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ENERGY DIVISION

RESIDENTIAL WOOD-USE IN THE PACIFIC NORTHWEST: 1979-1985

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EXECUTIVE SUMMARY

This report analyzes wood use for residential space heating in the Pacific Northwest. Issues addressed are the levels, trends, and determinants of wood use, as well as relationships of wood use to conservation program planning and evaluation. Six data sets were used in the analysis. Three contain data on representative samples of housing units in the Bonneville Power Administration's (BPA) service area. These data bases were collected starting in 1979 and extending to 1985. The other three are products of Oak Ridge National Laboratory evaluations of BPA's residential conservation programs' energy savings. The former data sets are used to provide insights into the extent and trends of wood use, whereas the latter data sets are used mostly to relate wood use to problems in accounting for program energy savings.

A large number of findings are reported in the text of this report. With respect to extent of use and trends, some of the more important findings are:

- the percentage of all households reporting that wood was used as the primary space heating fuel increased from 10% in 1979 to greater than 20% in 1983 (Table 3.1);
- ownership of wood stoves as wood heating systems (versus fireplaces, etc.) correspondingly increased, from 30% of wood burning systems in 1979 to 60% in 1983 (Table 3.6);
- wood use gained primarily at the expense of natural gas and fuel oil (Table 3.1);
- the share of all housing units using electricity as the primary space heating fuel remained constant from 1979 to 1983, at approximately 40% of all units (Table 3.1);
- most existing households that switched to wood did so at the time they were installing new primary space heating systems (Table 4.4);

- wood increased its market share as the primary space heating fuel in new single-family homes, rising from 12% in 1979 to 25% in 1983 (Table 4.5); and
- the equipment needed to use wood as a source of heat in 1983 was present in 48% of the housing units (Table 4.6).

These findings indicate that wood is a major fuel in the Pacific Northwest and its use has been growing. These data also suggest that the residential space heating fuel market is fast becoming a two-fuel market, electricity and wood. Thus, a situation is evolving where, in the short term, there could be potentially large swings in the residential demand for electricity, directly driven by the demand for wood.

We used discrete choice and simultaneous equation models to identify important correlates of wood use. Six such determinants were found:

- the number of members in the household is positively related to wood use;
- income is negatively related to wood use for primary space heating;
- wood use is more prevalent in rural areas;
- the size of the house is positively related to wood use;
- the price of electricity is positively related to wood use; and
- households using relatively large amounts of wood for space heating are less likely to have participateed in a conservation program.

A number of interesting hypotheses can be developed around these results. For instance, wood use may be highly related to the labor available in the household to maintain wood burning operations. Also, because of the negative relationship to income, wood could be classified as an inferior good, at least with respect to fuels such as electricity which do not require direct labor for their use. Lastly, it could be that households that need to reduce expenditures for energy either decide to use wood and possibly do their own retrofitting or decide to participate in conservation programs.

The conclusions suggested by recent trends in wood use vs expected future trends in the correlates of wood use conflict, however. While wood use has increased dramatically in the recent past, suggesting that there may be strong influences promoting continued increases in the use of wood, possible changes in the correlates of wood use (e.g., decreasing family size and increasing real incomes) suggest that wood use will either level off or decline. It is not entirely clear which conclusion is correct. Increases in electricity prices, thought until just recently to be stable, could result in further increases in wood use. Further evidence to support either hypothesis could be gained by surveying households that just replaced their main heating systems or added supplementary fuels to the existing system and by surveying new home buyers about their space heating decisions.

It is also important that BPA begin to formally recognize, in its modeling processes, the influence of wood use in the Pacific Northwest. Specifically, it would be useful to calculate the amount of conservation which exists in a virtual form in houses that have received retrofits but heat with wood. That is, the full potential of conservation of electricity measures is realizable only when houses heat exclusively with electricity and the difference between this gross potential and actual/net savings in houses that heat with wood is, in some sense, virtual conservation. Large amounts of virtual conservation may not benefit BPA immediately but could serve as an important damper on future electricity demand should the bottom fall out of wood use. In this way, conservation may be viewed as an important tool for reducing uncertainty about the potential magnitude of future electricity demands.

