DIVISION OF THE HUMANITIES AND SOCIAL SCIENCES

CALIFORNIA INSTITUTE OF TECHNOLOGY

PASADENA, CALIFORNIA 91125

ESTIMATION OF A NESTED LOGIT MODEL FOR APPLIANCE HOLDINGS

Jeffrey A. Dubin

SOCIAL SCIENCE WORKING PAPER 481

July 1983

ABSTRACT

This paper estimates a discrete choice model for room air conditioning, central air conditioning, space heating, and water heating, using data from two recent surveys of energy consumption by households—the 1978 National Interim Energy Consumption Survey (NIECS) and the 1980 Pacific Northwest Energy Survey (PNW). Estimation for these two data sets proceeds in parallel so that results based on the national level survey may be compared with those derived from Pacific Northwest regional data. We are thus able to address the important issue of model transferability.

The estimated structure involves a ten alternative logit model of space heat/air-conditioning system choice. We first match a time path of operating costs to each household using historical state level energy prices and then analyze the role of price expectation formation in the choice of heating and cooling equipment for single family owner occupied dwellings. We compare a basic static expectation model with two alternative models: perfect foresight over a limited planning horizon and adaptive expectation formation.

Finally we consider alternative conservation policies and alternative scenarios for the prices of electricity, natural gas, and fuel oil in order to predict the path of durable saturations from present to the year 2000.

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ESTIMATION OF A NESTED LOGIT MODEL FOR APPLIANCE HOLDINGS[1]

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I. INTRODUCTION

In this paper we estimate a discrete choice model for room air conditioning, central air conditioning, space heating, and water heating using data from the National Interim Energy Consumption Survey (NIECS) of 1978 and the Pacific Northwest (PNW) survey conducted in 1979-1980 by the Bonneville Power Administration. The reader is invited to consult the appendix for references to the data sets and a detailed discussion of procedures used to prepare the data for econometric analysis. The use of such micro-level disaggregated survey data to estimate discrete choice models of heating, ventilating, and air-conditioning (HVAC) systems has been very recent, but one can find a few related models in Dubin and McFadden (1983a), Brownstone (1980), Goett (1979), Hausman (1979), and McFadden, Puig, and Kirschner (1977). One of the virtues of the structure developed in this paper is that it has been successfully embedded in a larger micro-simulation system (the Residential End-Use Energy Policy System (REEPS)) for the purposes of policy forecasting (Goett (1979)).

Throughout this paper, we follow an estimation framework that compares the results based on national level data with those obtained using regional data. While the (NIECS) and (PNW) data sets are similar in content and scope (some 4000 households in each), important differences remain. During the early seventies, the Pacific Northwest

region experienced average and marginal electricity prices which were very low by national average standards. Early projections of sustained growth in electricity demand necessated increases in base load generating capacity. The decision to provide additional capacity with nuclear plants has greatly increased incremental cost of electricity and electricity using durables.

It is plausable to assume that economic agents in a region with an inexpensive power source behave differently than consumers faced with viable economic trade-off's among alternative fuel sources. The comparison of results in the two data sets allows us to address the important issue of model transferability as well as lend support to our preferred specifications.

The paper begins with a discussion (in Section II) of the nested logit model of appliance choice and the particular tree extreme value structure used in our analysis. Ten alternative HVAC systems are considered and matched with actual operating and capital costs using an engineering thermal model that predicts heating and cooling loads. An important connection is thus established between the engineering and economic aspects of the choice problem.

Section III then constructs a utility maximization problem, in which utility is a function of ambient temperature. This analysis produces a definition of the "energy price of comfort" and establishes its relationship to normalized operating costs. We then validate the utility maximization hypothesis (in sections IV and V) with the estimation of room air-conditioning and water heat fuel choice conditional on the outcomes of HVAC system choice. We then develop (in section VI) a nested logit model of space heat system choice. We consider the effect of income on the discount rate which annualizes capital cost and explore the role of price expectation formation in the choice of HVAC systems. A time path of operating costs is matched to each household using historical state level energy prices so that perfect, static, and adaptive expections may be contrasted.

Section VII estimates the full tree structure and discusses the determinants of central air-conditioning choice while section VIII considers alternative conservation policies and alternative scenarios for the prices of electricity, natural gas, and fuel oil to forecast the path of durable good saturations from present to the year 2000.

II. NESTED LOGIT MODEL OF APPLIANCE CHOICE

This section describes the discrete choice model of alternative appliance portfolio combinations estimated from the National Interim Energy Consumption Survey and the Pacific Northwest Energy Survey. From the onset we desired to include as many of the major household appliances in the choice system as possible. We have concentrated on the choices of nineteen alternative space heating and air-conditioning systems, three water heat fuel types, and the choice of room air-conditioning. The possible combinations of appliance portfolios and the possible number of tree structures which might explain the observed choices are essentially limitless.

The empirical searches for nested logit forms which would

produce sensible results concentrated on a subset of the nineteen alternative space heating systems. These alternatives form the trunk of the tree structure whose branches determine room air conditioning choice and the type of water heating fuel. The NIECS data revealed two important ingredients in this choice process: (1) the importance of eliminating gas heating system alternatives from the choice model when gas is not available as a fuel, and (2) the critical nature of scale effects which manifest themselves in deleterious heteroscedasticy.

1. Natural Gas Availability

Whether natural gas is available obviously determines whether a household will install a gas heating system. If we include in the choice set an economically attractive gas alternative which is in fact unavailable, then we are sure to risk specification bias.

Unfortunately, measures of gas availability were not available within the NIECS data base. To construct a measure of gas availability we followed two distinct procedures. First, we utilized a measure of gas availability which did exist for the Washington Center for Metropolitan Studies (WCMS) cross-sectional data. Given our ability to link locational information (at the level of primary sampling units) from one survey to the other, we were able to match the gas availability data from WCMS to NIECS. One problem is that gas availability is likely to be determined at the level of city blocks or in areas corresponding to secondary sampling units. This imparts a coarseness to a variable which is to be used at the individual level.

A second difficutly with this procedure is that the survey year for WCMS was 1975 while the NIECS survey was conducted in 1978. This gap in time might effect our information about households making choices after 1975.

Our second procedure used natural gas related information in two NIECS variables. The first variable indicates whether the household has gas appliances and is an index of their cumulative consumption. The second variable indicates whether the household uses natural gas for any purpose. We compute the percentage of households in each secondary sampling unit with either positive gas index or positive usage. Gas availability is accordingly assigned to each household in the relevant secondary sampling unit. The inherent weakness of this procedure is that it does not provide requisite historical information.

In early attempts to puzzle through the tree structure of appliance choice, we located a few cases in which a household would choose an oil heating system or an electric heating system when, in fact, a gas system would have been less expensive in terms of both operating and capital costs. For households in which we had previously assumed the availability of gas this posed an interesting problem: Why do households choose dominated alternatives? The answer might be explicable through variations in tastes yet it was most often the case that gas was the dominating non-chosen alternative and not other fuels. We resolved this issue by assuming that our discrete indicator of gas availability was incorrect for the household in question.

To improve our measure of gas availability we made two modifications. The first change assumes that gas is available (irrespective of our previous assignment) if a particular household chooses gas. Our second modification works in quite the opposite direction and imposes the condition that gas is not available whenever a household chooses an alternative which is dominated by a gas alternative.

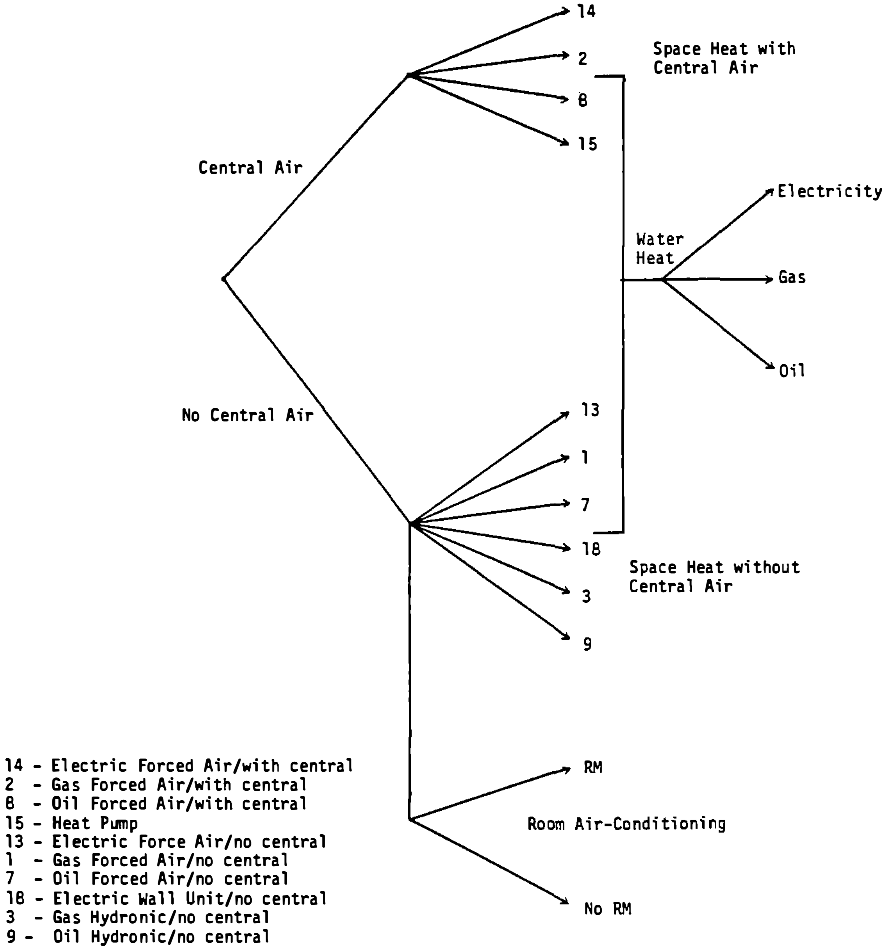
The treatment of dominated alternatives to modify our assignment of gas availability may well introduce a degree of measurement error. Fortunately, the Pacific Northest locational information did permit exact assignment of gas availability to each household at the point of dwelling construction.

In the estimation of a nested logit model of HVAC system choice we regard the availability of gas as an essentially discrete phenomenom. We thus assume that when gas is available, gas HVAC systems are in the choice set. When gas is not available, the chosen alternative is presumed selected from alternatives which exclude gas systems. This approach differs from other researchers who introduce dummy interaction terms to indicate gas availability.[2]

2. Tree Extreme Value Models

Figure 1 illustrates the nested logit choice model of four space heating systems with central air-conditioning, six space heating systems without central air, water heat fuel choice, and room air-conditioning. The postulated structure assumes that water heat choice

FIGURE 1



is made conditional on the choice of space heat system, that room air-conditioning is chosen only when central air is not chosen, and that space heat choice is made conditional on the choice of central air-conditioning.

We arrive at this structure through a mixture of common sense and the accumulated wisdom of previous research. Unfortunately, a classical procedure to discriminate amoung specifications is not easily implemented given the non-nested nature of alternative tree structures. Standard errors reported in the NIECS estimation should be viewed with these comments in mind. Estimation with the PNW data serves to formally test the structural hypothesis of interest and provides insight into the transferability of results from national to regional data. Furthermore this approach lends support to the underlying utility maximization hypothesis. This hypothesis is likely to be violated in a region like the Pacific Northwest where electricity is a cheap energy source and builders choose the least cost heating system.

