Title
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Publication Date
1983

LBL-14251
UC-95d

Lawrence Berkeley Laboratory

UNIVERSITY OF CALIFORNIA

ENERGY & ENVIRONMENT DIVISION

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January 1983

ENERGY
AND ENVIRONMENT
DIVISION

Prepared for the U.S. Department of Energy under Contract DE-AC03-76SF00098

LBL-14251

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This study was supported by the United States Department of Energy, Asst. Sec'y for Conservation, Buildings Energy Research Divison, under Contract DE-AC03-76F00098.

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Acknowledgements

The authors are grateful to Raymond Hartman, Eric Hirst, Edward Kahn, Mark Levine, Steve Meyers, Michael Rothkopf, Henry Ruderman, and Jayant Sathaye for their comments on an earlier draft of this report. The authors are particularly indebted to Peter Back, Calvin Kilgore, John Millhone, and David Sandoval of the Department of Energy for their helpful interactions and continuing support throughout the project.

ABSTRACT

The purpose of this study is to develop an econometric model of residential energy demand at the end-use level for the eight countries in the Organization of Economic Cooperation and Development (OECD).

A multinomial logit model was developed and estimated for the total residential demand and the space heating component. The model consists of an aggregate demand equation and a set of fuel share equations. Annual data for selected years during 1960-79 from eight countries are pooled for estimation. The statistical results show that energy price, income, heating degree days, house size, and the saturation of central heating are important determinants for total residential demand and its space heating component. In other words, the differences in residential energy use patterns among the eight OECD countries can be explained by the differences in these structural variables.

Four sets of energy demand elasticities were computed from the model's estimates. The estimates of the overall price elasticity are -0.513 and -0.356 for the total residential demand and space heating demand, respectively. The corresponding estimates of income elasticity are 0.771 and and 0.465. The other fuel share elasticities and conventional fuel demand elasticities were also computed and presented in the report.

1. INTRODUCTION

The purposes of this study are: (i) to formulate and estimate econometric models of residential energy demand at the end-use level from an inter-country perspective and (ii) to use the statistical results to determine the important economic and demographic factors -- as well as housing characteristics -- that explain the differences in residential energy use among the eight OECD countries analyzed (Canada, France, West Germany, Italy, Japan, Sweden, United Kingdom, and United States).

This study represents a continuation and extension of the work on international comparison of residential energy use documented in Lee Schipper et al.[1] This group at the Lawrence Berkeley Laboratory collected much of the needed data for the present study. One special feature of this data base is that it is by energy type for different end-uses. Even though the present study focuses on space heating because of its importance, studies of other types of end-uses such as water heating, cooking, etc., can be pursued later. The LBL group also developed various indicators such as energy use per dwelling, energy use per degree day etc. and conducted international comparison of the energy use patterns in the residential sector.

Table 1 shows that average energy consumption per dwelling varies widely across the eight OECD countries, even after the figures are adjusted by heating degree days. This energy consuming pattern suggests that there exists important economic, social, and demographic factors affecting energy consumption in the residential sector. This study employs statistical methods to quantify the extent to which the residential energy consumption pattern is affected by various economic and demographic factors for which data are available.

The plan for the remainder of the report is the following: In Section 2, the model for the present study is specified and the theoretical issues, as well as the procedures for calculating various energy demand elasticities, are discussed. Data sources and some historical trends are discussed in Section 3. Econometric estimation and regression results are presented in Section 4. Section 5 details the international comparisons of the estimated demand elasticities. The report is completed with some concluding remarks in Section 6.

Note that, throughout this report, energy usage or demand is measured using the following SI units:
1 Joule = 0.239 cal = 0.9484 x 10^{-3} BTU = 0.278 x 10^{-6} kWh;
1 KJ = 10^3 J; 1 MJ = 10^6 J; 1 GJ = 10^9 J; 1 PJ = 10^{15} J.

Table 1. Comparison of Residential Energy Use for Eight OECD Countries[a]

Country	Year	Residential Energy Use Indicators		
		Total Energy Use Per Dwelling, GJ	Heating Energy Use Per Dwelling, GJ	Heating Energy Use Per Dw./Degree-Day, MJ
Canada	1978	170	125	27
France	1978	80	59	26
West Germany	1978	87	70	22
Italy	1978	63	47	22
Japan	1979	36	11	6
Sweden	1978	102	67	17
U.K.	1978	81	52	18
U.S.	1978	139	90	33

a. All figures refer to end-use energy delivered at the building boundary.

2. MODEL SPECIFICATION

2.1 An Overview

Total residential energy demand, in general, can be obtained by summing up the subdemand components over end-uses and fuel types. Specifically, total demand (E) can be expressed as:

$$E = \sum_{i=1}^{N} \sum_{j=1}^{M} E_{ij} \qquad (1)$$

where E_{ij} is the demand for end-use i and fuel type j. The disaggregation of energy demand to end-use level by fuel type represents the most detailed tractable demoposition of demand components that one can hope for in a complete study of residential energy demand. In some instances of studying a particular end-use demand, of course, further disaggregation of the end-use demand to different end-use technologies such as central air conditioning and window-unit air conditioning is possible.

The residential end-use energy model developed by Hirst and his associates[2] and the micro-econometric simulation model developed by Goett and McFadden[3] represent the state of art in modeling residential energy demand components (E_{ij}) by end-use and by fuel type. These detailed end-use models, however, require an enormous data base, many elements of which are difficult, if not impossible, to determine. For example, electricity prices are generally not available by end-use even though there can be considerable differences in what customers have to pay for, say, lighting and air conditioning.

In order to avoid the problems of data limitations, energy analysts also try to model energy demand by further aggregation over either end-uses or fuel types. Specifically, one may work with aggregate demand by fuel type as:

$$E_j = \sum_{i=1}^{N} E_{ij} \qquad (2)$$

As such, we have seen many studies for electricity demand, natural gas demand and the demand for petroleum products.[4] The other category is the aggregate demand by end-use as:

$$E_i = \sum_{j=1}^{M} E_{ij} \tag{3}$$

As such, there are studies for space heating, air conditioning, water heating, etc.[5,6]

In the present study, the basic energy use data are developed by end-use and by fuel type, i.e., by E_{ij}. For the end-use category, we analyze only space heating. With further refinement of the data base, the methodology developed here can be easily applied to other end-uses such as water heating, cooking, and other electric appliances.

2.2 Selection of Econometric Specification

There are alternative specifications for modeling residential energy demand. Most obviously, various demand components in Equation (1) can be modeled independently as a function of energy prices (own-price and cross-price variables), income, degree days, and other pertinent variables. If consistent data are available only for one or limited types of fuels, this single-equation approach is generally used. However, if data are available for all types of fuels used for an end-use or a consuming sector, it would be better to use the fuel choice models so that market share and inter-fuel substitution can be better represented. There are several types of fuel choice models which were developed recently. One of the most popular models is the multinomial logit model previously used by Baughman and Joskow.[7] Basically, the model consists of one aggregate demand equation and a set of fuel choice equations. Let S_i be the market share of fuel i. The multinomial logit model specifies the fuel choice equation as

$$\ln (S_i / S_j) = \alpha_0 + \alpha_1 \ln (P_i / P_j) + \alpha_3 \ln X \tag{4}$$

where P_i = price of fuel i

X = other explanatory variables,

α = parameters to be estimated.

The number of fuel choice equations depends upon the number of fuels. For example, if there are four fuel types, three fuel choice equations like Equation (4) are needed. It is often constrained that the price coefficient, α_1 is the same across all fuel choice equations. Therefore, the estimated cross-price elasticities for market shares are identical for all fuels.

As an extension of the multinomial logit model Chern and Just[8] developed a generalized fuel choice model in which the fuel choice equation is expressed as:

$$\ln (S_i / S_j) = \alpha_0 + \alpha_1 \ln P_i + \alpha_2 \ln P_j + \alpha_3 \ln P_k + \alpha_4 \ln X \quad (5)$$

where P_k = prices of fuels other than i or j.

Comparing Equation (5) with Equation (4), one can see that no constraint on the cross-price elasticities is imposed in the generalized fuel choice model. Furthermore, a so-called "third price effect" is present in the generalized fuel choice model where it is omitted from the multinomial logit model. However, as a result of relaxing this constraints, there are more parameters to be estimated in the generalized fuel choice model than in the multinomial logit model.

Both fuel choice models were tested in our preliminary analysis. The results for the generalized fuel choice model are less than satisfactory because some of the estimated price coefficients (own-price and cross-price) do not have the correct sign It has been our experience that estimation of the generalized fuel choice model requires good and more disaggregate data on fuel prices to avoid the problem of multicollinearity. For example, the successful applications of the generalized fuel choice model to the paper industry[9] and more recently to the primary metals industry[10] were attributed to the availability of highly disaggregate state-level data. There were substantial variations of observed prices between fuels and between states for the two industries investigated. There was, however, an unsuccessful example. In another study Chern[11] attempted to estimate the fuel choice equations for 12 energy consuming sectors in Taiwan using aggregate data which exhibit similar movements among the energy price data series. The estimation of a generalized fuel choice model, in this case, encountered a severe problem of multicollinearity. Under this circumstance, it is better to estimate a multinomial logit model. A similar problem occurred in this study, so the multinomial logit model was finally adopted.

2.3 Specification of a Multinomial Logit Model

The scope of this study include the analysis of aggregate residential energy use and its major end-use component for space heating. For both of these categories, there are four different types of fuel: fuel oil, gas (including natural gas, LNG, LPG and city gas), solid fuels (including mostly coal, but also wood and charcoal), and electricity. District heat, as commonly used in France, West Germany, and Sweden, is treated as part of fuel oil which is the most predominant energy source for district heating.

Recall that the model consists of one aggregate demand equation (summary over all fuel types) and a set of fuel choice equations. For the aggregate demand equation, the dependent variable may be expressed as total or per unit consumption. In the residential sector, two common approaches for normalization can be adopted. One is to use population as the denominator; the other is to use the number of dwellings. The preliminary results show that both approaches of normalization work equally well. We decided to normalize energy use on a per dwelling basis and consider the variable of "number of people per dwelling" as one of the possible regressors. This allows a more accurate analysis of the importance of structural factors (dwelling size, dwelling type, central heating saturation, fuel shares) in explaining the differences among countries.

Before specifying the model, we define the econometric variables used for modeling the aggregate residential energy demand as follows:

E_1 = total consumption of gas in the residential sector (in GJ),

E_2 = total consumption of solid fuels in the residential sector (in GJ),

E_3 = total consumption of fuel oil in the residential sector (in GJ),

E_4 = total consumption of electricity in the residential sector (in GJ),

$E = E_1 + E_2 + E_3 + E_4$ = total energy consumption in the residential sector (in GJ),

P = weighted average real energy price in the residential sector (in US dollars per GJ),

$S_1 = E_1/E$ = market share of gas (maximum = 1.00),

$S_2 = E_2/E$ = market share of solids (maximum = 1.00),

$S_3 = E_3/E$ = market share of fuel oil (maximum = 1.00),

$S_4 = E_4/E$ = market share of electricity (maximum = 1.00),

P_1 = real price of gas used in the residential sector (in US dollars per GJ),

P_2 = real price of coal used in the residential sector (in US dollars per GJ),

P_3 = real price of fuel oil used in the residential sector (in US dollars per GJ),

P_4 = real price of electricity used in the residential sector (in US dollars per GJ),

DW = Number of occupied dwellings,

PPI = real disposable personal income per dwelling (in 1970 US dollars),

HDD = heating degree days,

CH = saturation level of central heating (%)

SIZ = average size of dwellings (in m^2),

C_i = country dummy having the value of 1.0 for country i, and zero otherwise.

Note that all prices and income are expressed in real 1970 U.S. dollars. The issues related to this currency conversion will be discussed later.

For the total residential energy demand, the model consists of one aggregate demand equation and three fuel choice equations:

Aggregate demand equation: There are two alternative specifications. One is to use total consumption as the dependent variable. The other is to use the consumption per dwelling as the dependent variable. Using the latter specification, the aggregate demand equation is expressed as:

$$\ln (E_{it}/DW_{it}) = \alpha_o + \alpha_1 \ln P_{it} + \alpha_2 \ln PPI_{it} + \alpha_3 \ln HDD_{it} + \alpha_4 \ln CH_{it} + \alpha_5 \ln SIZ_{it} + \sum_{i=1}^{7} \alpha_{5+i} C_i + e_{it} \qquad (6)$$

$$\text{and } P_{it} = \sum_{j=1}^{4} P_{jit} S_{jit} \; ; \; S_{jit} = E_{jit}/E_{it} \; ,$$

where i = country,
t = year,
j = fuel type,
S = market share,
α = coefficients to be estimated,
e = disturbance term,

and all other variables were defined previously. Note that, if the total consumption, ln E, is used as the dependent variable, the number of dwellings will be included as one of the explanatory variables.

Fuel choice equations: They are expressed as

$$\ln (S_{1it}/S_{3it}) = \beta_{13} + \beta_{131} \ln (P_{1it}/P_{3it}) + \beta_{132} \ln PPI_{it} + \beta_{133} \ln HDD_{it} + \beta_{134} \ln CH_{it}$$

$$+ \sum_{i=5}^{11} \beta_{13i} \, C_{i-4,t} + \mu_{it} \qquad (7)$$

$$\ln (S_{2it}/S_{3it}) = \beta_{23} + \beta_{231} \ln (P_{2it}/P_{3it}) + \beta_{232} \ln PPI_{it} + \beta_{233} \ln HDD_{it} + \beta_{234} \ln CH_{it} + \sum_{i=5}^{11} \beta_{23i} \, C_{i-4,t} + n_{it} \qquad (8)$$

$$\ln (S_{4it}/S_{3it}) = \beta_{43} + \beta_{431} \ln (P_{4it}/P_{3it}) + \beta_{432} \ln PPI_{it} + \beta_{433} \ln HDD_{it} + \beta_{434} \ln CH_{it} + \sum_{i=5}^{11} \beta_{43i} \, C_{i-4,t} + \epsilon_{it} \qquad (9)$$

and

$$\sum_j S_{jit} = 1$$

with the constraint:

$$\beta_{131} = \beta_{231} = \beta_{431}$$

where β = coefficients to be estimated, μ, n, ϵ = disturbance terms, and all other variables were defined previously. The constraint simplifies the symmetric condition, and consequently, the cross-price elasticities are assumed to be identical across the share equations.