LIST OF TABLES

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LIST OF ACRONYMS

BPA - Bonneville Power Administration

ORNL - Oak Ridge National Laboratory

PNWRES79 - 1979 Pacific Northwest Residential Energy Survey

PNWRES83 - 1983 Pacific northwest Residential Energy Survey

PILOT - Pilot Regionwide Residential Weatherization Program

INTERIM - Interim Regionwide Residential Weatherization Program

INTERIM82 - 1982 Participants and Nonparticipants of the Interim Regionwide Residential Weatherization Program

INTERIM83 - 1983 Participants and Nonparticipants of the Interim Regionwide Residential Weatherization Program

ROS-M - 1985 Residential Occupant Survey

SFD - Single Family Detached Dwelling

1. INTRODUCTION

Historically, wood has been a major fuel for human civilization. In most developing countries, wood is still the major fuel for cooking and heating. In the developed countries, wood was displaced by modern fuels, beginning early in this century. In most of the United States, for example, fuels such as electricity, natural gas, and fuel oil dominate residential end uses such as space heating, cooking, and water heating. However, recent increases in residential wood use for space heating have once again made wood a major energy source.

How much wood is used, under what conditions, and how much electricity is saved by its use has been of increasing interest to many energy research groups. Studies have ranged from strategies for monitoring the heat output of a wood stove (Modera 1985) to efforts to present data on total U.S. wood consumption by region and sector (U.S. DOE 1984).

A study of Central Maine Power customers concluded that the monthly energy use of those who used wood as a primary heat source varied by only 300 kWh between August and January, while those with no wood heat varied their monthly energy use by more than 2000 kWh between August and January (Central Maine Power 1983). Various studies have also examined winter air quality in areas of heavy wood use (Sexton et al. 1983, Taubman 1980, Petty 1981, and Burton and Senzel 1984).

The Pacific Northwest region of the United States has shared in the rebirth of wood as a space heating fuel. A number of factors are responsible. These include dramatic increases in electricity prices, dramatic increases in the price and uncertainty of the availability of natural gas and fuel oil, and a recession in the forestry industry which may have increased wood supplies for local fuel consumption. In addition, more households may now prefer wood heat to other fuels; desire wood heat because it is an independent, noninterruptible fuel; and perceive that wood is very cost efficient.

As a result, this area has been the location for a number of studies on residential wood use for space heating (Claxton and Cook 1982, Esvelt 1980, Puget Sound Power & Light Company 1981, and Washington Water Power Company 1982). Studies such as these indicate trends of increasing wood use. However, they are seldom linked to billing history data, and/or they cover a limited geographical area.

This report was prepared under the sponsorship of the Office of Conservation, Bonneville Power Administration (BPA) to analyze the extent of wood use for space heating in the Pacific Northwest, assess trends in its use, identify determinants of its use, and evaluate its effects upon BPA conservation program planning and evaluation. Six data sets were used in the analysis. Three contain households which are representative of all households in the Pacific Northwest and are derived from the Pacific Northwest Residential Surevys of 1979 and 1983. The other three are products of work at Oak Ridge National Laboratory in evaluating the BPA Pilot and Interim residential conservation programs. Section 2 provides details on the sampling frames, survey dates, and the types of variables contained in each data set.

Wood use is analyzed in three basic ways. First, descriptive statistics are prepared to indicate the extent of wood use and describe who uses wood (Section 3). Second, descriptive statistics and simple data analysis methods are applied to assess recent trends in wood use (Section 4). For example, we examine households switching primary space heating fuels and detail which fuels are losing or gaining market share.

Also, data are presented on what fuels are chosen when households replace old heating systems with new systems that use different fuels. From these two sections we find that wood use has grown significantly in the recent past and could become a significant factor in conservation program planning and evaluation.

Much work was also devoted to identifying the determinants of wood use (Section 5 and Appendix C). Specifically, various types of mathematical models related to wood use behavior were estimated with various combinations of the six data sets. Several discrete choice models were examined, including models involving: choosing wood as the primary space heating fuel; switching main fuels; and participating in a conservation program. A simultaneous linear equation model involving cords used and electricity used was also estimated. We find that important correlates include family size, ruralness, income, electricity prices, and conservation program participation.