To derive a nested logit model for Figure 1, let Y_{wrsc} denote a positive measure of the desirability of alternatives indexed by wrsc where w denotes water heat choice, r indicates room air-conditioning choice, s indicates space heat choice, and c indicates central air choice. We specify a generating function $G[\langle Y_{wrsc}\rangle]$ as the composition of four generating functions to reflect the levels of the tree in Figure 1:

$$(1) \quad G[\langle Y_{wrsc}\rangle] = G^c[\langle G^s[\langle G^w[\langle G^r[\langle Y_{wrsc}\rangle]\rangle]\rangle]\rangle].$$

We take logistic generating forms for G^c, G^s, G^w, and G^r so that:

$$(2)\quad G^r[\langle Y_{rc}\rangle] = [\sum_r Y_{rc}^{1/(1-\phi)}]^{1-\phi}$$

$$(3)\quad G^w[\langle Y_{wsc}\rangle] = [\sum_w Y_{wsc}^{1/1-\sigma}]^{1-\sigma}$$

$$(4)\quad G^s[\langle Y_{sc}\rangle] = [\sum_s Y_{sc}^{1/1-\delta_c}]^{1-\delta_c}$$

$$(5)\quad G^c[\langle Y_c\rangle] = \sum_c Y_c$$

where ϕ, σ, and δ_c are unobserved scale factors. It follows that:

$$P_{wrsc} = [\partial \ln G^c/\partial \ln G^s] \cdot [\partial \ln G^s/\partial \ln G^w] \cdot [\partial \ln G^w/\partial \ln G^r] \cdot [\partial \ln G^r/\partial \ln Y_{wrsc}]$$

$$= P_c \cdot P_{s|c} \cdot P_{w|sc} \cdot P_{r|wsc} = [\partial \ln G/\partial \ln Y_{wrsc}]$$

where P_{wrsc} denotes the probability of choosing portfolio combination wrsc, and $P_{j|k}$ denotes the conditional probability of choosing alternative j given that alternative k has been selected. To derive the structure in Figure 1 we assume that the probability of having room air-conditioning conditional on HVAC choice is independent of heating system choice. Furthermore, we assume that the probability of water heat fuel choice is independent of room air-conditioning choice. To impose this structure on the probability generating function G, we let $Y_{wrsc} = Y_{wsc} \cdot Y_{rc} \cdot Y_{sc} \cdot Y_c$. This model is consistent with the assumption that households maximize utility:

$$(6)\quad U_{wrsc} = V_{wrsc} + \varepsilon_{wrsc}$$

where: $V_{wrsc} = \ln Y_{wrsc}$ denotes the strict utility of alternative wrsc and $\langle \varepsilon_{wrsc}\rangle$ have a joint generalized extreme value distribution. Note that the assumption $Y_{wrsc} = Y_{wsc} \cdot Y_{rc} \cdot Y_{sc} \cdot Y_c$ implies that strict utility may be written as $\ln Y_{wsc} + \ln Y_{rc} + \ln Y_{sc} + \ln Y_c = V_{wsc} + V_{rc} + V_{sc} + V_c$—a decomposition which exhibits the components of indirect utility. The generating function under the conditional independence assumption has the form:

$$(7)\quad G[Y_{wrsc}] = G^c[\langle Y_c G^s[\langle Y_{sc} G^w[\langle Y_{wsc}\rangle]] \cdot G^r[\langle Y_{rc}\rangle]\rangle].$$

It is possible to show that:

$$(8)\quad P_{r|c} = e^{V_{rc}/(1-\phi)} \Big/ \sum_r e^{V_{rc}/(1-\phi)} \equiv P_{r|wsc}$$

$$(9)\quad P_{w|sc} = e^{V_{wsc}/(1-\sigma)} \Big/ \sum_w e^{V_{wsc}/(1-\sigma)}$$

$$(10)\quad P_{s|c} = e^{(V_{sc} + J_{sc}(1-\sigma))/(1-\delta_c)} \Big/ \sum_s e^{(V_{sc} + J_{sc}(1-\sigma))/(1-\delta_c)}$$

$$(11)\quad P_c = e^{(J_c^s(1-\delta_c) + V_c + J_c^r(1-\delta))} \Big/ \sum_c e^{J_c^s(1-\delta_c) + V_c + J_c^r(1-\phi))}$$

where:

$$(12)\quad J_{sc} \equiv \ln[\sum_w e^{V_{wsc}/1-\sigma}]$$

$$(13)\quad J_c^s \equiv \ln[\sum_s e^{(V_{sc} + J_{sc}(1-\sigma))/(1-\delta_c)}]$$

and

$$(14) \quad J_c^r \equiv \ln[\sum_r e^{V_{rc}/(1-\partial)}]$$

The terms J_c^s, J_c^r, and J_{sc} are, respectively, the inclusive values of space heat choice given central air choice, room air choice given central air choice, and water heat choice given space heat and central air choice; the symbols $(1-\partial)$, $(1-\delta_c)$, and $(1-\sigma)$ are the corresponding inclusive value coefficients.[3] Here we allow the inclusive value coefficient $(1-\delta_c)$ to be different depending on central air choice to reflect a possible dissimilarity in the degree of association in the space heat choice branches. Estimation of the central air conditioning choice model will identify the coefficients δ_c.

III. RESIDENTIAL HEATING AND COMFORT

Let $u[t,Z]$ denote the utility derived from consumption of a vector of goods Z in an environment with ambient temperature t. It is reasonable to assume that utility is increasing in t up to a temperature T^* which provides blissful comfort. Below T^* occupants feel too cool and above T^* feel too hot. If heating were a free good consumers would set their thermostats at T^*. However as heating to an interior temperature T^* requires a costly energy input there exists a trade-off between the comfort of the ambient space and the price of obtaining this comfort.

Following Brownstone (1980) and Hausman (1979), we assume that the utility function $u[t,Z]$ is separable in comfort and goods consumption.

Futhermore, we suppose that $u[t]$, the utility derived from ambient temperature t, takes the linear form $u[t] = -\alpha[T^*-t]$ for $\alpha > 0$ and $t \lesssim T^*$. Let $F[t]$ denote the cummulative distribution for the number of days in which the daily mean temperature is less than or equal to t. Utility during the heating season from thermostat setting τ is:

$$(15) \qquad u[\tau] = \int_{-\infty}^{\tau} -\alpha(T^*-\tau)\, F'(t)dt + \int_{\tau}^{T^*} -\alpha(T^*-t)\, F'(t)dt$$

The first integral assumes that comfort is constant at the level $(T^*-\tau)$ degrees per hour when outside temperature is below the thermostat level τ. The second integral assumes that comfort increases proportionally to increases in temperature below the bliss temperature point. It is straightforward to demonstrate that equation (15) has an interpretation measured in degree days of heating. From equation (15):

$$\begin{aligned} u[\tau] &= -\alpha[(T^*-\tau)F(\tau) + T^*(F(T^*) - F(\tau)) - \int_{\tau}^{T^*} tF'(t)dt] \\ &= -\alpha[T^*F[T^*] - \tau F[\tau] - \int_{\tau}^{T^*} tF'(t)dt] \\ &= -\alpha[(T^*F[T^*] - \int_{-\infty}^{T^*} tF'(t)dt) - (\tau F(\tau) - \int_{-\infty}^{\tau} tF'(t)dt)] \\ &= \alpha[H(\tau) - H(T^*)] \end{aligned}$$

where $H(t_o)$ denotes total heating degree days measured at base t_o, i.e.

$$H[t_o] = \int_{-\infty}^{t_o} (t_o-t)F'(t)dt = t_oF(t_o) - \int_{-\infty}^{t_o} tF'(t)dt$$

Suppose that the BTUH heating required to maintain interior temperature τ with exterior temperature t is given by the function $Q(\tau-t)$. Then the seasonal heating load resulting from thermostat setting τ is:

$$(16) \qquad B[\tau] = \int_{-\infty}^{\tau} \mathrm{MAX}[Q[\tau-t],0]F'(t)dt$$

The problem of maximizing the utility function $U[\tau,Z]$ subject to a budget constraint allocates wealth W between expenditure on goods Z and on fuel $(P_i/e_i)B(\tau)$ where P_i is the price of fuel i and e_i is the efficiency of the heating system using fuel i. We write:

$$(17) \qquad \underset{\tau,Z}{\text{maximize}}\ U[\tau,Z] \text{ subject to } (P_i/e_i)B[\tau] + Z \leq W$$

for which the Lagrangian (with multiplier ξ) is:

$$(18) \qquad L = U[\tau,Z] + \xi[W - Z - (P_i/e_i)B(\tau)] \ .$$

The first order conditions are:

$$(19) \qquad L_\tau = U_\tau - \xi(P_i/e_i)B'(\tau) = 0 \quad \text{and}$$

$$(20) \qquad L_Z = U_Z - \xi = 0 \qquad\qquad \text{so that:}$$

$$(21) \qquad \frac{U_\tau}{U_Z} = (P_i/e_i)B'(\tau)$$

We see from (21) that the price of comfort depends on the level of comfort. It is possible to re-formulate the optimization problem using an appropriately defined rate structure premium. Let τ^* denote the solution to (21) so that $(P_i/e_i)[B(\tau^*)-B'(\tau^*)\tau^*]$ is the rate structure premium adjustment. The equivalent standarized problem is then:

$$(22) \qquad \underset{\tau,Z}{\text{Maximize}}\ U[\tau,Z] \text{ subject to } [(P_i/e_i)B'(\tau^*)\tau] + Z \leq$$

$$W - (P_i/e_i)[B(\tau^*) - B'(\tau^*)\tau^*]$$

The indirect utility associated with equation (22) is a function of W and the price of comfort $(P_i/e_i)B'(\tau^*)$. The thermal model discussed in Dubin and McFadden (1983b) is used to estimate the price of comfort for alternative HVAC systems. The procedure approximates the derivative $B'(\tau^*)$ by calculating the change in seasonal utilization associated with a one degree change in the thermostat setting. In our empirical work we ignore the rate structure premium adjustment to W of equation (22).

IV. ROOM AIR-CONDITIONING CHOICE MODEL

This section describes the estimation of the choice model for room air-conditioning. The analysis considers room air-conditioning only as an alternative to central air-conditioning; it does not take into account either the choice of the number of room air-conditioning units or their efficiencies. For details concerning these latter aspects of the choice process see Brownstone (1980) and Hausman (1979).[4] We begin with a review of the operating and capital costs which enter the utility maximization problem.

Our allocation of capital costs to central air conditioning units assumes that households purchase units of design capacity.

Design capacity measures the thousands of BTU's per hour required to maintain a given household at summer design temperatures.[5] We follow the same procedure for room air conditioners and assume that room air conditioners are purchased to meet design cooling loads.

More precisely we assume that the total cooling load in the residence is distributed equally among the number of rooms in the residence; we then and determine the capital costs (materials and installation) for providing one room air conditioning unit per room. Casual empiricism suggests this is a departure from average behavior, yet the assumption allows us to determine total capital costs in a manner which recognizes substantial returns to scale in purchasing larger air conditioning units. For additional details concerning the construction of room air-conditioning costs the reader is referred to Cowing, Dubin, and McFadden (1981e).

Consistent with our determination of room air-conditioning capital costs, we assume that the operating costs for room units distributing the total cooling load are identical to those for a central air-conditioning system. This supposes (perhaps unrealistically) that room air conditioners operated in paralell are as efficient as central systems.

Following the discussion in Section III, we would expect, other things being equal, that the probability of choosing room air-conditioning given that the household does not have central air-conditioning should increase with income and decrease as operating and capital costs increase. We have attempted an empirical specification

in which these variables are interacted with the "purchase" alternative. In the "no purchase" alternative we enter the number of household members and cooling degree days with the latter a measure of the discomfort the household suffers in not having air-conditioning. Table 1 presents the mean values of variables used in the room air-conditioning choice model while Table 2 presents the estimated models. RINC1, CDD2, and PERS2 are RINCOME, CDD78, and NHSLDMEM interacted with alternative specific dummies for alternative one, alternative two, and alternative two respectively. A1 is the alternative one specific dummy.

The operating and capital cost coefficients in Table 2 follow the pattern of results obtained by Goett (1979). Generally we observe that specifications which include operating and capital costs as well as cooling degree days produce incorrect signs and insignificance in certain explanatory variables. It is possible to offer a few reasons for this result: 1) measurement error (which is likely given the assumptions made in assigning capital costs) would tend to bias the coefficient of capital cost towards zero, and 2) the desirability of room air-conditioning is likely to be greatest, when the cooling load is greatest, introducing a spurious correlation between operating costs, capital costs, and room air-conditioning purchases.

To investigate the second effect in more detail, we present in Table 3 the room air-conditioning choice model in which operating and

TABLE 1 (NIECS)

MEAN VALUES FOR EXPLANATORY VARIABLES IN ROOM AIR CONDITIONING CHOICE MODEL

Variable	Description	Mean[a]
RMOPCST	Operating Cost for Room Air-Conditioning (1967$)	49.22
RMCPCST	Capital Cost for Room Air-Conditioning (1967$)	1231.
RMOPCST1	RMOPCST/(Base Load Usage)	0.00819
RMCPCST1	RMCPCST/(Base Load Usage)	3.33
CDD78	Cooling Degree Days in 1978	1110
RINCOME	Income (1967$)/$10^3$	10.38
NHSLDMEM	Number of Household Members	3.3

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[a] Sample size 770 households corresponds to the set of single family detached owner occupied dwelling built since 1955 which do not have central air-conditioning. 591 of these homes appear in the nested logit model of HVAC system choice.

TABLE 2 (NIECS)

BINARY LOGIT MODEL OF ROOM AIR-CONDITIONING CHOICE GIVEN NO CENTRAL AIR-CONDITIONING[a]

Alternative 1 - Purchase Room Air-Conditioning	45.06 percent
Alternative 2 - Do Not Purchase Room Air-Conditioning	54.94 percent

Variable Name	Logit Estimate	Standard Error	t-Statistic
RMOPCST	0.1139E-01	0.4493E-02	2.535
RMCPCST	-0.1335E-03	0.2235E-03	-0.5975
RINC1	0.3186E-1	0.1478E-01	2.156
CDD2	-0.6152-03	0.2111E-03	-2.915
PERS2	0.2308E-01	0.4907E-01	0.4703
A1	-1.498	0.3393	-4.416

Auxiliary Statistics	At Convergence	At Zero
Log Likelihood	-467.9	-533.7
Percent Correctly Predicted[b]	68.18	50.00

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[a] Estimation is by maximum likelihood using the QUAIL (Qualitive, Intermittent, and Limited Dependent Variable Statistical Program) developed by Daniel McFadden and Hugh Wills.

[b] A case is taken as being correctly predicted when the chosen alternative is forecast to have the highest probability of being chosen.

