CHAPTER 6

Estimation of the demand for electricity and natural gas from billing data

6.1. Introduction

In this chapter we estimate a residential demand model for electricity and natural gas using data from the National Interim Energy Consumption Survey conducted during the year 1978-1979. This study differs from previous work in two major respects. First, we utilize individual monthly billing data in a pooled time-series cross-section framework. This permits a seasonally disaggregated analysis that considers individual behavior over time. Second, we use the engineering thermal load of Chapter 2 to model the household production technology for space heating and air conditioning, allowing more precise separation of the effects of economic variables from those of climate.

The thermal load technique is combined with billing cycle data in our study in two ways. First, we use the thermal model to estimate billing cycle load on a household-by-household basis. In this approach, two households with equivalent building characteristics facing identical weather patterns would be predicted to have the same energy demand. In this way we adopt a strategy of incorporating an engineering thermal projection into our energy demand analysis. In reality, we realize that the demands may vary significantly between otherwise identical households due to differences in income, household size, activity patterns, and the cost of energy. Thus departures from the engineering estimates are due to socioeconomic sensitivity in the rate of appliance stock utilization.

Secondly, we use the engineering thermal load techniques to estimate the cost of comfort. Here the estimated change in energy input required to effect a one-degree change in ambient temperature is multiplied by the marginal price of the fuel input. In the next section we combine the engineering economic approach in an econometrically estimable model.

Section 3 presents the electricity demand and natural gas estimation while Section 4 concludes with an analysis of energy demand under the ASHRAE conservation standards discussed in Chapter 3. Detailed descriptions of the data preparation procedures are given in Appendix A.

$$Y_{it}^{M} = X_{it}^{M}\beta^{M} + \varepsilon_{it}^{M}$$

denote respectively the fuel demands for space heating, air conditioning, water heating, and other uses. The error ε_{it} is precisely $\varepsilon_{it}^{SH} + \varepsilon_{it}^{AC} + \varepsilon_{it}^{WH} + \varepsilon_{it}^{M}$. This representation allows correlation of each component error term for fuel usage with the random components of utility that affect the presence or absence of a given HVAC system. In practice some correlation of unobserved variables is likely. For an appliance such as an air conditioner, an unobserved effect that increases the utility of the service supplied by the appliance (e.g., poor natural ventilation in the dwelling) is likely to increase both its probability of selection and its intensity of use. For an appliance such as a water heater, unobserved factors that increase intensity of use (e.g., tastes for hot-water clothes washing) are likely to decrease the probability of choosing the electric alternative that has a higher operating-to-capital cost ratio than the alternative fuel.

Dubin and McFadden (1984) introduced a family of models that permit consistent estimation of the parameters in equation (1). Their specification assumed that the choice model was multivariate logistic. Appendix B extends their analysis to include the generalized extreme value family of disturbances. The specification of fuel demand given in equation (5) is then consistent with the nested logistic choice models employed in Chapter 3.

We assume that each component error term for fuel usage has a conditional expectation that is linear in the choice model unobservables and has a conditional variance that is constant. Following the discussion in Chapter 5, we adopt the Amemiya-Heckman selectivity correction method and include estimated conditional expectations of the equation error given the observed portfolio choice as additional explanatory variables. Appendix B demonstrates that each conditional expectation is a simple function in the probabilities estimated from the nested logit model.

Our stochastic specification further assumes that each component fuel demand (i.e., fuel demand for space heating, fuel demand for air conditioning, etc.), follows a binary switching regression. The first regime represents the observed choice and the alternate regime represents collectively the unchosen alternatives. In the electricity demand equation, for example, δ_{i}^{WH} denotes the presence of an electric water-heating system. Given the structure in Chapter 3, electric water heating is selected if and only if its utility exceeds the utility of gas or oil systems. In the electricity demand equation, we treat gas and oil water-heating systems simply as "non electric." The conditional logistic structure of water-heating fuel all relevant available engineering data and emphasizes the structure of the estimated equation.

Our empirical work focuses on space and water heating and air conditioning as the end-uses that are the largest contributors to cross-sectional and seasonal variation in energy consumption. To reduce the number of parameters to be estimated, we subtract the term $Z_i\gamma$ from the left-hand side of equation (1), using values of γ reported in the literature. If the UEC values γ are measured with error, this approach may reduce the precision of the estimates of the parameters, β^j, but will not bias their estimates if measurement errors are uncorrelated with the explanatory variables. The form of equation (1) used in our study is:

$$\begin{aligned} Y_{it}^{f} - Z_i\gamma = {} & UEC_{it}^{SH}\,\delta_i^{SH}\,(X_{it}^{SH}\beta^{SH}) + UEC_{it}^{AC}\,\delta_i^{AC}\,(X_{it}^{AC}\beta^{AC}) \\ & + UEC_{it}^{WH}\,\delta_i^{WH}\,(X_{it}^{WH}\beta^{WH}) + X_{it}^{M}\beta^{M} + \varepsilon_{it} \qquad (4) \end{aligned}$$

where the superscripts *SH*, *AC*, *WH*, and *M* denote space heating, air conditioning, water heating, and miscellaneous uses respectively. The "miscellaneous" term captures consumer response for all end-uses, other than space and water heating and air conditioning, that are not contained in Z_i.

Several features of our empirical specification deserve note. First, the expression $UEC_{it}^{SH}\delta_i^{SH}$ is in reality an inner product of several space-heating system with a corresponding vector of dummy indicator variables that select the chosen alternative. This observation is important for space-heating systems as several system types are capable of providing the same delivered service. We do not, however, differentiate the utilization factor for space heating by system type. This is due primarily to computational considerations but also is implied by our theoretical structure, which incorporates engineering attributes of alternative systems in the calculation of UEC_{it}^{SH}. For air conditioning and water heating, we follow the model of Chapter 3 and consider one system type for each fuel type.

Our second observation concerns the specification of the error ε_{it}. We write equation (4) as

$$\begin{aligned} Y_{it}^{f} - Z_i\gamma &= Y_{it}^{SH} + Y_{it}^{AC} + Y_{it}^{WH} + Y_{it}^{M} \qquad \text{where} \qquad (5) \\ Y_{it}^{SH} &= UEC_{it}^{SH}\,\delta_i^{SH}\,(X_{it}^{SH}\beta^{SH}) + \varepsilon_{it}^{SH} \\ Y_{it}^{AC} &= UEC_{it}^{AC}\,\delta_i^{AC}\,(X_{it}^{AC}\beta^{AC}) + \varepsilon_{it}^{AC} \\ Y_{it}^{WH} &= UEC_{it}^{WH}\,\delta_i^{WH}\,(X_{it}^{WH}\beta^{WH}) + \varepsilon_{it}^{WH} \qquad \text{and} \end{aligned}$$

QGBASE (therms) = [0.114 (clothes dryer) + 0.319 (first gas oven) + 0.160 (second gas oven)] × [number of days in billing period].