Under the logit specification, it is necessary to adjust all fuel consumption variables on an equivalent useful energy basis to account for differences in system efficiency.[12] The efficiency conversion factor is assumed to be 1.0 for electricity, 0.65 for gas, 0.55 for fuel oil, and 0.45 for solids. District heating energy use has an assumed efficiency factor of 1.0 at its point of use. These nominal efficiencies are approximate but sufficient for the present work.[13] The observed fuel consumption variables are multiplied by their efficiency conversion factors. Likewise, all observed fuel prices are divided by their efficiency conversion factors to obtain the comparability on the equivalent useful energy basis.

For the space heating component, the same model specification is adopted. The fuel consumption and market shares variables in Equations (6) - (9) are replaced by the following variables for space heating:

HE_1 = total consumption of gas for space heating (in GJ),

HE_2 = total consumption of solid fuels for space heating (in GJ),

HE_3 = total consumption of fuel oil for space heating (in GJ),

HE_4 = total consumption of electricity for pace heating (in GJ),

$HE = HE_1 + HE_2 + HE_3 + HE_4$ = total energy consumption for space heating (in GJ),

$HS_1 = HE_1/HE$ = market share of gas used for space heating (between 0 and 1),

$HS_2 = HE_2/HE$ = market share of solid fuels used for space heating (between 0 and 1),

$HS_3 = HE_3/HE$ = market share of fuel oil used for space heating (between 0 and 1),

$HS_4 = HE_4/HE$ = market share of electricity used for space heating (between 0 and 1),

HP = weighted average real energy price for space heating (in 1970 US dollars per GJ).

Note that the weighted average energy price (HP) differs from P in Equation (6) because the market shares, as weighting factors, are different.

Instead of using the fuel shares, it may be preferable to use the fuel choices defined as the percentage of dwellings using a particular fuel for space heating. These percentages can be computed from the stock of appliances. Unfortunately, the available data for appliance stocks are much more limited than that for energy use. Totally, we have only 22 observations. Furthermore, if the fuel choices, based on the stock of appliances are used, we have to estimate demand equations for individual fuels rather than an aggregate demand equation; otherwise, the demand for individual fuel can not be derived. We tested the model using the fuel choices and found that the choice equations did not differ considerably from the fuel share equations. However, the individual fuel demand equation are more difficult to estimate because of the small number of observations. In general, data for fuel shares are more reliable than stock of appliances. Consequently, we used the same fuel share approach as used for the aggregate residential demand.

2.4 Theoretical Issues

There are several theoretical issues related to the specification of the model used for the present study. The first and the most important issue deals with the distinction between short-run or long-run responses. In order to discuss this issue, we first note that the available data for this study are not continuous time-series data. Therefore, a dynamic specification, such as the Koyck-type distributed lag model is not feasible.

The model presented in Section 2.3 is basically a static model. Conventionally, the elasticity in a static model, when it is estimated from a single time-series, is often interpretated as a short-run elasticity. If it is estimated from cross-sectional data, it is often interpretated as a long-run elasticity. But if pooled time-series and cross-section data are used to estimate the parameters in a static model, the distinction between short-run and long-run is not obvious. Consequently, this distinction is often not discussed in this situation. However, Pindyck[14] argued that his "pooled" model captured the long-run response largely on the basis of empirical results.

Houthakker[15] provided useful interpretations for the results obtained from a pooled model in his earlier work on international consumption analysis. Specifically, he analyzed two sources of the pooled sample variation -- a cross-section or "between" country variation and time-series or "within" country variation. He argues that if the time series observations are drawn for a long period over which each country was reasonable close to its long-run equilibrium, then the "between" country variation reflect the long-run response. To capture the long-run responses, one should thus estimate a model from the sample means for each country. On the other hand, the model with country dummies which consequently eliminates "between" country variation reflects short-run responses. The pooled model without country dummies yields the result that is mixture of short-run and long-run variation. However, to the extent that the "between" country variation dominates the "within" country variation as likely to be the case in the present study, the coefficient estimate will approach the long-run value in such a model (without country dummy variables).

Since the time-series is not continuous and the number of countries is small, our data base is not adequate to estimate a model with only the "between" country variation. Nevertheless, the Houthakker's analysis provides a basis for interpretating our econometric results. Specifically, if Equations (6) - (9) are estimated with country dummies, the estimated coefficients may be interpreted as short-run coefficients. When country dummies are excluded, we are likely to obtain coefficients that reflect closely the long-run responses. Note further that theoretically, the short-run elasticities are smaller than the long-run elasticities. Unfortunately, these theoretical results are sometimes complicated by other statistical problem. As will be discussed later, the high correlations between the country dummies and several explanatory variables distort some of these theoretical expectations.

Note that the saturation level for central heating is included as one of explanatory variables in the aggregate demand equation. It was shown previously by Chern et al.,[16] and Parti and Parti[17] that, when the saturation levels of all appliances are included in the end-use equation, this results in a conditional short-run demand equation. It is a conditional demand equation because the appliance saturations (or stock of appliances) are fixed or exogenous in the model. Consequently, the price elasticity should be smaller in the conditional demand equation than that in the demand equation without appliance saturations. For empirical estimation, a sensitivity analysis, will be conducted to examine the impacts of the inclusion of this saturation variable. Note that even though this saturation variable only accounts for central heating, there exists a high correlation between its saturation level and the average energy use (Table 2).

Table 2. The Relationship between Average Energy Use and Saturation of Central Heating[a]

Country	Year	Saturation of Central Heating (%)	Average Energy Use per Dwelling, GJ
Canada	1978	93	122
France	1978	60	51
Germany	1978	66	56
Italy	1978	57	39
Japan	1979	4	25
Sweden	1978	99	76
U.K.	1978	54	53
U.S.	1978	86	105

a. All figures were converted to useful energy demand.

The fuel choice is generally considered as a long-run phenomenon. However, since we are working with aggregate fuel shares, there exist both short-run and long-run responses. Our careful examination of the data on aggregate fuel shares indicates that there is stronger "inter-country" variation than "within country" variation. Thus, the estimated coefficients in the relative share equations may reflect more the long-run than short-run impacts, especially when country dummies are excluded.

Despite the preceding attempt to analyze, on a theoretical ground, the properties of the model in terms of the distinction between short run and long run, the ultimate judgement lies in the empirical results. We should also compare our estimates with available statistical evidence to see whether the model more reasonably captures long-run or short-run responses.

2.5 Demand Elasticities

There are four sets of demand elasticities that can be directly obtained or calculated from the model specified in Section 2.3.

First, the estimated parameter α_1 in Equation (6) is the aggregate price elasticity, measuring the percent change in total demand in response to a 1% change in aggregate energy price. This elasticity is assumed to be the same for all countries. The statistical significance of this elasticity would, of course, indicate that energy price is an important factor for explaining the differences in residential energy use patterns across countries.

Second, market share elasticities can be computed from the estimated parameters in Equations (7) - (9). The most interesting elasticities are the own-price and cross-price elasticities. As shown by Baughman and Joskow[18], the own-price elasticities can be computed as

$$m_{ii} = \frac{\partial \ln S_i}{\partial \ln P_i} = \beta_{131} \ (1 - S_i).$$

The cross-price elasticities are computed by

$$m_{ij} = \frac{\partial \ln S_i}{\partial \ln P_j} = -\beta_{131} \ S_j.$$

Since these market share elasticities depend upon the value of market shares, the estimated elasticities vary from country to country.

The third set of elasticities are aggregate demand elasticities with respect to individual fuel prices. They can be computed as follows:

$$A_j = \frac{\partial \ln(E/DW)}{\partial \ln P_j} = \frac{\alpha_1}{P}\left\{\sum_{i=1}^{4} P_i\ S_i\ m_{ij} + S_j\ P_j\right\}$$

where α_1 = the estimated price elasticity in Equation (6),

m_{ij} = market share elasticities.

These elasticities can be computed using the mean values of P, P_j ,and S_i. Thus, the elasticity estimates vary from country to country.

The last set of elasticities are generally referred to as the conventional fuel demand elasticities. The conventional own-price and cross-price elasticities can be calculated from market share elasticities (m_{ij}) and aggregate demand elasticities (A_j) as follows:

$$L_{ij} = \frac{\partial \ln(E_i/DW)}{\partial \ln P_j} = A_j + m_{ij}$$

When i=j, L_{ij} is the own-price elasticity; when i≠j, L_{ij} is the cross-price elasticity. Since A_j and m_{ij} are different between countries, the estimated L_{ij} also vary from one country to another.

3. DATA

3.1 Original Sources

Most of the energy data used in this study were previously collected by Schipper, Ketoff, and Meyers for their efforts in developing energy use indicators for conservation analysis.[19] As recognized by these authors, data on different uses of energy in the residential sector are difficult to obtain. International organizations like the International Energy Agency (IEA) in Paris, as well as most member countries, still mix the residential energy use with the "other" sector, which accounts for all segments except the transportation and industrial sectors. The unavailability of detailed end-use data has hindered national and international efforts to develop a coherent policy for improving energy use efficiency in the residential sector, and to measure recent progress in energy conservation.

The data were collected through "on site" visits to various countries. Basic information was gathered from both official and unofficial sources. Unfortunately, time constraints forced us to develop data only for selected years. Table 3 shows the years of available observation in these eight countries. Although the data series is not continuous, it covers both "pre-embargo" and "post-embargo" periods. Data was originally assembled for seven major OECD countries: Canada, France, West-Germany, Italy, Japan, Sweden, and the United Kingdom. Additional consistent data for the United States were recently assembled by Meyers[20] and integrated for the purpose of this study.

Table 3 – Residential Data Base: Years and Countries Pooled[a]

	Year																			
Country	1960	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79
Canada	–	X	–	–	–	–	X	–	–	–	–	X	–	–	–	–	X	–	X	–
France	–	–	X	–	–	–	–	–	–	–	–	–	–	X	–	–	–	–	X	–
W. Germany	X	–	–	–	–	X	–	–	–	–	–	–	X	–	–	X	–	–	X	–
Italy	–	–	–	–	–	–	–	–	–	–	–	–	X	–	–	X	–	–	X	–
Japan	–	–	–	–	–	X	–	–	X	–	–	–	–	X	–	X	–	X	–	X
Sweden	–	–	–	X	–	X	–	–	–	–	–	–	X	–	–	–	–	–	X	–
U.K.	–	–	–		–	–	–	–	–	–	X	–	–	–	–	X	–	–	X	–
U.S.	X	–	–	–	–	–	–	–	–	–	X	–	–	–	X	–	–	–	X	–

a. The "X" mark indicates year with available data.

3.2 Dependent Variables

As discussed in Section 2, the dependent variables in the aggregate demand equation can be either total demand or the average demand per dwelling. It is constructive to show how different these energy indicators are among different countries. Table 4 shows the aggregate energy use for total residential uses and for space heating in the eight OECD Countries. This aggregate figure is simply the sum of oil gas, solid fuels, and electricity. Clearly the United States consumed more energy for household purposes than any other countries in the group. Of course, the U.S. also has a larger number of dwellings. Table 5 shows the two average energy use indicators for the 1960-1978 period. These figures refer to the household energy use in the occupied dwellings only. The per dwelling normalization of the space heating end-use assumes that all occupied dwellings are heated, thus inducing a slight underestimation of the indicator for earlier observations. This is true especially for Italy and Japan, the countries with warmest climate and lower level of disposable income, where heating was present in only 75-80 per cent of the homes in 1960.

For a better comparison of the trends in energy intensities, the space heating figures presented in Table 5 were corrected for the yearly climatic variations, using actual heating degree-days values to normalize the demand to the long-range average local climate. These variations can sensibly affect the data although they rarely exceed 10% in either direction. Since it is preferable to estimate the explanatory relationship between energy use and climatic conditions, we, in this study, use the quantities of useful energy demand at the actual climate.

The need for maintaining consistency among countries requires a uniform format for aggregation over different energy types. Here are the important definitions:

1. Oil includes heavy and light heating oil, and kerosene.

2. Gas includes natural gas, city gas, liquified petroleum gas (LPG), and liquified natural gas (LNG).

3. Solids include coal, coke, and wood.

4. District heating is accounted in the fuel of origin (mostly oil), but without converting it for the efficiency factor.

Table 4. Aggregate Delivered Energy for Total End-Uses and Space Heating in the Residential Sector[a]

Country	Year	Total Energy Use (PJ) Space Heating	All End-Uses	percent of Space Heating Usage %
Canada	1978	1009.8	1353.9	74.6
France	1978	1061.5	1452.1	73.1
Germany	1978	1693.2	2024.0	83.7
Italy	1978	794.4	1060.0	74.7
Japan	1979	350.8	1184.0	29.6
Sweden	1978	267.5	336.8	79.4
U.K.	1978	1053.5	1620.0	65.0
U.S.	1978	6630.0	11518.0	57.6

[a]The energy use figures are not adjusted by the efficiency factors.

Table 5 - Indicators of Residential Energy Demand[a]

Country	1960-65	1970-73	1978-79
AGGREGATE END-USE ENERGY PER DWELLING (GJ)			
CANADA (1961-71-78)[b]	95	112	122
FRANCE (1962-73-78)	NA[c]	50	51
GERMANY (1960-72-78)	30	52	56
ITALY (1960-72-78)	NA	36	39
JAPAN (1965-73-79)	13	22	25
SWEDEN (1963-72-78)	60	71	76
U.K. (1961-70-78)	NA	50	53
U.S. (1960-70-78)	90	112	105
SPACE HEATING PER DWELLING (GJ)			
CANADA	81	85	83
FRANCE	NA	37	34
GERMANY	32	41	42
ITALY	NA	27	27
JAPAN	4	8	7
SWEDEN	42	45	48
U.K.	NA	30	32
U.S.	56	69	55

a. All figures refer to useful energy demand.

b. Indicates the specific years used during various periods.

c. NA = not available. Although we had the total aggregate and total space heating energy figures for those years, we could not split them by fuel type, thus the conversion to useful energy was not performed.

