sectional model

λ_j, β_{jk} are unknown parameters.

This model is used to determine both short- and long-run fuel use responses to change in the explanatory variables. All dynamic model equations are estimated using either the variance components (VC)[7,8] approach or least squares with dummy variables method (LSDV).[9] The VC approach assumes that the regression error is separable into three independent components (time, cross-section, and a combination of both) where information on the β's is obtained from the between state and between time-period variation of the dependent and independent variables. The LSDV approach assumes that each cross-sectional unit and each time period are characterized by their own intercept. This feature is incorporated in the regression equation by the introduction of binary (dummy) variables.

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*This model, used previously by Mount, et al.[5] and Houthaker, et al.[6] in their studies of electricity demand, assumes that β is a short-run (one-year) elasticity and $\beta_j/(1 - \lambda)$ is the corresponding long-run elasticity where $1 - \lambda$ is the proportion of demand response that is completed in the first year.

3. Data

We used several new data sources in our efforts to estimate accurate household fuel demand equations. Adjustments were made to several existing data sets to more precisely reflect household fuel uses. This section describes these data sources and adjustments.

3.1 Fuel use

The Edison Electric Institute[10] reports annual sales of electricity to residential customers. These figures include sales to individually-metered dwellings and to gang-metered buildings with less than five households. Electricity sales to gang-metered buildings with five or more apartments are classified as commercial. To correct for this definitional problem, we increased the EEI figures for residential electricity sales by 4% for each state and each year.[11]

In a similar fashion, the American Gas Association[12] reports annual sales of gas to residential customers. To correct for the consumption of gas in gang-metered apartment units assigned by gas utilities to the commercial sector, we increased the AGA residential gas figure for each year and each state by 22% of the AGA commercial gas figure.[11]

The Bureau of Mines and American Petroleum Institute[13] report annual consumption of petroleum products (kerosene, Nos. 1-6 heating oils) for heating purposes. However, they do not estimate the fractions of these fuels consumed in the residential and commercial sectors. Based on conversations with staff in the Bureau of Economic Analysis (U.S. Department of Commerce) and ref. 11, we assumed that 100% of the kerosene and Nos. 1, 2, and 4 distillate heating oils classified by the Bureau of Mines as household/commercial were consumed in the residential sector. (This implies that 100% of the Nos. 5 and 6 residual heating oils were used in the commercial sector.)

3.2 Fuel prices

All prices used are state average prices. Prices for electricity and gas are obtained from EEI[10] and AGA,[12] respectively. The reported residential fuel prices are weighted with the reported commercial fuel prices to account for the adjustments in fuel use described above. Thus, state average fuel price is defined as total residential revenues divided by total residential consumption.

Developing appropriate price measures for residential petroleum use is much more difficult. Electricity and gas prices are based on complete records provided by electric and gas utilities to EEI, AGA, and the Federal Power Commission. Retail petroleum prices, however, can only be inferred from limited sample data.

Lin et al.[14] compared four different price series for No. 2 fuel oil for 1970. They found low correlation coefficients among these data series, presumably because of different sampling techniques. For example, the Platt's oil estimates[15] are for wholesale prices, obtained from cities in 23 states. The USDA estimates[16] are based on prices paid by farmers in each state. Other sources collect estimates from local gas utilities on the price of No. 2 fuel oil in their utility district.

Because of these differences among fuel oil price series, we developed three different sets and estimated fuel demand equations with each one. The three prices series are: Platt's,[15] USDA,[16] and a combination of the two. As discussed later, we ultimately used the combined series because it gave the best (or the least bad, depending on one's outlook) results in terms of correct signs and t-statistics for the elasticity estimates.

The Platt's price series is available for cities in 23 states for each year from 1951 through 1974. States for which Platt's did not report prices were given the price from the geographically nearest state that did contain a Platt's price. These prices were not adjusted to account for markups between wholesale and retail levels. Because we use a log-log formulation, an assumed constant markup would change only the constant term in each equation.

The USDA price series is available for each state for the years 1959 through 1974. To "create" fuel oil prices for the years 1951 through 1958, we developed regression equations to relate USDA kerosene prices for each year and state to corresponding fuel oil prices for the 1959-1974 period. These equations were then used with the USDA kerosene prices for 1951-1958 to estimate state fuel oil prices for these years. Finally, we adjusted the USDA prices each year by the national fuel oil price estimated by the Bureau of Labor Statistics.[17] BLS prices are obtained in several cities and we felt that urban prices would more accurately reflect state oil prices than would prices paid by farmers.*

The third residential fuel oil price series was based on a combination of Platt's and USDA prices. Platt's prices were first multiplied

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*Details of the development of this fuel oil price data set are available from the authors.

by the ratio of BLS national fuel oil price to Platt's U.S. average price; this adjustment was made to correct Platt's wholesale prices to a retail level. States that had no Platt's price were then assigned a price based on the following formula:

$$P_{i,t} = P(\text{Platts})_{j,t} \cdot \left[\frac{P(\text{USDA})_{i,t}}{P(\text{USDA})_{j,t}}\right] \cdot \left[\frac{P(\text{BLS})_{t}}{P(\text{Platts})_{t}}\right]$$

where i represents a state without Platt's data and j represents a state adjacent to the ith state having a Platt's price. Thus, the USDA prices are used to provide greater cross-sectional variation to the Platt's series.

The development of the third fuel oil price series was necessary because neither the Platt's nor the USDA series alone gave satisfactory results. When cross-sectional models were developed for fuel oil consumption using the Platt's series, the own-price coefficient frequently gave incorrect (positive) signs. The USDA oil price series often gave negative signs for cross-price coefficients.