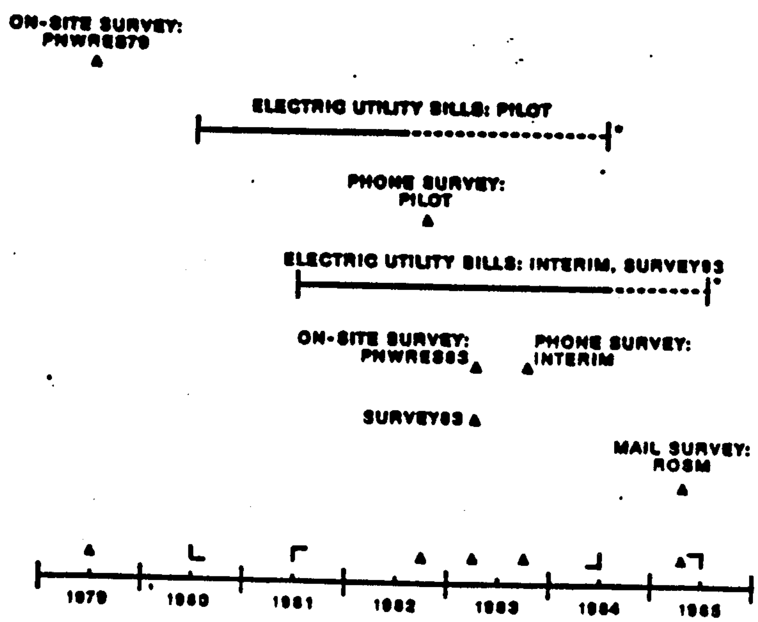
A discussion section concludes the report (Section 6). An important point of discussion is the apparent conflict between recent wood use trends and future trends in the correlates of wood use. While wood use trends suggest increasing wood use, future trends of correlates such as growing income and decreasing family size suggest otherwise. Recommendations are made concerning new studies, on heating system replacement, for example, which could help resolve these conflicts. Also, we indicate that because a fair number of conservation program participants do use wood for space heating, wood use should be formally represented in BPA's conservation planning activities. For example, explicit accounting of virtual conservation (i.e., conservation measures installed under BPA programs in houses that use wood that do not save as much energy as if the houses used no wood*), and of actual conservation, could better help BPA assess the costs and benefits of acquiring each type of conservation resource.

*For example, weatherstripping will save more electricity in houses that use only electricity for space heating than in houses that use wood for space heating. The difference between what a conservation measure could save and does save in a wood burning house is virtual conservation. The savings would become realized when wood is displaced with electricity for space heating.

2. DATA BASE DESCRIPTIONS

The data base for this study consists of six household surveys administered between 1979 and 1985. The surveys were designed to measure attitudes and behaviors related to energy conservation and to collect information about structural and demographic characteristics that determine residential energy consumption. Information about fuel types and equipment, thermostat settings, household size and income, heated living space, etc., was collected. Appendix A shows examples of selected survey questions and their comparability over time.

Electric utility bills and rate data for samples of participants and eligible nonparticipants of the BPA Pilot and Interim weatherization programs are available for subsets of three of the household surveys (Fig. 1). These surveys and billing histories have been used previously in evaluations of BPA residential weatherization programs.



*Bills for the period represented by the broken line were not used in this study.

Fig. 1. Significant dates associated with the regional and evaluation data sets.

2.1 REGIONAL SURVEYS

Three of the six surveys provide information on households distributed throughout the four BPA regions: Oregon, Washington, Idaho, and Montana. These regional surveys provide a good representation of the region's climate zones, rate levels, housing types, and other factors.

The 1979 Pacific Northwest Residential Energy Survey (PNWRES79) was administered by Elrick and Lavidge, Inc. (E&L) during mid-Summer of that year. E&L selected 37 utilities from which random samples of residential meter reading routes were selected. Approximately 10 households were then randomly sampled from each of the 400 meter reading routes. This survey contains information on 4030 households. Useful to this analysis are data on primary and supplementary fuels, demographics, and thermostat settings. For the descriptive statistics presented in Sections 3 and 4, the data are weighted to account for over and under sampling by state. The weights used are: Idaho, 0.5142; Montana, 0.7035; Washington, 1.3310; and Oregon, 1.0720.

The 1983 Pacific Northwest Residential Energy Consumption Survey (PNWRES83) was administered by Louis Harris and Associates, Inc. (Lou Harris), during late Spring of that year. Utilities were selected by a multistage stratified sampling technique. Meter reading routes were then selected from each utility. Next, residential accounts were selected systematically. This survey contains information on 4703 households. These data are also weighted for the descriptive statistics in Sections 3 and 4. However, these weights are too complex to detail here. For the interested reader, please refer to the final individual weight described in Louis Harris (1984).