3.3 Explanatory Variables

A. Energy Prices

The price data series were obtained from the Energy Information Administration of the U.S Department of Energy,[21] and from other national publications when available. These price series are the average energy prices paid by the residential consumers, taking into account the local price variations from town to town (or region to region). In the case of electricity or gas, however, we do not differentiate between prices paid by customers with and without heat. This difference is as high as a factor of two, and introduces a bias in the study, since increasing fractions of gas and electricity are used for heating as time goes on. That is, the average price of each of these sources falls if the number of customers with heat rises relative to those without. Second, prices for district heat, electricity, and gas include high fixed charges in all of Europe, which is not the case for oil. The cost of the energy itself is significantly lower than the average cost we have given, particularly so for electric heat. Finally, in some cases (e.g. in Sweden) consumers in apartments do not pay for heat in proportion to consumption. It is noted that, at the present, we do not have adequate data to construct any marginal price measure in a consistent manner for all countries under investigation. In future work we hope to attend to these problems.

To make international comparisons of energy prices (and income), it is necessary to convert the values in local currency to a comparable unit, such as U.S. dollars. Two alternative approaches were studied: the use of market exchange rates; and the use of conversion rates reflecting the purchasing power parities among countries. The second approach appears theoretically superior since the purchasing power parities relate to the total national expenditures, while the market exchange rates relate only to the portion of expenditures for international transactions.

Although various colleagues had suggested the adoption of the well tested European index "Standard de Pouvoir d'Achat",[22] we preferred the use of "Purchasing Power Parities" (PPP) developed by Kravis et al.[23,24] for the United Nations International Comparison Project (ICP). In their latest report, Kravis et al. present different sets of PPP for sixteen countries for 1970 and 1973. There are three conventional indices for U.S.-other country binary comparisons, based on U.S. quantity weight, other country quantity weight, and "ideal" weight -- simply a combination of the other two. They also computed a multilateral parity (according to Geary-Khamis method) using as a base total expenditure at international prices. These prices are determined by quantity-weighted average of PPP adjusted national prices. However, this later approach while allowing us to take whichever country as base, included countries like India, Iran, Colombia, and Kenya, whose economies are considerably different from the OECD nations.

We finally chose the ideal binary parity, in accordance with an ICP exercise of bridging countries through binary parities, and with the Resource for the Future (RFF) comparative analysis of energy use in industrial societies by Darmstadter et al.[25]

The ICP study provides the PPP index for only five of the seven countries we needed -- France, Germany, Italy, Japan, and United Kingdom. Therefore, consistent estimates are required for Canada and Sweden. Since both countries show a considerable similarity in per capita income levels with the United States, their binary parities were estimated by using the 1970 market exchange rates. For Sweden the parity is further interpolated -- as done in the RFF analysis -- on the basis of the differences in conversion rates observed among other countries.

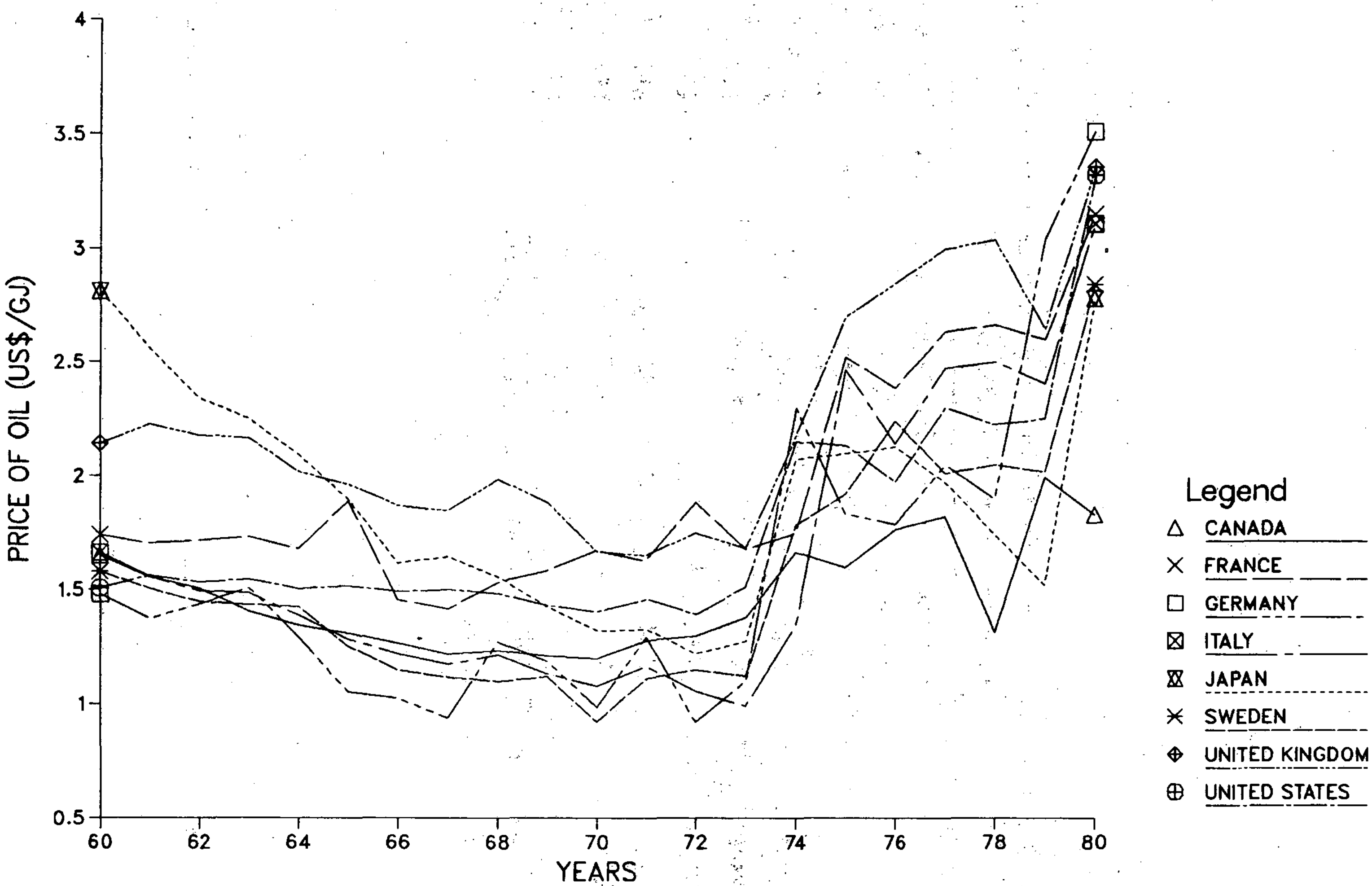
The PPP values adopted are all for 1970 (the base year for prices and incomes) and are presented in Table 6. The market exchange rate are also presented in the table. For all countries, the parity is below the market rate, implying that the levels of other countries' energy prices and income would be substantially underevaluated if they were converted using market exchange rates.

Figures 1 through 4 show the comparisons of the historical real prices of oil, gas, solids, and electricity among the eight OECD countries. These fuel prices were not adjusted by the efficiency conversion factors. There is substantial variation in energy prices among the eight countries. In general, the fuel prices reversed their declining trend after the 1973 oil embargo with a few exceptions. As Figure 4 shows, the real price of electricity has been increasing since the early 1970's for all countries except France and Italy where electricity price declined consistently throughout the entire sample period.

Table 6 - Purchasing Power Parities and Market Exchange Rates, 1970
(foreign currency unit per US $)

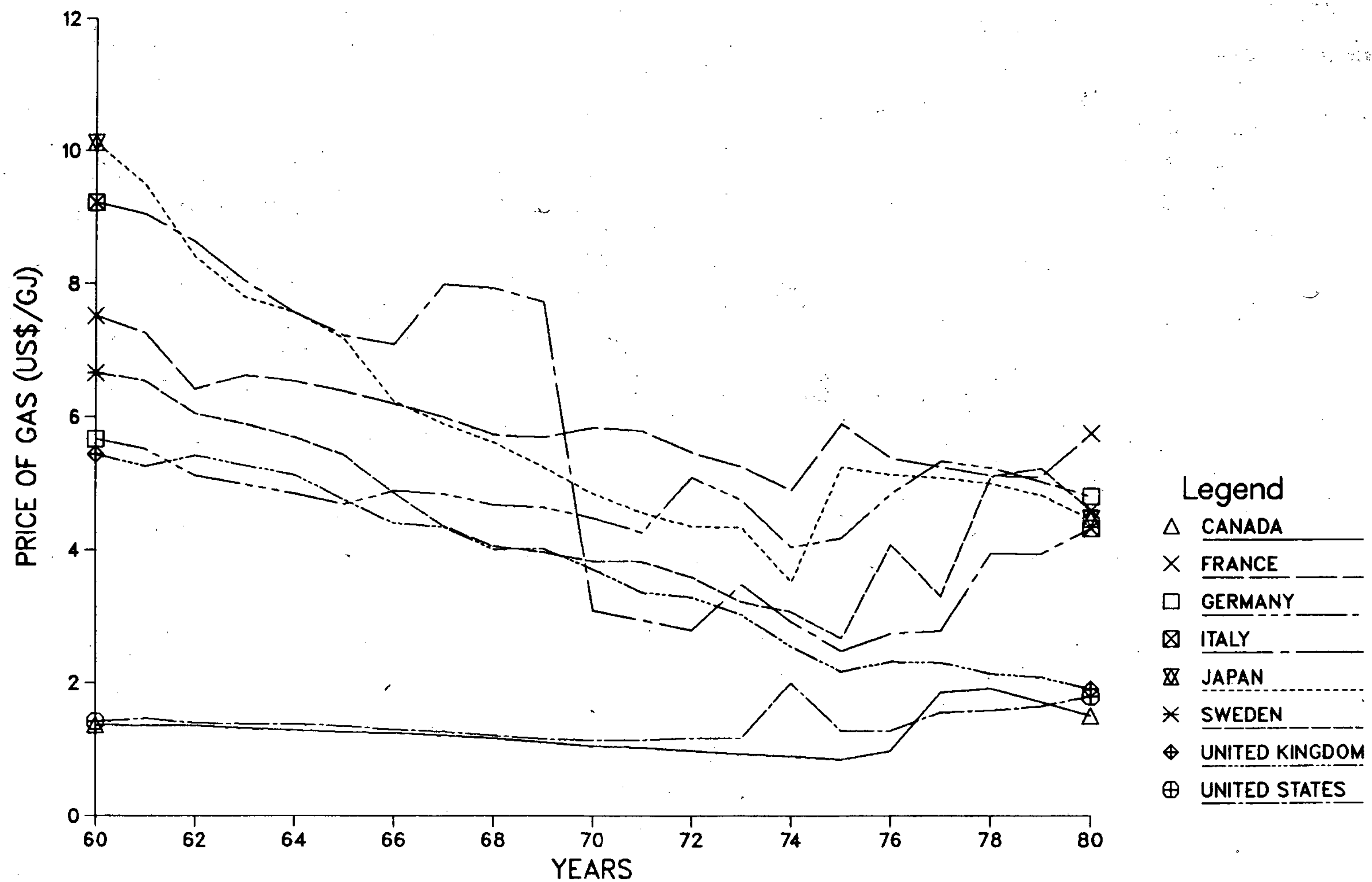
	Binary Ideal Parity	Market Exchange Rate	Index of Exchange Rate Deviation
CANADA(C$)	1.01	1.01	100
FRANCE(FF)	4.49	5.52	123
GERMANY(DM)	3.16	3.65	116
ITALY(Li)	455	623	137
JAPAN(Y)	254	358	141
SWEDEN(Kr)	4.60	5.17	112
U.K.(L)	0.304	0.417	137

Source: ICP Report, 1978. Canadian and Swedish parities are LBL estimates.