3.3 Other variables

Heating degree-days and mean July temperature are used as explanatory variables to account for the effects of weather on fuel consumption for space heating and air conditioning. State heating degree days, compiled on a monthly basis, were obtained from the U.S. Department of Commerce.[18] These data were converted to a calendar year basis for this study. Mean July temperatures were also obtained from the Department of Commerce.[19] Data from several cities in each state were weighted by population to develop state estimates for mean July temperature.

Values of per capita income for each state and year were obtained from various issues of *Survey of Current Business.*[20]

All fuel price and income variables were deflated by the Consumer Price Index[20] (to account for temporal changes in price levels) and by Anderson's metropolitan cost of living index[4] (to account for regional differences in price levels). Anderson's index was developed for 1970 from Bureau of Labor Statistics estimates of living costs for a family of four in several different cities. A typical price variable is deflated for state i and year t as:

$$P_{i,t} = P^*_{i,t}/(MCL_i \cdot CPI_t)$$

where

$P^*_{i,t}$ is the undeflated price

MCL_i is the metropolitan cost-of-living index for state i

CPI_t is the national consumer price index for year t.

The number of households in each state was obtained from the Bureau of the Census for the years 1950, 1960, 1965-1968, 1970, and 1972-1974.[21] To create data for the missing years we used estimates of state population from the Bureau of the Census[21] (provided for each year) and a simple interpolation scheme:

$$\left(\frac{HH_i}{Pop_i}\right)_t = \left(\frac{HH_i}{Pop_i}\right)_{t_1} + \left(\frac{t-t_1}{t_2-t_1}\right)\cdot\left[\left(\frac{HH_i}{Pop_i}\right)_{t_2} - \left(\frac{HH_i}{Pop_i}\right)_{t_1}\right] \qquad \begin{array}{l} i = 1, \ldots, 47 \\ t_1 < t < t_2 \end{array}$$

where

$\left(\frac{HH_i}{Pop_i}\right)_t$ is the ratio of number of households to population for state i in year t

t_1 and t_2 are the years for which household data were available.

Table 2 lists the data series used in this study and their sources. Each data element is defined for each year from 1951 through 1974 and for each of 47 states. North and South Carolina are combined because separate state electricity use figures were not reported before 1957. Maryland and Washington, D.C. are also combined for the same reason. Alaska and Hawaii are excluded because only recent data are available for these states.

Table 2. Definition and Unit of Measurement for Variables Used in Econometric Models

Variable	Definition	Unit of measurement	Data sources
Real price of electricity	P_{elec}	\$/MWhrs	10
Real price of natural gas	P_{gas}	\$/10^3 Therms	12
Real price of fuel oil	P_{oil}	\$/gal.	15, 16
Real per capita income	PCI	10^3 \$	20
Heating degree days	HDD	days	18
Mean July temperature	COOL	^oF	19
Electricity consumption	Q_{elec}	10^6 KWhrs	10
Natural gas consumption	Q_{gas}	10^6 Therms	12
Fuel-oil consumption	Q_{oil}	10^3 BBLS	13
Dependent variable lagged one period	Q_{t-1}		
Number of households per state	Household	10^3	21

4. Empirical Results

As described in Section 2, two models were used to investigate household demands for fuels. The first is a cross-sectional model using state data for a particular year; the second is a dynamic model using state data for a specified time period (usually greater than five years).

The following tables present regression results obtained with the equations of Section 2 and the data of Section 3. Coefficient estimates and corresponding t-statistics for cross-sectional equations are given in Table 3 for electricity, Table 4 for gas, and Table 5 for oil. Coefficients and t-statistics obtained with dynamic models for four different time periods are given in Tables 6, 7, and 8 for the three fuels.

The combined Platt's-USDA fuel oil price series was used for all regressions reported here because it gave better results than either the Platt's or USDA prices alone; see Sections 3 and 5, and ref. 14.

4.1 Cross-sectional results

The cross-sectional models show considerable stability over time for the own-price coefficients for electricity and natural gas; long-run elasticities average -1.0 and -2.1 respectively. The own-price elasticity of demand for oil shows more variation, with values ranging from -0.2 in 1955 to -2.5 in 1965. From 1965 to 1973 this elasticity declined steadily in absolute magnitude from -2.5 to -1.2. This covers a period during which oil consumption per household declined 28%, signifying a possible structural change in the demand for oil.

Cross-price elasticities for both electricity and gas generally increased in magnitude and statistical significance over time, especially during the last six years of the data series. This suggests that households have become more aware of relative fuel costs and have acted accordingly in their fuel choice decisions.

The absolute magnitude of the own-price elasticity for oil, averaging -1.3, is considerably less (44%) than the cross-price elasticity of oil with respect to the price of gas, averaging 1.8. The implication that