TABLE 3 (NIECS)

BINARY LOGIT MODEL OF ROOM AIR-CONDITIONING CHOICE GIVEN NO CENTRAL AIR-CONDITIONING NORMALIZED OPERATING AND CAPITAL COSTS

Alternative 1 - Purchase
Alternative 2 - Do Not Purchase

Variable Name	Logit Estimate	Standard Error	t-Statistic
RMOPCST1	116.8	34.34	3.402
RMCPCST1	0.6826E-02	0.4417E-02	1.545
RINC1	0.3934E-1	0.1439E-01	2.734
CDD2	-0.1158-02	0.1273E-03	-9.098
PERS2	0.1186E-01	0.4884E-01	0.2429
A1	-2.813	0.4156	-6.768

Auxiliary Statistics	At Convergence	At Zero
Log Likelihood	-466.4	-533.7
Percent Correctly Predicted	68.70	50.00

capital costs are normalized by predicted base load usage (ACUEC). Note that the operating cost variable is now significant, but of wrong sign, while the normalized capital cost variable remains insignificant. The significance of the normalized operating cost variable may be attributable to a regional effect in which the largest average costs of room air-conditioning are associated with regions in which there is a summer peaking marginal electricity price. The summer peak rate is again associated with high average loads per customer due to the presence of very high ambient temperatures and a large percentage of homes using air-conditioning.

Given the small change in log likelihood and percentage correctly predicted we adopt the specification presented in Table 4 for use in the estimation of the HVAC choice tree. For the parameter estimates in Table 4 we construct the inclusive value of room air-conditioning choice in the NIECS sample of 911 households. The mean value of RMINCV [room air-conditioning inclusive value] is -.5041 with standard deviation .4022.

V. WATER HEAT CHOICE MODEL

This section describes the estimation of the choice model for water heat fuel using NIECS and PNW data. Related studies are Dubin and McFadden (1983a) and Goett (1979). We begin with a review of the construction of operating and capital costs.

TABLE 4 (NIECS)

BINARY LOGIT MODEL OF ROOM AIR-CONDITIONING CHOICE GIVEN NO CENTRAL AIR-CONDITIONING NO OPERATING OR CAPITAL COSTS

Alternative 1 - Purchase
Alternative 2 - Do Not Purchase

Variable Name	Logit Estimate	Standard Error	t-Statistic
RINC1	.3765E-1	.1380E-01	2.729
CDD2	-0.1104-02	.1190E-03	-9.281
A1	-1.796	.2322	-7.732

Auxiliary Statistics	At Convergence	At Zero
Log Likelihood	-472.6	-533.7
Percent Correctly Predicted	70.26	50.00

1. Water Heat Operating Costs

We define the end-use service of water heating to be a gallon of heated water. To determine energy service ratios (ESR) we used the March 1978 Consumer Report which reviewed eleven electric and twelve gas water heaters. Consumer Reports determined annual consumption in KWH per year and therms per year for electric and gas units respectively based on 100 gallons of hot water consumption per day. We used the mean value of annual consumption across models to calculate ESR by fuel type. For electric water heaters the energy-to-service ratio is:

$$(10434.55\ \frac{\text{KWH}}{\text{Yr.}})\ (\frac{1\ \text{Yr.}}{365\ \text{days}})\ (\frac{1\ \text{day}}{100\ \text{dal.}}) = 0.28588\ \text{KWH/gal.}$$

and for gas water heaters the energy service ratio is:

$$(502.33\ \frac{\text{Therms}}{\text{gas}})\ (\frac{1\ \text{Yr.}}{365\ \text{days}})\ (\frac{1\ \text{day}}{100\ \text{gal.}}) = 0.01376\ \text{Therms/gal.}$$

Following Dubin and McFadden (1979) we assume that oil water heaters are 74 percent as efficient as electric water heaters. Conversion to units of thousand of BTU's per gallon heated implies energy service ratios: 1.376-gas, 0.97542-elec., and 1.318-oil. To determine expected usage we use the relation:

$$\begin{aligned}\text{Average annual usage in KWH for hot water heating} &= (2819. + 360.* (\text{NHSLDMEM}-2)\\ &+ 360.* (\text{If NHSLDMEM equals } 1))\\ &+ 365.* 3.98 * \text{HELDISHW}\end{aligned}$$

This equation is discussed in Dubin and McFadden (1983a). Note that NHSLDMEM and HELDISHW are, respectively, the number of household members and a dummy variable indicating that the household has a dishwasher. Finally, operating costs by fuel type are the product of (1) expected annual usage, (2) the ratio of the ESR of the fuel under consideration to the ESR of the electric water heater, and (3) the price of the fuel at the point of house construction converted to real 1967 dollars.

2. Water Heat Capital Costs

Construction of water heating capital costs requires a relationship between assumed capacity and structural characteristics of the dwelling and family. We follow the recommended practice ("Handbook of Buying 1978," Consumer Research Magazine) of relating capacity utilization to the number of bathrooms and the number of bedrooms (a proxy for number of persons). This relationship includes allowance for recovery rate differentials that occur between fuel types. Materials and installation costs for different capacity water heaters are obtained from MEANS (1981). These estimates do not include the vent costs for each water heater. We consulted the National Construction Estimator (Craftsman Book Co., Solano Beach, CA 1978) and determined that in 1981 dollars material costs would be $18 while installation costs would be $26. The National Construction Estimator also indicated electrical contracting charges of $145 and $161 for water heaters with capacity less than and greater than 40 gallons. These costs were included in the installation costs obtained

from MEANS (1981). Finally, we have included all cost components which are conditional on the type of space heating system installed. When space heating type is gas or electric, the cost for materials and installation of an oil tank are included with the costs of oil water heating. When space heating type is gas or oil, an additional charge of $112 is added to the labor costs of the electric water heater due to the installation of increased amp service (National Construction Estimator, 1978). Other charges for all systems are assumed reflected in the cost of the heating systems.

3. Estimation of Water Heat Choice Model

Tables 5 and 6 present the mean values of NIECS and PNW variables used in the choice models as well as their descriptions. Estimation is based on a sample of households who live in single family owner occupied dwellings built since 1955 and who choose either electric, gas, or oil water heaters.[6] As discussed above, the natural gas alternative is eliminated from the choice set whenever gas is unavailable to the household. Thus, in Table 5, the number of included observations drops from 911 in the electric and oil alternatives to 655 in the natural gas alternative. A similar effect is seen in Table 6.

We considered both binary and trinary specifications which used water heat operating and capital costs as well as space heat fuel-type dummies as explanatory variables. Models in which costs were not adjusted for scale provided generally wrong signs on variables and were difficult to interpret.

TABLE 5 (NIECS)

MEAN VALUES OF VARIABLES IN WATER HEAT CHOICE MODEL (1967 Dollars)[a]

Variables	Alt[b]	Nobs	Description	Mean
WHOPCST	(1)	911	Water heat operating costs	113.40
WHOPCST	(2)	655	(by alternative)	23.69
WHOPCST	(3)	911		16.74
WHOPCST1	(1)	911	Water heat operating cost	0.02773
WHOPCST1	(2)	655	divided by usage	0.00582
WHOPCST1	(3)	911	(by alternative)	0.00406
WHCPCST	(1)	911	Water heat capital cost	201.50
WHCPCST	(2)	655	(by alternative)	130.90
WHCPCST	(3)	911		631.50
WHCPCST1	(1)	911	Water heat capital cost	0.05079
WHCPCST1	(2)	655	divided by usage	0.03336
WHCPCST1	(3)	911	(by alternative)	0.1621
SHE	(1)	911	(Space heat fuel electricity)*(ALT1)	.2086
SHG	(2)	655	(Space heat fuel gas)*(ALT2)	.8198

[a] Mean values for included alternatives.

[b] Electricity, natural gas, and fuel oil respectively.

TABLE 6 (PNW)

MEAN VALUES OF VARIABLES IN WATER HEAT CHOICE MODEL (1967 Dollars)[a]

Variables	Alt	Nobs	Description	Mean
WHOPCST	(1)	912	Water heat operating costs	58.94
WHOPCST	(2)	803	(by alternative)	36.49
WHOPCST	(3)	912		18.10
WHOPCST1	(1)	912	Water heat operating cost	0.01413
WHOPCST1	(2)	803	divided by usage	0.00861
WHOPCST1	(3)	912	(by alternative)	0.00423
WHCPCST	(1)	912	Water heat operating cost	213.10
WHCPCST	(2)	803	(by alternative)	135.50
WHCPCST	(3)	912		628.80
WHCPCST1	(1)	912	Water heat capital cost	0.05237
WHCPCST1	(2)	803	divided by usage	0.03302
WHCPCST1	(3)	912	(by alternative)	0.1555
SHE	(1)	912	(Space heat fuel electricity)*(ALT1)	0.4287
SHG	(2)	803	(Space heat fuel gas)*(ALT2)	0.4231

[a] Mean values for included alternatives.

We present only specifications in which operating and capital costs are normalized by predicted utilization. Here normalized operating and capital costs are interpreted as the service price and capital cost per unit of service. Results for the NIECS and PNW data for binary choice models are given in Tables 7 and 8. Specifications which include electric, natural gas, and oil alternatives are given in Tables 9 and 10.

All coefficients are highly significant and of the right sign. Generally we see that increases in operating and capital costs decrease the probability that an alternative is selected. The gas space heat system dummy in the second alternative is positive and very significant in all four models. Thus the presence of a gas space heating system strongly influences the decision to choose gas as the fuel for water heating.

The coefficient of the alternative specific dummy for the electric alternative is positive and significant across the specifications, indicating a preference for electric systems not accounted for by the other explanatory variables. The electric space heat system dummy, however, is not significant, which suggests the likely interaction of alternative specific and space heat system effects.

The ratio of capital to operating cost coefficients in the different specifications measures the real rate of transformation of capital cost into annualized life-cycle cost--in other words, the discount rate. The binary logit model including only electric and

TABLE 7 (NIECS)

BINARY LOGIT MODEL OF WATER HEAT FUEL CHOICE
GIVEN SPACE HEAT FUEL CHOICE
NORMALIZED COSTS

Alternative Label	Description	Frequency	Percent of Cases	Frequency Chosen	Percent Chosen
1.000	elec.	640.0	100.0	118.0	18.44
2.000	nat. gas	640.0	100.0	522.0	81.56

Variable Name	Logit Estimate	Standard Error	t-Statistic
WHOPCST1	-82.05	24.00	-3.419
WHCPCST1	-47.79	19.58	-2.441
A1	3.910	0.8756	4.465
SHE	-0.3276	0.5807	-0.5641
SHG	3.698	0.3839	9.632

Auxiliary Statistics	At Convergence	At Zero
Log Likelihood	-176.3	-443.6
Percent Correctly Predicted	91.25	50.00

TABLE 8 (PNW)

BINARY LOGIT MODEL OF WATER HEAT FUEL CHOICE GIVEN SPACE HEAT FUEL CHOICE - NORMALIZED COSTS

Variable Name	Logit Estimate	Standard Error	t-Statistic
WHOPCST1	-163.9	23.95	-6.844
WHCPCST1	-14.18	11.48	-1.236
A1	5.053	0.7133	7.083
SHE	0.7644	0.9538	0.8015
SHG	4.067	0.6279	6.477

Auxiliary Statistics	At Convergence	At Zero
Log Likelihood	-211.8	553.8
Percent Correctly Predicted	85.86	50.00

TABLE 9 (NIECS)

THREE ALTERNATIVE MULTINOMIAL LOGIT MODEL OF WATER HEAT FUEL CHOICE GIVEN SPACE HEAT FUEL CHOICE - NORMALIZED COSTS[a]

Variable Name	Logit Estimate	Standard Error	t-Statistic
WHOPCST1	-104.1	17.41	-5.981
WHCPCST1	-45.72	8.535	-5.357
A1	2.043	0.5149	3.968
A2	-2.308	0.5983	-3.857
SHE	-0.2155	0.5248	-0.4107
SHG	3.722	0.3574	10.42

Auxiliary Statistics	At Convergence	At Zero
Log Likelihood	-272.6	-897.0
Percent Correctly Predicted	88.80	38.02

[a] Alternatives are electricity, natural gas, and fuel oil respectively.

TABLE 10 (PNW)

THREE ALTERNATIVE MULTINOMIAL LOGIT MODEL OF WATER HEAT FUEL CHOICE GIVEN SPACE HEAT FUEL CHOICE - NORMALIZED COSTS

Variable Name	Logit Estimate	Standard Error	t-Statistic
WHOPCST1	-158.2	22.47	-7.039
WHCPCST1	-15.20	8.689	-1.750
A1	5.298	0.7048	7.517
A2	0.1803	1.001	0.1802
SHE	0.5535	0.7955	0.6958
SHG	4.147	0.5968	6.949

Auxiliary Statistics	At Convergence	At Zero
Log Likelihood	-239.7	-957.7
Percent Correctly Predicted	86.84	35.33

natural gas alternatives implies that these discount factors are 58.24 percent and 8.65 percent for the NIECS and PNW data respectively. The trinary models imply discount factors of 43.92 percent and 9.61 percent for the NIECS and PNW data respectively.

These differences in estimated discount rates are too large to be explained away through minor changes in the modeling assumptions. One likely explanation is that the historically low price of electricity in the Pacific Northwest lead to a high saturation of electric water heat systems with much smaller attention paid to initial capital costs. This effect is further seen in the coefficients of capital costs in Tables 8 and 10. Although the qualitative results are very similar, it would not appear that the national results are directly transferable to a region such as the Pacific Northwest, where energy prices have had such a profoundly different history.