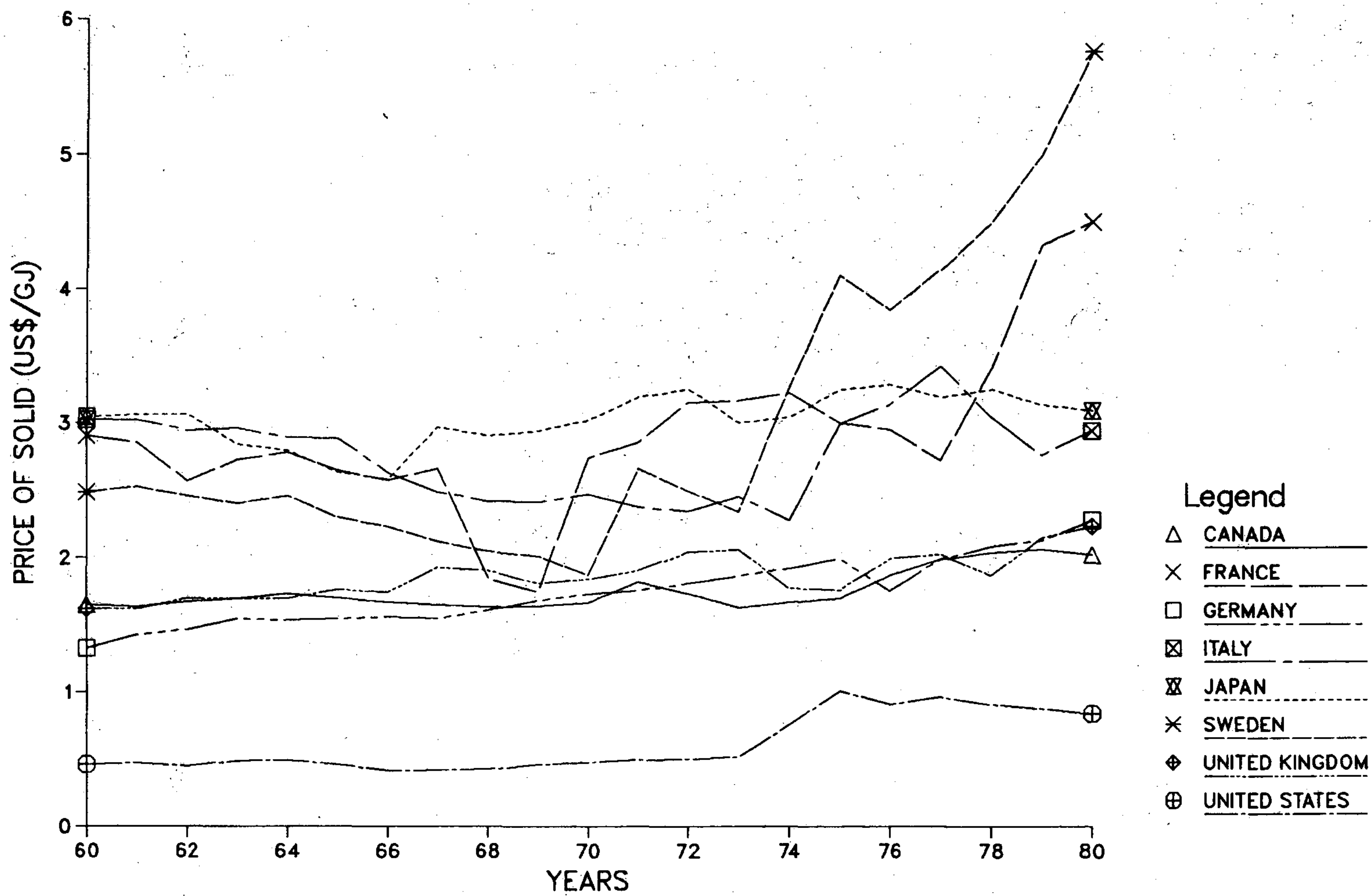
DELIVERED OIL PRICE FOR EIGHT OECD COUNTRIES

FIGURE 1



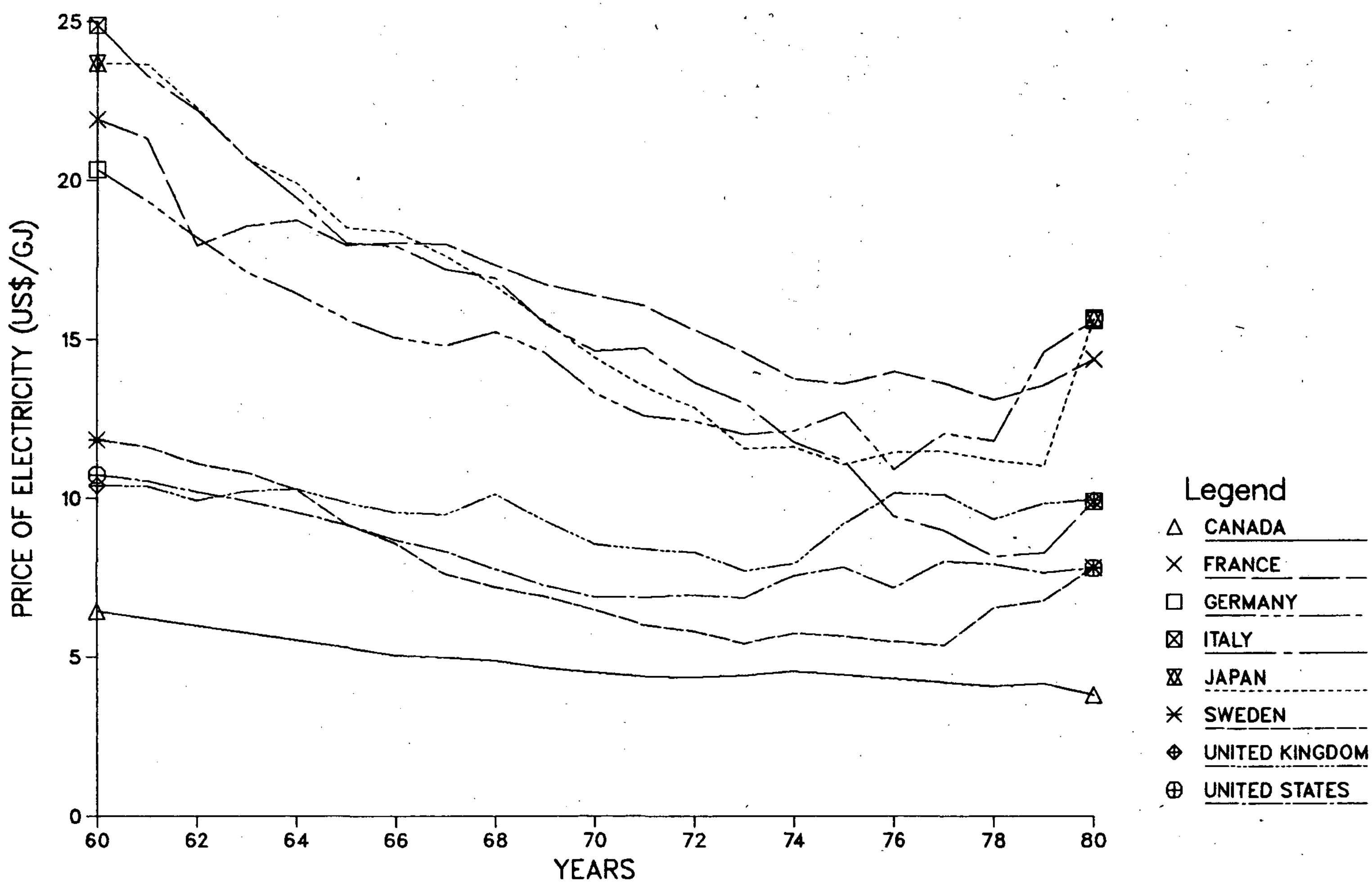
DELIVERED GAS PRICE FOR EIGHT OECD COUNTRIES

FIGURE 2



DELIVERED SOLID PRICE FOR EIGHT OECD COUNTRIES

FIGURE 3



DELIVERED ELECTRICITY PRICE FOR EIGHT OECD COUNTRIES

FIGURE 4

B. Income

There are considerable differences in the level of personal disposable income among the countries analyzed. However, as Table 7 shows, for all countries, income steadily increased over the period before 1973, and had much slower rates of growth for the post-embargo period, especially during 1975-78.

As with energy prices, income figures in local currency were converted to U.S. dollars by using the Purchasing Power Parities.

Table 7 - Household Real Disposable Income Growth Rates (%/yr)

Country	1960-78	Pre-embargo (1960-73)	Post-embargo (1974-78)
CANADA	4.0	4.2	3.6
FRANCE	3.8	4.6	2.1
GERMANY	3.5	4.0	2.4
ITALY	3.9	4.9	1.9
JAPAN	5.1	9.7	-0.9
SWEDEN	2.7	3.9	0.9
U.K.	2.0	2.5	1.5
U.S.	2.5	2.7	2.3

C. Climate

When comparing energy use either over time or among countries, it is necessary to account for the effects of climate. In this study, the number of heating degree-days (HDD) is used. This variable gives a measure of heating requirements by integrating over the heating season the difference between the actual outdoor temperature and some reference indoor temperature. Although the "official" reference temperature differ among countries, we have adopted here the common base temperature of 18^oC and adjusted the published degree-days numbers accordingly. In Table 8 we present these adjusted values of the long term averages. Japan has the warmest climate while Canada and Sweden are the coldest countries in the group.

Table 8 - Average Heating Degree-Days (Base 18^oC)

Country	Degree-Days
CANADA	4581
FRANCE	2200
GERMANY	3163
ITALY	2140
JAPAN	1800
SWEDEN	4010
U.K.	2917
U.S.	2630

D. Structure-Related Variables

The structural factors refer to such things as house size, single-family vs. multi-family dwellings, saturation of central heating systems, etc. There appears to be a high correlation between these structure factors and income level. For example, larger homes, warmer internal temperature, high rate of single-family dwellings, and high saturation level of central heating all seem to be characteristics of a rich country. However, data show that these characteristics cannot be simply related to the income level. The average dwelling area is larger in U.S., Canada, and Sweden (the three richest countries) than elsewhere. However, Japanese homes are larger than French ones although Japanese average income per dwelling is only three fifth of French income. Central heating, which almost reaches a full saturation in Sweden, Canada, and the U.S., is highly dependent on climatic conditions. In this study, we include the dwelling size, and the saturation level of central heating as explanatory variables in the model.

The general definition of central heating varies among countries, and, therefore, original data were adjusted for consistency. In Germany and U.K., for example, electric storage heat, which represents the bulk of all electrical heating in those countries, consists of room heaters and is not considered central. In Sweden and Canada, however, storage heating is often water-borne and found in every room ("baseboard" heaters), and is considered central. Central heating in Italy means heating from one central system in the basement of apartment buildings. So, for consistency, the Italian central heating fraction considered here includes the so-called autonomous systems, where the furnace is inside the dwelling. In England, every room may have a heater but each heater is autonomous and fuels may differ. Electric heating in Sweden, France, and Canada is primarily central; but in Germany, U.K., Italy, and Japan it is not.

Table 9 summarizes the historical saturation level of central heating systems. For our purposes, central heating means heating produced in most or all rooms of a house by a single heating device, or heating produced in most or all rooms by modern electric or gas heaters. Small wood, oil, gas or coal stoves are not counted as central heating systems. Floor heating, common in German apartment buildings, is included with central heating, as is heating service provided by district heating stations.

Table 9 - Central Heating Saturation (%)

Country		1960-65	70-73	78-79
CANADA	(1961-71-78)[a]	67	81	93
FRANCE	(1962-73-78)	20	48	60
GERMANY	(1960-72-78)	16	49	66
ITALY	(1960-72-78)	10	41	57
JAPAN	(1965-73-79)	0.5	2	4
SWEDEN	(1963-72-78)	83	94	99
U.K.	(1961-70-78)	8	30	54
U.S.	(1960-70-78)	68	78	86

a. These are the years from which data are taken for the three periods.

Another important factor determining differences in energy use is the dwelling area, measured in square meters of useful living area. Dwellings have increased in size in all countries, while the number of persons per dwelling has generally decreased. Consequently, the dwelling area per person increased 20-35% over the 1960-78 period in the countries analyzed. Thus, there is more space to be heated per person, and more heat loss surface per person. A considerable variation between countries exists, as shown in Table 10.

Table 10 - Average Dwelling Area (m^2)

Country		1960-65	70-73	78-79
CANADA	(1961-71-78)[a]	97	98	99
FRANCE	(1962-73-78)	65	72	77
GERMANY	(1960-72-78)	68	74	76
ITALY	(1960-72-78)	58	65	73
JAPAN	(1965-73-79)	73	77	80
SWEDEN	(1963-72-78)	75	83	86
U.K.	(1961-70-78)	75	80	82
U.S.	(1960-70-78)	119	123	125

a. These are the years from which data are taken for the three periods.

E. Demographic variables

As discussed earlier, the number of dwellings is used either to normalize the energy use as the dependent variable or as one of the exploratory variables. In addition, we also have data on the household size measured as the number of people per dwelling. Unfortunately, there is a high correlation between average household size and per capita personal income. This variable was not included in the final model because of the problem of multicollinearity.

4. ECONOMETRIC ESTIMATION

4.1 Estimation Methods

There are alternative procedures for estimating the parameters in the model specified in Section 2. In this study, we compared two basic estimation procedures. The first is ordinary least squares (OLS). When country dummy variables are included in all the structural equations, OLS is generally termed as least squares with dummy variables (LSDV). In this study, we did not use the error components model for estimation. Since our time series are not continuous, it is difficult to implement the error components estimation.

The second method is two-stage generalized least squares (GLS) for a set of seemingly unrelated regression equations. Using this method, we estimate jointly the four equations in the model. This is a more efficient method because it considers the correlations among the structural equations. The results showed that the use of GLS substantially improved the estimates of the coefficients (i.e., lower estimated standard errors). Therefore, GLS was used for our final analysis. Note that, if hetroscadasticity exists, further improvement in efficiency can be made by allowing different variances among countries.

4.2 Preliminary Testing of Variables and Data Set

Extensive preliminary testing of the model was conducted before adopting the final specification presented in Section 2. The testing of alternative ways of normalization by either population or the number of dwellings was discussed previously. Here we report some of the important findings and observations from our preliminary testing of the model.

(1). Currency Conversion. As discussed in section 3, we examined two general approaches of currency conversion for the price and income variables. Specifically, we can use either the yearly exchange rates, or the purchasing power parity between the U.S. and each of the other countries under investigation. The converted data were then deflated by each country's consumer price index (1970 = 1.00) to obtain the real values.

It turned out that both approaches of conversion yielded similar results in estimation. Since using the purchasing power parity yielded the converted data series with a more reasonable trend than using the exchange rates did, purchasing power parity was used in the final analysis. The same approach was also adopted by Griffin[26] and Pindyck[27].

(2). Inclusion of Japan. On surface, it appears that the Japanese energy use pattern is quite different from the seven other OECD countries. It is, therefore, possible that the inclusion of Japan may distort the estimated demand structure, or in other words, the explanatory variables such as income and prices may not be able to explain the differences in energy use. To examine this possibility we run many sets of demand equations with and without Japan. The results showed that the estimated price and income coefficients were fairly similar between the two sets of sample data. This finding is consistent with the fact that Japan represents an extremum in many ways--mildest climate, most people per household, smallest dwellings, lowest consumer expenditures (i.e., income after savings), and high energy prices. We therefore, concluded that it was appropriate to pool Japan with other countries.

(3) Multicollinearity. Our initial analysis was based on data for seven countries (U.S. was not included). It was found that heating degree days and population (or the number of dwellings) had a high negative correlation (the correlation coefficients were greater than -0.8). This correlation was considerably reduced after the U.S. data were included, due to the fact that the U.S. has both a large population and a relatively high heating degree days.

Also, as discussed earlier, the household size variable was not included because of its high correlation with per capita personal income, resulting in a problem of multicollinearity. In the aggregate demand equation for total residential end-uses, the weighted average energy price has a relatively high negative correlation with income (R =

-0.66), degree days (R = -0.70), central heating saturation (R = -0.77), and dwelling size (R = -0.58). Therefore, it may be expected that the inclusion of these explanatory variables, especially the saturation variable, may reduce the explanatory power of the energy price. Note that these correlations are somewhat smaller in the space heating equation. Relatively high correlation is also found between the saturation variable and income (R = 0.72), the saturation variable and degree days (R = 0.75), and dwelling size and income (R = 0.78).