Table 3. Estimated Household Demand for Electricity; Cross-Sectional Model*

Estimation Method: Ordinary Least Squares

Dependent Variable: $\ln (Q_{elec}/\text{Household})$

Year	$\ln P_{elec}$	$\ln P_{gas}$	$\ln P_{oil}$	$\ln$ PCI	$\ln$ HDD	$\ln$ COOL	Constant	R^2
1951	−1.039	0.120	0.347	0.282	0.105	0.021	2.028	0.853
	(−12.48)[a]	(3.30)[a]	(1.91)[c]	(2.24)[b]	(1.85)[c]	(0.09)	(1.48)[d]	
1955	−1.035	0.089	0.619	0.007	0.100	−0.057	2.062	0.826
	(−11.29)[a]	(2.02)[b]	(2.47)[b]	(0.05)	(2.07)[b]	(−0.26)	(1.58)[d]	
1960	−1.029	0.094	0.738	0.148	0.115	0.238	0.700	0.803
	(−11.40)[a]	(1.55)[d]	(2.77)[a]	(0.90)	(1.59)[d]	(0.93)	(0.37)	
1965	−1.073	0.007	0.053	−0.211	−0.025	−0.002	5.54	0.785
	(−11.21)[a]	(0.12)	(0.20)	(−1.18)	(−0.35)	(−0.01)	(2.85)[a]	
1969	−1.082	0.107	0.029	−0.280	−0.063	0.233	4.911	0.781
	(−10.66)[a]	(1.35)[d]	(0.11)	(−1.31)[d]	(−0.85)	(1.02)	(2.66)[b]	
1970	−1.077	0.092	0.114	−0.376	−0.062	0.467	4.164	0.801
	(−10.53)[a]	(1.27)	(0.48)	(−1.82)[c]	(−0.99)	(1.89)[c]	(2.48)[b]	
1971	−0.867	0.121	0.127	−0.397	−0.115	0.186	4.735	0.759
	(−9.33)[a]	(1.62)[d]	(0.52)	(−1.80)[c]	(−1.77)[c]	(0.80)	(2.97)[a]	
1972	−1.069	0.146	0.037	−0.227	−0.112	0.156	5.36	0.793
	(−10.32)[a]	(2.15)[b]	(0.16)	(−1.07)	(−1.98)[c]	(0.72)	(3.63)[a]	
1973	−1.11	0.162	0.416	0.199	−0.085	0.504	2.511	0.834
	(−12.68)[a]	(2.68)[b]	(2.08)[b]	(1.07)	(−1.60)[d]	(2.49)[b]	(1.96)[c]	
1974	−1.032	0.403	0.555	0.007	−0.105	0.552	0.838	0.866
	(−14.70)[a]	(6.30)[a]	(3.24)[a]	(0.04)	(−2.82)[a]	(3.05)[a]	(0.78)	

*The figures in parentheses are t-statistics, R^2 is the multiple coefficient of determination. There are 47 observations in each equation. See Table 2 for definitions of variables.

[a]Statistically significant at the 1% level.

[b]Statistically significant at the 5% level.

[c]Statistically significant at the 10% level.

[d]Statistically significant at the 20% level.

Table 4. Estimated Household Demand for Natural Gas; Cross-Sectional Model*

Estimation Method: Ordinary Least Squares
Dependent Variable: *ln* (Q_{gas}/Household)

Year	*ln* P_{elec}	*ln* P_{gas}	*ln* P_{oil}	*ln* PCI	*ln* HDD	Constant	R^2
1951	1.309 (3.64)[a]	−1.744 (−11.95)[a]	−0.548 (−0.75)	1.966 (3.84)[a]	−0.129 (−0.74)	3.21 (1.16)	0.821
1955	1.167 (2.99)[a]	−2.039 (−10.20)[a]	−0.449 (−0.39)	2.18 (3.56)[a]	−0.076 (−0.37)	4.57 (1.08)	0.762
1960	0.530 (2.22)[c]	−2.026 (−13.72)[a]	−0.329 (−0.46)	1.332 (3.10)[a]	0.036 (0.25)	6.58 (2.04)[b]	0.835
1965	0.381 (1.21)	−1.539 (−9.47)[a]	0.348 (0.41)	1.590 (2.71)[a]	0.116 (0.71)	1.895 (0.48)	0.725
1969	0.197 (0.86)	−2.368 (−14.62)[a]	−0.656 (−1.14)	1.684 (3.52)[a]	0.144 (1.19)	8.269 (3.00)[a]	0.848
1970	0.193 (0.75)	−2.42 (−13.39)[a]	−0.521 (−0.88)	1.876 (3.58)[a]	0.174 (1.37)	7.626 (2.56)[b]	0.825
1971	0.225 (1.07)	−2.256 (−13.33)[a]	−0.346 (−0.63)	2.175 (4.36)[a]	0.201 (1.80)[c]	5.706 (2.22)[b]	0.826
1972	0.204 (0.75)	−2.091 (−11.67)[a]	−0.569 (−0.93)	1.929 (3.43)[a]	0.254 (2.15)[b]	5.318 (1.89)[c]	0.792
1973	0.520 (1.87)[c]	−2.047 (−10.62)[a]	−1.060 (−1.66)[d]	1.195 (2.01)[c]	0.141 (1.09)	7.323 (2.93)[a]	0.771
1974	0.654 (2.72)[a]	−2.227 (−11.22)[a]	−0.100 (−1.66)[d]	1.771 (2.94)[a]	0.231 (2.12)[b]	6.547 (2.73)[a]	0.781

*The figures in parentheses are t-statistics, R^2 is the multiple coefficient of determination. There are 47 observations in each equation. See Table 2 for definitions of variables.

[a]Statistically significant at the 1% level.
[b]Statistically significant at the 5% level.
[c]Statistically significant at the 10% level.
[d]Statistically significant at the 20% level.