We use the choice model in Table 9 in the estimation of the HVAC nested logit model. The calculation of inclusive values correctly accounts for the availability of natural gas. Thus, when gas is not available, the inclusive value corresponds to the electric and oil alternatives only.

VI. SPACE HEAT SYSTEM CHOICE

Dubin and McFadden (1983b) and Cowing, Dubin, and McFadden (1981e) examine nineteen alternative heating, ventilating, and air-conditioning systems which provide combinations of heating and cooling

capacity at design temperature conditions. We list the nineteen alternative HVAC systems in Table 11. Seven of the nineteen HVAC (numbers 4, 6, 10, 12, 16, 17, 19) have very small sample frequencies and are not considered further in the NIECS data.

Additionally, we have been forced to eliminate gas and oil wall units from further study. These systems have both lower operating and capital costs than other HVAC systems. However, wall units (especially gas and oil) are relatively infrequently selected. It is possible that non-pecuniary aspects of these systems make them unattractive for installation, but it is more likely that the definitions of non-central systems used in the NIECS and PNW surveys are ambiguous.

Based on these considerations and various attempts with specifications which included these alternatives, we have opted to eliminate gas and oil wall units from the analysis. The remaining set of ten HVAC systems represent 911 single-family owner occupied detached dwellings built since 1955 with electric, gas, or oil water heat. Four of the ten alternatives include central air-conditioning, and the sample is selected so that households choosing central air-conditioning use electricity as the primary fuel (a small fraction of homes used gas central air-conditioning). The two branches of the space heat choice model are illustrated in Figure 1 of Section II.

Similar considerations in the Pacific Northwest data select ten alternative HVAC systems, which represent 912 single-family owner occupied detached dwellings built since 1955. Alternatives that

TABLE 11 (NIECS)

SHARES OF ALTERNATIVE HVAC SYSTEMS

HVAC System No.	Frequency[a]	Description	
1	0.2676	Gas Forced Air	No Central Air
2	0.1234	Gas Forced Air	Center Air
3	0.0639	Gas Hot Water	No Central Air
4	0.00496	Gas Hot Water	Central Air
5	0.1214	Gas Wall Unit	No Central Air
6	0.00396	Gas Wall Unit	Central Air
7	0.09118	Oil Forced Air	No Central Air
8	0.02725	Oil Forced Air	Central Air
9	0.06838	Oil Hot Water	No Central Air
10	0.00396	Oil Hot Water	Central Air
11	0.01933	Oil Wall Unit	No Central Air
12	0.00050	Oil Wall Unit	Central Air
13	0.01288	Elec. Forced Air	No Central Air
14	0.03023	Elec. Forced Air	Central Air
15	0.01685	Electric Heat Pump	
16	0.00149	Elec. Hot Water	No Central Air
17	0	Elec. Hot Water	Central Air
18	0.05401	Elec. Baseboard	No Central Air
19	0.00694	Elec. Baseboard	Central Air

[a] Based on the sample of 2018 owner occupied single-family detached dwellings built since 1955.

include central air conditioning are excluded due to their small numbers. Table 12 presents the alternatives and their frequencies for the PNW data.

Tables 13 and 14 present the mean values of operating and capital costs by alternative and year of house construction in the NIECS data, while Tables 15 and 16 provide analogous means for the Pacific Northwest. All prices have been converted to 1967 dollars by cost indices using actual costs in the year built. An examination of Tables 13 and 15 indicates that in the post 1955 period, operating costs for oil systems were less expensive in real terms than operating costs for gas systems. This situation changed dramatically in the post 1972 period. Operating costs for electric systems are lower in the Pacific Northwest than corresponding average costs in the national data.

1. Water Heat Fuel and Space Heat System Choice

Having slected a set of alternative HVAC systems we now examine the cross-classification of water heat fuel and space heat system choices. These are presented in Tables 17 and 18 for the NIECS and PNW data respectively. A striking feature of these tables is the tendency for gas and oil water heat fuels to be selected most commonly with gas and oil space heating systems.

Following Dubin and McFadden (1983a) we tried a simple binary choice model of all electric versus all gas systems. In this model, operating and capital costs included the combined costs of forced air and water heating. Table 19 presents the estimated choice models in

TABLE 12 (PNW)

SHARES OF ALTERNATIVE HVAC SYSTEMS

HVAC System No.	Frequency[a]	Description	
1	0.2549	Gas Forced Air	No Central Air
3	0.0271	Gas Hot Water	No Central Air
5	0.0389	Gas Wall Unit	No Central Air
7	0.1647	Oil Forced Air	No Central Air
9	0.0135	Oil Hot Water	No Central Air
11	0.0299	Oil Wall Unit	No Central Air
13	0.0761	Elec. Forced Air	No Central Air
15	0.0017	Electric Heat Pump	
16	0.0039	Elec. Hot Water	No Central Air
18	0.2047	Elec. Baseboard	No Central Air

[a] Based on the sample of 1773 owner occupied single-family detached dwellings built since 1955.

TABLE 13 (NIECS)

MEAN VALUES OF SPACE HEAT OPERATING COSTS BY ALTERNATIVE AND YEAR HOUSE BUILT (1967 Dollars)

HVAC#	Alt	1955-1969	1960-1964	1965-1969	1970-1974	1975+	All Years
1	2	247	229	169	179	247	223
3	5	243	225	166	176	244	219
2	8	313	287	216	214	284	277
7	3	171	154	141	135	290	171
9	6	168	152	138	133	286	168
8	9	237	213	188	171	327	255
13	1	1142	897	672	631	743	911
15	10	718	553	395	389	471	566
14	7	1208	956	720	667	779	966
18	4	1056	825	615	578	685	840
Nobs		373	181	134	124	99	911

HVAC #	Description	
1	Gas Forced Air	No Central Air
3	Gas Hot Water	No Central Air
2	Gas Forced Air	Central Air
7	Oil Forced Air	No Central Air
9	Oil Hot Water	No Central Air
8	Oil Forced Air	Central Air
13	Elec. Forced Air	No Central Air
15	Elec. Heat Pump	
14	Elec. Forced Air	Central Air
18	Elec. Baseboard	No Central Air

TABLE 14 (NIECS)

MEAN VALUES OF SPACE HEAT CAPITAL COSTS BY ALTERNATIVE AND YEAR HOUSE BUILT (1967 Dollars)

HVAC#	Alt	1955-1959	1960-1964	1965-1969	1970-1974	1975+	All Years
1	2	1110	1055	1017	1063	1043	1072
3	5	2279	2327	2343	2623	2594	2379
2	8	2057	1880	1902	1839	1786	1940
7	3	1843	1698	1609	1637	1595	1725
9	6	2818	2809	2795	3076	3027	2871
8	9	2489	2261	2256	2187	2123	2329
13	1	918	876	843	880	862	887
15	10	4935	4514	3920	4353	4504	4576
14	7	1938	1879	1824	1863	1815	1886
18	4	912	889	837	917	929	899
Nobs		373	181	134	124	99	911

TABLE 15 (PNW)

MEAN VALUES OF SPACE HEAT OPERATING COSTS BY ALTERNATIVE AND YEAR HOUSE BUILT (1967 Dollars)

HVAC#	Alt	1955-1959	1960-1964	1965-1969	1970-1974	1975+	All Years
1	2	536	329	288	218	250	352
3	5	527	324	284	215	246	346
5	8	493	303	265	200	229	323
7	3	205	214	200	171	278	217
9	6	202	211	197	168	273	213
11	9	189	197	184	157	254	199
13	1	799	729	633	477	361	614
15	10	311	256	245	173	202	232
16	7	786	718	624	470	354	604
18	4	738	673	584	438	330	566
Nobs		282	136	150	140	204	912

HVAC #	Description	
1	Gas Forced Air	No Central Air
3	Gas Hot Water	No Central Air
5	Gas Wall Unit	No Central Air
7	Oil Forced Air	No Central Air
9	Oil Hot Water	No Central Air
11	Oil Wall Unit	No Central Air
13	Elec. Forced Air	No Central Air
15	Elec. Heat Pump	
16	Elec. Hot Water	No Central Air
18	Elec. Baseboard	No Central Air

TABLE 16 (PNW)

MEAN VALUE OF SPACE HEAT CAPITAL COSTS BY ALTERNATIVE AND YEAR HOUSE BUILT (1967 Dollars)

HVAC#	Alt	1955-1959	1960-1964	1965-1969	1970-1974	1975+	All Years
1	2	1129	1099	1065	1106	999	1081
3	5	2417	2562	2599	2851	2466	2546
5	8	1063	1160	1185	1322	1173	1162
7	3	1870	1750	1656	1687	1565	1721
9	6	2964	3052	3054	3312	2913	3034
11	9	1467	1520	1517	1651	1489	1516
13	1	951	933	890	927	828	907
15	10	5060	4854	4697	4655	3738	4612
16	7	3041	3072	3042	3247	2844	3033
18	4	978	992	969	991	825	946
Nobs		282	136	150	140	204	912

TABLE 17 (NIECS)

CROSS-CLASSIFICATION OF WATER HEAT FUEL AND SPACE HEAT SYSTEM CHOICE

			Water	Heat	Fuel
No.	Space Heat System	Description	Electric	Gas	Oil
1	Elec. Forced Air	No Central Air	21	0	0
2	Gas Forced Air	No Central Air	23	271	0
3	Oil Forced Air	No Central Air	79	9	11
4	Elec. Baseboard	No Central Air	75	3	0
5	Gas Hot Water	No Central Air	1	56	0
6	Oil Hot Water	No Central Air	6	3	33
7	Elec. Forced Air	Central Air	55	5	0
8	Gas Forced Air	Central Air	12	174	0
9	Oil Forced Air	Central Air	39	1	3
10	Electric Heat Pump		31	0	0

(Based on a sample of 911 households.)

TABLE 18 (PNW)

CROSS-CLASSIFICATION OF WATER HEAT FUEL AND SPACE HEAT SYSTEM CHOICE

			Water	Heat	Fuel
No.	Space Heat System	Description	Electric	Gas	Oil
1	Elec. Forced Air	No Central Air	118	0	0
2	Gas Forced Air	No Central Air	104	198	0
3	Oil Forced Air	No Central Air	136	3	2
4	Elec. Baseboard	No Central Air	262	1	1
5	Gas Hot Water	No Central Air	5	26	0
6	Oil Hot Water	No Central Air	13	0	1
7	Elec. Hot Water	No Central Air	5	1	0
8	Gas Wall Unit	No Central Air	10	4	0
9	Oil Wall Unit	No Central Air	18	0	1
10	Electric Heat Pump		3	0	0

(Based on a sample of 912 households.)

TABLE 19 (NIECS)

BINARY LOGIT MODEL OF SPACE HEAT AND WATER HEAT FUEL CHOICE NORMALIZED COSTS

Description	Alternative Label	Frequency	Percent of Cases	Frequency Chosen	Percent Chosen
Elec. Forced Air and Water	1.000	683.0	100.0	182.0	26.65
Gas Forced Air and Water	2.000	683.0	100.0	501.0	73.35

Means of Independent Variables

Alt.Label	OPCST1	CPCST1	CAPINC1
1.000	1.0000	1.334	15.33
2.000	0.2604	1.517	17.39

Variable Name	Logit Estimate	Standard Error	t-Statistic
OPCST1	-12.15	1.187	-10.24
CPCST1	-2.704	1.110	-2.435
CAPINC1	0.9854E-013	0.9098E-01	1.083
A1	7.558	0.9421	8.023

Auxiliary Statistics	At Convergence	At Zero
Log Likelihood	-267.8	-473.4
Percent Correctly Predicted	85.80	50.00

normalized forms for the NIECS data, while Table 20 presents corresponding results for the Pacific Northwest. We note again that pre-normalization of operating and capital costs is a necessary step to achieve sensible results. For direct comparison to the Dubin and McFadden (1983a) model, we include an additional explanatory variable which interacts capital cost with real income. This variable permits a discount factor specification which varies linearly in income. The NIECS discount factor (using the coefficient estimates in the normalized model) is [19.79 - 0.81*(RINCOME/1000.)] while the PNW discount factor is [61.61 - 5.14 (RINCOME/1000)]. Dubin and McFadden (1983a), using national data in the Washington Center for Metropolitan Studies Energy Survey, estimate the linear-in-income discount factor to be [37.93 - 1.028*(RINCOME)]. While this estimated relationship is bracketed by the NIECS and PNW results, it is not surprising that it is closer to the NIECS estimates. However, the evidence in the cross-classification tables and the assumptions under which costs are assigned would tend to reject these models in favor of a richer specification in which each HVAC system is expressed as an individual alternative and in which water heat choice is estimated conditionally upon space heat system choice.