On the right-hand side, space-heating usage (UEC_{it}^{SH}) is the fuel usage (kwh for electricity, therms for natural gas) required to maintain an indoor temperature of 70 °F. This quantity is calculated by the integration of daily thermal load over the billing cycle and then adjusted for the efficiency of the heating system and for delivery loss. Details are given in Appendix A. Air-conditioning usage (UEC_{it}^{AC}) is the predicted kwh required to maintain the dwelling at 75 °F.

In the specification of the utilization factor for HVAC systems, we use a constant, income, and the marginal price of comfort. The marginal price of comfort represents the cost of increasing indoor temperature by one degree Fahrenheit (decreasing temperature in the case of air conditioning). It is calculated by multiplying the tail-block marginal fuel price by the energy usage required to increase indoor temperature from 69 to 70 degrees.

Water-heating usage (UEC_{it}^{WH}) is calculated using the formula developed in Chapter 3 to calculate operating costs. An adjustment is made to reflect the length of the billing period. The utilization factor for water heating uses the tail-block marginal fuel price, income, and a constant term.

Variables in the "miscellaneous usage" term include an intercept, the number of household members, income, the marginal fuel price, and the number of days in the billing period. Definitions of all variables and constructions used in this analysis are presented in Table 6.1 and 6.2. for electricity and natural gas respectively.

The data used to estimate this model are a subset of the 911 households used in estimating the nested logit model in Chapter 3. Of the 911 households, 862 had some data on electricity demand while 504 had data on natural gas demand. We define the billing periods using information about the starting dates of actual bills. A household is assumed to have an observation in a given calendar month if it has a billing period with a start date in that month. This procedure serves to define relatively precise calendar effects and separates observations into homogeneous groups.

Variable means over billing periods are presented in Tables 6.3 and 6.4 for electricity and natural gas respectively. Results in these and later tables are presented in three groups: "Winter," which contains the months November, December, January, and February; "Summer," which choice given space-heating system choice permits the aggregation of unchosen alternatives into a generic category whose deterministic utility is the exponentially weighted average of the primary utilities. In estimation we therefore include three conditional expectation terms, one each for space heating, water heating, and air conditioning, as additional explanatory variables. We assume that the component error term, ε_{it}^{M}, is uncorrelated with the choice of HVAC systems.

The time-series cross-section structure of the billing data permits separate estimates of the correlation of fuel usage and appliance choice by season. These estimates refine the empirical evidence obtained in Dubin and McFadden (1984), which relied on annual data. The separate estimation of electricity and natural gas allows the appliance endogeniety issue to be additionally analyzed by fuel type.[1]

6.3. Estimation of the demand for electricity and natural gas

6.3.1. *Variable definitions*

The form of equation (4) used in estimation contains the unit-energy-consumption terms, UEC_{it}^{j}, as well as the utilization variables represented by $X_{it}^{j}\delta_{i}^{j}$ on the right-hand side, and net consumption, $Y_{it}^{f} - Z_{i}\gamma$, on the left-hand side. In the electricity demand models, the dependent variable, NETQUAN, is calculated as the difference QUAN minus QEBASE. Using typical UEC's values, we assume:

QEBASE (kwh) = [3.99 (number of automatic refrigerators) + 1.87 (number of manual refrigerators) + 2.8 (number of ovens) + 0.5 (microwave oven) + 3.8 (separate food freezer) + 0.9 (dishwasher) + 0.2 (clothes washer)] × [number of days in billing period] and

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[1] We recognize that the time-series cross-section structure of the billing data permits a stochastic specification in which individual effects induce correlation over time. Viewing individual demand equations as Seemingly Unrelated Regressions (SUR) should increase efficiency in the estimation. In this study, we estimate the demand equations as separate cross sections, focusing on the differences in parameter estimates over the billing cycle rather than on the possibilities for pooling.

Table 6.1—continued

SUSHEP	SUSHE × SHP
SUSHEY	SUSHE × INCOME
SUCACP	SUCAC × ACP
SUCACY	SUCAC × INCOME
CAC	Central air-conditioning dummy
WHE	Water-heating electric dummy
SHE	Space-heating electric dummy
SUWHE	SUWHE × MPE
SUWHEP	SUWHE × INCOME
H1	[(PSHE-SHE) · log (PSHE)/PSHNE - (PSHNE - SHNE) · log (PSHNE)/PSHE] where PSHE is the estimated probability of choosing electric space heating, PSHNE is the estimated probability of choosing non-electric space heating, SHE is an alternative specific variable for electric space heating, and SHNE = 1 - SHE.
H2	[(PCAC - CAC) · log (PCAC)/PNCAC - (PNCAC - NCAC) · log (PNCAC/PCAC] where PCAC is the estimated probability of choosing central air conditioning, PNCAC is the estimated probability of not choosing central air conditioning, CAC is an alternative specific variable for central air conditioning, and NCAC = 1 - CAC.
H3	[(PWHE-WHE) · log (PWHE)/PWHNE - (PWHNE - WHNE) · log (PWHNE)/PWHE] where PWHE is the estimated probability of choosing electric water heating, PWHNE is the estimated probability of choosing non-electric water heating, WHE is an alternative specific variable for electric water heating, and WHNE = 1 - WHE.
NETQUAN	Difference between actual consumption, QUAN, and base consumption, QEBASE (kwh)

Interestingly, SHP varies from a high value of $1.27 for the month of November to essentially zero in the summer months. The peak cost of air-conditioning services occurs in July at $1.15 per degree per billing period. Inspection of Table 6.4 indicates that the marginal cost for heating services is at its highest in December at the level of $2.48.

6.4. Estimation results

Ordinary least squares estimates of the demand models by billing period are presented in Tables 6.5 and 6.6 for electricity and natural gas respectively. Interpretation of coefficients on miscellaneous usage variables is straightforward. The number of household members, NHSLDMEM,

Table 6.1

Variable definitions (electricity models)

SUSHE	Space-heating energy consumption from thermal model for HVAC systems 13, 14, 15, 18 — electric forced-air without central air conditioning, electric forced-air with central air conditioning, electric heat pump, electric baseboard heat without central air conditioning (kwh)
SUCAC	Air-conditioning energy consumption from thermal model for HVAC systems 2, 8, 14, 15 — gas forced-air with central air, oil forced-air with central air, electric forced-air with central air, electric heat pump (kwh)
SUWHE	Water-heating energy consumption from average usage relationship (see text) for electric hot-water systems (kwh)
DSHE	Space-heating energy required to increase indoor temperature one degree from thermal model (kwh)
DCAC	Air conditioning energy required to decrease indoor temperature one degree from thermal model (kwh)
SHP	Marginal cost of increasing indoor temperature one degree F $\equiv$ DSHE × MPE ($)
ACP	Marginal cost of decreasing indoor temperature one degree F $\equiv$ DCAC × MPE ($)
MPE	Marginal cost of electricity ($/kwh)
INCOME	Total annual income (thousands $)
DAYS	Number of days in billing period
ONE	Constant term
NHSLDMEM	Number of household members

contains the months of June, July, August, and September; and "Off-Season," which contains the months of March, April, May, and October.