Table 5. Estimated Household Demand for Fuel Oil; Cross-Sectional Model*

Estimation Method: Ordinary Least Squares
Dependent Variable: $ln\ (Q_{oil}/\text{Household})$

Year	$ln\ P_{elec}$	$ln\ P_{gas}$	$ln\ P_{oil}$	ln PCI	ln HDD	Constant	R^2
1951	0.605 (2.94)[a]	1.106 (13.23)[a]	−0.229 (−0.55)	0.854 (2.92)[a]	0.885 (8.83)[a]	−13.71 (−8.62)[a]	0.880
1955	0.594 (2.46)[b]	1.303 (10.53)[a]	−0.159 (0.22)	0.596 (1.57)[d]	1.148 (9.16)[a]	−16.74 (−6.40)[a]	0.846
1960	0.100 (0.28)	1.799 (8.18)[a]	−1.780 (−1.68)[c]	1.008 (1.58)[d]	1.535 (7.04)[a]	−17.06 (−3.55)[a]	0.797
1965	0.067 (0.159)	1.329 (6.08)[a]	−2.446 (−2.13)[b]	0.355 (0.45)	1.405 (6.40)[a]	−11.12 (−2.08)[b]	0.747
1969	−0.012 (−0.033)	2.250 (8.47)[a]	−1.855 (−1.96)[c]	−0.557 (−0.71)	1.611 (8.08)[a]	−17.27 (−3.82)[a]	0.813
1970	−0.248 (−0.61)	2.298 (8.01)[a]	−1.762 (−1.87)[c]	−0.369 (−0.44)	1.450 (7.20)[a]	−15.86 (−3.35)[a]	0.798
1971	−0.057 (−0.19)	2.376 (8.75)[a]	−1.477 (−1.68)[c]	0.094 (0.12)	1.269 (7.06)[a]	−16.57 (−4.02)[a]	0.798
1972	0.164 (0.48)	2.128 (9.48)[a]	−1.148 (−1.50)[d]	0.240 (0.34)	1.234 (8.34)[a]	−16.83 (−4.77)[a]	0.831
1973	0.497 (1.65)[d]	2.005 (9.57)[a]	−1.244 (−1.79)[c]	−0.483 (−0.75)	1.273 (9.06)[a]	−16.05 (−5.90)[a]	0.817
1974	0.560 (1.90)[c]	1.742 (7.17)[a]	−0.650 (0.88)	−0.801 (−1.09)	1.221 (9.13)[a]	−15.44 (−5.27)[a]	0.784

*The figures in parentheses are t-statistics, R^2 is the multiple coefficient of determination. There are 47 observations in each equation. See Table 2 for definitions of variables.

[a]Statistically significant at the 1% level.
[b]Statistically significant at the 5% level.
[c]Statistically significant at the 10% level.
[d]Statistically significant at the 20% level.

Table 6. Estimated Household Demand for Electricity: Dynamic Model*

Pooled time-series and state data.
Dependent Variable: $ln\,(Q_{elec}/\text{Household})_t$

Time Span	Estimation Method	$ln\left[\frac{Q_{elec}}{\text{Household}}\right]_{t-1}$	$ln\,P_{elec}$	$ln\,P_{gas}$	$ln\,P_{oil}$	ln PCI	ln HDD	ln COOL	Constant	R^2
1951–74	LSDV	0.879	−0.140	0.005	−0.065	0.020	0.034	0.043	0.451	0.993
	cross-section	(114.38)[a]	−1.163	0.037	−0.542	0.162	0.281	0.357	3.74	
	effect only		(−9.14)[a]	(0.74)	(−7.29)[a]	(1.27)	(3.01)[a]	(2.15)[b]	(2.98)[a]	
1960–74	LSDV	0.781	−0.195	0.005	−0.060	0.100	0.057	0.069	0.809	0.981
	cross-section	(51.84)[a]	−0.890	0.021	−0.272	0.455	0.260	0.317	3.690	
	effect only		(−10.46)[a]	(0.37)	(−7.11)[a]	(4.46)[a]	(0.38)	(2.62)[a]	(3.88)[a]	
1965–74	LSDV	0.801	0.155	−0.006	−0.059	0.056	0.033	0.071	0.476	0.973
	cross-section	(49.24)[a]	−0.779	−0.032	−0.296	0.430	0.167	0.359	2.364	
	effect only		(−8.62)[a]	(−0.32)	(7.95)[a]	(3.13)[a]	(2.04)[b]	(2.62)[a]	(2.10)[b]	
1969–74	LSDV	0.706	−0.137	0.038	−0.049	0.163	0.024	0.095	0.283	0.936
	cross-section	(19.83)[a]	−0.468	0.128	−0.166	0.556	0.080	0.322	0.963	
	effect only		(−5.14)[a]	(0.89)	(−4.99)[a]	(4.19)[a]	(0.92)	(1.94)[c]	(0.74)	

*Coefficients are: short-run elasticities = β_1; long-run elasticities = $\beta_i/(1-\lambda)$ where λ is the coefficient of the lagged dependent variable. t-statistics in parentheses. R^2 is the multiple coefficient of determination. See Table 2 for definitions of variables.

[a]Statistically significant at the 1% level.
[b]Statistically significant at the 5% level.
[c]Statistically significant at the 10% level.
[d]Statistically significant at the 20% level.