2. Nested Logit Model of Space Heat System Choice

The variables SHOPCST and SHCPCST represent the operating and capital costs of ten alternative HVAC systems. These variables are calculated using annual predictions of usage and capacity developed in the thermal model. Operating and capital costs for alternatives which

TABLE 20 (PNW)

BINARY LOGIT MODEL OF SPACE HEAT AND WATER HEAT FUEL CHOICE NORMALIZED COSTS

Description	Alternative Label	Frequency	Percent of Cases	Frequency Chosen	Percent Chosen
Elec. Forced Air and Water	1.000	527.0	100.0	332.0	63.00
Gas Forced Air and Water	2.000	527.0	100.0	195.0	37.00

Means of Independent Variables

Alt.Label	OPCST1	CPCST1	CAPINC1
1.000	1.0000	2.242	22.62
2.000	0.6260	2.500	25.23

Variable Name	Logit Estimate	Standard Error	t-Statistic
OPCST1	-3.996	0.4801	-8.322
CPCST1	-2.462	1.032	-2.385
CAPINC1	0.1265	0.06557	1.929
A1	2.016	0.3446	5.850

Auxiliary Statistics	At Convergence	At Zero
Log Likelihood	-270.3	-365.3
Percent Correctly Predicted	75.71	50.00

include air conditioning reflect additional costs associated with the central air conditioner and any economies that result from shared costs.[7] The variables SHOPCST1 and SHOPCST2 are SHOPCST divided by two scaling factors: predicted usage (SHUECE) and the operating cost of an electric baseboard heating system, respectively. The empirical analysis indicates that either method of scaling provides adequate results. Furthermore, the scaled variables have strong intuitive appeal. To see this, let us consider the operating cost of system j:

$$\text{SHOPCST}_j = (\text{SHUECE})(D_j)(1/\text{COP}_j) \cdot P_j \quad \text{where}$$

SHOPCST_j = operating cost of system j

SHUECE = base load usage estimate (delivered BTU's)

D_j = adjustment factor for delivery system losses

COP_j = coefficient of performance for system j

P_j = price of fuel used by system j

Note that the electric baseboard system (HVAC no. 18) has a coefficient of performance equal to one, that it has a delivery factor one and that because it uses electricity its operating cost is ($\text{SHUECE}*P_e$). The normalization rules imply that:

$$\text{SHOPCST1}_j = (D_j)(1/\text{COP}_j)P_j$$

$$\text{SHOPCST2}_j = (D_j)(1/\text{COP}_j)(P_j/P_e)$$

The first normalization method replaces operating cost by an efficiency adjusted price, while the second method further scales all costs by the price of electricity. The efficiency adjusted price SHOPCST1_j is related to the price of comfort since the latter is SHOPCST1_j multiplied by the marginal increase in usage required to change the thermostat setting one degree. For a given household, this quantity would be constant across alternatives and would change all normalized operating costs in a proportional manner. Empirical results obtained using the calculated price of comfort rather than normalized operating costs were very similar. The normalized variables have the additional advantage of being sensible on econometric grounds, since the unobserved component of utility would otherwise be heteroscedastic. Furthermore, the normalization has psychometric appeal given the assumption that households evaluate relative rather than absolute system costs.

Table 21 presents the estimation of space heat choice models based on subsets of the ten alternative systems. Specifications 3 and 4 present subsets of the alternatives appearing in specifications 1 and 2. Similarly, specifications 5 and 6 are nested cases of specifications 7 and 8. Departures from the assumption of independence of irrelevent alternatives (I.I.A.) or from the _a priori_ grouping of alternatives should be detectable in significant changes in the estimated coefficients. We maintain that grouping space heat systems into subsets with and without central air conditioning is sensible given the distinct nature of unobserved effects which characterize each technology.

TABLE 21 (NIECS)

ESTIMATION OF SPACE HEAT CHOICE MODEL - ALTERNATIVE SPECIFICATIONS[a]

Model	Alternative Label	Frequency	Percent of Cases	Frequency Chosen	Percent Chosen
Specifications 1,2, 9,10,and 13	1.000	591.0	100.0	21.00	3.553
	2.000	424.0	71.74	294.0	69.34
	3.000	591.0	100.0	99.00	16.75
	4.000	591.0	100.0	78.00	13.20
	5.000	424.0	71.74	57.00	13.44
	6.000	591.0	100.0	42.00	7.107
Specifications 3,4	1.000	414.0	100.0	21.00	5.072
	2.000	334.0	80.68	294.0	88.02
	3.000	414.0	100.0	99.00	23.91
Specifications 5,6	7.000	289.0	100.0	60.00	20.76
	8.000	223.0	77.16	186.0	83.41
	9.000	289.0	100.0	43.00	14.88
Specifications 7,8, 11,12 and 14	7.000	320.0	100.0	60.00	18.75
	8.000	231.0	72.19	186.0	80.52
	9.000	320.0	100.0	43.00	13.44
	10.00	320.0	100.0	31.00	9.688

[a] Total cases 911.

TABLE 21 (NIECS)

Model:	1	2	3	4	5	6	7
Alt:	123456	123456	123	123	789	789	789 10
Variable							
SHOPCST1	-722.9	-	-901.1	-	-439.2	-	-324.6
	(79.94)	-	(141.7)	-	(104.9)	-	(88.03)
SHCPCST1	-46.93	-	-71.91	-	-26.80	-	-9.519
	(20.85)	-	(39.09)	-	(17.90)	-	(8.527)
SHOPCST2	-	-6.108	-	-8.105	-	-7.907	-
	-	(1.158)	-	(1.625)	-	(1.757)	-
SHCPCST2	-	-0.6385	-	-.7874	-	-.1730	-
	-	(0.1337)	-	(.2704)	-	(.1150)	-
WHINCV	-0.2654	0.1867	0.1510	0.1978	0.3262	0.5105	0.9263
	(0.3151)	(0.3204)	(0.4157)	(0.4663)	(0.5036)	(0.4833)	(0.4650)

TABLE 21 (NIECS) continued

Model:	1	2	3	4	5	6	7
Alt:	123456	123456	123	123	789	789	789 10
Variable							
A1	2.627	2.578	1.929	3.270	-	-	-
	(.6676)	(1.167)	(0.6897)	(1.420)	-	-	-
A2	3.175	1.589	1.602	1.347	-	-	-
	(.8070)	(0.8344)	(1.002)	(1.167)	-	-	-
A3	.3949	.04288	-	-	-	-	-
	(.2799)	(.2460)	-	-	-	-	-
A4	3.556	3.206	-	-	-	-	-
	(.6294)	(1.064)	-	-	-	-	-
A5	2.097	0.8637	-	-	-	-	-
	(.7646)	(.8030)	-	-	-	-	-
A6	-	-	-	-	-	-	-
	-	-	-	-	-	-	-
A7	-	-	-	-	2.911	6.736	1.495
	-	-	-	-	(0.7229)	(1.520)	(0.4368)
A8	-	-	-	-	1.864	1.704	.00634
	-	-	-	-	(1.074)	(1.053)	(.8184)
A9	-	-	-	-	-	-	-0.6996
	-	-	-	-	-	-	(0.4429)
Log Likelihood	-570.9	-582.2	-136.1	-137.9	-148.3	-143.7	-232.7
Percent Correctly Predicted	64.47	64.97	89.37	88.89	79.24	79.93	70.94
Discount Factor (Percent)	6.49	10.45	7.98	9.71	6.10	2.19	2.93

Standard errors in parenthesis.

TABLE 21 (NIECS) continued

Model: Alt Variable	8 789 10	9 123456	10 123456	11 789 10	12 789 10	13 123456	14 789 10
SHOPCST1	-	-728.0	-	-233.4	-	-	-
	-	(79.86)	-	65.40	-	-	-
SHCPCST1	-	-70.06	-	-1.603	-	-	-
	-	(14.03)	-	(5.950)	-	-	-
SHOPCST2	-3.110	-	-6.066	-	-2.210	-6.420	-4.499
	(0.8889)	-	(1.130)	-	.6415	(1.031)	(.8240)
SHCPCST2	-0.0578	-	-0.6538	-	-.000234	-0.6400	-0.08259
	(0.0585)	-	(0.1014)	-	(.0412)	(0.1336)	(0.05766)
WHINCV	1.414	-0.2971	0.1883	1.277	1.621	-	-
	(.4168)	(0.3148)	(0.3203)	(0.4161)	(0.3953)	-	-

TABLE 21 (NIECS) continued

Model: Alt Variable	8 789 10	9 123456	10 123456	11 789 10	12 789 10	13 123456	14 789 10
A1	-	2.100	2.485	-	-	2.868	-
	-	(0.5551)	(1.036)	-	-	(1.058)	-
A2	-	2.742	1.534	-	-	2.030	-
	-	(0.7468)	(0.7740)	-	-	(.3564)	-
A3	-	-	-	-	-	.04673	-
	-	-	-	-	-	(.2452)	-
A4	-	3.004	3.114	-	-	3.468	-
	-	(0.4973)	(0.9228)	-	-	(.9660)	-
A5	-	1.949	0.8305	-	-	1.308	-
	-	(0.7574)	(0.7806)	-	-	(.2586)	-
A6	-	-	-	-	-	-	-
	-	-	-	-	-	-	-
A7	2.045	-	-	1.560	1.959	-	2.694
	(0.5552)	-	-	(0.4224)	(0.5428)	-	(0.5376)
A8	-0.9816	-	-	-0.0868	-0.7589	-	1.296
	(.7978)	-	-	(.8185)	(.7796)	-	(0.4358)
A9	-0.7027	-	-	-	-	-	-1.309
	(0.4682)	-	-	-	-	-	(0.4387)
Log Likelihood	-233.4	-571.9	-582.2	-234.0	-234.5	-582.4	-239.8
Percent Correctly Predicted	70.94	65.31	65.14	71.25	71.25	65.14	69.69
Discount Factor (Percent)	1.86	9.62	10.78	0.69	0.01	9.97	1.84

Standard errors in parenthesis.

The results of the estimation are quite sensible in terms of significance and sign. Nor do there appear to be any obvious departures from our selected groupings of alternatives. Without extensive specification testing it would be difficult to reject the assumption of I.I.A. or evaluate its consequences for point estimation.[8]

We find the inclusive value coefficient to be insignificant across the various specification. This is not inconsistent with the assumption of random utility maximization. It indicates that consumers respond to the maximum utility of possible water heat fuel alternatives in their selection of a space heating system.

Given the small differential in mean water heat inclusive value across space heat fuel types, it is likely that there is significant interaction between the inclusive value variable and the alternative specific dummies. This is further confirmed by the fact that the estimated coefficients of operating and capital costs remain robust even when the inclusive value coefficient is constrained to be zero (specifications 13 and 14 of Table 21).

To explore this interaction hypothesis we have estimated specifications 9, 10, 11, 12 in Table 21. These models eliminate the alternative specific effect for oil alternatives. The estimates of the inclusive value coefficients in specifications 9 and 10 remain insignificant. However, the hypothesis that the estimated inclusive value coefficients in the central air conditioning branch (specifications 11 and 12) equal one cannot be rejected under either normalization procedure. There is no <u>a priori</u> reason to expect that the inclusive value coefficients should differ in the two branches. Any difference in the two estimates of the inclusive value coefficient could be explicable only by differences in the degree of intra-correlations in each space heat choice cluster. The sequential estimation procedure cannot impose the constraint that the inclusive value coefficients be equal. It is thus uncertain whether water heat choice given space heat choice is the indicated specification. We therefore adopt the strategy of excluding the water heat choice inclusive value in the space heat choice estimation. The argument is that the differences in the inclusive values are small and are adequately captured in the alternative specific effects.

Estimation of discount factors appear robust across specifications. The discount factors are much lower for the set of alternatives that includes air conditioning as compared with the set of alternatives that does not include air conditioning. This may be a reflection of shared cost components in all-electric HVAC systems. It should be further noted that these estimates are considerably lower than obtains in non-nested or binary specifications (Hausman (1979), Dubin and McFadden (1983a)).

To explore the validity of these conjectures we re-estimate the space heat choice model using the Pacific Northwest data. Here we confine ourselves to the first six NIECS alternatives which do not include central air-conditioning. Table 22 presents five alternative

TABLE 22 (PNW)

ESTIMATION OF SPACE HEAT CHOICE MODEL - ALTERNATIVE SPECIFICATIONS[a]

	Alternative Label	Frequency	Percent of Cases	Frequency Chosen	Percent Chosen
Specifications 1,2,3,4,5	1	752.0	100.0	118.0	15.69
	2	574.0	76.33	194.0	33.80
	3	752.0	100.0	141.0	18.75
	4	752.0	100.0	264.0	35.11
	5	574.0	76.33	21.00	3.659
	6	752.0	100.0	14.00	1.862

[a] Total cases 912.