In reading Tables 6.3 and 6.4 one should observe that the mean values for the unit energy consumption variables and their interactions reflect the indicator for HVAC system type. Thus the variables SUSHE, SUSHEP, and SUSHEY should be divided by the proportion of households with electric space heating, SHE, in order to determine the mean values for the subpopulation consisting only of households with electric space heating.

Generally, the SUSHE variables increase in the colder months and decrease in the warmer months, as expected. The SUCAC variables reverse this pattern, exhibiting their largest magnitudes during the summer months. The variables DSHE and DCAC represent the energy usage (in kwh and therms respectively) required to change indoor temperature by one degree. SHP and ACP are the costs of making these changes.

Table 6.3a
Variable means by billing period—Winter

Variable	November	December	January	February
SUSHE	582.6	1118.	1048.	843.1
SUSHEP	3423.	8532.	6406.	4934.
SUSHEY	14870.	29170.	25960.	21870.
SUCAC	9.620	1.392	0.7268	2.603
SUCACP	24.09	1.877	0.2004	1.952
SUCACY	229.4	34.44	13.72	55.68
SUWHE	148.6	165.1	157.5	157.6
SUWHEP	5.497	5.770	5.748	5.446
SUWHEY	3532.	3910.	3736.	3777.
SHP	1.056	1.269	1.259	1.204
ACP	0.0983	0.0165	0.0076	0.02736
DSHE	29.55	39.38	35.63	37.24
DCAC	2.854	0.4594	0.1855	0.7170
MPE	0.0392	0.0392	0.0389	0.0387
INCOME	22.32	22.88	22.38	22.66
NHSLDMEM	3.195	3.238	3.231	3.202
DAYS	34.65	40.21	35.20	34.33
H1	0.03236	0.02728	-0.00964	0.06660
H2	0.06575	-0.03021	0.04316	0.01854
H3	0.06225	0.04874	0.03790	0.07709
SHE	0.2378	0.2349	0.2385	0.2526
WHE	0.4269	0.4108	0.4354	0.4324
CAC	0.4077	0.3570	0.3954	0.3744
QUAN	1200.	1686.	1628.	1527.
QEBASE	465.8	529.6	471.1	463.9
Observations	677	762	650	673

Interpretation of the space-heat interaction terms is less straightforward because they are multiplied by the unit energy consumptions for heating. If the thermal model were to predict exactly the space-heating consumption necessary to maintain an indoor temperature of 70 degrees, and if there were no response to economic variables, then the coefficient on SUSHE would be unity and the other coefficients would be zero. The coefficients on SUSHEP and SUSHEY can be interpreted as the amounts by which changes in the price of comfort and in income respectively modify the effect of unit energy consumption on net usage. The signs on these coefficients conform to the predictions of our model in that price effects are generally negative and income effects are generally positive.

The estimated coefficient of SUSHE varies across the 12 billing periods. However, the magnitude of the average effect suggests that the thermal model may be overestimating usage by more than can be

Table 6.2

Variable definitions (natural gas models)

SUSHG	Space-heating energy consumption from thermal model for HVAC systems 1, 2, 3 — gas forced-air with central air conditioning, gas forced-air without central air conditioning, gas hot water without central air conditioning (therms)
SUWHG	Water-heating energy consumption from usage relationship (see text) for gas hot water systems (therms)
DSHG	Energy required to increase indoor temperature one degree from thermal model (therms)
SHP	Marginal cost of increasing indoor temperature one degree F ≡ DSHG × MPG ($)
MPG	Marginal cost natural gas ($/therm)
INCOME	Total annual income (thousands $)
DAYS	Number of days in billing period
ONE	Constant term
NHSLDMEM	Number of household members
SHG	Space-heating gas dummy
WHG	Water-heating gas dummy
SUSHGP	SUSHG × SHP
SUSHGP	SUSHG × INCOME
SUWHGP	SUWHG × MPG
SUWHGY	SUWHG × INCOME
H1	[(PSHG-SHG) · log (PSHG)/PSHNG - (PSHNG - SHNG) · log (PSHNG)/PSHG] where PSHG is the estimated probability of choosing gas space heating, PSHNG is the estimated probability of choosing non-gas space heating, SHG is an alternative specific variable for gas space heating, and SHNG = 1 - SHG.
H2	[(PWHG-WHG) · log (PWHG)/PWHNG - (PWHNG - WHNG) · log (PWHNG)/PWHG] where PWHG is the estimated probability of choosing gas water heating, PWHNG is the estimated probability of choosing non-gas water heating, WHG is an alternative specific variable for gas water heating, and WHNG = 1 - WHG.
NETQUAN	Difference between actual consumption, QUAN, and base consumption, QGBASE (therms)

affects usage at the approximate rate of 80 kwh per person per billing period. An additional day in the billing period represents on average an extra 10 kwh not accounted in other effects.[2]

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[2] In Tables 6.5 through 6.6, t-statistics for coefficient significance are given in the line following the parameter estimates.

Table 6.3c

Variable means by billing period—Off-Season

Variable	March	April	May	October
SUSHE	396.0	273.3	55.10	419.7
SUSHEP	1980.	1174.	141.5	2079.
SUSHEY	10680.	6928.	1402.	10520.
SUCAC	15.24	47.73	97.02	13.47
SUCACP	47.98	163.2	346.4	44.72
SUCACY	305.4	1127.	2460.	314.6
SUWHE	135.1	158.1	145.2	150.0
SUWHEP	4.814	5.486	5.240	5.212
SUWHEY	3323.	3741.	3474.	3596.
SHP	0.8396	0.6755	0.2697	0.8140
ACP	0.1569	0.3680	0.7052	0.1678
DSHE	25.34	23.77	8.825	27.12
DCAC	4.240	13.86	35.44	5.085
MPE	0.03842	0.03926	0.03944	0.03922
INCOME	23.93	23.25	22.25	23.27
NHSLDMEM	3.200	3.257	3.206	3.231
DAYS	31.22	35.77	35.29	35.79
H1	-0.007479	0.02737	0.02305	0.007580
H2	0.1280	0.01261	0.07868	-0.001253
H3	-0.007844	0.08786	0.01397	0.03617
SHE	0.2198	0.2386	0.2308	0.2276
WHE	0.3802	0.4199	0.4031	0.4092
CAC	0.4286	0.3922	0.4046	0.3696
QUAN	1158.	1087.	1039.	1047.
QEBASE	431.5	481.1	464.6	478.1
Observations	455	612	650	782

Regarding the correlation of appliance choice and utilization, we see that the selectivity correction terms vary in significance by billing period and system type. In the electricity demand models, the winter months are associated with positive and significant selectivity coefficients for the endogeniety of space heating. Air-conditioning choice effects are present in the summer months of June and July. Choice of water-heating fuel is indicated to be endogenous in five of 12 months (January, March, May, July, and December). Only two months reveal no correlation between usage and system choice behaviors: April and September.[3]

In the natural gas estimation, space-heating endogeniety is indicated in the months of August and October while water-heating endogeniety is indicated in January, April, July, August, November, and December.