Table 7. Estimated Household Demand for Natural Gas: Dynamic Model*

Pooled Time-Series and State Data
Dependent Variable: $ln\ [Q_{gas}/\text{Household}]_t$

Time Span	Estimation Method	$ln\left[\frac{Q_{gas}}{\text{Household}}\right]_{t-1}$	$ln\ P_{elec}$	$ln\ P_{gas}$	$ln\ P_{oil}$	ln PCI	ln HDD	Constant	R^2
1951–74	VC both effects	0.869 (103.14)[a]	−0.076 −0.578 (−1.65)[c]	−0.324 −2.470 (−14.40)[a]	0.104 0.792 (2.37)[b]	−0.048 −0.368 (−0.85)	0.296 2.258 (6.06)[a]	−1.011 −7.706 (−2.02)[b]	0.972
1960–69	LSDV both effects	0.818 (43.16)[a]	−0.064 −0.354 (−1.12)	−0.148 −0.817 (−6.47)[a]	0.055 0.305 (1.13)	0.017 0.093 (0.33)	0.416 2.288 (11.63)[a]	−2.843 −15.650 (−6.94)[a]	0.944
1960–74	VC both effects	0.835 (59.00)[a]	0.015 0.091 (0.54)	−0.164 −0.994 (−8.22)[a]	0.033 0.201 (1.12)	0.058 0.348 (1.49)	0.519 3.148 (16.76)[a]	−3.91 −23.69 (−11.93)[a]	0.914
1969–74	VC both effects	0.560 (12.94)[a]	0.047 0.108 (1.27)	−0.391 −0.887 (−4.99)[a]	0.038 0.087 (0.96)	−0.013 −0.030 (−0.16)	0.443 1.006 (9.90)[a]	−2.361 −5.359 (−3.89)[a]	0.859

*Coefficients are: short-run elasticities = β_i; long run elasticities = $\beta_i/(1-\lambda)$ where λ is the coefficient of the lagged dependent variable. t-statistics in parentheses. R^2 is the multiple coefficient of determination. See Table 2 for definitions of variables.

[a]Statistically significant at the 1% level.
[b]Statistically significant at the 5% level.
[c]Statistically significant at the 10% level.
[d]Statistically significant at the 20% level.

Table 8. Estimated Household Demand for Fuel Oil: Dynamic Model*

Pooled Time-Series and State Data
Dependent Variable: $ln\ [Q_{oil}/\text{Household}]_t$

Time Span	Estimation Method	$ln\left[\frac{Q_{oil}}{\text{Household}}\right]_{t-1}$	$ln\ P_{elec}$	$ln\ P_{gas}$	$ln\ P_{oil}$	ln PCI	ln HDD	Constant	R^2
1951–74	VC	0.836	0.062	0.137	−0.181	0.100	0.246	−2.222	0.956
	cross-section	(54.66)[a]	0.376	0.836	−1.101	0.610	1.502	−13.554	
	effect only		(1.14)	(4.33)[a]	(−3.59)[a]	(1.42)[d]	(5.50)[a]	(−4.28)[a]	
1960–74	VC	0.733	0.041	0.222	−0.145	0.255	0.601	−5.785	0.954
	cross-section	(25.33)[a]	0.155	0.833	−0.542	0.957	2.253	−21.674	
	effect only		(0.40)	(2.74)[a]	(−3.00)[a]	(2.04)[b]	(4.44)[a]	(−4.16)[a]	
1965–74	LSDV	0.745	−0.-68	0.443	−0.186	0.318	0.458	−5.275	0.966
	cross-section	(24.23)[a]	−0.265	1.736	−0.729	1.237	1.790	−20.662	
	effect only		(−0.74)	(4.17)[a]	(−4.01)[a]	(2.29)[b]	(5.78)[a]	(−5.25)[a]	
1969–74	LSDV	0.626	−0.172	0.726	−0.191	0.498	0.558	−7.168	0.953
	cross-section	(11.96)[a]	−0.459	1.939	−0.511	1.330	1.492	−19.153	
	effect only		(−1.25)	(3.85)[a]	(−4.47)[a]	(2.31)[b]	(5.11)[a]	(−4.92)[a]	

*Coefficients are: short-run elasticities = β_i; long-run elasticities = $\beta_i/(1-\lambda)$ where λ is the coefficient of the lagged dependent variable. t-statistics in parentheses. R^2 is the multiple coefficient of determination. See Table 2 for definitions of variables.

[a]Statistically significant at the 1% level.
[b]Statistically significant at the 5% level.
[c]Statistically significant at the 10% level.
[d]Statistically significant at the 20% level.

the quantity of oil demanded by households is more responsive to changes in gas price than to changes in oil price is counter-intuitive. This result appears to stem from gas availability problems in the Northeast. Although the price of natural gas is high in large oil-consuming states (Maine, New Hampshire, Vermont), oil consumption is also influenced by the unavailability of gas. Thus the elasticity of oil demand with respect to gas price reflects both a price effect and an availability effect.

The per capita income elasticity of demand for natural gas was considerably higher and more stable over time than corresponding values for electricity and oil. Since 1951, the income elasticity of demand for gas averaged 1.8. For electricity and oil these elasticities averaged -0.1 and +0.1 respectively, indicating a clear preference for natural gas in high income states.

Fuel oil consumption shows a greater response to cold weather than either natural gas or electricity. The average elasticity of oil use with respect to HDD is 1.3. For natural gas and electricity the values averaged 0.11 and -0.02, respectively. The negative value for electricity reflects the fact that electric heating is widely used only in mild climates, such as the Southeast. For example, in 1970 only 0.3% of single-family homes in the 14 state New England, Middle Atlantic and East North Central regions were heated by electricity, whereas in the 14 state South Atlantic and East South Central regions, electric space heating was used in 15% of single-family homes.[4]

The percentage of households with air conditioning in the U.S. increased from 1% in 1950 to 36% in 1970 and 49% in 1974.[1] The variable, mean July temperature, is included in our equations to capture the influence of air conditioning on electricity demand. For all years before 1969 the coefficient of this variable is statistically insignificant (Table 3), probably because only a small fraction of households in each state owned air conditioning equipment. From 1969 on, both the magnitude and statistical significance of this variable increased. The average value of the coefficient for mean July temperature was +0.34 for the 1970 to 1974 period.