4.3 Estimation Results for the Aggregate Demand Equations

We made considerable efforts to examine the sensitivity of estimation results among alternative specifications of the structural equations. This sensitivity analysis focuses on the following areas: (1) the choice of the dependent variable in the aggregate demand equation, (2) the inclusion of country dummies, and (3) the presence of the two structure-related variables--house size and central heating saturation. Since these alternative specifications have stronger impacts on the estimation of the aggregate demand equation than the fuel share equations, the results for the formal equation are used as the basis for choosing the final model. Even though the four structural equations are always estimated jointly, only the results for the aggregate demand equation are presented here (the estimated fuel share equations for the preferred model are presented later).

Consider first the results for the total residential sector, i.e., for all end-uses. Table 11 presents the results for alternative specifications when the dependent variable is the normalized per-dwelling demand. There are four sets of results. Each set consists of two equations--one with country dummies and one without the dummies. In the first set of equations, all five explanatory variables (price, income, heating degree days, central heating saturation, and house size) are included. For the other three sets, we examine the sensitivity of deleting one or both of the two structure-related variables.

A comparison of these alternative sets of regression reveals several interesting findings. First, the estimated coefficients of the five explanatory variables are sensitive to the inclusion of the country dummies. Specifically, all coefficient estimates except those for the two structure-related variables tend to have a larger value when the country dummies are excluded. These results confirm the theoretical expectation discussed earlier that the model reflects more closely the long-run responses when the country dummies are not present. The estimated coefficient of dwelling size (ln SIZ) is larger in the equations with dummies. But note that the estimated coefficients (elasticities) of 1.58 in Eq. (A1a) and 2.67 in Eq. (A.3a) in Table 11 appear to be unreasonably large.

Second, the estimated price elasticities are also sensitive to alternative specifications. The sensitivity is apparently due to the relatively high correlations between energy price and other explanatory variables, particularly, the central heating saturation. As one can see from Table 11, when both the saturation and dwelling size variables are present, the estimated price elasticities tend to have a smaller magnitude than when one or both of these variables are deleted. Also, when the country dummies are excluded, the estimated price elasticity increases its magnitude as expected theoretically. It appears that the set of Eqs. (A3a) and (A3b) gives the most plausible estimates of the price elasticity between short run and long-run. Following the theoretical argument discussed in Section 2, this set of estimates would show a short-run price elasticity of -0.242 and a long-run price elasticity of -0.513. Note, of course, that if the dwelling size is excluded, the long-run price elasticity increased to -0.641 as shown in Eq. (A4b).

Third, the estimated coefficients of the heating degree day variable are insignificant whenever the country dummies are included. Thus, they are competing with each other in their explanatory power. There are also apparent correlations between the dwelling size and country dummy variables. Consequently, when dwelling size is excluded, most of the coefficients of country dummies change their sign from positive to negative.

The results in Table 11 clearly indicate that the statistical significance of the estimated coefficient for the energy demand factors (price, income, heating degree days, and structure-related variables) increases when the country dummies are excluded. Without the dummy variables, the results would reflect more closely the long-run responses. Furthermore, the inclusion of the two structure-related variables (central heating saturation and dwelling size) tends to reduce the explanatory power of energy price and income. This result can, indeed, be expected on theoretical grounds because the level of central heating saturation and dwelling size should be influenced by both income and energy price. Therefore, the presence of these structure-related variables already accounts for some of the income and price effects. Finally, when the country dummy variables are excluded, the results for alternative specifications all appear to be reasonable (all estimated coefficients have the correct sign and mostly are statically significant).

Eq. (A3b) appears to be the best equation from the standpoints of capturing the total price and income effects and the impacts of housing characteristics such as house size. Since the saturation variable is not included in Eq. (A3b), the price and income elasticities should measure their impacts on both the choice and utilization of electric appliances. The inclusion of the dwelling size also contributes substantially to the explanatory power of the estimated equation. Without this variable, as shown in Eq. (A4b), both the estimated price and income elasticities increase in absolute value, but R^2 decreases.

For the purpose of comparison, the same sets of equations are estimated using total energy demand as the dependent variable. In this case, the number of dwellings is included as one of the explanatory variables. The results of this estimation are presented in Table 12. All estimated coefficients are fairly similar to those estimated in Table 11 except for heating degree days whose estimated coefficient increases substantially for the sets of regressions without the saturation variable. The similarities can be attributed to the fact that the estimated coefficients for the number of dwellings are all close to unity All the previous discussions of the results in Table 11 apply to those in Table 12.

Let us consider next the estimation of the aggregate demand equations for space heating. Exactly the same sets of equations previously estimated for all end-uses are estimated for the space heating component. Table 13 shows the results when the per dwelling energy demand is used as the dependent variable. The major findings are summarized below.

(1) The effects of the country dummies are similar to those found earlier in the estimation results for all end-uses. Therefore, the equations without dummies are preferable to those with dummies.

(2) In general, energy price, disposable personal income per dwelling, the saturation of central heating, heating degree days are all found to be significant factors for determining total energy demand for space heating. The estimated coefficients for dwelling size always have a low t-ratio. In Eq. (C3b), this variable even has a negative coefficient which is not plausible. The poor results for the dwelling size appear to be due to its relative high correlation with income.

(3) A comparison with the results presented in Table 11 show that the estimated coefficients for heating degree days and the central heating saturation have a larger magnitude for space heating. The t-ratios for these coefficients are also higher in the estimated equations for space heating. These results are plausible because these variables should have stronger effects on the space heating demand than the demand for the entire residential sector.

(4) Eq. (C2b) in Table 13 appears to be the best equation where all estimated coefficients are statistically significant at the 1% level.

Again, for the purpose of comparison, the total demand instead of the per-dwelling demand is used as the dependent variable as an alternative specification. Table 14 presents these estimation results. The first thing to be noted in Table 14 is that the estimated coefficients for the number of dwellings are very sensitive to alternative combinations of explanatory variables and are generally far from unity. Careful examination and comparison of the alternative regression results indicate that these sensitivities must result from the multicollinearity among explanatory variables. We conclude that the specification with the normalization is preferable because the estimation results in Table 13 are much more stable than those in Table 14.

4.4 Estimation Results for the Entire Model

The entire multinomial logit model consists of one aggregate demand equation and three market share equations. These four structural equations are estimated jointly by generalized least squares (GLS) as discussed earlier. In the preceding section, the results for alternative aggregate demand equations were discussed. For both the residential total end-uses and the space heating component, a preferred aggregate demand equation was chosen. The entire systems of structural equations associated with these preferred aggregate equation are presented here.

Table 15 shows the multinomial logit model estimated for all end-uses in the residential sector. The aggregate demand equation is the same as the one presented in Table 11. The other three equations, (A1) - (A3) are the market share equations. Note that the dwelling size is not included in the market share equations because (1) its inclusion distorts the estimates of several structural coefficients and (2) the sign of its coefficients cannot be explained. Since the results for the aggregate demand equation were discussed already in the previous section, we focus here only on the market share equations. Highlights of the statistical results are summarized as follows:

(1) The relative fuel prices are the most significant variables for determining the relative shares of alternative fuels. The estimated market share elasticities will be discussed later.

Table 11. Estimated Alternative Normalized Aggregate Demand Equations for Total Residential Sector[a]

Dependent Variable: Normalized Aggregate Demand -- ln (E/DW)
Estimation Method: GLS

Eq. No.	Constant	Average Energy Price ln P	Income ln PPI	Heating Degree Days ln HDD	Central Heating Saturation ln CH	Dwelling Size ln SIZ	Canada Dummy C_1	France Dummy C_2	Germany Dummy C_3	Italy Dummy C_4	Japan Dummy C_5	Sweden Dummy C_6	U.K. Dummy C_7	R^2	MSE	N
	-8.947	-0.187	0.470	0.144	0.154	1.575	0.328	0.291	0.311	0.265	0.005	0.370	0.330	0.996	0.0025	33
A1a	(-3.32)	(-2.12)	(3.90)	(0.73)	(3.54)	(2.94)	(2.21)	(0.96)	(1.18)	(0.86)	(0.02)	(1.46)	(1.55)			
	-8.638	-0.157	0.469	0.404	0.205	1.037								0.993	0.0036	33
A1b	(-10.5)	(-2.62)	(5.64)	(7.94)	(17.9)	(11.2)										
	-2.643	-0.0002	0.650	0.023	0.221		0.068	-0.598	-0.459	-0.631	-0.582	-0.301	-0.290	0.995	0.0033	33
A2a	(-1.36)	(-0.003)	(5.27)	(0.10)	(5.27)		(0.52)	(-7.21)	(-8.21)	(-7.25)	(-2.82)	(-2.59)	(-4.63)			
	-9.172	-0.293	1.098	0.360	0.180									0.959	0.0195	33
A2b	(-5.16)	(-2.65)	(7.51)	(3.16)	(7.00)											
	-11.07	-0.242	0.736	-0.042		1.953	0.512	0.478	0.545	0.499	-0.328	0.733	0.542	0.994	0.0038	33
A3a	(-4.05)	(-2.58)	(5.80)	(-0.18)		(4.18)	(3.59)	(1.70)	(2.39)	(1.79)	(-1.19)	(3.70)	(2.90)			
	-11.86	-0.513	0.771	0.707		0.881								0.906	0.0445	33
A3b	(-4.14)	(-2.52)	(2.78)	(4.12)		(2.82)										
	-3.593	-0.0003	1.149	-0.332			0.271	-0.651	-0.382	-0.607	-1.356	0.026	-0.195	0.988	0.0074	33
A4a	(-1.24)	(-0.004)	(10.2)	(-1.08)			(1.51)	(-5.98)	(-4.77)	(-4.84)	(-7.80)	(0.19)	(-2.24)			
	11.40	-0.641	1.250	0.610										0.893	0.0493	33
A4b	(-3.75)	(-3.06)	(5.23)	(3.45)												

[a]The figures in parenthesis are estimated asymptotic t-ratios; R^2 and MSE are, respectively, the coefficient of determination and the mean square error computed from the first stage (OLS) estimation; and N is the number of observations.

Table 12. Estimated Alternative Aggregate Demand Equations for Total Residential Sector[a]

Dependent Variable: Aggregate Demand -- ln E
Estimation Method: GLS

Eq. No.	Constant	Average Energy Price ln P	Income ln PPI	Heating Degree Days ln HDD	Number of Dwellings ln DW	Central Heating Saturation ln CH	Dwelling Size ln SIZ	Canada Dummy C_1	France Dummy C_2	Germany Dummy C_3	Italy Dummy C_4	Japan Dummy C_5	Sweden Dummy C_6	U.K. Dummy C_7	R^2	MSE
	-8.654	-0.172	0.487	0.140	0.987	0.156	1.531	0.291	0.246	0.275	0.223	-0.024	0.313	0.297	0.998	0.002
B1a	(-2.81)	(-1.66)	(2.99)	(0.68)	(6.82)	(3.38)	(2.77)	(0.71)	(0.65)	(0.84)	(0.60)	(-0.09)	(0.58)	(1.06)		
	-8.476	-0.129	0.468	0.378	0.985	0.208	1.094								0.997	0.003
B1b	(-8.23)	(-1.99)	(5.50)	(4.88)	(39.4)	(17.3)	(8.79)									
	-2.838	-0.005	0.633	0.011	1.026	0.219		0.135	-0.569	-0.432	-0.604	-0.578	-0.222	-0.264	0.998	0.003
B2a	(-1.21)	(-0.06)	(3.80)	(0.05)	(6.48)	(4.92)		(0.31)	(-2.69)	(-2.47)	(-3.13)	(-2.68)	(-0.44)	(-1.51)		
	-11.64	-0.313	0.918	0.642	1.116	0.175									0.987	0.014
B2b	(-6.35)	(-2.83)	(6.68)	(4.78)	(31.6)	(7.93)										
	-14.13	-0.269	0.516	-0.044	1.127		2.558	0.947	0.929	0.943	0.940	-0.025	1.345	0.865	0.998	0.003
B3a	(-4.57)	(-0.240)	(2.75)	(-0.18)	(7.21)		(4.72)	(2.31)	(2.54)	(3.16)	(2.68)	(-0.08)	(2.69)	(3.38)		
	-15.49	-0.555	0.946	1.029	1.50		0.208								0.960	0.040
B3b	(-4.70)	(-2.74)	(3.39)	(4.25)	(14.1)		(0.52)									
	-5.570	-0.047	0.922	-0.427	1.274			0.968	-0.322	-0.110	-0.328	-1.243	0.843	0.067	0.995	0.007
B4a	(-1.78)	(-0.45)	(5.17)	(-1.36)	(7.80)			(2.18)	(-1.44)	(-0.59)	(-1.52)	(-6.38)	(1.67)	(0.36)		
	-14.78	-0.619	1.049	0.967	1.142										0.959	0.043
B4b	(-4.52)	(-3.13)	(4.39)	(4.12)	(17.4)											

[a]The figures in parathenses are estimated asmyptotic t-ratios; R^2 and MSE are, respectively, the coefficiet of determination and the mean square error computed from the first stage (OLS) estimation; there are 33 observations used for estimation.