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[3] Under the null hypothesis of exogeneity of appliance choice decisions, the usual t-tests need not be corrected for the two-stage estimation method employed.

Table 6.3b

Variable means by billing period—Summer

Variable	June	July	August	September
SUSHE	37.72	7.455	83.93	136.8
SUSHEP	111.8	6.461	395.8	533.0
SUSHEY	935.7	193.6	2074.	3531.
SUCAC	152.9	155.0	163.6	110.7
SUCACP	625.0	944.5	836.8	328.2
SUCACY	4359.	4477.	4752.	2795.
SUWHE	150.7	147.9	159.5	141.6
SUWHEP	5.210	5.495	5.559	5.130
SUWHEY	3541.	3530.	3848.	3378.
SHP	0.1351	0.04286	0.1879	0.4797
ACP	0.9367	1.151	1.094	0.6438
DSHE	7.083	1.882	9.488	14.49
DCAC	57.82	67.11	56.42	24.98
MPE	0.03909	0.03958	0.03873	0.03918
INCOME	22.97	22.73	23.26	22.57
NHSLDMEM	3.251	3.208	3.233	3.187
DAYS	36.32	35.73	36.75	33.30
H1	0.04006	0.002390	0.02343	0.006142
H2	0.01705	0.05941	0.01728	0.08123
H3	0.02807	0.03432	0.04476	0.03720
SHE	0.2347	0.2245	0.2398	0.2332
WHE	0.4025	0.4106	0.4210	0.4198
CAC	0.3711	0.3988	0.3760	0.4052
QUAN	1272.	1352.	2713.	1057.
QEBASE	483.1	471.6	493.5	442.6
Observations	733	677	734	686

accounted for by the effects of price and income. While the significance of individual coefficients varies somewhat in the different periods, we see that the models predict well in the winter and off-season periods but not as well during the summer months. The poor performance of the electricity demand model in the summer is apparently caused by colinearity among the explanatory variables.

A very similar pattern is exhibited in the natural gas estimation. Here the sample is selected to include all households for which gas is an available fuel. An additional household member represents a modest increase of approximately three therms during the billing period. An additional day in the billing period increases consumption by fewer than four therms. The individual coefficients are generally significant but reveal some discrepancies in the expected signs. The general magnitudes of the coefficients suggest again that the thermal model may overestimate utilization, but not in a fashion that prevents its usefulness in forecasting.

Table 6.4c
Variable means by billing period—Off-Season

Variable	March	April	May	October
SUSHG	146.6	94.46	36.59	155.1
SUSHGP	267.1	230.5	112.2	519.0
SUSHGY	3700.	2397.	945.7	3838.
SUWHG	15.69	18.96	20.92	19.97
SUWHGP	3.138	4.312	4.750	4.461
SUWHGY	384.8	460.8	506.2	480.5
SHP	1.491	1.618	1.114	1.905
DSHG	7.477	7.294	5.000	8.588
WHG	0.9276	0.9242	0.9370	0.9262
SHG	0.9864	0.9606	0.9685	0.9644
QGBASE	8.757	12.65	14.46	12.88
QUAN	159.4	105.3	69.06	153.3
MPG	0.2012	0.2223	0.2239	0.2213
INCOME	23.15	22.88	22.66	22.88
NHSLDMEM	3.063	3.203	3.189	3.209
DAYS	31.24	38.18	41.73	39.16
H1	0.4007	0.4058	0.4345	0.4061
H3	0.2625	0.3326	0.3807	0.3413
Observations	221	330	349	393

These results support the findings of Dubin and McFadden (1984) and indicate that behavioral correlations in HVAC-system choice and utilization occur in those periods in which systems are most intensely used.

To gauge the effects of price and income and to determine the sources of their sensitivity, we calculate short-run price and income elasticities. Tables 6.7 and 6.8 present the elasticities for the electricity and natural gas models respectively. Recall that the estimated model has the form:

$$\begin{aligned} \mathrm{NETQUAN} &= \mathrm{QUAN} - \mathrm{QEBASE} = \mathrm{SUSHE}\gamma_0 + \mathrm{SUSHEP}\gamma_1 + \\ &\quad \mathrm{SUSHEY}\gamma_2 + \mathrm{SUCAC}\gamma_3 + \mathrm{SUCACP}\gamma_4 + \mathrm{SUCACY}\gamma_5 + \mathrm{SUWHE}\gamma_6 \\ &\quad + \mathrm{SUWHEP}\gamma_7 + \mathrm{SUWHEY}\gamma_8 + \gamma_9 + \mathrm{MPE}\gamma_{10} + \mathrm{INCOME}\gamma_{11} + \\ &\quad \mathrm{NHSLDMEM}\gamma_{12} + \mathrm{DAYS}\gamma_{13} + \mathrm{H1}\gamma_{14} + \mathrm{H2}\gamma_{15} + \mathrm{H3}\gamma_{16}. \end{aligned}$$

It then follows that the elasticity of total energy usage with respect to price is

$$\begin{aligned} (\mathrm{MPE/QUAN})\,(\partial\mathrm{QUAN}/\partial\mathrm{MPE}) &= (\mathrm{MPE/QUAN}) \times \\ &\quad [\,(\mathrm{SUSHE})(\mathrm{DSHE})\,\gamma_1 + (\mathrm{SUCAC})(\mathrm{DCAC})\,\gamma_4 + (\mathrm{SUWHE})\,\gamma_7 + \gamma_{10}\,]. \end{aligned}$$

Table 6.4a

Variable means by billing period—Winter

Variable	November	December	January	February
SUSHG	298.4	375.3	350.6	268.2
SUSHGP	1462.	1279.	1033.	763.6
SUSHGY	8515.	9001.	8349.	6768.
SUWHG	20.95	21.39	18.95	18.32
SUWHGP	4.766	4.742	4.392	4.098
SUWHGY	536.3	503.3	443.2	446.0
SHP	2.456	2.483	2.279	2.098
DSHG	10.86	11.28	10.09	9.520
WHG	0.9260	0.9211	0.9300	0.9246
SHG	0.9644	0.9690	0.9621	0.9623
QGBASE	13.81	13.41	12.75	10.78
QUAN	261.8	340.1	307.2	241.3
MPG	0.2263	0.2223	0.2261	0.2231
INCOME	23.10	22.26	22.34	22.91
NHSLDMEM	3.173	3.254	3.120	3.304
DAYS	40.98	42.19	38.05	35.28
H1	0.4265	0.4150	0.4118	0.4029
H3	0.3507	0.3214	0.3521	0.3439
Observations	365	355	343	345