In general, the own-price elasticities of electricity and natural gas show good stability over time and are highly significant statistically. This is not the case with the oil own-price elasticity which has an average t-statistic of -1.4 over the sample period. (The average t-statistics for electricity and natural gas are -11.5 and -12.0, respectively). Oil consumption shows the greatest response to cold weather with natural gas use showing the greatest response to per capita income changes.

4.2 Dynamic results

Tables 6, 7, and 8 present results obtained with dynamic models of electricity, gas, and oil demands for four time periods: 1951-1974, 1960-1974, 1965-1974, and 1969-1974.

No *a priori* assumption was made regarding the selection of estimation technique chosen; each dynamic model was estimated with four techniques:

(1) Least squares with dummy variable (LSDV), cross-sectional dummy variables only.

(2) Variance component (VC), cross-sectional dummy variables only.

(3) LSDV, both time and state dummy variables.

(4) VC, both time and state dummy variables.

The technique reported for each equation in Tables 6-8 was chosen on the basis of which method produced the highest multiple coefficient of determination (R^2) combined with the most plausible elasticities. For example, an estimation technique that produced cross-price elasticities with negative values and an R^2 lower than that produced by one of the remaining three techniques which estimated positive cross-price elasticities, was rejected in favor of the latter.

All three Tables show declines in the lagged coefficient as the time period becomes shorter and more recent. Because of this, long-run own-price elasticities decline in magnitude with shorter time intervals. These changes in long-run elasticities are quite significant (see Tables 6-8).

Cross-price elasticities also change from time period to time period. Unfortunately, many of the cross-price coefficients have incorrect signs, are statistically insignificant, or both.

Long-run income elasticities for electricity and oil are positive for all time periods; both the magnitude and statistical significance of these elasticities increase from the base period to the 1969-1974 period. The long-run income elasticity for gas, however, is always insignificant and sometimes negative.

The coefficients for the weather variables show no significant changes as the time interval is shortened.

The dynamic model results (1951-1974) show good agreement with the cross-sectional regressions with respect to the own-price long-run elasticities of demand, but are not consistent with the cross-sectional cross-price elasticities in the electricity and gas equations. Natural gas use is highly elastic with respect to its own-price with an estimated value of -2.5. Electricity and oil own-price elasticities are about -1.0. The effects of oil price on gas consumption and gas price on oil consumption are approximately the same (a cross-price elasticity of 0.8). These two cross-price elasticities are significantly larger than the other four cross-price coefficients demonstrating the high substitutability between gas and oil over time. The cross-elasticity of demand for electricity with respect to oil price is estimated to be -0.54 (+0.30 in the cross-sectional model), giving further evidence that the fuel oil price series is inadequate. The possibility of complementarity between oil and electricity is not likely.

Oil consumption shows a greater response to income in the dynamic model (income elasticity of 0.61) than either electricity or gas. This contradicts the findings of the cross-sectional models where gas shows the greatest response to income.

Colder weather affects gas consumption more than either electricity or oil use in the dynamic model. The effects of cold weather on oil consumption is estimated to be the same in both dynamic and cross-sectional models with an elasticity of 1.5. The same is true regarding warm weather effects of electricity use — an estimated elasticity of 0.35 in both cross-section and dynamic models.

A Chow test was performed for the three dynamic fuel demand models to test the null hypothesis of no structural change in the regression coefficients between the 1951-1962 and 1963-1974 time periods. These tests showed significant differences in coefficient estimates for the two time periods. Only a more detailed analysis of the dynamic model formulation can show whether these differences occur because of model misspecification or because of structural change. Difficulties with the dynamic model specification are discussed in the next section.

5. Assumptions and Limitations for Data and Model

All analytical efforts involve assumptions and limitations related both to the data used to construct the model and to the structure of the model itself. Our work is not different: we "adjusted" and "created" data series where an existing one did not match our needs or where none existed. In defining our models, we made simplifying assumptions because of data unavailability, computational simplicity, or lack of adequate theory.

5.1 Data

The EEI and AGA estimates of residential electricity and gas consumption are incomplete. Consumption of electricity and gas in gang-metered apartment houses with five or more units is generally classified by utilities as "commercial." We corrected for this definitional problem using rather scanty evidence. Unfortunately, lack of data forced us to apply the same correction for all years and all states. We do not know what errors are introduced into our results because of this ad hoc adjustment.

In a similar fashion, data on residential consumption of petroleum products was "derived" from estimates prepared by the Bureau of Mines for the combined household/commercial sector. We assigned all of the kerosene and all of the Nos. 1, 2, and 4 distillate heating oils to the residential sector. Surely some of these petroleum products are used in commercial buildings; similarly some of the Nos. 5 and 6 residual fuel oils (assigned completely to the commercial sector) may be used in multi-family dwellings. It is also likely that the fractions of each petroleum product consumed in each sector vary from year to year and from state to state. However, lack of data prevented us from developing a better disaggregation scheme.

Problems associated with retail fuel oil prices were discussed earlier. Basically, estimates of No. 2 fuel oil prices for different states and years are available only from small-sample surveys that use different techniques and sample different populations (e.g., wholesale dealers, farmers, urban residents, gas utilities). Lack of agreement among these series is startling.