The Residential Occupant Survey (ROS-M) was administered by Evaluation Research Corporation (ERC) and by Columbia Research Center (CRC) during Spring (ERC, by mail) and mid-Summer (CRC, by phone), 1985. This survey was conducted to describe the attitudes, characteristics, and demographic status of household occupants participating in one of three separate but interrelated studies. These studies include the Residential Standards Demonstration Program (RSDP), the End-Use Load and Conservation Assessment Program (ELCAP), and the Pacific Northwest Residential Energy Survey (PNWRES83). We use information collected from the 269 households that were surveyed in both 1983 and 1985, and that did not participate in either RSDP or ELCAP.* These households were all surveyed by ERC by mail or by CRC by phone. ROS-M is not used as extensively in this report as PNWRES79 and PNWRES83 because no weights were available. Table 2.1 presents sample sizes and data elements available for this study.

*Since these 269 households have been categorized and used in previous program evaluations as control households, we did not use information from other households that have participated, or are participating, in RSDP or ELCAP in order to minimize the amount of treatment our control (nonparticipant) households receive.

Table 2.1. Number of households in the wood heat study

	BPA Program participant 1981	1982	1983	BPA Program Nonparticipant
PNWRES79				4030
PILOT (1982)	203*			385*
PNWRES83				4703**
SURVEY83				1501*,**
INTERIM (1983)		464*	509*	
ROS-M				269

*Billing histories, daily temperature data, and electricity prices are available for most of these households.

**The control (i.e., nonparticipant) group for previous evaluations was selected from SURVEY83 because of the form and method of data transfer. Data on 987 households are found in both SURVEY83 and PNWRES83. Our approach to data processing and evaluation was simplified by accepting this overlap and "remembering" it in reiterative code. Billing histories are available for 426 of these 987 households; billing histories were not available for our analysis for the balance of the 1501 households in SURVEY83.

2.2 EVALUATION-SPECIFIC SURVEYS

During the course of evaluating the effectiveness of its Regionwide Residential Weatherization Program, BPA authorized the collection of demographic, economic, and structure characteristics from samples of participants and eligible non-participants in the Pilot and Interim programs (not to be confused with PILOT and INTERIM surveys). These data were needed for the evaluations in order to help explain the variation in energy savings across program participants and nonparticipants and over time. The data base for the present study also includes electric billing histories for the PILOT survey (nonparticipants included); the INTERIM survey (1982 and 1983 participants only); and SURVEY83 (the nonparticipants used in the previous evaluation of INTERIM) that includes 987 households from PNWRES83 and 514 households from a supplemental purposive sample but not included in PNWRES83.

The PILOT survey was administered to program participants and eligible nonparticipants by ERC in late Summer 1982. The INTERIM survey was administered to program participants by ERC, also, in early Fall 1983. SURVEY83 was administered to interim program nonparticipants by Lou Harris in late Spring 1983. As previously noted, Lou Harris conducted the surveys on site; the PILOT survey and the INTERIM survey were conducted by phone. In analyses in the remainder of the report, INTERIM82 refers to 1982 participants and associated nonparticipants, and INTERIM83 refers to 1983 participants and associated nonparticipants.

3. WOOD USE: SOME DESCRIPTIVE STATISTICS

The purpose of this section is to explore whether wood use is a major factor in Pacific Northwest residential space heating. First, basic descriptive statistics about the extent of wood use are presented and analyzed (Section 3.1). These statistics are complemented by additional data describing wood use by housing type, the extent of wood used as a supplemental heating fuel, and the type of wood heat systems being used by households in the various samples over the years 1979 to 1985.

Next, the relationships between wood use and energy savings are explored (Section 3.2). We find, using the evaluation data sets, that wood use can significantly confound calculations of energy savings attributable to BPA conservation programs and that swings in wood use could significantly affect future residential electricity demand.

The final subsection presents and analyzes wood use over a set of household characteristics (Section 3.3). This discussion creates a foundation from which to explore possible future trends of wood use (Section 4) and upon which to more effectively analyze correlates of wood use (Section 5).