Table 13. Estimated Alternative Normalized Aggregate Demand Equations for Space Heating[a]

Dependent Variable: Normalized Aggregate Demand -- ln (HE/DW)
Estimation Method: GLS

Eq. No	Constant	Average Energy Price ln P	Income ln PPI	Heating Degree Days ln HDD	Central Heating Saturation ln CH	Dwelling Size ln SIZ	Canada Dummy C_1	France Dummy C_2	Germany Dummy C_3	Italy Dummy C_4	Japan Dummy C_5	Sweden Dummy C_6	U.K. Dummy C_7	R^2	MSE	N
	-8.984	-0.148	0.752	0.303	0.030	0.751	0.275	0.064	0.122	0.063	-1.409	0.130	0.025	0.994	0.00782	33
C1a	(-1.65)	(-1.30)	(3.67)	(0.83)	(0.39)	(0.75)	(1.04)	(0.11)	(0.25)	(0.11)	(-3.04)	(0.30)	(0.06)			
	-6.234	-0.299	0.265	0.589	0.405	0.342								0.962	0.0359	33
C1b	(-2.92)	(-2.47)	(1.06)	(4.07)	(11.8)	(1.29)										
	-5.516	-0.078	0.823	0.211	0.061		0.155	-0.368	-0.237	-0.373	-1.690	-0.185	-0.278	0.994	0.0078	33
C2a	(-1.79)	(-0.94)	(4.44)	(0.60)	(0.94)		(0.77)	(-2.92)	(-2.84)	(-2.76)	(-5.52)	(-1.03)	(-2.84			
	-6.355	-0.356	0.465	0.577	0.399									0.956	0.04035	33
C2b	(-2.85)	(-2.99)	(2.30)	(3.77)	(11.1)											
	-9.239	-0.154	0.816	0.262		0.773	0.303	0.072	0.143	0.081	-1.499	0.182	0.049	0.094	0.00746	33
C3a	(-2.00)	(-1.43)	(4.39)	(0.74)		(0.97)	(1.45)	(0.15)	(0.38)	(0.17)	(-3.37)	(0.57)	(0.15)			
	-20.82	-0.408	1.584	1.530		-0.448								0.763	0.21736	33
C3b	(-4.75)	(-1.37)	(2.78)	(5.14)		(-0.71)										
	-5.905	-0.091	0.960	0.131			0.202	-0.370	-0.214	-0.358	-1.887	-0.099	-0.245	0.993	0.00789	33
C4a	(-1.92)	(-1.16)	(8.35)	(0.40)			(1.08)	(-3.07)	(-2.63)	(-2.66)	(-10.4)	(-0.67)	(-2.56)			
	-20.76	-0.357	1.328	1.560										0.763	0.20911	33
C4b	(-4.82)	(-1.26)	(3.07)	(5.39)												

[a]The figures in parentheses are estimated asymptotic t-ratios; R^2 and MSE are , respectively, the coefficient of determination and mean square error computed from the first stage (OLS) estimation; and N is the number of observations.

Table 14. Estimated Alternative Demand Equations for Space Heating[a]

Dependent Variable: Normalized Aggregate Demand -- ln HE
Estimation Method: GLS

Eq. No.	Constant	Average Energy Price ln P	Income ln PPI	Heating Degree Days ln HDD	Number of Dwellings ln DW	Central Heating Saturation ln CH	Dwelling Size ln SIZ	Canada Dummy C_1	France Dummy C_2	Germany Dummy C_3	Italy Dummy C_4	Japan Dummy C_5	Sweden Dummy C_6	U.K. Dummy C_7	R^2	MSE
D1a	-0.935 (-0.16)	-0.033 (-0.26)	1.225 (4.82)	0.576 (1.73)	0.291 (1.21)	0.112 (1.49)	0.254 (0.27)	-1.678 (-2.41)	-1.017 (-1.50)	-0.826 (-1.45)	-0.950 (-1.42)	-1.637 (-3.68)	-2.286 (-2.44)	-0.875 (-1.72)	0.997	0.00633
D1b	-11.22 (-4.20)	-0.269 (-2.29)	0.238 (0.99)	1.048 (4.95)	1.178 (18.0)	0.394 (12.11)	0.032 (0.10)								0.976	0.03124
D2a	0.255 (0.07)	-0.011 (-0.12)	1.251 (5.74)	0.552 (1.73)	0.286 (1.26)	0.123 (2.07)		-1.733 (-2.87)	-1.166 (-3.85)	-0.953 -3.93)	-1.101 (-3.96)	-1.728 (-6.22)	-2.409 (-3.39)	-0.981 (-3.87)	0.996	0.00612
D2b	-11.42 (-4.90)	-0.268 (-2.43)	0.250 (1.32)	1.065 (5.71)	1.184 (23.1)	0.394 (12.6)									0.976	0.03023
D3a	-4.008 (-0.84)	-0.072 (-0.63)	1.304 (5.20)	0.415 (1.26)	0.416 (1.86)		0.640 (0.86)	-1.199 (-2.04)	-0.683 (-1.27)	-0.488 (-1.15)	-0.595 (-1.15)	-1.794 (-4.11)	-1.604 (-2.19)	-0.564 (-1.47)	0.996	0.00638
D3b	-31.48 (-5.58)	-0.348 (-1.22)	1.452 (2.67)	2.543 (5.53)	1.418 (8.99)		-1.175 (-1.56)								0.842	0.2000
D4a	-1.327 (-0.38)	-0.022 (-0.25)	1.417 (7.14)	0.306 (0.99)	0.423 (2.01)			-1.263 (-2.30)	-1.039 (-3.56)	-0.775 (-3.46)	-0.949 (3.57)	-2.11 (-10.5)	-1.812 (-2.84)	-0.798 (-3.38)	0.996	0.00681
D4b	-27.34 (-5.29)	-0.246 (-0.887)	1.013 (2.21)	2.208 (5.22)	1.252 (9.89)										0.835	0.20096

[a]The figures in parentheses are estimated asymptotic t-ratios; R^2 and MSE are, respectively, the coefficient of determination and mean square error computed from the first state (OLS) estimation; there are 33 observations used for estimation.

(2) The results show that higher income would result in an increase in the share of fuel oil relative to solid fuels. The effects of income on the relative shares between gas and oil are not statistically significant; they are only marginally significant on the relative shares between electricity and oil.

(3) The estimated coefficients of the heating degree days show that higher degree days would increase the share of fuel oil relative to both gas and electricity. However, between the share of solids and fuel oil, the degree days variable has a positive coefficient. Thus, higher degree days would increase the share of solids relative to fuel oil. This surprising result may merely reflect the fact that there are a few countries like Canada and U.S. with relatively high degree days and a low market shares for fuel oil and other countries like U.K. with relatively high degree days and a large share for solids.

Despite the relatively high t-ratios for the estimated coefficients for the degree days variable, the interpretation of its impacts on the relative fuel shares is not straightforward because of incompatibility among countries. For example, U.K. and Canada have high degree days and also high gas consumption. In contrast, Sweden has high degree days but little consumption of gas because of its unavailability. In econometric estimation, only the strongest correlation prevails in the estimated coefficient (or in some cases, opposite correlations result in an insignificant impact of the variable).

Table 16 shows the estimated preferred version of the multinomial logit model for the space heating component. Again we focus only on the results for the fuel share equations. The most interesting results are summarized as follows:

(1) Similar to the results for the residential sector, the relative fuel prices are the most significant determinants for the relative market shares. The estimated price coefficient has a larger magnitude than that estimated for the total sector. Again the estimated market share elasticities will be discussed later.

(2) Income appears to have a significant impact only on the relative shares between solids and fuel oil. The negative coefficient implies that higher income would result in a lower share of solids relative to fuel oil. This, of course, can be expected because the share of solid fuels has been declining over the sample period while income has been increasing.

(3) The heating degree days variable is significant only in the equation relating solids to fuel oil. Higher degree days results in a higher share of solids relative to fuel oil. This result reflects the contrasting pattern between U.K. and most other countries. U.K. with relatively high heating degree days, has a small market share for oil and a large share for solids. For example, in U.K. the oil share was 10% in 1978 while the share for solids was 24%. For most other countries, a large oil share is generally accompanied with a low share for solid fuels.

(4) The central heating saturation shows a very weak impact on the relative shares of heating fuels. In the case of the choice between electricity and fuel oil, the negative coefficient (with t-ratio of -1.74) indicates that a higher central heating saturation would increase the share of oil relative to electricity.

Table 15. Estimated Multinomial Logit Model for Total Residential Sector[a]
Estimation Method: GLS

Eq. No.	Dependent Variable	Constant	Average Energy Price ln P	Income ln PPI	Heating Degree Days ln HDD	Dwelling Size ln SIZ	Ratio of Gas Price to Oil Price $\ln(P_1/P_3)$	Ratio of Coal Price to Oil Price $\ln(P_2/P_3)$	Ratio of Electricity Price to Oil Price $\ln(P_4/P_3)$	R^2	MSE	N
A3b	Aggregate Demand $\ln(E/DW)$	-11.86	-0.513	0.771	0.707	0.881				0.906	0.0445	33
		(-4.14)	(-2.53)	(2.78)	(4.12)	(2.82)						
A_1	Ratio of Gas Share to Oil Share $\ln(S_1/S_3)$	20.66		-0.748	-1.744		-1.341			0.620	0.8775	33
		(2.79)		(-0.86)	(-3.12)		(-8.15)					
A_2	Ratio of Solid Fuel Share to Oil Share $\ln(S_2/S_3)$	49.35		-6.768	1.468			-1.341		0.660	0.9367	33
		(6.90)		(-7.94)	(2.54)			(-8.15)				
A_3	Ratio to Electricity Share to Oil Share $\ln(S_4/S_3)$	19.54		-1.220	-0.906				-1.341	0.319	0.5031	33
		(3.44)		(-1.89)	(-2.13)				(-8.15)			

[a]The figures in parentheses are estimated asympotic t-ratios; R^2 and MSE are, respectively, the coefficient of determination and the mean square error computed from the first stage (OLS) estimation; and N is the number of observations.

Table 16. Estimated Multinomial Logit Model for Space Heating[a]
Estimation Method: GLS

Eq. No.	Dependent Variable	Constant	Average Energy Price ln P	Income ln PPI	Heating Degree Days ln HDD	Dwelling Size ln CH	Ratio of Gas Price to Oil Price $\ln(P_1/P_3)$	Ratio of Coal Price to Oil Price $\ln(P_2/P_3)$	Ratio of Electricity Price to Oil Price $\ln(P_4/P_3)$	R^2	MSE	N
C2b	Aggregate Demand ln(HE/DW)	-6.355 (-2.85)	-0.356 (-2.99)	0.465 (2.30)	0.577 (3.77)	0.399 (11.1)				0.956	0.0403	33
C_1	Ratio of Gas Share to Oil Share $\ln(S_1/S_3)$	13.33 (1.35)		-0.781 (-0.80)	-0.887 (-1.21)	0.098 (0.55)	-1.448 (-7.69)			0.628	0.9602	33
C_2	Ratio of Solid Fuel Share to Oil Share $\ln(S_2/S_3)$	44.38 (4.62)		-6.533 (-6.92)	1.905 (2.57)	-0.190 (-1.06)		-1.448 (-7.69)		0.665	0.9730	33
C_3	Ratio of Electricity Share to Oil Share $\ln(S_4/S_3)$	-1.524 (-0.12)		0.512 (0 40)	-0.314 (-0.32)	-0.415 (-1.74)			-1.448 (-7.69)	0.261	1.7790	33

[a]The figures in parentheses are estimated asympotic t-ratios; R^2 and MSE are, respectively, the coefficient of determination and the mean square error computed from the first stage (OLS) estimation; and N is the number of observations.

5. INTERNATIONAL COMPARISON OF ESTIMATED DEMAND ELASTICITIES

5.1 Aggregate Price and Income Elasticities

As discussed previously, there are four sets of demand elasticities which can be estimated from the present model. The first set is the aggregate demand elasticities. In the case of price, it is the elasticity of aggregate demand with respect to the weighted average energy price. This elasticity can be obtained directly from the estimated aggregate demand equations in Tables 15 and 16. In Table 17, the estimates for total residential demand and space heating component are compared with the results from other selected studies. We recognize that the comparison cannot be precise because different studies adopted different models and used different data bases. Also, in some cases, the residential sector was embedded in other sectors.

In comparison, our estimates of both price and income elasticities are smaller than most of the other estimates. We have argued, previously, that our estimates should reflect the long-run responses when the country dummies are excluded from the structural equations as in our preferred final equations. The differences between our estimates and those of other studies may be due to the following reasons. First, the end-use data used in this study are most appropriate for analyzing residential energy use pattern.

No other studies cited in Table 17 used the end-use data strictly for residential users. Therefore, the available estimates from other studies can not adequately be used as the ranges for short-run and long-run elasticities for the residential sector.

Table 17. Comparison of Estimated Price and Income Elasticities for Aggregate Energy Use in the Residential Related Sectors

Study	Sector	Country	Data Base	Price[a] Elasticity	Income[a] Elasticity
Present	Residential Aggregate	8 OECD Countries	Pooled[b] 1960-1979	-0.513	0.771
Present	Residential Space Heating	8 OECD Countries	Pooled[b] 1960-1979	-0.356	0.465
Pindyck[c]	Residential	9 OECD Countries	Pooled 1960-1974	-1.05~-1.15(L)[d]	1.00
Griffin[e]	Residential & Commercial	18 OECD Countries	Pooled 1960-1972	-0.8 (L)	1.39 (L)
Nordhaus[f]	Residential & Commercial	7 OECD Countries	Pooled	-0.7 (L)	1.09 (L)
Matsui[g]	Residential & Commercial	Japan	Time-Series (1) 1965-1972 (2) 1965-1977	-0.220 -0.022	1.70 1.11
Baughman[h] & Joskow	Residential & Commercial	USA	Pooled 49 states 1968-1972	-0 16 (S) -0.63 (L)	0.20(S) 0.80 (L)
Chern[i]	Residential & Commercial	USA	48 States 1972	-0.71 (L)	0.44 (L)

[a] S = Short-Run, and L = Long-Run.

[b] Not continuous time-series.

[c] See Reference 14.

[d] The range of estimates for the nine countries.

[e] See Reference 26.

[f] See Reference 28.

[g] See Reference 29.

[h] See Reference 7.

[i] See Reference 30.

Second, we used more recent data than most of other studies. In particular, 40% of our observations are in post-embargo years. A recent study by Chern et al. for electricity demand shows that adding data for more post-embargo years results in a lower estimate of price elasticity.31 One explanation for this phenomenon is given by the evolution in the saturation level of energy appliances. According to this study, price elasticity of electricity demand tends to be higher during a period of a rapid increase in appliances holdings such as in 1960's and early 1970's, than in a period of slow stock adjustments as in more recent years. Also, the changes in fuel prices have been much more dramatic in the post-embargo years than in previous years.