In addition, we assume that the price of No. 2 fuel oil is a good proxy for prices of all petroleum products consumed by households: kerosene and three different grades of distillate fuel oils. We use only prices for No. 2 fuel oil because adequate estimates for the other prices do not exist.

The problems associated with different fuel oil price series are illustrated in Table 9, which presents own-price elasticities for petroleum use estimated with the three different fuel oil price series discussed earlier. Elasticities obtained with Platt's estimates consistently show the incorrect sign. Elasticities obtained with USDA prices show the correct sign but are much larger than elasticities obtained in other studies (see Section 6). Results obtained with the conbined Platt's-USDA price series give reasonable values for own-price

Table 9. Own-Price Elasticities for Household Fuel Oil Demands

Year	Fuel Oil Own-Price Elasticities		
	USDA	Combined Platts–USDA	Platts
1960	–2.96	–1.78	0.56
1965	–3.18	–2.45	0.68
1970	–2.41	–1.76	1.25
1973	–2.11	–1.24	0.25

elasticities. However, our choice of the combined series was based on expedience, not on theory or additional information. Thus the problem of an adequate price series for fuel oil is both important and unresolved.

5.2 Models

Our models assume implicitly that all fuels are always available at stated prices and that consumption is a function only of prices, incomes, and weather. No information is included in the model concerning availability of fuels; this is quite important for gas.

During the early years covered by our models, gas was unavailable in many states because pipelines had not yet been constructed in these regions. During later years, gas shortages occurred; utilities in many regions were unable to provide gas to new customers. Thus the usual supply-demand balance was influenced by both prices and availability. If we had been able to obtain quantitative information on gas availability in each state and year, we would have constructed models that included this variable. However, such information does not exist.

As a check on the sensitivity of our results to changes in gas availability, we reestimated our cross-sectional model of gas demand for 1965 and 1970 (Table 10). The first and third lines show coefficients estimated using all 47 observations for each year. The second and fourth lines in Table 10 exclude those states in which per household gas consumption was less than 30% of the national average for that year. (We implicitly assume here that low gas consumption per household is a reasonable proxy for gas unavailability, a plausible but unsupported hypothesis.)

For both years, excluding states with low gas consumption reduces the magnitude of own-price elasticities. Similarly, deleting low consumption states raises the elasticity of gas demand with respect to electricity price; the oil price coefficients are statistically insignificant in all four runs. These equations show that estimated coefficients change significantly when a few low gas-using states are dropped. This suggests that it is important to properly account for gas availability in fuel demand equations.

In our study, average prices of electricity and natural gas were used instead of marginal prices because suitable data series on state marginal prices were not available. A recent study by Taylor et al.,[22] concerning residential energy demands, developed an electricity price series that includes not only changes in marginal prices, but also customer charges and intramarginal prices as well.*

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*Comments received on a draft of this report showed mixed opinions on whether average or marginal price was a more important determinant of electricity demand. Chapman et al.,[23] in their investigation of the effects of rate schedules on electricity demand concluded that the level of the rate schedule is a more important determinant of electricity demand than is the shape of the rate schedule.

Table 10. Estimated Household Demand for Natural Gas; Cross-Sectional Model*

Estimation Method: Ordinary Least Squares
Dependent Variable: *ln* (Q_{gas}/Household)

Year	*ln* P_{elec}	*ln* P_{gas}	*ln* P_{oil}	*ln* PCI	*ln* HDD	Constant	R^2
1965	0.381	−1.539	0.348	1.591	0.116	1.895	0.725
	(1.21)	(−9.47)[a]	(0.41)	(2.71)[a]	(0.71)	(0.48)	
1965**	0.807	−0.780	0.698	0.887	0.072	−2.723	0.594
	(3.35)[a]	(−5.18)[a]	(1.18)	(1.81)[c]	(0.54)	(−0.97)	
1970	0.193	−2.421	−0.521	1.876	0.174	7.626	0.825
	(0.75)	(−13.39)[a]	(−0.88)	(3.58)[a]	(1.37)[d]	(2.56)[b]	
1970**	0.620	−1.549	−0.254	1.162	0.158	2.766	0.818
	(3.68)[a]	(−10.04)[a]	(−0.69)	(3.45)[a]	(1.703)[c]	(1.40)[d]	

*The figures in parentheses are t-statistics. R^2 is the multiple coefficient of determination. See Table 2 for definitions of variables.

**Eliminating those states with less than 30% of the U.S. average consumption of natural gas per household; six states in 1965, four in 1970.

[a]Statistically significant at the 1% level.
[b]Statistically significant at the 5% level.
[c]Statistically significant at the 10% level.
[d]Statistically significant at the 20% level.

Specification of our cross-sectional models may not be complete. Excluded variables that may play a statistically significant role in the regressions include household size, fraction of households living in single-family units, fraction of households living in rural areas, and fraction of households with income below $3,000. Unfortunately, such data are available from the Bureau of the Census only for Census years (1960 and 1970).

Interpretation of the cross-sectional results assumes that the system is in long-run equilibrium. This may not be true for 1951 when the shift in fuel choice from coal to other fuels was still in progress, and in 1973 and 1974 when the effects of the Arab oil embargo were very much in evidence.

The dynamic model formulation is quite simple. We assume that responses to changes in all exogenous variables follow the same time path. This is clearly incorrect. The response to a change in own-fuel price or income can occur more quickly than a similar change in cross-price.

Changes in fuel use due to changes in own-fuel price and income can occur through changes in both equipment ownership and equipment usage. However, the response to a change in cross-fuel price can involve only changes in equipment ownership. Thus, the dynamics must be slower for cross-price changes than for own-price and income changes.