3.1 BASIC DESCRIPTIVE STATISTICS ON WOOD USE

Regional data sets, PNWRES79, PNWRES83, and ROS-M are used because they contain representative samples of space heating fuel use throughout the Pacific Northwest. Our first task is to inventory household reports of primary fuels used between 1979 and 1985 (Table 3.1). The percentages indicate that electricity has maintained its market share. However, the relative use of natural gas, fuel oil, and wood has changed. Specifically, use of natural gas and fuel oil has declined since the late 1970s and

Table 3.3b. Housing type by main heating fuels: PNWRES83 (N=4703)

House Type	Fuel: Natural gas PNWRES83	Fuel oil PNWRES83	Electricity PNWRES83	Wood PNWRES83	Other PNWRES83
Single family detached					
Row percent*	25	14	33	26	2
Column percent**	83	95	50	85	65
Single family attached, 2-4 units					
Row percent*	18	3	69	10	0
Column percent**	9	3	16	5	1
Mobile home					
Row percent*	9	2	63	19	7
Column percent**	5	2	15	10	33
Multiple unit, 5+					
Row percent*	8	1	91	0	0
Column percent**	4	1	20	0	1

*Row percent represents the percentage of the house type that uses a primary space heating fuel within a sample. Example: 25% of the single family detached units used natural gas in 1983.

**Column percent represents the percentage of the houses of a particular type that use a particular fuel. Example: 83% of the units using natural gas in 1983 were single family detached.

Single family detached dwellings are the main users of wood. Multiple unit dwellings are essentially nonwood users. Mobile homes use approximately the same percentage of wood as SFD but represent a much smaller portion of the total housing stock. Single-family attached units are not major wood users, possibly because of the prevalence of shared heating systems and multiple story buildings.

Almost identical observations can be made about supplemental fuels used in the various housing types (Tables 3.4a and 3.4b). Use of wood as the supplemental fuel occurs almost exclusively among SFD and SFA dwellings, with SFD accounting for the largest proportion of dwellings (refer to Table 4.1 for housing type breakdowns). Electricity is the

Table 3.4a. Housing type by supplemental space heating fuel: PNWRES79 (N=4030)

House Type	Fuel				
	Natural gas PNWRES79	Fuel oil PNWRES79	Electricity PNWRES79	Wood PNWRES79	Other PNWRES79
Single family detached					
Row percent*	3	3	24	66	5
Column percent**	85	89	75	79	76
Single family attached, 2-4 units					
Row percent*	2	0	19	75	4
Column percent**	11	2	11	17	12
Mobile home					
Row percent*	3	3	44	41	8
Column percent**	4	6	8	3	7
Multiple unit, 5+					
Row percent*	0	2	55	34	8
Column percent**	0	3	6	1	5

*Row percent represents the percentage of the house type that uses a supplemental space heating fuel within a sample. Example: 3% of the single family detached units used natural gas as a supplemental space heating fuel in 1979.

**Column percent represents the percentage of the houses of a particular type that use a particular fuel. Example: 85% of the units using natural gas as a supplemental space heating fuel in 1979 were single family detached.

Table 3.4b. Housing type by supplemental space heating fuel: PNWRES83 (N=4703)

House Type	Fuel				
	Natural gas PNWRES83	Fuel oil PNWRES83	Electricity PNWRES83	Wood PNWRES83	Other PNWRES83
Single family detached					
Row percent*	6	7	30	57	1
Column percent**	89	88	82	86	50
Single family attached, 2-4 units					
Row percent*	1	8	19	71	1
Column percent**	1	9	4	9	2
Mobile home					
Row percent*	3	2	56	28	11
Column percent**	4	2	12	3	45
Multiple unit, 5+					
Row percent*	15	0	36	48	1
Column percent**	6	0	6	2	2

*Row percent represents the percentage of the house type that uses a supplemental space heating fuel within a sample. Example: 6% of the single family detached units used natural gas as a supplemental space heating fuel in 1983.

**Column percent represents the percentage of the houses of a particular type that use a particular fuel. Example: 89% of the units using natural gas as a supplemental space heating fuel in 1983 were single family detached.

prefered supplemental fuel in mobile homes, with a large increase from 44% in 1979 to 56% in 1983. Possibly, as wood increases as a primary fuel in mobile homes, these households are using more small electrical space heating units as a backup source to achieve a wider dispersion of space heating.