5.2 Market Share, Conventional Fuel Demand and Aggregate Demand Elasticities

The market share elasticities depend upon the shares of individual fuels. Therefore, we may compute these elasticities country by country. Typically, one may compute these elasticities using the sample means for each country. However, our sample covers different years for different countries. Using the sample means would not provide proper comparisons. We thus use the shares for the latest year which is 1978 for all countries except Japan whose last observation is 1979 (there were no 1978 data available for Japan). Table 18 shows the market shares by fuel type for aggregate residential demand while Table 19 presents the market shares for space heating energy demand. Using these market shares and the formulas presented in Section 3, the market share elasticities are computed and shown in Table 20-27. There is one table for each country. In order to facilitate further comparison, the two other sets of elasticities (aggregate demand elasticities and conventional fuel demand elasticities) are also presented in the same table for each country. The procedures for computing these elasticities were described previously. Two types of comparisons can be made of the elasticities presented in these tables as discussed in the following sections.

Table 18. Market Shares of Fuels for Aggregate Residential Use

Country	Year	Oil	Share (%) of Gas	Solids	Electricity
Canada	1978	32	33	1	35
France	1978	53	21	6	20
West Germany	1978	55	18	5	22
Italy	1978	55	23	3	19
Japan	1979	39	20	1	40
Sweden	1978	65	1	4	30
U.K.	1978	8	49	17	29
U.S.	1978	16	50	2	32

Table 19. Market Share of Fuels for Space Heating Energy Use

Country	Year	Share(%) of Oil	Gas	Solids	Electricity
Canada	1978	45	38	1	16
France	1978	66	21	6	7
West Germany	1978	66	20	6	8
Italy	1978	71	26	2	1
Japan	1979	78	7	4	11
Sweden	1978	79	1	6	14
U.K.	1978	10	55	24	11
U.S.	1978	27	56	4	13

Table 20. Estimated Energy Demand Elasticities, Canada, 1978

Item	Aggregate Residential Demand				Space Heating Demand			
	Oil Price	Gas Price	Coal Price	Electricity Price	Oil Price	Gas Price	Coal Price	Electricity Price
	Market Share Elasticities							
Share of fuel oil	-0.911	0.436	0.010	0.466	-0.806	0.560	0.013	0.233
Share of Natural gas	0.429	-0.905	0.010	0.466	0.641	-0.887	0.013	0.233
Share of Solid Fuels	0.429	0.436	-1.331	0.466	0.641	0.560	-1.434	0.233
Share of Electricity	0.429	0.436	0.010	-0.875	0.641	0.560	0.013	-1.214
	Aggregate Demand Elasticities							
Aggregate Demand	-0.166	-0.176	-0.003	-0.169	-0.156	-0.145	-0.003	-0.052
	Individual Fuel Demand Elasticities							
Demand of Fuel Oil	-1.077	0.260	0.006	0.297	-0.963	0.414	0.011	0.181
Demand of Natural Gas	0.264	-1.081	0.006	0.297	0.684	-1.033	0.011	0.181
Demand of Solid Fuels	0.264	0.260	-1.334	0.297	0.684	0.414	-1.436	0.181
Demand of Electricity	0.264	0.260	0.006	-1.043	0.684	0.414	0.011	-1.266

Table 21. Estimated Energy Demand Elasticities, France, 1978

Item	Aggregate Residential Demand Oil Price	Aggregate Residential Demand Gas Price	Aggregate Residential Demand Coal Price	Aggregate Residential Demand Electricity Price	Space Heating Demand Oil Price	Space Heating Demand Gas Price	Space Heating Demand Coal Price	Space Heating Demand Electricity Price
Market Share Elasticities								
Share of Fuel oil	-0.634	0.275	0.085	0.274	-0.496	0.308	0.088	0.099
Share of Natural Gas	0.707	-1.066	0.088	0.274	0.951	-1.139	0.088	0.099
Share of Solid fuels	0.707	0.275	-1.256	0.274	0.951	0.308	-1.359	0.099
Share of Electricity	0.707	0.275	0.085	-1.067	0.951	0.308	0.088	-1.348
Aggregate Demand Elasticities								
Aggregate Demand	-0.302	-0.103	-0.302	-0.077	-0.257	-0.067	-0.020	-0.012
Individual Fuel Demand Elasticities								
Demand of Fuel oil	-0.936	0.173	0.053	0.197	-0.753	0.241	0.069	0.087
Demand of Natural Gas	0.405	-1.168	0.053	0.197	0.697	-1.206	0.069	0.087
Demand of Solid Fuels	0.405	0.173	-1.288	0.197	0.697	0.241	-1.378	0.087
Demand of Electricity	0.405	0.173	0.053	-1.144	0.697	0.241	0.069	-1.360

Table 22. Estimated Energy Demand Elasticities, West Germany, 1978

Item	Aggregate Residential Demand				Space Heating Demand			
	Oil Price	Gas Price	Coal Price	Electricity Price	Oil Price	Gas Price	Coal Price	Electricity Price
Market Share Elasticities								
Share of Fuel Oil	-0.604	0.204	0.273	0.292	-0.480	0.287	0.081	0.111
Share of Natural Gas	0.736	-1.101	0.073	0.292	0.987	-1.160	0.081	0.111
Share of Solid Fuels	0.736	0.204	-1.268	0.292	0.987	0.287	-1.366	0.111
Share of Electricity	0.736	0.204	0.273	-1.049	0.987	0.287	0.081	-1.336
Aggregate Demand Elasticities								
Aggregate Demand	-0.324	-0.082	-0.030	-0.077	-0.272	-0.052	-0.021	-0.011
Individual Fuel Demand Elasticities								
Demand of Fuel Oil	-0.928	0.157	0.043	0.215	-0.752	0.235	0.060	0.100
Demand of Natural Gas	0.412	-1.183	0.043	0.215	0.095	-1.212	0.060	0.100
Demand of Solid fuels	0.412	0.157	-1.298	0.215	0.095	0.235	-1.387	0.100
Demand of Electricity	0.412	0.157	0.043	-1.126	0.095	0.235	0.060	-1.347

Table 23. Estimated Energy Demand Elasticities, Italy, 1978

Item	Aggregate Residential Demand				Space Heating Demand			
	Oil Price	Gas Price	Coal Price	Electricity Price	Oil Price	Gas Price	Coal Price	Electricity Price
Market Share Elasticities								
Share of Fuel Oil	-0.600	0.309	0.038	0.252	-0.416	0.371	0.035	0.010
Share of Natural Gas	0.741	-1.039	0.038	0.252	1.031	-1.076	0.035	0.010
Share of Solid Fuels	0.741	0.309	-1.302	0.252	1.031	0.371	-1.412	0.010
Share of Electricity	0.714	0.309	0.038	-1.089	1.031	0.371	0.035	-1.437
Aggregate Demand Elasticities								
Aggregate Demand	-0.303	-0.115	-0.014	-0.082	-0.264	-0.083	-0.007	-0.002
Individual Fuel Demand Elasticities								
Demand of Fuel Oil	-0.902	0.194	0.025	0.170	-0.680	0.288	0.028	0.008
Demand of Natural Gas	0.439	-1.147	0.025	0.170	0.767	-1.159	0.028	0.008
Demand of Solid Fuels	0.439	0.194	-1.316	0.170	0.767	0.288	-1.429	0.008
Demand of Electricity	0.439	0.194	0.025	-1.171	0.767	0.288	0.028	-1.439

Table 24. Estimated Energy Demand Elasticities, Japan, 1979

Item	Aggregate Residential Demand				Space Heating Demand			
	Oil Price	Gas Price	Coal Price	Electricity Price	Oil Price	Gas Price	Coal Price	Electricity Price
				Market Share Elasticities				
Share of Fuel Oil	-0.820	0.262	0.020	0.537	-0.326	0.105	0.058	0.163
Share of Natural Gas	0.521	-1.079	0.020	0.537	1.121	-1.342	0.058	0.163
Share of Solid Fuels	0.521	0.262	-1.321	0.537	1.121	0.105	-1.389	0.163
Share of Electricity	0.521	0.262	0.020	-0.803	1.121	0.105	0.058	-1.284
				Aggregate Demand Elasticities				
Aggregate Demand	-0.241	-0.099	-0.008	-0.166	-0.318	-0.017	-0.010	-0.011
				Individual Fuel Demand Elasticities				
Demand of Fuel Oil	-1.060	0.164	0.012	0.371	-0.644	0.088	0.048	0.152
Demand of Natural Gas	0.280	-1.177	0.012	0.371	0.803	-1.359	0.048	0.152
Demand of Solid Fuels	0.280	0.164	-1.329	0.371	0.803	0.088	-1.399	0.152
Demand of Electricity	0.280	0.164	0.012	-0.970	0.803	0.088	0.048	-1.295

Table 25. Estimated Energy Demand Elasticities, Sweden, 1978

Item	Aggregate Residential Demand: Oil Price	Gas Price	Coal Price	Electricity Price	Space Heating Demand: Oil Price	Gas Price	Coal Price	Electricity Price
Market Share Elasticities								
Share of Fuel Oil	-0.465	0.011	0.051	0.403	-0.304	0.014	0.086	0.204
Share of Natural Gas	0.875	-1 329	0.051	0.403	1.143	-1.433	0.086	0.204
Share of Solid Fuels	0.875	0.011	-1.290	0.403	1.143	0.014	-1.361	0.204
Share of Electricity	0.875	0.011	0.051	-0.938	1.143	0.014	0.086	-1.243
Aggregate Demand Elasticities								
Aggregate Demand	-0.362	-0.003	-0.012	-0.136	-0.304	-0.002	-0.010	-0.040
Individual Fuel Demand Elasticities								
Demand of Fuel Oil	-0.827	0.008	0.039	0.267	-0.608	0.012	0.076	0.164
Demand of Natural Gas	0.514	-1.333	0.039	0.267	0.839	-1.435	0.076	0.164
Demand of Solid Fuels	0.514	0.008	-1.302	0.267	0.839	0.012	-1.371	0.164
Demand of Electricity	0.514	0.008	0.039	-1.074	0.839	0.012	0.076	-1.283

Table 26. Estimated Energy Demand Elasticities, U.K., 1978

Item	Aggregate Residential Demand				Space Heating Demand			
	Oil Price	Gas Price	Coal Price	Electricity Price	Oil Price	Gas Price	Coal Price	Electricity Price
				Market Share Elasticities				
Share of Fuel Oil	-1.237	0.626	0.233	0.388	-1.300	0.792	0.342	0.166
Share of Natural Gas	0.104	-0.715	0.233	0.388	0.147	-0.655	0.342	0.166
Share of Solid Fuels	0.104	0.626	-1.118	0.388	0.147	0.792	-1.105	0.166
Share of Electricity	0.104	0.626	0.233	-0.952	0.147	0.792	0.342	-1.281
				Aggregate Demand Elasticities				
Aggregate Demand	-0.041	-0.273	-0.083	-0.115	-0.036	0.222	-0.075	-0.023
				Individual Fuel Demand Elasticities				
Demand of Fuel Oil	-1.278	0.352	0.139	0.273	-1.335	0.570	0.267	0.142
Demand of Natural Gas	0.062	-0.988	0.139	0.273	0.112	-0.877	0.267	0.142
Demand of Solid Fuels	0.062	0.352	-1.201	0.273	0.112	0.570	-1.180	0.142
Demand of Electricity	0.062	0.352	0.139	-1.068	0.112	0.570	0.267	-1.305

Table 27. Estimated Energy Demand Elasticities, United States, 1978

Item	Aggregate Residential Demand				Space Heating Demand			
	Oil Price	Gas Price	Coal Price	Electricity Price	Oil Price	Gas Price	Coal Price	Electricity Price
	Market Share Elasticities							
Share of Fuel Oil	-1.130	0.671	0.028	0.432	-1.057	0.818	0.057	0.182
Share of Natural Gas	0.211	-0.670	0.028	0.432	0.390	-0.629	0.057	0.182
Share of Solid Fuels	0.211	0.671	-1.313	0.432	0.390	0.818	-1.390	0.182
Share of Electricity	0.211	0.671	0.028	-0.909	0.390	0.818	0.057	-1.265
	Aggregate Demand Elasticities							
Aggregate Demand	-0.083	-0.296	-0.013	-0.121	-0.090	-0.229	-0.017	-0.020
	Individual Fuel Demand Elasticities							
Demand of Fuel Oil	-1.213	0.374	0.015	0.310	-1.147	0.588	0.040	0.162
Demand of Natural Gas	0.128	-0.966	0.015	0.310	0.300	-0.859	0.040	0.162
Demand of Solid Fuels	0.128	0.374	-1.326	0.310	0.300	0.588	-1.407	0.162
Demand of Electricity	0.128	0.374	0.015	-1.031	0.300	0.588	0.040	-1.285

5.3 Comparisons Among Countries

From Tables 20-27 one can see there exists substantial variation of the estimated elasticities for market share and fuel demand among the eight countries. For example, the own-price elasticities of market share for fuel oil for aggregate residential demand are -1.130 in U.K. and in U.S. and they are all less than unity (in absolute value) for the other six countries (it is only -0.465 for Sweden). The reasons for these differences are because both U.K. and U.S. have much lower shares of fuel oil than the others (see Tables 18 and 19). These results are reasonable because the elasticity measures the incremental changes at the margin. Thus, a fuel with small share or small demand is likely to be more sensitive to any incremental changes than a fuel with large share or large demand. This is, indeed, a property of the multinomial logit model.

Consider the estimated own-price elasticities for various fuels. The pattern of differences among fuels vary across country, apparently due to the composition of fuels used for space heating or aggregate residential sector. For most cases, solid fuels have the largest own-price elasticity for both market share and its demand. However, the own-price elasticities for fuel oil, natural gas, and electricity have different pattern of their relative values among countries. For example, the estimated own-price elasticities for both total end-uses and the space heating component for gas are considerably higher than that for fuel oil in France, West Germany, Italy, Japan (less dramatic), and Sweden. In Canada, these two elasticities have roughly the same magnitude. On the other hand, the elasticity for gas is considerably lower than that for fuel oil in U.K. and U.S. All these elasticities can be used to evaluate the impacts of changes in the relative prices of fuels on both market shares and demand among these countries.