Table 6.4b

Variable means by billing period—Summer

Variable	June	July	August	September
SUSHG	14.72	22.35	28.66	69.12
SUSHGP	30.96	144.5	108.6	235.4
SUSHGY	378.5	652.5	756.1	1871.
SUWHG	21.23	21.40	20.04	18.49
SUWHGP	4.829	4.929	4.524	4.226
SUWHGY	512.6	538.9	486.8	452.0
SHP	0.7331	0.6699	0.9198	1.377
DSHG	3.241	2.972	3.920	5.890
WHG	0.9321	0.9246	0.9263	0.9278
SHG	0.9674	0.9623	0.9632	0.9639
QGBASE	14.13	13.15	13.12	11.93
QUAN	54.00	58.63	59.24	75.66
MPG	0.2248	0.2247	0.2217	0.2242
INCOME	22.85	23.29	22.56	22.98
NHSLDMEM	3.204	3.255	3.224	3.219
DAYS	41.19	42.04	39.15	36.48
H1	0.4191	0.4189	0.4056	0.4121
H3	0.3708	0.3532	0.3412	0.3474
Observations	368	345	353	360

Table 6.5b
Electricity demand model—Summer

Variable	June	July	August	September
SUSHE	-0.2217	1.006	-9.408	0.001985
	-0.4188	0.2847	-0.7851	0.01340
SUSHEP	-0.07204	-0.2988	0.02488	0.02148
	-1.015	-0.09922	0.03204	1.421
SUSHEY	0.03627	-0.05019	0.2226	0.005645
	2.811	-1.236	0.6690	1.368
SUCAC	0.2222	0.6895	-2.066	1.001
	1.126	3.187	-0.2097	4.380
SUCACP	0.1602	0.06957	0.1765	-0.1803
	4.884	3.783	0.1757	-3.132
SUCACY	-0.01329	-0.006580	0.04246	0.02972
	-2.205	-1.024	0.1369	4.155
SUWHE	1.661	-0.1283	16.24	1.714
	2.889	-0.1514	0.5266	3.114
SUWHEP	-31.44	37.85	-277.7	-25.79
	-2.425	1.953	-0.3902	-1.978
SUWHEY	0.01436	0.01868	-0.4795	0.002812
	1.271	1.701	-0.7865	0.2839
ONE	-309.9	141.1	5417.	173.8
	-1.758	0.7106	0.5735	1.333
MPE	6252.	-12070.	-81460.	-11930.
	1.493	-2.594	-0.3539	-3.840
INCOME	9.289	8.582	13.79	0.8496
	3.336	2.666	0.08831	0.4075
NHSLDMEM	71.04	79.40	-867.2	84.22
	4.151	4.045	-0.8818	6.497
DAYS	4.841	10.44	91.66	10.07
	2.666	5.690	0.8265	5.251
H1	42.96	19.80	4200.	28.46
	1.630	0.6631	3.001	1.185
H2	70.77	65.24	-1044.	-8.614
	2.999	2.528	-0.8176	-0.5659
H3	5.457	-105.8	2165.	-6.041
	0.1808	-3.289	1.265	-0.2553
R^2	0.3430	0.5093	0.02489	0.4846
Obsevations	733	677	734	686
Standard error	669.2	734.4	36820.	468.0

Table 6.5a
Electricity demand model—Winter

Variable	November	December	January	February
SUSHE	0.5602	0.2385	0.4380	0.6304
	6.945	5.340	5.996	8.750
SUSHEP	0.004739	0.009684	-0.006719	-0.002097
	0.7972	5.351	-1.159	-4.396
SUSHEY	-0.006487	-0.0002629	-0.003334	0.8217
	-4.304	-0.2433	-2.091	0.5177
SUCAC	-2.283	-5.158	-36.52	3.079
	-1.397	-0.5151	-1.728	0.5773
SUCACP	-0.01747	-0.3552	34.05	3.447
	-0.08841	-0.09030	0.4769	0.9342
SUCACY	0.09381	0.1136	0.3962	-0.3470
	1.446	0.2877	0.4029	-1.265
SUWHE	1.509	4.501	5.148	5.368
	1.761	6.246	4.445	7.164
SUWHEP	-15.81	-75.10	-56.29	-101.5
	-0.8046	-5.029	-2.259	-6.398
SUWHEY	0.009234	0.01835	0.007412	0.3478
	0.7024	1.226	0.3933	2.054
ONE	-219.8	-100.1	-257.8	-507.1
	-1.196	-0.4501	-1.030	-2.307
MPE	-7041.	-5931.	-9895.	6155.
	-1.647	-1.117	-1.698	1.215
INCOME	3.175	4.022	9.962	5.031
	1.113	1.064	2.393	1.422
NHSLDMEM	87.75	79.04	44.83	26.26
	5.006	3.278	1.839	1.181
DAYS	13.27	10.50	17.34	7.984
	6.382	4.645	5.468	2.681
H1	26.08	176.9	306.6	41.48
	0.5790	3.122	4.285	0.7988
H2	39.49	-14.13	27.22	-1.521
	2.054	-0.5057	1.001	-0.06066
H3	3.796	-118.7	-195.7	-122.1
	0.1092	-2.355	-3.819	-2.679
$\bar{R}^2$	0.6159	0.7385	0.6956	0.7780
Observations	677	762	650	673
Standard error	642.8	943.6	889.1	808.0

Table 6.6a

Natural gas demand model—Winter

Variable	November	December	January	February
SUSHG	-0.00502	0.4425	0.4864	0.6028
	-0.06020	5.206	5.728	7.479
SUSHGP	0.01479	-0.02919	-0.05784	-0.08690
	5.901	-4.817	-6.112	-9.434
SUSHGY	0.00635	0.00637	0.00669	0.00988
	2.326	2.472	2.470	3.739
SUWHG	6.423	3.493	3.255	-10.10
	2.394	1.014	0.9789	-3.572
SUWHGP	-7.288	-3.866	5.780	42.42
	-1.198	-0.3346	0.5256	4.611
SUWHGY	0.03068	0.05402	-0.1333	0.08079
	0.4864	0.7748	-2.262	1.544
ONE	50.36	-42.89	-82.00	167.5
	1.144	-0.6622	-1.472	3.889
MPG	-210.2	-29.26	-28.10	-629.6
	-1.092	-0.1047	-0.1237	-3.592
INCOME	-1.311	-2.495	0.4447	-3.195
	-1.405	-1.936	0.4016	-3.673
NHSLDMEM	-7.059	3.817	2.567	0.7171
	-1.583	0.7559	0.6227	0.2098
DAYS	2.707	3.670	4.607	2.659
	3.465	5.126	7.012	3.724
H1	10.12	4.570	3.285	-5.157
	1.008	0.3746	0.3612	-0.6605
H3	-22.18	-22.17	-18.32	-13.10
	-2.250	-1.968	-1.944	-1.660
$\overline{R}^2$	0.8709	0.7431	0.6939	0.6522
Observations	365	355	343	345
Standard error	105.3	121.2	90.07	79.25