Tables 3.5a and 3.5b describe primary fuel/supplemental fuel combinations. These data indicate that wood is the additional fuel most frequently used when electricity is the primary fuel. Also, electricity is the additional fuel of choice when wood is the primary fuel. When natural gas and fuel oil are the primary fuels both wood and electricity are used as supplemental fuels, with wood as the more frequent choice. What these data suggest is that if trends away from natural gas and fuel

Table 3.5a. Primary space heating fuel by supplemental space heating fuel: PNWRES79 (N=4030)

	Supplemental Fuel				
Primary Fuel	Natural gas PNWRES79	Fuel oil PNWRES79	Electricity PNWRES79	Wood PNWRES79	Other PNWRES79
Natural gas					
Row percent*	2	0	20	73	5
Column percent**	17	5	23	31	27
Fuel oil					
Row percent*	0	1	27	65	7
Column percent**	3	9	22	21	27
Electricity					
Row percent*	1	0	10	85	3
Column percent**	11	3	14	46	24
Wood					
Row percent*	14	14	61	4	7
Column percent**	70	82	35	1	18
Other					
Row percent*	0	0	47	47	6
Column percent**	0	0	6	2	3

*Row percent represents the percentage of the primary fuel type that uses a supplemental space heating fuel within a sample. Example: 20% of the natural gas primary fuel users also used electricity as a supplemental fuel in 1979.

**Column percent represents the percentage of the supplemental fuel users of a particular type that use a particular primary fuel. Example: 23% of the electricity supplemental fuel users used natural gas as a primary fuel in 1979.

Table 3.5b. Primary space heating fuel by supplemental space heating fuel: PNWRES83 (N=4703)

Primary Fuel	Supplemental Fuel: Natural gas PNWRES83	Fuel oil PNWRES83	Electricity PNWRES83	Wood PNWRES83	Other PNWRES83
Natural gas					
Row percent*	0	0	25	74	0
Column percent**	1	0	17	28	5
Fuel oil					
Row percent*	0	0	24	74	1
Column percent**	1	0	10	18	11
Electricity					
Row percent*	2	2	2	92	2
Column percent**	12	9	2	51	39
Wood					
Row percent*	15	17	64	2	2
Column percent**	86	89	68	1	43
Other					
Row percent*	0	4	38	56	2
Column percent**	0	2	3	2	3

*Row percent represents the percentage of the primary fuel type that uses a supplemental space heating fuel within a sample. Example: 25% of the natural gas primary fuel users also used electricity as a supplemental fuel in 1983.

**Column percent represents the percentage of the supplemental fuel users of a particular type that use a particular primary fuel. Example: 17% of the electricity supplemental fuel users used natural gas as a primary fuel in 1983.

oil as primary heating fuels continue, the region's systems will be dominated by electricity and wood. To support this observation, notice that between 1979 and 1983 other fuels, such as solar, have not expanded their market share for either primary or supplemental fuels.

The change in the composition of wood heating systems also indicates that wood heat is playing a more prevalent role in the Pacific Northwest (Table 3.6). Most significant is the gain in wood heating system share made by wood stoves and furnaces. Focusing on the regional data sets, the share increased from 30% in 1979 to 60% in 1983. Of those burning wood, almost 90% of the ROS-M survey sample reported wood stoves and

Table 3.6. Wood heating systems*

Wood heating systems**	PNWRES79	PNWRES83	ROS-M	PILOT	INTERIM Part.	INTERIM Nonpart.
None	56	65	62	37	45	51
Wood heating system	44	35	38	63	55	49
Wood stove/furnace	30	60	89	54	65	57
Fireplace	70	39	11	43	33	43
Other	0	1	0	3	2	0
N	(4030)	(4703)	(269)	(588)	(973)	(1501)

*PNWRES79 and PNWRES83 are weighted. See Section 2.

**A "wood heating system" is expressed as the percent of households with a wood heating system, which includes wood stove/furnace and fireplaces with and without inserts). The presence of a "wood heating system" should not be construed as a capability for producing primary space heating.

furnaces as being their primary wood heating system. Data from the evaluation data sets also show an increase over time in the share of wood burning systems that are primarily for heating rather than asthetics (i.e., wood stoves versus fireplaces).

Concommitantly, the regional data sets indicate that the amount of reported wood use has also increased over time (Table 3.7). For the single-family detached, owner-occupied subsample, the average number of cords used per year increased from 2.34 to 2.95 between 1979 and 1983. Most of this increase is attributable to additional use of wood as supplemental fuel. The installation of high-efficiency wood burning equipment would appear to encourage and/or facilitate increased use of wood but this is not necessarily so because the amount per house may not have increased due to improvements in equipment efficiency.

To summarize, the data suggest that wood is a major space heating fuel in the Pacific Northwest. Its share of the primary heating market has risen dramatically over the last five years and households have invested capital in wood stoves and furnaces to support increased wood use. Use of electricity has remained fairly constant, whereas the two other major fuels, natural gas and fuel oil, have declining market shares. In single family homes and mobile homes, electricity and wood heating systems are increasingly dominant. For BPA, this trend could have important effects on electricity demand forecasting, and, as we shall see in the next subsection, significant effects on conservation planning.