Consider next the estimated cross-price elasticities, which measure the extent to which interfuel substitution has taken place. The results show that fuel oil is the strongest substitute for other fuels in France, West Germany, Italy, Japan, and Sweden, the five countries with least gas available. The estimated cross-elasticity with respect to fuel oil price has the largest magnitude among all cross-price elasticities in these countries. These results hold for both aggregate residential demand and space heating demand. For Canada, the estimated cross-price elasticities with respect to the prices of oil, gas, and electricity have a similar magnitude and are stronger than that with respect to coal price for aggregate residential demand. These results imply that for the total residential sector, oil, gas, and electricity are equally substitutable among each other in Canada. However, changes in coal price had little impact on either the shares or demand for the other three major fuels. In U.K. and U.S., the pattern of interfuel substitution is different from other countries. The results in Tables 26 and 27 show that the estimated cross-price elasticity with respect to gas price has the largest value for both aggregate and space heating demands. The next largest figure is the cross-electricity-price elasticity for aggregate demand and the cross-oil-price elasticity for the space heating demand. These results indicate that natural gas has been a more important substitute fuel than the other three fuels under investigation. Furthermore, fuel oil played a more significant role in fuel switching for space heating than for aggregate residential demand in both U.K. and U.S.

Finally, consider the estimated aggregate demand elasticities. These elasticities measure the changes in total fuel demand in response to changes in the prices of various fuels. The results show that all the estimated aggregate demand elasticities have a negative value, implying that increases in any fuel prices would likely result in a reduction in overall energy use. The strongest impact lies in the price of oil for total residential demand in France, West Germany, Italy, Japan, and Sweden. In these countries, the estimated aggregate demand elasticity with respect to oil price are all greater than -0.24 in absolute value. On the other hand, in U.K. and U.S., natural gas price appears to have the strongest impact on both the total residential and space heating demands. These results are due, in part, to the fact that the share of natural gas is the largest in U.K. and U.S.

5.4 Comparisons between Aggregate Residential Demand and Space Heating Demand

As one can see from the estimated aggregate demand equations presented in Tables 15 and 16, the estimated aggregate price elasticity is larger in absolute value for total residential demand (-0.513) than for space heating demand (-0.356). This result implies that the heating use of energy is likely to be less responsive to changes in energy price than other end-uses. Note that this comparison is rather casual because, as shown in Tables 11 and 13, the estimated aggregate price elasticities are sensitive to alternative combinations of explanatory variables.

With respect to market share elasticities, comparisons can be made with the results presented in Tables 20-27. For fuel oil, the estimated own-price elasticities for aggregate residential demand are consistently higher than their comparable estimates for space heating demand. These results indicate that changes in the price of fuel oil would affect its market share of aggregate use more than its share of space heating use. For solid fuels and electricity, the estimated own-price elasticities are larger for space heating demand than for aggregate residential demand. A larger own-price elasticity for the share of gas for space heating is found for all countries except Canada, U.K., and U.S. Thus, in these three countries, changes in the price of gas would affect its market share of aggregate use more than its share of space heating use while the opposite pattern of effects would prevail in other countries. The cross-price effects are also different. For example, in France, changes in electricity prices would have substantial impacts on the shares of oil, natural gas, and solid fuels for aggregate residential demand while these impacts are very marginal for space heating demand. Obviously, this result is due to the fact that the market share of electricity was substantially higher for aggregate demand than for space heating demand in France.

The comparisons of the aggregate demand elasticities reveal that, in general, changes in the price of any fuel would have relatively larger impacts on total demand for total residential use than on total heating use. Therefore, an increase in any fuel price would result in a larger percentage reduction in total residential use of energy than in heating use of energy. The strongest impact was found to be that of oil prices in Sweden. The estimated elasticity implies that a 1% increase in oil price would result in a 0.362% reduction of total residential use of energy in Sweden. As noted, the market share of oil for total residential use in Sweden was 68% in 1978 which was the largest among countries under study.

Turning to comparisons of the estimated individual fuel demand elasticities, one finds again that for fuel oil the estimated own-price elasticities are generally higher for aggregate residential demand than for space heating demand. However, the opposite pattern holds for solid fuels and electricity. For gas, the own-price elasticity is smaller in space heating demand than in total residential demand for all countries except Canada, U.K. and U.S. Consider the cross-price elasticities, the estimates for the prices of fuel oil and gas are generally higher in space heating demand than in total residential demand. However, the estimated cross-price elasticities for electricity price are generally larger in aggregate residential demand than the space heating component. These results imply that fuel oil and gas are stronger substitutes for other fuels in space heating than in other uses. On the other hand, electricity appears to be a stronger substitute in total residential use than for space heating. These results are, of course, reasonable.

6. CONCLUSIONS

This study represents the first attempt to model residential energy demand at the end-use level from an inter-country perspective. A multinominal logit model was specified and estimated with data for selected years during 1960-1979 from eight OECD countries.

We have shown that the variations in residential energy use can be explained by a model incorporating physical and economic variables that describe energy use. The model found aggregate income and price elasticities substantially lower than that usually calculated. These findings have important implications.

Consider first the low aggregate price elasticity. We argue that the low value arose because the model considered aggregate energy price, and because of the long adjustment time required for households to adjust equipment to the increased energy prices after 1973. However, our data base shows clearly that even during periods of falling energy prices, residential space heating uses were becoming more efficient in the engineering sense of less heat used per dwelling per unit area, and per degree day. Thus when and if the size of dwellings stops growing, or when the number of dwellings ceases to grow faster than the population itself, or when the ownership of energy-using devices is saturated, energy use growth will slow and may halt or turn downward. Just as in the case of energy use in industry, energy use in homes has actually become more efficient through technological progress. Measuring the impact of prices in a period when falling prices and improved technologies worked in opposite directions will yield a reduced sensitivity to prices, compared with other models relying only on price and income as explanatory variables. But when prices increase, technological change should be accelerated. As energy using equipment saturates, then, there may be a great drop in energy use/dwelling or for each purpose. Thus the low price elasticities calculated herein do not mean that higher prices will not reduce energy intensities in the future.

The role of higher incomes and saturation must also be seen in an important policy context. The income elasticity of residential energy use is lower than usually calculated. We can surmise that once a household acquires central heating, for example, further increases in income do not increase energy use for heating. The number of loads of wash, the volume of refrigerated space, and the quantity of hot water (and its temperature) are also certainly subject to saturation. The electronic appliances (video games, computers) now appearing in the OECD, in contrast with the uses studied herein, consume relatively small amounts of electricity relative to their cost or per hour of use. Hence we believe saturation in energy using services in households in the upper-income countries is occurring.

The space heating equation reveals an important relationship between heat and climate similar to that suggested on microeconomic grounds by Selmer and Sjoelund.[32] They found that heating use for a given home should increase with the square root of the climate intensity, close to the relation implied by the heating equation in Table 16.

This study also found strong interfuel substitutions among fuels used for space heating and other uses. Consequently, the estimated own-price elasticities are fairly high for both total residential demand and space heating demand. In fact, a majority of the estimates have a magnitude greater than unity in absolute value. The estimated cross-price elasticities show strong cross-price effects even though the elasticities are generally smaller than unity.

Judging from the estimated aggregate demand elasticities with respect to individual fuel prices, the increases in fuel oil prices have contributed most to the reduction in total energy use in the residential sector for France, West Germany, Italy, Japan, and Sweden. In Canada, U.K. and U.S., the impacts of the increases in the prices of gas and electricity on the overall reduction in energy use in the residential sector are much more notable than the increases in the prices of fuel oil and coal.

1. Lee Schipper, Andrea Ketoff, and Stephen Meyers, International Comparison of Residential Energy Use: Indicators of Residential Energy Use and Efficiency, Part One: The Data Base, LBL-11703, Lawrence Berkeley Laboratory, May 1981.

The following reports and articles have also been published within the context of the study:

Lee Schipper, International Comparison of Residential Energy Use, Proceedings of the "Second International Conference on Energy Use Management - Los Angeles", Pergamon Press, New York, October 1979.

Lee Schipper, International Residential Energy Use and Conservation Analysis: Structural and Economic Data Base, LBL-10960, May 1980.

Lee Schipper and Andrea Ketoff, International Comparison of Gas Use and Conservation, LBL-10896, Proceedings of "First International Gas Research Conference", Chicago, June 1980.

Lee Schipper and Andrea Ketoff, International Comparison of Residential Energy Use and Conservation: Data Base and Analysis. LBL-10587, Proceedings of "First International Conference on Energy Conservation and Consumer Behavior", Banff, Canada, September 1980.

Lee Schipper, Stephen Meyers, and Andrea Ketoff, Progress in Residential Energy Conservation: A Multi-Country Perspective, LBL-11701, Proceedings of the Conference "New Energy Conservation Technologies" sponsored by the International Energy Agency Berlin, Germany, April 1981.

Lee Schipper, Andrea Ketoff, and Stephen Meyers, Indicators of Residential Energy Use and Conservation - An International Study -, Proceedings of the "Third International Conference on

Energy Use Management" - Berlin, Pergamon Press, New York, October 1981.

Lee Schipper, Andrea Ketoff, and Stephen Meyers, "Residential Energy Use and Conservation Progress: An International Comparison", Energy - The International Journal, April 1982.

2. Eric Hirst and Janet Carney. The ORNL Engineering - Economic Model of Residential Energy Use, ORNL/CON-24. Oak Ridge National Laboratory, Oak Ridge, Tennessee, July 1978.

3. Andrew Goett and Daniel McFadden, Residential End-Use Energy Planning System, EPRI EA-2512, Final Report, Electric Power Research Institute, Palo Alto, California 1980.

4. Douglas R. Bobi, Analyzing Demand Behavior, A Study of Energy Elasticities, The Johns Hopkins University Press, 1982.

5. Wen S. Chern and William W. Lin, "Energy Demand for Space Heating in the United States", Econometric Studies in Energy Demand and Supply, eds. G.S. Maddala, Wen S. Chern, and G S. Gill, Praeger Publishers, Inc., 1978.

6. J.A. Hausman, "Individual Discount Rates and the Purchase and Utilization of Energy-Using Durables", The Bell Journal of Economics, Vol. 10, No.1, Spring 1979, pp. 33-54.

7. Martin L. Baughman and Paul L. Joskow, "Energy Consumption and Fuel Choice by Residential and Commercial Customers in the United States," Energy Systems and Policy, Vol. 1 No. 4, 1976.

8. Wen S. Chern, and Richard E. Just, "A Generalized Model for Fuel Choices with Application to the Paper Industry," Energy Systems and Policy, Vol. 4, No. 4, 1980.

9. See Reference 8.

10. LuAnn McClernan and Wen S. Chern, Energy Demand in the Primary Metals Industry: An Econometric Analysis, Lawrence Livermore National Laboratory, Report UCRL-53283, May 1981.

11. Wen S. Chern, An Econometric Model of Sectoral Energy Demand in Taiwan, under preparation.

12. Gearld Leach, Christopher Lewis, Frederic Romig, Ariane van Buren, Gerald Foley, A Low Energy Scenario for the United Kingdom, International Institute for Environment and Development, London, 1978.

13. Bertrand Chateau and Bruno Lapillonne, Energie et Habitat, Institut Economique et Juridique de l'Energie, Grenoble, 1981.

14. Robert S. Pindyck, "International Comparisons of the Residential Demand for Energy," European Economic Review Vol. 3 No. 1, pp. 1-24, January 1980.

15. H.S. Houthakker, "New Evidence on Demand Elasticities," Econometrica Vol. 33, No. 2, pp. 277-88, April 1965.

16. Wen S. Chern, Richard E. Just, and Hai S. Chang, A Varying Elasticity Model of Electricity Demand With Given Appliance Saturation , ORNL/NUREG/TM-438, Oak Ridge National Laboratory, 1982.

17. M. Parti and C. Parti, "The Total and Appliance-Specific Conditional Demand for Electricity in the Household Sector," The Bell Journal of Economics, Vol. II, No. 1, pp. 309-321, Spring 1980.

18. See Reference 7.

19. See Reference 1.

20. Stephen Meyers, Residential Energy Use in the United States, LBL-Draft,December 1981.

21. Patricia Baade, International Energy Prices, The Energy Information Administration, U.S. Department of Energy, April 1980.

22. Eurostat, National Accounts ESA, 1960-1978, Bruxelles, 1980.

23. Irving B. Kravis, A. Heston, R. Summers, International Comparisons of Real Product and Purchasing Power, Baltimore, John Hopkins University Press 1978.

24. Irving B. Kravis, Z. Kenessey, A. Heston, R. Summers, A System of International Comparisons of Gross Product and Purchasing Power, Baltimore, John Hopkins University Press, 1975.

25. Joel Darmstadter, Joy Dunkerley, and Jack Alterman, How Industrial Societies Use Energy, Baltimore, The John Hopkins University Press, 1977.

26. James M. Griffin, Energy Conservation in the OECD: 1980-2000, Cambridge, Mass: Ballinger Publishing Co. 1979.

27. See Reference 14.

28. W.D. Nordhaus, "The Demand for Energy: An International Perspective", in Proceedings of the Workshop on Energy Demand, W.D. Nordhaus, ed. Laxenburg, Austria, IIASA 1975.

29. K. Matsui, "Income and Price Elasticities of Energy Demand in Japan", Energy in Japan, Quarterly Report No. 46, September 1979.

30. Wen S. Chern, "Demand and Conservation of End-Use and Primary Energy in the Residential and Commercial Sectors", Energy Systems and Policy, Vol. 2, No 3, 1978.

31. Wen S. Chern et al., The ORNL State-Level Electricity Demand Forecasting Model, ORNL/NUREG-63, Oak Ridge National Laboratory Report, July 1980.

32. Sjoelund, J., 1979. <u>Vaermeisderingskonomi</u>. (Thermal Insulation Economies), Rapport R8:1979 Stockholm: Steotens Raad foer Byggforskning.

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