The price interaction term SUSHEP is defined as the product of SUSHE with the marginal cost of comfort SHP. On the other hand, SHP is the product of the change in kwh, DSHE, and the marginal price of electricity MPE. Thus the price derivative of SUSHEP produces SUSHE × DSHE as indicated in the elasticity formula. The elasticity of total energy usage with respect to income is

Table 6.5c
Electricity demand model—Off-Season

Variable	March	April	May	October
SUSHE	0.1007	0.5632	0.7067	-0.04551
	0.7312	5.888	2.134	-0.8272
SUSHEP	0.003324	-0.03387	0.2622	0.1208
	0.2169	-4.198	3.186	3.238
SUSHEY	0.006488	0.005812	-0.04139	0.003601
	1.865	2.371	-3.599	2.471
SUCAC	-1.403	-0.2077	0.7335	-1.173
	-0.8885	-0.6318	3.177	-1.446
SUCACP	-0.1852	-0.1950	0.08567	0.05117
	-0.4703	-3.170	2.132	0.4563
SUCACY	0.02726	0.08173	-0.007448	0.05366
	0.5821	6.812	-0.8363	1.616
SUWHE	4.643	3.141	1.372	1.784
	3.947	6.821	2.112	3.867
SUWHEP	-57.39	-40.63	-7.829	-22.00
	-2.173	-4.237	-0.4863	-2.134
SUWHEY	0.01289	-0.01331	0.01608	0.002791
	0.7555	-1.429	1.355	0.3019
ONE	-281.5	-589.3	-384.3	66.22
	-0.8650	-4.696	-2.140	0.5137
MPE	-4175.	3236.	694.3	-9553.
	-0.5964	1.036	0.1652	-3.072
INCOME	8.132	3.721	8.199	5.094
	2.365	1.760	2.862	2.500
NHSLDMEM	37.76	49.32	66.09	96.10
	1.599	3.652	3.852	7.301
DAYS	11.59	11.04	6.273	6.648
	2.227	6.780	3.298	4.140
H1	283.0	-27.87	40.32	118.3
	4.375	-1.069	1.402	5.152
H2	32.10	0.5656	10.83	-5.837
	1.299	0.03618	0.5386	-0.3884
H3	-177.4	-19.63	-64.58	-13.37
	-3.621	-0.8231	-2.078	-0.5421
R^2	0.6350	0.7318	0.3613	0.5172
Observations	455	612	650	782
Standard error	686.0	472.4	624.0	520.4

Table 6.6c
Natural gas demand model—Off-Season

Variable	March	April	May	October
SUSHG	0.5985	0.4169	0.2373	0.2712
	2.918	3.510	2.240	3.153
SUSHGP	-0.09167	-0.06732	0.07501	-0.001710
	-3.629	-3.292	4.521	-0.2561
SUSHGY	0.00095	0.00948	-0.00162	0.00301
	0.1403	3.170	-0.3595	1.085
SUWHG	-3.136	-1.561	-0.5396	2.197
	-0.6556	-0.8688	-0.6526	1.063
SUWHGP	12.03	12.79	-0.7165	-3.768
	0.7189	2.113	-0.3099	-0.6357
SUWHGY	0.1648	0.01130	0.03900	0.01825
	1.925	0.4741	2.747	0.4313
ONE	87.57	52.02	14.77	-50.36
	1.121	1.839	0.9288	-1.613
MPG	-275.6	-173.5	-98.63	-215.5
	-0.9145	-1.574	-1.524	-1.653
INCOME	-2.694	-0.9628	0.06898	0.00927
	-1.836	-1.693	0.2026	0.01339
NHSLDMEM	2.536	2.391	1.441	-0.04289
	0.6951	1.098	0.8760	-0.01504
DAYS	1.736	0.4740	0.8594	3.619
	2.084	1.548	3.690	7.967
H1	7.750	5.714	2.469	23.00
	0.6474	1.201	0.6502	3.461
H3	-11.18	-12.63	-4.711	-3.749
	-1.302	-2.628	-1.349	-0.5886
$\overline{R}^2$	0.3728	0.4420	0.8432	0.7989
Observations	221	330	349	393
Standard error	58.76	50.94	37.92	72.37

To explain the sources of price and income sensitivity, we make a separate calculation of the "individual" price elasticity (MPE/QUAN) × γ_{10} as well as the elasticities for water heating, central air-conditioning, and space heating.

In the winter period, the relatively largest fraction of price and income sensitivity comes from water heating and other end-uses. Space-heating elasticities are relatively small while air-conditioning effects are not relevant. The total elasticities are well within the usual range of

Table 6.6b

Natural gas demand model—Summer

Variable	June	July	August	September
SUSHG	0.9063	0.7620	-0.07526	0.7513
	2.044	7.193	-0.4280	5.704
SUSHGP	-0.00133	-0.03000	0.04950	0.002045
	-0.01347	-2.565	4.066	0.2143
SUSHGY	-0.02381	0.008236	0.01043	-0.01296
	-1.881	3.328	2.006	-3.386
SUWHG	-3.715	0.9190	1.850	0.2676
	-2.828	1.002	1.417	0.1246
SUWHGP	15.32	0.9982	5.923	-1.276
	3.155	0.3537	1.386	-0.2042
SUWHGY	0.05563	-0.00402	-0.08782	0.01350
	2.826	-0.2351	-3.958	0.3393
ONE	59.25	7.050	-39.86	-5.085
	2.515	0.3926	-1.779	-0.1486
MPG	-259.0	-76.85	-190.2	-146.6
	-2.646	-1.141	-2.152	-1.107
INCOME	-0.1343	0.3778	1.862	0.9519
	-0.2709	0.9448	4.311	1.539
NHSLDMEM	0.3080	2.545	3.455	-0.05463
	0.1535	1.493	1.948	-0.02298
DAYS	0.3133	0.02302	1.100	1.232
	1.008	0.09119	3.505	2.787
H1	2.337	4.134	7.697	2.382
	0.5439	1.151	2.114	0.4672
H3	-2.369	-12.96	-10.09	0.6339
	-0.5549	-3.733	-2.656	0.1173
$\overline{R}^2$	0.3206	0.8511	0.7433	0.5758
Observations	368	345	353	360
Standard error	47.70	39.04	41.17	53.34

$$(\mathrm{INCOME/QUAN})\,(\partial\mathrm{QUAN}/\partial\mathrm{INCOME}) = (\mathrm{INCOME/QUAN}) \times [\,(\mathrm{SUSHE})\,\gamma_2 + (\mathrm{SUCAC})\,\gamma_5 + (\mathrm{SUWHE})\,\gamma_7 + \gamma_{11}\,]$$

We evaluate the elasticities at the sample average values for the variables in a given billing period. We interpret these elasticities as short-run indicators of price and income responsiveness because they do not include the effect of price changes on portfolio compositions.