TABLE 22 (PNW) continued

SPECIFICATIONS WHICH INCLUDE WATER HEAT INCLUSIVE VALUE

Model:	1	2	3	4
Alt:	123456	123456	123456	123456
Variable				
SHOPCST1	-576.9	-	-582.7	-
	(67.23)	-	(68.49)	-
SHCPCST1	-87.09	-	-164.01	-
	(22.77)	-	(17.27)	-
SHOPCST2	-	-1.8212	-	-1.569
	-	(0.3523)	-	(0.3471)
SHCPCST2	-	-0.4968	-	-0.6902
	-	(0.07967)	-	(0.06792)
WHINCV	0.2165	0.7203	0.1890	0.8007
	(1.148)	(0.1778)	(0.1900)	(0.1787)

TABLE 22 (PNW) continued

SPECIFICATIONS WHICH INCLUDE WATER HEAT INCLUSIVE VALUE

Model:	1	2	3	4
Alt:	123456	123456	123456	123456
Variable				
A1	2.082	0.6862	0.2152	-.9615
	(0.5343)	(0.5604)	(0.3441)	(.3821)
A2	2.035	0.9164	0.2731	-.5391
	(0.4763)	(0.4579)	(0.2726)	(.2726)
A3	1.521	1.214	-	-
	(.3484)	(0.3225)	-	-
A4	2.659	1.230	0.7402	-.4330
	(0.5296)	(0.5450)	(0.3262)	(.3564)
A5	0.7478	-0.1123	0.1891	-1.173
	(0.4238)	(0.4426)	(0.3448)	(.3427)
Log Likelihood	-951.5	-945.2	-27.24	-38.99
Percent Correctly Predicted	44.02	44.68	64.86	52.50
Discount Factor Percent	15.10	27.28	28.16	43.99

Standard errors in parenthesis.

TABLE 22 (PNW) continued

SPECIFICATIONS WHICH DO NOT INCLUDE WATER HEAT INCLUSIVE VALUE

Model:	5	6	7
Alt:	123456	123456	123456
Variable			
SHOPCST	-	-	-.004832
	-	-	(.0003588)
SHCPCST	-	-	.001072
	-	-	(.0002014)
SHOPCST1	-	-699.3	-
	-	(54.98)	-
SHCPCST1	-	-99.11	-
	-	(22.71)	-
SHOPCST2	-3.082	-	-
	(0.2875)	-	-
SHCPCST2	-0.4301	-	-
	(0.07369)	-	-
A1	2.500	2.500	6.587
	(.4480)	(.4733)	(.6131)
A2	2.540	2.595	6.491
	(.3668)	(.4249)	(.5678)
A3	1.437	1.432	4.087
	(.3123)	(.3456)	(.4557)
A4	2.947	3.035	7.226
	(.4380)	(.4742)	(.6091)
A5	1.391	1.386	2.418
	(.3364)	(.3396)	(.3628)
Log Likelihood	-1107.	-1094.	-1078.
Percent Correctly Predicted	44.94	44.37	47.47
Discount Factor (Percent)	13.96	14.17	-22.19

(Standard errors in parenthesis.)

specifications. Specifications 1 and 2 correspond to specifications 1 and 2 of Table 21 while specifications 3 and 4 correspond to specifications 9 and 10 of Table 21. Finally, we estimate a non-normalized model in specification 5.

Qualitatively, the results in the PNW data are similar to those obtained in the NIECS data. Remarkably, the second normalization is now identified to be superior to the first normalization. Under the second normalization (specifications 2 and 4) we find larger likelihoods at convergence and significant water heat inclusive value coefficients which lie in the unit interval.

Estimated discount factors are somewhat larger in the PNW data than those in the NIECS data. This is possibly a reflection that difficulties in the measurement of gas availability in the NIECS data have been adequately corrected in the PNW data. Specification 5 of Table 22 strengthens our conclusions regarding the importance of pre-normalization of operating and capital costs.

To summarize our findings in the comparison of the NIECS and PNW estimated choice models, we note that while qualitatively, they reinforce one another there are strong regional effects which make it impossible to transfer parameter estimates from one data set to the other. The national data reveal small discount factors in the space heat choice models, while much larger discount factors prevail in the water heat choice models. This pattern is reversed in the Pacific Northwest, where historically low energy costs are not as heavily weighted in the utility maximization.

3. Space Heat System Choice - Income Effects

We now investigate the significance of income on the choice of space heat system using the Pacific Northwest data. Following the specification of Dubin and McFadden (1983a), we do this by creating an interaction variable which is the product of normalized capital cost and real income. The estimated choice models are presented in Table 23.

The coefficient estimates of operating and capital cost are interpreted as a linear-in-income discount factors. Each relationship is precisely determined and provides robust estimates of the income effect. A rule-of-thumb would indicate that each increase of $1000 in real income decreases the discount factor by 1 percent. That lower income levels are associated with higher discount rates is consistent with the hypothesis that the capital market constrains low income individuals to purchase high operating and low capital cost systems.

4. The Role of Price Expectation Formation In The Choice of Heating and Cooling Systems

In each of the specifications considered above we have maintained the hypothesis that expectations of fuel prices were static. Implicitly, we have assumed that the real price of alternative fuels would remain constant at the levels which prevailed at the point of dwelling construction. However it is plausible to assume that consumers view a trade-off between initial capital cost and the life-cycle cost of durable service. The components of life-cycle cost are determined primarily through the price of the

TABLE 23 (PNW)

ESTIMATION OF SPACE HEAT CHOICE MODEL SPECIFICATIONS WITH INCOME INTERACTIONS[a]

Alternative Label	Frequency	Percent of Cases	Frequency Chosen	Percent Chosen
1.000	733.0	100.0	102.0	13.92
2.000	646.0	88.13	254.0	39.32
3.000	733.0	100.0	113.0	15.42
4.000	733.0	100.0	226.0	30.83
5.000	646.0	88.13	26.00	4.025
6.000	733.0	100.0	12.00	1.637

[a] Total cases 912. Some observations are missing due to incomplete data on real income.

TABLE 23 (PNW) continued

Model: Alt: Variable	1 123456	2 123456
SHOPCST1	-696.3	-
	(58.99)	-
SHCPCST1	-152.1	-
	(29.29)	-
SHOPCST2	-	-3.097
	-	(0.3100)
SHCPCST2	-	-0.7028
	-	(0.1109)
SHCAP1[a]	7.997	-
	(1.915)	-
SHCAP2[b]	-	0.03086
	-	(0.0066)
A1	3.144	2.845
	(0.5368)	(.4903)
A2	3.168	2.836
	(0.4827)	(.4013)
A3	1.814	1.633
	(0.3915)	(.3439)
A4	3.666	3.266
	(0.5371)	(.4791)
A5	1.525	1.453
	(0.3715)	(.3650)
Log Likelihood	-911.9	-924.4
Percent Correctly Predicted	45.98	45.98

Standard errors in parenthesis.

[a] SHCAP1 = RINCOME * SHCPCST1.

[b] SHCAP2 = RINCOME * SHCPCST2.

Specification	Discount Factors (Percent)
1	21.84 - 1.1485 * (RINCOME/1000)
2	22.69 - 0.9664 * (RINCOME/1000)

indirectly demanded fuel input. Since these prices are unknown to the consumers at the point of dwelling construction, one must assume that some expectation formation mechanism determines future prices.

Rather than postulate a particular expectation formation pattern, we specify alternative choice models which include both past, present, and future operating costs. We then test the hypothesis that only past and present operating costs are jointly significant and interpret the estimated coefficients as an "adaptive expectation system." A test of the hypothesis that current operating costs are solely significant reveals a "static expectation system." Finally, the joint significance of future operating costs might be interpreted as "perfect foresight."

Each household in the NIECS data is located at the level of its primary sampling unit. Primary sampling units are matched to the State Energy Data Base (SEDS) from which we access historical energy prices. The NIECS data base provides categorical information on the year of dwelling construction. The interval length changes from five year periods in the years 1960 to 1975 to ten year periods prior to 1960. It is not possible to determine precisely the year of dwelling construction prior to 1974 and it is therefore impossible to define exact lag and lead lengths.

We adopt the strategy of using five year length periods to define leads and lags. During each period a representative year is selected. We make the assumption that the real price of energy remains constant in each year built category. Table 24 summarizes the

TABLE 24 (NIECS)

DEFINITION OF PAST AND FUTURE OPERATING COSTS STRUCTURE OF LEADS AND LAGS

Lags		Yearbt		Leads
8	9	0	1	2
67	72	77	77	77
62	67	72	77	77
57	62	67	72	77
52	57	62	67	72
47	52	57	62	67

Key:

47	1945-1949
52	1950-1954
57	1955-1959
62	1960-1964
67	1965-1969
72	1970-1974
77	1975-1979

assignment of selected years to categories and defines the lead and lag structure. We see from Table 30 that our assignments are further disturbed for houses built during the seventies. The difficulty arises because the (SEDS) data base extends from 1928 to 1980 and we cannot easily match additional information to define precise two period leads.

The estimation of the space heat choice model with past, present, and future operating costs is given in Table 25. We consider two specifications. Specification 1 includes both leads and lags while specification 2 constrains lead price coefficients to be zero.[9] A comparison of the two models indicates the significance of future prices. Past prices on the other hand do not appear jointly significant. On balance it would appear that there is evidence to support the hypothesis that future prices matter to consumers. The model with future prices has greater predictive power than previous specifications which impose the static expectation hypothesis.

A pattern emerges in which an increase in next period price will decrease the probability of selection for alternatives of that fuel type while an expected increase in two period forward prices works in the opposite direction. If this structure receives further empirical support it should have important implications for both policy and prediction.

TABLE 25 (NIECS)

ESTIMATION OF SPACE HEAT CHOICE MODEL WITH PAST AND FUTURE OPERATING COST MEASURES

	Alternative Label	Frequency	Percent of Cases	Frequency Chosen	Percent Chosen
Specifications 1,2	1.000	580.0	100.0	21.00	3.621
	2.000	396.0	68.28	288.0	72.73
	3.000	580.0	100.0	99.00	17.07
	4.000	580.0	100.0	78.00	13.45
	5.000	396.0	68.28	52.00	13.13
	6.000	580.0	100.0	42.00	7.241

TABLE 25 (NIECS) continued

Model: Alt:	1 123456	2 123456
Variable		
SHCST82	-1.483 (0.9428)	-1.585 (0.9426)
SHCST92	2.714 (2.291)	2.353 (2.341)
SHCST02	-5.734 (2.541)	-6.012 2.154)
SHCST12	-3.687 (1.886)	- -
SHCST22	3.633 (1.481)	- -
A1	1.728 (1.187)	2.173 (1.155)
A2	2.159 (.3618)	2.110 (.3631)
A3	0.033 (.248)	0.056 (.247)
A4	2.483 (1.079)	2.864 (1.054)
A5	1.401 (0.2684)	1.334 (0.2654)
SHCPCST1	-0.6511 (0.1368)	-0.6356 (0.1373)
Log Likelihood	-550.6	-553.5
Percent Correctly Predicted	66.21	66.21

(Standard errors in parenthsis.)

VII. CENTRAL AIR-CONDITIONING CHOICE

This section presents the estimation of the central air-conditioning choice model. From equation (11) of Section II, we see that the probability of air-conditioning choice depends on the inclusive value of room air-conditioning (when central air is not chosen), the inclusive values of space heat choice given air-conditioning choice, and on other attributes of the utility of purchasing an air-conditioning system. We follow the formulation of Section IV and use income and cooling degree days interacted with the first and second alternatives (central vs. non-central) as determinants of the utility associated with either alternative. The inclusive value of room air-conditioning choice interacts with the second alternative, as does the inclusive value of space heat choice given no central air-conditioning. The inclusive value of space heat choice given central air-conditioning interacts with alternative one.

The results of the estimation are presented in Table 26. While real income and cooling degree days are significant and have the expected sign the coefficients of the inclusive value terms are insignificant in two of three cases. The coefficient estimates on the inclusive value terms are consistent with the hypothesis of random utility maximization.

For comparison we present in Table 27 a simple binary logit model of central air-conditioning choice which excludes the inclusive values. For the present we argue that either model may be used as a good predictor of the choice of central air-conditioning and should

TABLE 26 (NIECS)

BINARY LOGIT MODEL OF CENTRAL AIR-CONDITIONING CHOICE WITH INCLUSIVE VALUE TERMS

	Alternative Label	Frequency of Cases	Percent Chosen	Frequency Chosen	Percent
Central AC	1.000	911.0	100.0	320.0	35.13
No Central AC	2.000	911.0	100.0	591.0	64.87

Means of Independent Variables:

Alt. Label	SHINCVC	SHINCVNC	RMINCV	RINCOME1	CDD2
1.000	-0.7905	0.0	0.0	12.03	0.0
2.000	0.0	-0.9160	-0.5041	0.0	1121.

Variable Name	Logit Estimate	Standard Errors	t-Statistic
SHINCVC	0.5471	0.2061	2.655
SHINCVNC	0.1701	0.1467	1.160
RMINCV	0.7280	0.9987	0.7290
RINCOME1	0.9354E-01	0.2271E-01	4.118
CDD2	-0.1808E-02	0.5587E-03	-3.236
A2	4.009	0.3503	11.44

Auxiliary Statistics	At Convergence	At Zero
Log Likelihood	-449.4	-631.5
Percent Correctly Predicted	78.27	50.00

TABLE 27 (NIECS)

BINARY LOGIT MODEL OF CENTRAL AIR-CONDITIONING CHOICE WITHOUT INCLUSIVE VALUE TERMS

Variable Name	Logit Estimate	Standard Error	t-Statistic
RINCOME1	.7869-01	.1273E-01	6.181
CDD2	-.1632E-02	.1329E-03	-12.28
A2	3.477	.2550	13.64

Auxiliary Statistics	At Convergence	At Zero
Log Likelihood	-460.1	-631.5
Percent Correctly Predicted	77.39	50.00

perform adequately in the construction of instrumental variables used in the estimation of utilization equations.