Table 3.7. Average amount of wood burned as primary or supplemental heating fuel per household (single family detached, owner-occupied dwellings)*

Cords	PNWRES79	PNWRES83	PILOT	INTERIM Part.	INTERIM Nonpart.
Average ([this subset/ N]*100%)	2.34 (54)	2.95 (59)	3.78 (50)	2.82 (49)	4.8 (8)
Primary fuel is wood (% this subset)	4.40 (23)	4.11 (52)	4.80 (47)	3.65 (43)	4.0 (40)
Supplemental fuel is wood (% this subset)	1.81 (77)	2.67 (48)	3.00 (53)	2.19 (57)	3.7 (60)
N	4030	4703	588	973	1501

*PNWRES79 and PNWRES83 are weighted.

3.2 WOOD USE AND ENERGY SAVINGS

To gauge the effects that wood use may have on electricity use, this subsection uses data from the evaluations of BPA conservation programs to track differences in electricity use between primary electrically space heated and wood space heated homes. To explore how wood use may complicate calculations of energy savings attributable to BPA conservation programs, data are presented that describe actual energy savings for homes heated primarily and supplementally with either electricity or wood.

A first, and obvious, observation is that wood users use less electricity than homes whose primary fuel is electricity (Table 3.8). For example, for PILOT program participants prior to weatherization, electricity use, when electricity is the primary fuel, is a weather-adjusted 31,600 kWh, whereas when wood is the primary fuel the use is 24,400 kWh. This relationship holds for program participants and nonparticipants over all the data sets. Very roughly over all the evaluation data sets, if no wood were used as the primary heating fuel, all those houses heating with wood would demand about 6000 more kWh per year (approximately 23%).

Another interesting observation from Table 3.8 is that nonparticipants that switched to wood reported much less electricity use than did the nonparticipant nonswitchers. This relationship is not as apparent for the program participants. What this observation hints at is that nonparticipants may consider switching to wood as effective, or more effective, at saving energy dollars than participation in conservation programs would be. This hypothesis is strongly supported by the results concerning wood use correlates that are presented in Section 5.

Table 3.8. Electricity use for space heating as a function of wood use

Subsamples	Sample: PILOT Mean Value Yes	PILOT No	INTERIM82 Mean Value Yes	INTERIM82 No	INTERIM83 Mean Value Yes	INTERIM83 No
	Average total preretrofit NAC* (kWh/year)**					
Program Participant***						
Electricity is primary fuel	31600	24400	27800	23000	25600	19800
(N)	(138)	(57)	(338)	(119)	(368)	(116)
Wood is primary fuel	24400	31500	22800	27800	19300	25600
(N)	(56)	(139)	(111)	(346)	(111)	(373)
Electricity is suppl. fuel	26000	30600	22600	27300	19400	25200
(N)	(47)	(148)	(77)	(380)	(85)	(399)
Wood is supplemental fuel	30900	28600	28400	25800	25200	23700
(N)	(72)	(123)	(131)	(326)	(166)	(318)
Did not switch fuels	29400	30100	26400	28000	24400	21800
(N)	(186)	(9)	(417)	(40)	(448)	(36)
Switched to wood†	28800	29500	27700	26400	20800	24300
(N)	(8)	(187)	(35)	(422)	(22)	(462)
Nonparticipants						
Electricity is primary fuel	27800	19800	25500	19200	24800	17500
(N)	(137)	(57)	(268)	(120)	(268)	(120)
Wood is primary fuel	20900	27000	19500	25000	17500	24400
(N)	(48)	(146)	(105)	(283)	(105)	(283)
Electricity is suppl. fuel	21200	26200	19200	25400	17500	24700
(N)	(30)	(164)	(116)	(272)	(116)	(272)
Wood is supplemental fuel	28100	24000	25700	22200	25300	20800
(N)	(70)	(124)	(149)	(239)	(149)	(239)
Did not switch fuels	25600	18600	23600	23000	23000	18400
(N)	(190)	(4)	(349)	(39)	(349)	(39)
Switched to wood†	19800	25500	23100	23600	18000	23000
(N)	(1)	(193)	(33)	(355)	(33)	(355)
Years	1980/81		1981/82		1982/83	

*Normalized Annualized Consumption, or NAC, i.e., weather adjusted to account for changes in average daily temperature across houses, over time.