Table 6.8a

Elasticities by billing period and HVAC system—Winter

Price Effect / Income Effect	November	December	January	February
Individual	-0.182 / -0.116	-0.019 / -0.163	-0.021 / 0.032	-0.582 / -0.303
Water Heating	-0.132 / 0.057	-0.054 / 0.076	0.081 / -0.184	0.719 / 0.141
Space Heating	0.041 / 0.167	-0.081 / 0.156	-0.151 / 0.171	-0.205 / 0.252
Total	-0.272 / 0.108	-0.154 / 0.069	-0.091 / 0.019	-0.069 / 0.089

Table 6.8b

Elasticities by billing period and HVAC system—Summer

Price Effect / Income Effect	June	July	August	September
Individual	-1.078 / -0.057	-0.295 / 0.150	-0.712 / 0.709	-0.434 / 0.289
Water Heating	1.354 / 0.499	0.082 / -0.034	0.444 / -0.670	-0.069 / 0.076
Space Heating	-0.000 / -0.148	-0.007 / 0.073	0.021 / 0.114	0.002 / -0.272
Total	0.276 / 0.295	-0.220 / 0.189	-0.247 / 0.153	-0.502 / 0.093

Table 6.8c

Elasticities by billing period and HVAC system—Off-Season

Price Effect / Income Effect	March	April	May	October
Individual	-0.348 / -0.391	-0.366 / -0.209	-0.319 / 0.023	-0.311 / 0.001
Water Heating	0.238 / 0.376	0.512 / 0.047	-0.049 / 0.268	-0.109 / 0.054
Space Heating	-0.127 / 0.020	-0.098 / 0.194	0.044 / -0.019	-0.003 / 0.069
Total	-0.236 / 0.005	0.048 / 0.032	-0.324 / 0.271	-0.423 / 0.126

The off-season period is characterized by income sensitivity in both air conditioning and space-heating. However, price sensitivity is again determined by water heat and other uses. The magnitudes of total price and income effects are similar to those obtained in the winter period. Electricity demand is estimated to reveal greatest price sensitivity in September and largest income elasticity in June.

Estimation of natural gas demand indicates larger price effects and somewhat smaller or equal-size income effects as compared with electricity demand. A striking feature of the elasticities in Table 6.8 is that much greater price sensitivity may be attributed to space heating. In the summer period, price sensitivity arises from the combination of water

Table 6.7a
Elasticities by billing period and HVAC system—Winter

Price Effect / Income Effect	November	December	January	February
Individual	-0.230 / 0.059	-0.138 / 0.055	-0.236 / 0.137	0.156 / 0.075
Water Heating	-0.077 / 0.026	-0.288 / 0.041	-0.212 / 0.016	-0.405 / 0.081
Central Air	-0.000 / 0.017	-0.000 / 0.002	0.000 / 0.004	0.000 / -0.013
Space Heating	0.003 / -0.070	0.010 / -0.004	-0.006 / -0.048	-0.017 / 0.010
Total	-0.304 / 0.031	-0.416 / 0.094	-0.454 / 0.109	-0.266 / 0.153

Table 6.7b
Elasticities by billing period and HVAC system—Summer

Price Effect / Income Effect	June	July	August	September
Individual	0.192 / 0.168	-0.353 / 0.144	-1.163 / 0.118	-0.442 / 0.018
Water Heating	-0.146 / 0.039	0.164 / 0.046	-0.632 / -0.656	-0.135 / 0.009
Central Air	0.043 / -0.037	0.021 / -0.017	0.023 / 0.059	-0.018 / 0.070
Space Heating	-0.001 / 0.025	-0.000 / -0.006	0.000 / 0.160	0.002 / 0.016
Total	0.089 / 0.195	-0.168 / 0.167	-1.771 / -0.318	-0.594 / 0.113

Table 6.7c
Elasticities by billing period and HVAC system—Off-Season

Price Effect / Income Effect	March	April	May	October
Individual	-0.139 / 0.168	0.117 / 0.079	0.026 / 0.176	-0.358 / 0.113
Water Heating	-0.257 / 0.036	-0.232 / -0.045	-0.043 / 0.050	-0.124 / 0.009
Central Air	-0.000 / 0.009	-0.004 / 0.083	0.011 / -0.015	0.000 / 0.016
Space Heating	0.001 / 0.053	-0.008 / 0.034	0.005 / -0.048	0.005 / 0.034
Total	-0.395 / 0.266	-0.128 / 0.152	-0.001 / 0.161	-0.476 / 0.172

estimated energy usage elasticities. In the summer period, price and income responsiveness are less precisely determined. Sensitivity arises from water heating and other end-uses. The air-conditioning price elasticities are estimated to be positive for three of the four months, but the combined effects are negative. Overall there appears to be lower price and greater income sensitivity in the summer compared with winter months.

Table 6.9

Variable means annual model

SUSHE	5311.	SUSHG	1436.
SUSHEP	258100.	SUSHGP	30570.
SUSHEY	135800.	SUSHGY	36010.
SUCAC	325.	-	-
SUCACP	1523.	-	-
SUCACY	8676.	-	-
SUWHE	1528.	SUWHG	158.6
SUWHEP	54.45	SUWHGP	36.34
SUWHEY	36480.	SUWHGY	3857.
MPE	0.04005	MPG	0.2380
INCOME	23.0	INCOME	23.2
NHSLDMEM	3.26	NHSLDMEM	3.24
QUAN (kwh)	13000.	QUAN (therms)	1186.
QEBASE (kwh)	4847.	QGBASE (therms)	105.2
DSHE	267.7	DSHG	68.0
SHP	8.80	SHP	15.33
SHE	0.2086	SHG	0.5895
DCAC	55.7	-	-
ACP	1.20	-	-
CAC	0.3513	-	-
Observations	911		655

With the specification and estimation of the annual model completed, we proceed to the simulations. Recall that the period for the simulation begins in 1978 and ends in the year 2000. Our price forecast assumes that the price of natural gas doubles during this period while the price of electricity grow somewhat less rapidly. The policy simulations in Chapter 3 indicate that electric forced-air and electric baseboard will show increased penetration while gas space-heating systems will decline. Conservation policies were seen to emphasize these trends while causing further shifts from electric forced-air to baseboard systems. The conservation policies affect demand in two ways. First, expected demand depends on the probability of HVAC-system choice. Second, the conservation policies affect the predicted unit energy consumption levels in the thermal model.

Taking expectations in equation (4) yields

$$E\,(\,Y_{it}^{f}\,) = Z_i\gamma + UEC_{it}^{SH}\,P_i^{SH}\,(X_{it}^{SH}\beta^{SH}) + UEC_{it}^{AC}\,P_i^{AC}\,(X_{it}^{AC}\beta^{AC}) + UEC_{it}^{WH}\,P_i^{WH}\,(X_i^{WH}\beta^{WH}) + X_{it}^{M}\beta^{M} \qquad (6)$$

We evaluate equation (6) using the estimated parameters from the annual regression models. Each conservation policy affects the unit heating and other uses. Again, the off-season appears more like the winter in terms of price and income elasticities. The largest price sensitivity for natural gas demand occurs in the off-season while the largest income sensitivity occurs in the summer.