VIII. THE EFFECTIVENESS OF PROPOSED ENERGY POLICIES TO INFLUENCE THE SELECTION OF HOUSEHOLD APPLIANCE STOCKS

This section calculates the mean predicted probabilities of HVAC system choice under six alternative levels of building thermal characteristics. The first alternative is the observed dwelling. The second alternative increases existing wall and ceiling insulation to minimum standards proposed by ASHRAE. The third alternative modifies heating and cooling capacities by changing recommended design temperatures.[10] The fourth policy alternative focuses on infiltration loses and recommends that all windows be stormed or double glazed and that simple maintenance reduce the number of air changes by sealing obvious cracks near windows and doors. A fifth alternative to be examined would increase indoor summer temperatures by 5°F and decrease indoor winter temperatures by 5°F. Finally, a sixth alternative combines alternatives two through five to achieve a maximal conservation response. Tables 28 and 29 summarize the alternative policies for the NIECS and PNW geographic regions.

Our simulation procedure selects for each data set a sample of dwellings of recent vintage. For these dwellings we re-estimate predicted capacities and usages under each of the six alternative levels of thermal integrity. The capacities and heating and cooling loads are then used to calculate HVAC capital and operating costs.

TABLE 28 (NIECS)

THERMAL POLICIES FOR SIMULATION STUDIES

Policy 1 (Insulation)
Minimum Insulation Standards for Walls and Ceilings:

	Northeast	Northcentral	South	West
R-Value Ceiling Insulation	17.14	17.14	19.5	19.5
R-Value Wall Insulation	15.44	15.44	9.45	9.45

Policy 2 (Design Temperatures)
Reduction in Heating and Cooling Design Temperatures:

	Northeast	Northcentral	South	West
Heating Design Temp	12	14	12	14
Cooling Design Temp	7	6	6	5

Policy 3 (Infiltration and Window Glazing)
1) All windows are stormed or double glazed
2) Number of air changes reduced 7 percent

Policy 4 (Thermostat Temperature)

1) Increase indoor summer temperature from 75°F to 80°F
2) Decrease indoor winter temperature from 70°F to 65°F

TABLE 29 (PNW)

THERMAL POLICIES FOR SIMULATION STUDIES

Policy 1 (Insulation)
Minimum insulation standards for walls and ceilings:
1) R-value ceiling insulation: 19.5
2) R-value wall insulation: 9.45

Policy 2 (Design Temperatures)
Reduction in heating and cooling design temperatures:
1) heating design temp: 14°F, 2) cooling design temp: 5°F

Policy 3 (Infiltration and Window Glazing)
1) all windows are stormed or double glazed
2) number of air changes reduced 7 percent

Policy 4
1) increase indoor summer temperature from 75°F to 80°F
2) decrease indoor winter temperature from 70°F to 65°F

TABLE 30 (NIECS)
ENERGY PRICE PROJECTIONS (NATIONAL AVERAGES)[a]

	REAL GROWTH FACTORS			
	1978	1985	1990	2000
Electricity	1.0	1.08	1.13	1.22
Natural Gas	1.0	1.28	1.50	1.94
Oil	1.0	1.15	1.23	1.40

[a] Fuel price projections are from the Department of Energy and the Brookhaven National Laboratory as described in Hirst, E., and Carney, J. (July, 1978).

TABLE 31 (PNW)
ENERGY PRICE PROJECTIONS (PACIFIC NORTHWEST)[a]

	REAL GROWTH FACTORS			
	1978	1985	1990	2000
Electricity	1.0	1.31	1.45	1.78
Natural Gas	1.0	1.09	1.18	1.43
Oil	1.0	1.06	1.10	1.33

[a] Fuel price projections are from Cambridge Systematics (1979).

The procedure by which the output of thermal program under alternative policy scenarios is mapped into capital and operating costs is identical to that used to create explanatory variables in the HVAC choice models using the observed sample data.

We have evaluated operating costs using 1978 energy prices and the forecasted values of energy prices for the years 1985, 1990, and 2000. Tables 30 and 31 summarize the real growth factors in alternative fuels assumed in the simulations.[11] The forecasts indicate that the price of natural gas will nearly double by the year 2000. Electricity and fuel oil are assumed to grow somewhat less rapidly: they experience real growth of 22 percent and 40 percent respectively. The price projections for the Pacific Northwest indicate that electricity will grow most rapidly at approximately 3.5 percent per year. Natural gas and fuel oil are assumed to grow more slowly at approximately 2.0 and 1.5 percent per year, respectively. Given six alternative levels of thermal integrity and four forecast years we have defined 24 distinct projections. We employ the HVAC choice model illustrated in Figure 1 to forecast the sample mean predicted probabilities for six alternative space heat systems without central air conditioning and four systems with central air conditioning. Specifically we assume specification 13 and 14 in Table 21 for the NIECS data and specification 5 of Table 22 for the PNW data. The availability of natural gas is assumed to remain constant under each scenario.

We graph the sample mean forecast probabilities by HVAC alternative, policy scenario, and forecast year in Figure 2. For each HVAC alternative a corresponding graph in Figure 2 provides scale information and an identification of each plotted curve. The labels for each alternative are easily found in Figure 1 or Table 17.

In the NIECS data we see an increase in electric forced air and electric baseboard systems. Conservation policies, however, could decrease the overall share of electric forced air systems while increasing the share of electric baseboard systems relative to current standards.

Gas systems reveal decreases in overall saturations. Conservation policies appear to reinforce this effect by further reducing predicted market shares. Oil alternatives show a moderate decrease in market share by 1985 while the overall trend is to increase market share slightly from 3 to 6 percent. Conservation policies will decrease the prevalence of this alternative by the year 2000. This pattern continues to hold in systems with air conditioning. Interestingly, electric heat pumps, which are forecast to enjoy an increasing market share in new construction and conservation policies, will reinforce this pattern.

In the Pacific Northwest electric systems are forecast to gain relative to other fuel types. However electric baseboard systems initially increase and then decrease in market share as electricity prices reach relatively high levels in the year 2000. Gas forced air systems are forecast to decrease in prevalence and conservation policies will strenghten this trend. Oil heating systems, which have

relatively little market share in the Pacific Northwest, are not revealed to demonstrate large changes in their penetration.

The proposed ASHRAE standards would appear to generally increase the shares of energy efficient heating and cooling systems. Forecasts for actual energy usage which result under alternative conservation scenarios will be reported elsewhere.

FIGURE 2a

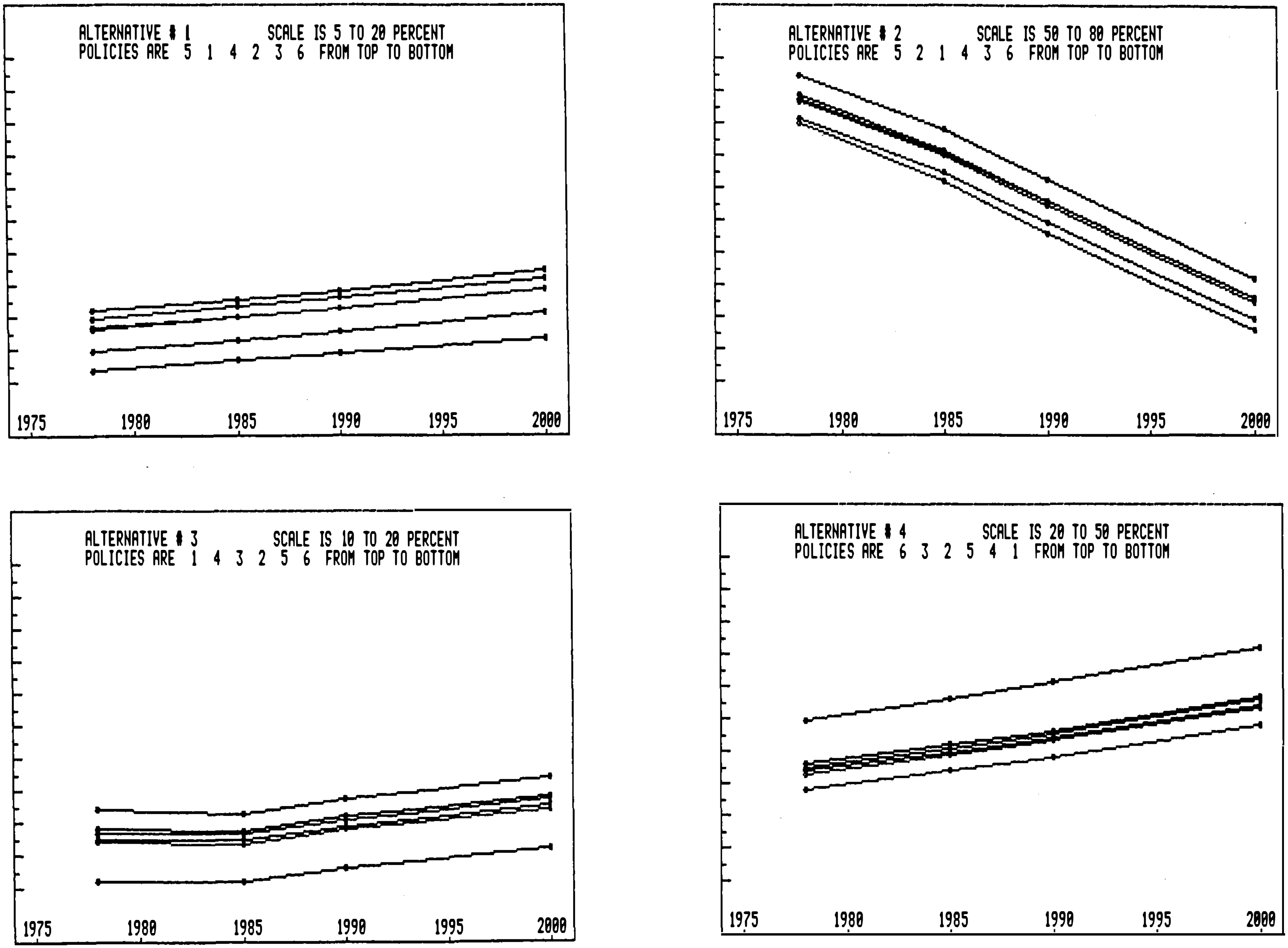

ALTERNATIVE # 1
SCALE IS 5 TO 20 PERCENT
POLICIES ARE 5 1 4 2 3 6 FROM TOP TO BOTTOM
1975
1980
1985
1990
1995
2000
ALTERNATIVE # 2
SCALE IS 50 TO 80 PERCENT
POLICIES ARE 5 2 1 4 3 6 FROM TOP TO BOTTOM
1975
1980
1985
1990
1995
2000
ALTERNATIVE # 3
SCALE IS 10 TO 20 PERCENT
POLICIES ARE 1 4 3 2 5 6 FROM TOP TO BOTTOM
1975
1980
1985
1990
1995
2000
ALTERNATIVE # 4
SCALE IS 20 TO 50 PERCENT
POLICIES ARE 6 3 2 5 4 1 FROM TOP TO BOTTOM
1975
1980
1985
1990
1995
2000