It is also unreasonable to assume that the dynamics of changes in fuel use are uniform across different fuels and time periods. For example, the response of oil consumption is constrained by the lifetime of oil-using equipment, i.e., primarily oil space heating systems. On the other hand, the dynamics of the response of electricity consumption depends on lifetimes of several types of equipment and also on saturations for major electricity using functions (e.g., freezers, air conditioners). Therefore, we expect electricity use to respond more rapidly to changes in prices and incomes than would oil use. Also, electricity use should respond most rapidly during the early years of our time period when ownership of large electricity-using appliances was small. However, the structure assumed in our model does not allow for these changes.

Even ignoring interfuel differences in response dynamics, the dynamic adjustment of households to an optimal fuel consumption implied by the partial adjustment model is a gross simplification. The partial adjustment framework assumes that households adjust to a new optimal fuel consumption at a rate which is a constant fraction of the difference between present consumption and optimal consumption.

6. Summary

This study developed econometric models of household demands for electricity, gas, and oil using a large data base containing observations for 47 states and 24 years. Both cross-sectional models — for nine years — and time series models — for four time periods — are estimated for each fuel (a total of 39 equations). The cross-sectional equations assume that fuel demands are functions of fuel prices, incomes, and weather variables. In addition, the dynamic models assume that fuel demands are functions of last year's fuel demand.

In the long-run, own-price elasticities for all three fuels are greater than unity. Gas shows the greatest sensitivity to own-price changes and electricity shows the smallest response. The cross-price elasticities are all less than unity with one exception. The elasticity of demand for oil with respect to the price of gas is about 1.8, considerably larger than the own-price elasticity of demand for oil (-1.3). The coefficients of per capita income (cross-sectional models) show considerable variation in both signs and magnitudes across different time periods. It appears that the income elasticity of demand for gas is greater than +1, that demand for oil is almost independent of income, and that demand for electricity may decline with increases in incomes.*

Two key deficiencies with respect to the data used in constructing these models are the price series for fuel oil and the use of *ex post* average prices for electricity and natural gas. Biased coefficients due to problems of simultaneity are a possibility when average rather than marginal prices are used. Another data problem concerns disaggregation of combined household/commercial petroleum use for the two sectors. We feel that improved data series on residential consumption of petroleum products would substantially improve the reliability and stability of the coefficients.

The major problem with the assumed model structures is simplicity. In both the cross-section and time series models, we ignore problems of gas availability, changes in equipment ownership, and other factors that may cause structural changes over time. In addition, the lag structure used in the dynamic model is much too simple.

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*However, the dynamic models show positive income elasticities for electricity and oil demands.

These data and methodology problems require additional study. We plan to develop econometric models of commercial fuel uses (similar to these for the residential sector). In developing the commercial sector models, we will try to obtain or create improved data on commercial oil consumption, oil prices, and marginal electricity prices. In structuring our equations, we will try to account for natural gas availability and to specify a better dynamic model. If the results show improvements because of these changes, we will then reestimate the residential fuel use equations in a similar fashion.

Despite these problems in both data and equations, the results obtained here are quite useful. Table 11 presents a synthesis of our long-run elasticities (based primarily on the cross-section models reported in Tables 3-5) and compares these results with those obtained in other studies of either the residential or combined residential/commercial sector.

Agreement among the different studies is much greater for own-price elasticities than for cross-price and income elasticities. Our results for cross-price elasticities generally fall within the range of values estimated in other studies. All our cross-price elasticities are positive, except for gas demand with respect to the price of oil. Income elasticities show the greatest variation among studies. Ours is the only study that yields a negative income elasticity of the demand for electricity.

The key features of the models developed here include:

1. Explicit consideration of only the residential sector using improved definitions of residential fuel uses.

2. Use of a large data base containing 1128 observations.

3. Development of 13 different cross-section and time series equations for each fuel.

While these improvements over previous econometric models of household fuel demands do not always lead to more consistent coefficient estimates, the large data base and large number of equations estimated show clearly which coefficients are stable and reliable and which are not.

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Table 11. Price and Income Elasticity Estimates

Fuel	Source	P_{elec}	P_{gas}	P_{oil}	Income
Electricity	This study[b]	−1.04	0.13	0.30	−0.11
	Chern (ref. 3)[a]	−1.46	0.02	0.29	0.86
	Baughman & Joskow (ref. 2)[a]	−1.00	0.17	0.05	–
	FEA (ref. 22)[a]	−1.01	0.42	0.12	–
	Anderson (ref. 4)[b]	−1.12	0.30	0.27	0.80
	Taylor (ref. 22)[b]	−0.78	–	–	1.18
Natural Gas	This study[b]	0.54	−2.08	−0.42	1.77
	Chern[a]	0.92	−1.50	0.51	0.70
	Baughman & Joskow[a]	0.17	−1.01	0.06	–
	FEA[a]	0.32	−0.82	0.05	–
	Anderson[b]	−0.67	−2.75	−0.25	1.42
	Taylor[a]	–	−1.77	–	1.23
Fuel Oil	This study[b]	0.23	1.83	−1.28	0.09
	Chern[a]	0.22	0.81	−1.16	−0.29
	Baughman & Joskow[a]	0.16	0.19	−1.12	–
	FEA[a]	0.12	0.07	−0.87	0.63
	Anderson[a]	0.21	2.10	−1.58	–
	Taylor[b]	–	–	−1.00	0.62

[a]Combined residential and commercial sectors.
[b]Residential sector only.

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