The elasticities calculated in Tables 6.7 and 6.8 do not account for substitution of HVAC systems in the long run. In the next section we illustrate the long-run effects by analyzing once again the consequences of the ASHRAE mandatory thermal standards.

6.5. Effects of ASHRAE standards on energy demand

In this section we calculate electricity and natural gas demand under alternative mandatory energy conservation policies proposed by ASHRAE. The effects of these policies on HVAC-system choice was considered in Chapter 3. Recall that the six cases to consider are in turn: (1) baseline scenario, (2) increased wall and ceiling insulation, (3) relaxed design temperatures, (4) stormed windows and sealed air cracks, (5) modified thermostat settings, and (6) employment of a combination of policies two through four to achieve maximal conservation.

For long-term forecasting we do not require predictions at the monthly level. Instead, we estimate equation (5) using annual data formed from the monthly billing data. The thermal model is used to provide annual estimates of heating and cooling unit energy consumptions. Variable means for the annual model are given in Table 6.9 while regression results are given in Table 6.10. The results of the regression analysis are in accord with the theory and with the results obtained using the billing data. Coefficients are generally significant in the electricity demand model and indicate positive income and negative price effects. In the natural gas model, the estimated coefficients are again quite significant but the water-heating variables appear with anomalous price and income effects. Interestingly, the selectivity correction terms are not significant in the annual models, which suggests that the aggregation masks the correlation effect found in the billing data.

Table 6.11 presents elasticities calculated at sample means based on the annual data. The elasticity estimates are comparable to those obtained using the billing data. Overall, water heating and other uses provide the greatest price sensitivity in the electricity model while both price and income sensitivity arise principally from space heating usage in the natural gas demand model.

Table 6.10

Annual electricity and natural gas regressions

SUSHE	0.3909 6.816	SUSHG	0.5694 7.592
SUSHEP	-0.002159 -3.638	SUSHGP	-0.009291 -7.282
SUSHEY	0.002508 1.899	SUSHGY	0.009522 4.767
SUCAC	1.921 2.127	-	- -
SUCACP	-0.1891 -1.842	-	- -
SUCACY	.07398 3.153	-	- -
SUWHE	1.582 3.139	SUWHG	0.5173 0.4586
SUWHEP	-16.80 -1.559	SUWHGP	7.363 2.157
SUWHEY	0.01227 1.506	SUWHGY	-0.04546 -2.014
ONE	869.2 0.7929	ONE	267.6 1.441
MPE	-13830. -0.5897	MPG	-985.4 -1.627
INCOME	31.94 1.662	INCOME	-2.818 -0.9311
NHSLDMEM	712.0 6.186	NHSLDMEM	18.92 1.284
H1	580.4 1.772	H1	27.23 0.8831
H2	20.36 0.1206	-	- -
H3	-311.1 -1.198	H3	-58.75 -1.533
R^2	0.6963		0.6038
Observations	911		655
Standard error	4913.		476.9

energy consumption terms as well as the predicted probabilities. We calculate the unconditional probabilities for water-heating fuel, space-heating fuel, and central air conditioning using the nested logit specifications estimated in Chapter 3. The assumed growth in energy prices influences both the probabilities through operating costs and the forecasted fuel usage through the utilization terms. Results of the forecasts are presented in Tables 6.12 and 6.13 for electricity and natural gas respectively.

Table 6.11

Elasticities in annual model by HVAC system

Price Effect / Income Effect	Electricity	Natural Gas
Individual	-0.043 / 0.057	-0.198 / -0.055
Water Heating	-0.079 / 0.033	0.234 / -0.141
Central Air	-0.011 / 0.002	
Space Heating	-0.009 / 0.024	-0.182 / 0.267
Total	-0.142 / 0.116	-0.146 / 0.072

Table 6.12

The effect of ASHRAE thermal policies on electricity demand

Policy	1978	1985	1990	2000
1. Baseline	1.000	1.005	1.011	1.025
2. Wall and ceiling insulation	0.964	0.969	0.974	0.989
3. Design temperatures	1.003	1.009	1.014	1.029
4. Window treatment and infiltration	1.004	1.009	1.016	1.032
5. Thermostat setting	0.950	0.954	0.959	0.973
6. Policies 2-4	0.970	0.977	0.983	0.999

Table 6.13

The effect of ASHRAE thermal policies on natural gas demand

Policy	1978	1985	1990	2000
1. Baseline	1.000	0.911	0.833	0.679
2. Wall and ceiling insulation	0.855	0.781	0.715	0.581
3. Design temperatures	1.011	0.918	0.838	0.679
4. Window treatment and infiltration	1.004	0.917	0.841	0.688
5. Thermostat setting	0.875	0.802	0.738	0.607
6. Policies 2-4	0.866	0.789	0.721	0.585

Average demand for the baseline scenario in 1978 is normalized to unity so that all estimates are given relative to this period. In the baseline scenario, electricity demand is seen to increase. This is not surprising, as we have assumed that the relative price of electricity to natural gas is declining in real terms. The increased usage in electricity arises solely from portfolio shifts that increase the share of electric space- and water-heating systems.

Increased wall and ceiling insulation lowers the utilization of electricity but does not reverse the trend toward greater electrification. Moderated design temperatures and effective window and infiltration treatment raise usage relative to the baseline scenario. Decreased winter and increased summer thermostat settings produce the greatest response in terms of lowering electricity demand. The maximal conservation scenario, which combines wall and ceiling insulation improvements with moderated design temperatures and effective window treatments, is seen to result in quick reductions in electricity that grow to the 1978 baseline values by the year 2000.

The demand for natural gas falls inversely with the projected forecasts for electricity usage. Under the baseline scenario, natural gas usage falls to 68 percent of its 1978 baseline level. A policy of moderate thermostat levels leads to lower penetration of gas heating systems and lower usage levels than under the increased insulation scenario. Under maximal conservation and rising relative gas prices, usage falls to 59 percent of baseline values.

In summary, we have examined a model of residential electricity and natural gas demand using a pooled cross-sectional time-series of microdata on individual households. The objective has been to provide more precise explanations of household behavior than have been previously available from studies using annual consumption data. We have been able to predict seasonal variation in fuel usage demand using a combined engineering economic model.

The availability of highly disaggregated data provides an opportunity to explain more detailed, subtle variation in consumer behavior than is possible with aggregate data. Indeed, we have seen that the endogeneity of the appliance choice decision is a seasonal phenomenon suggesting that households at some times behave as if the appliance stock is exogenous, but at other times behave according to the underlying selection rules that match usage and system types.

We have also been able to determine the composition of short-run elasticities and have found that fuel price sensitivity varies both seasonally and by equipment types. Finally, we have investigated the long-run elasticity of fuel utilization by including the effect of portfolio shift as well as price and income substitution. The next step in appliance choice and energy demand analysis should be to incorporate these results into existing microforecasting models.