FIGURE 2b

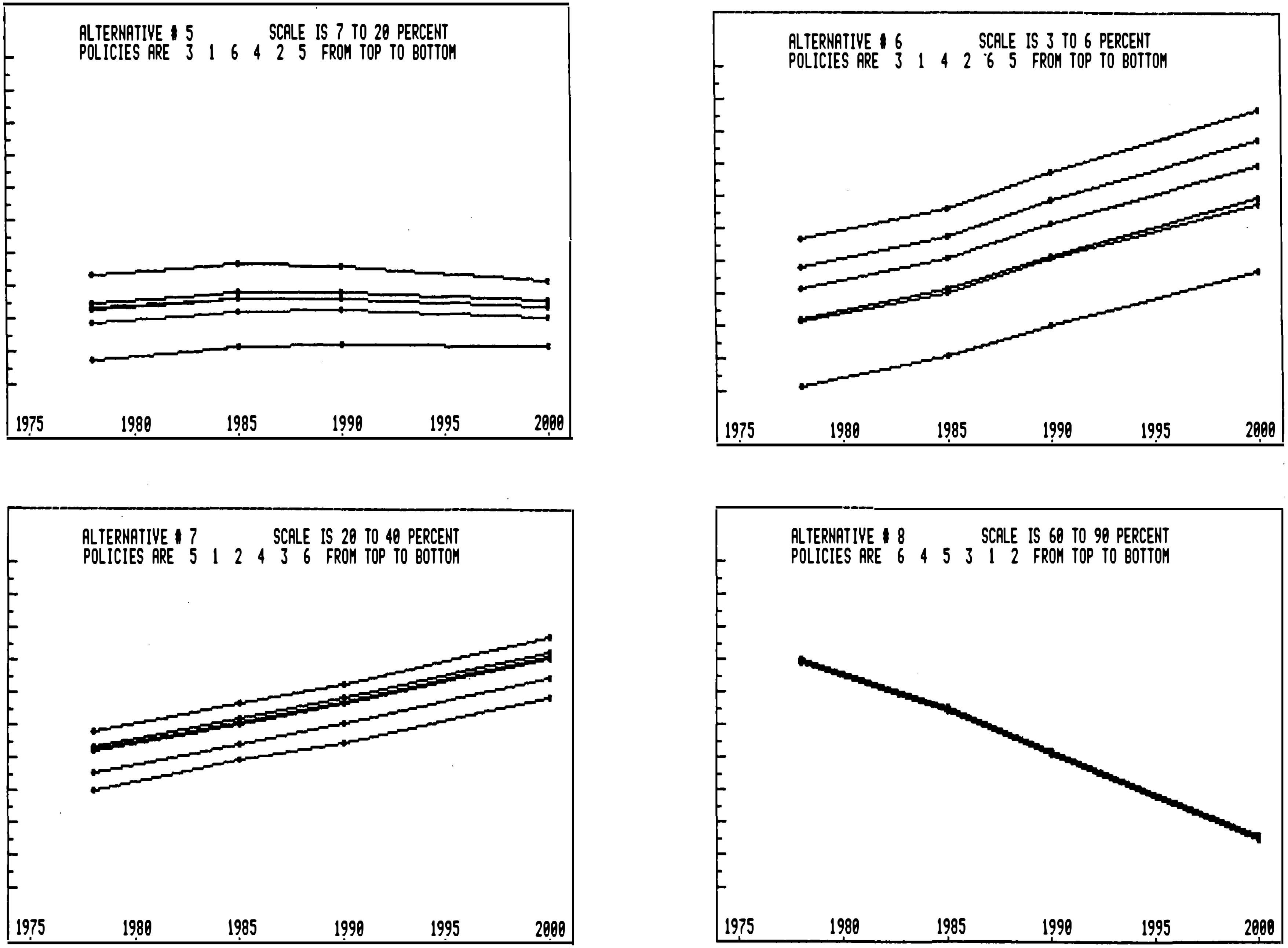

ALTERNATIVE # 5 SCALE IS 7 TO 20 PERCENT
POLICIES ARE 3 1 6 4 2 5 FROM TOP TO BOTTOM
1975
1980
1985
1990
1995
2000
ALTERNATIVE # 6 SCALE IS 3 TO 6 PERCENT
POLICIES ARE 3 1 4 2 6 5 FROM TOP TO BOTTOM
1975
1980
1985
1990
1995
2000
ALTERNATIVE # 7 SCALE IS 20 TO 40 PERCENT
POLICIES ARE 5 1 2 4 3 6 FROM TOP TO BOTTOM
1975
1980
1985
1990
1995
2000
ALTERNATIVE # 8 SCALE IS 60 TO 90 PERCENT
POLICIES ARE 6 4 5 3 1 2 FROM TOP TO BOTTOM
1975
1980
1985
1990
1995
2000

FIGURE 2c

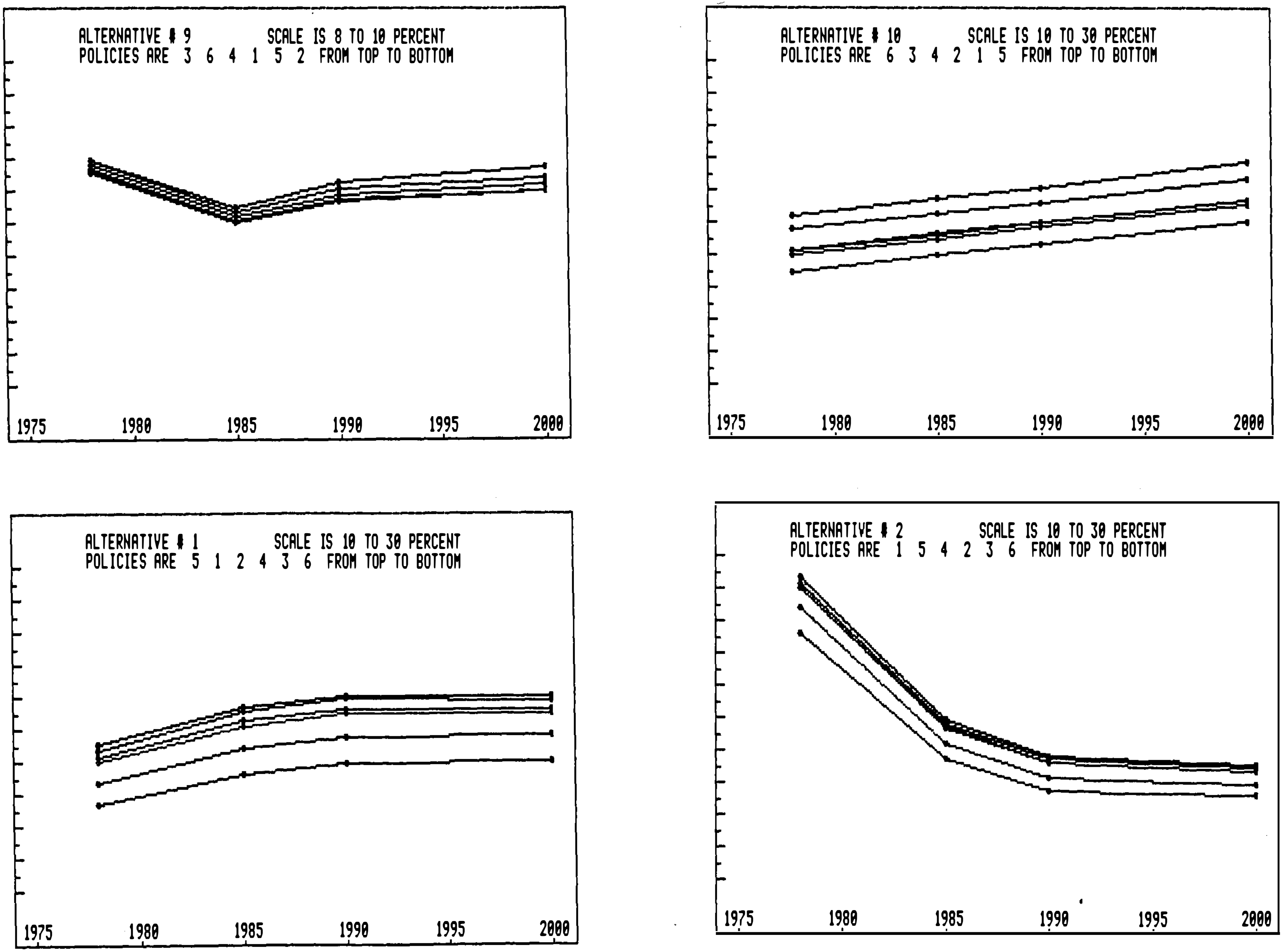
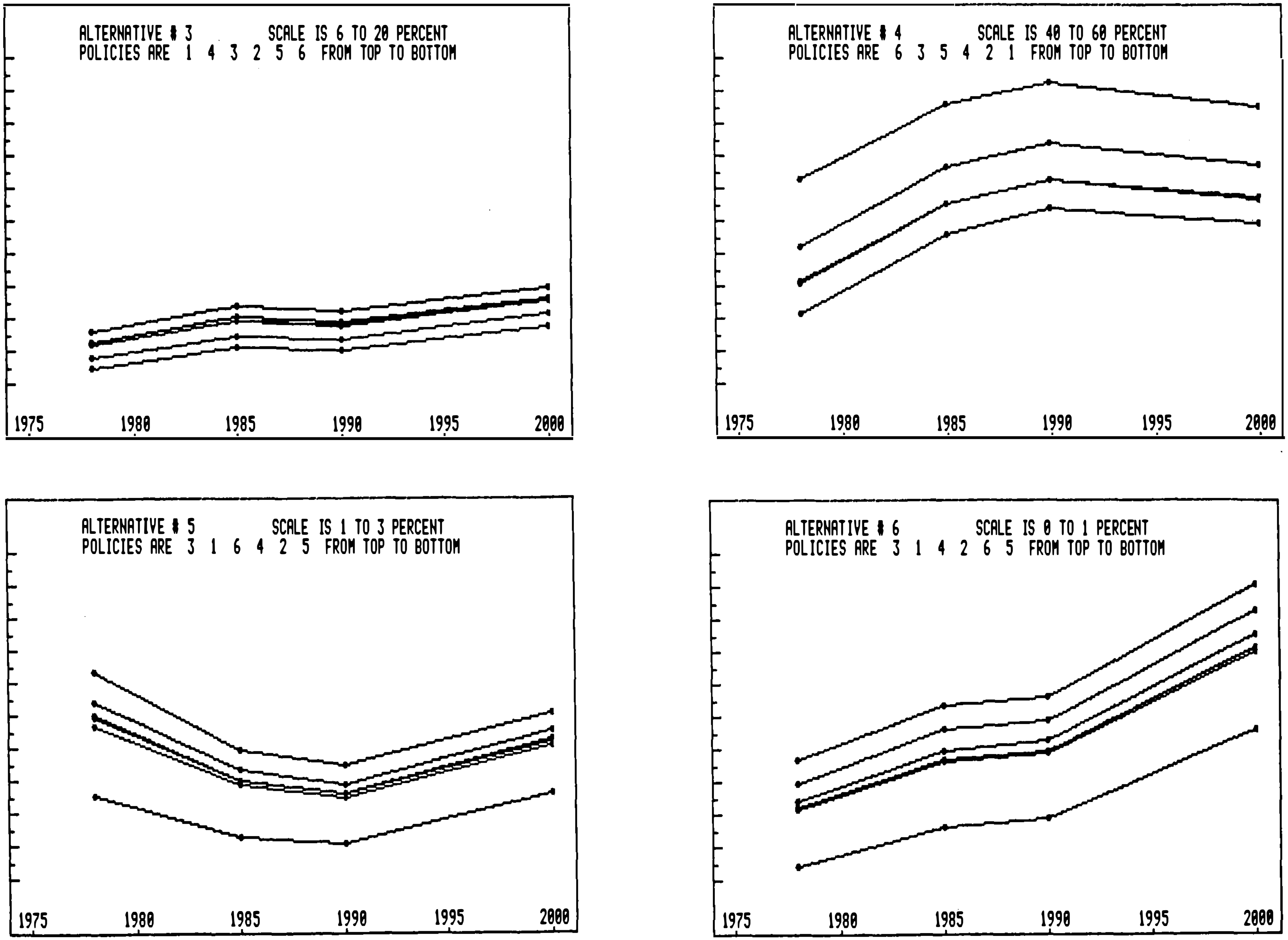

ALTERNATIVE # 9 SCALE IS 8 TO 10 PERCENT
POLICIES ARE 3 6 4 1 5 2 FROM TOP TO BOTTOM
1975
1980
1985
1990
1995
2000
ALTERNATIVE # 10 SCALE IS 10 TO 30 PERCENT
POLICIES ARE 6 3 4 2 1 5 FROM TOP TO BOTTOM
1975
1980
1985
1990
1995
2000
ALTERNATIVE # 1 SCALE IS 10 TO 30 PERCENT
POLICIES ARE 5 1 2 4 3 6 FROM TOP TO BOTTOM
1975
1980
1985
1990
1995
2000
ALTERNATIVE # 2 SCALE IS 10 TO 30 PERCENT
POLICIES ARE 1 5 4 2 3 6 FROM TOP TO BOTTOM
1975
1980
1985
1990
1995
2000

FIGURE 2d


ALTERNATIVE # 3 SCALE IS 6 TO 20 PERCENT
POLICIES ARE 1 4 3 2 5 6 FROM TOP TO BOTTOM
ALTERNATIVE # 4 SCALE IS 40 TO 60 PERCENT
POLICIES ARE 6 3 5 4 2 1 FROM TOP TO BOTTOM
ALTERNATIVE # 5 SCALE IS 1 TO 3 PERCENT
POLICIES ARE 3 1 6 4 2 5 FROM TOP TO BOTTOM
ALTERNATIVE # 6 SCALE IS 0 TO 1 PERCENT
POLICIES ARE 3 1 4 2 6 5 FROM TOP TO BOTTOM
1975
1980
1985
1990
1995
2000

FOOTNOTES

1. The author acknowledges the research assistance of Paul Bjorn who aided in the simulation experiments of section VIII. He further thanks Philip Hoffman and Steven Hensen for reading and commenting on a preliminary draft.

2. See Goett (1982) for an example of this approach.

3. The inclusive value coefficient is defined and interpreted in McFadden (1983).

4. The NIECS data provide information about the number of room air conditioners owned by the household and the number of rooms air conditioned but no information is available on individual room air conditioner efficiency. Estimation is confined to the NIECS data as air conditioning is not an important consideration in the Pacific Northwest.

5. The thermal model of Dubin and McFadden (1983b) provides direct estimates of air conditioning design capacity given household characteristics and location specific temperature information.

6. The sample is additionally edited to eliminate infrequently selected space heating systems. This point will be taken up below.

7. For details the reader is referred to Cowing, Dubin, and McFadden (1981e).

8. McFadden, Tye, and Train (1978) and Hausman and McFadden (1982) discuss two tests of the I.I.A. property.

9. Normalization method two is used in the estimation of specifications 1 and 2.

10. Dubin and McFadden (1983b) discuss details of the ASHRAE thermal standards and the connection between design temperature and HVAC capacity.

11. We assume that the real price of capital goods and household demographics remain constant at 1978 levels.

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