**Not adjusted for the size of homes.

***Prior to weatherization, i.e., weatherized by the program.

†Switched to wood as primary heating fuel within one year prior to survey date.

Interesting observations can also be made about the effects of wood use on energy savings (Table 3.9). As might be expected, program participants' savings are greater when electricity is the primary fuel. This is because of the larger pre-program electricity use. However, major problems in calculating savings arise when households switch to wood just after retrofit. In these cases, the methodology indicates that these households save 2000 kWh to 4000 kWh more than nonswitchers. Obviously, these additional savings are not due to the conservation program but to wood use, and if a large number of switches do occur, program savings estimates that do not take fuel switching into account may become misleadingly high.

On the other hand, wood use may lead to an under counting of conservation savings. For example, retrofit houses that report electricity as a supplemental fuel generally show less electricity savings than houses with electricity as the main fuel. If some of these houses eventually switch to electricity as the primary fuel, then the effective conservation savings will be greater, even though the total electricity demand will also be greater.

What these observations suggest is that the effects of improving the energy efficiency of dwellings are highly dynamic. In some sense, conservation exists as a virtual resource in houses that are not totally heated with electricity. Changes in wood use are the primary driving force in determining the actual levels of real conservation and virtual conservation. The amount of wood use, and therefore, of virtual conservation appears large enough that BPA should consider keeping track of virtual conservation in its evaluation and planning activities. The final section of this report offers recommendations on how to accomplish this goal.

Table 3.9. Electricity savings as a function of wood use (kWh/year)*

Subsamples	PILOT Mean Value Yes	PILOT Mean Value No	INTERIM82 Mean Value Yes	INTERIM82 Mean Value No	INTERIM83 Mean Value Yes	INTERIM83 Mean Value No
	Average total postretrofit - preretrofit NAC**(kWh/year)†					
Program Participant						
Electricity is primary fuel	5670	4700	4760	5770	2790	2570
(N)	(138)	(57)	(338)	(119)	(368)	(116)
Wood is primary fuel	4700	5660	5740	4790	2530	2800
(N)	(56)	(139)	(111)	(346)	(111)	(373)
Electricity is suppl. fuel	5020	5500	5380	4950	2460	2800
(N)	(47)	(148)	(77)	(380)	(85)	(399)
Wood is supplemental fuel	5870	5100	5460	4850	2370	2830
(N)	(72)	(123)	(131)	(326)	(166)	(318)
Did not switch fuels	5230	8670	4690	8466	2710	3150
(N)	(186)	(9)	(417)	(40)	(448)	(36)
Switched to wood	9750	5200	9000	4690	4620	2650
(N)	(8)	(187)	(35)	(422)	(22)	(462)
Nonparticipants						
Electricity is primary fuel	2130	1850	710	1630	1030	70
(N)	(137)	(57)	(268)	(120)	(268)	(120)
Wood is primary fuel	2180	2010	1960	630	130	960
(N)	(48)	(146)	(105)	(283)	(105)	(283)
Electricity is suppl. fuel	1400	2170	1710	690	140	990
(N)	(30)	(164)	(116)	(272)	(116)	(272)
Wood is supplemental fuel	2360	1880	430	1340	880	640
(N)	(70)	(124)	(149)	(239)	(149)	(239)
Did not switch fuels	2030	3320	590	4560	940	-1110
(N)	(190)	(4)	(349)	(39)	(349)	(39)
Switched to wood	4450	2040	5050	610	-1080	900
(N)	(1)	(193)	(33)	(355)	(33)	(355)

*One year savings.

**Normalized annualized consumption.

†Not adjusted for the size of the homes.

3.3 WOOD USER DEMOGRAPHICS

This subsection explores the demographic make-up of the wood using population and the characteristics of the houses using wood in the Pacific Northwest. The goals are to better understand who is using wood and in which houses wood is being used. These observations will help us to speculate on future trends of wood use.

First, let's review descriptive statistics on wood users (Table 3.10). Staying within the column of wood used as primary fuel, in 1983 compared to 1979, wood users are living in newer and larger houses, have slightly smaller families headed up by slightly older heads, and are setting their thermostats lower in the day and slightly higher in the evening and night.

Table 3.10. Selected regional survey responses by primary space heating fuel (means)

	PNWRES79/PNWRES83											
	Averages		Natural gas		Fuel oil		Electricity		Wood		Other	
Frequency	4030	4703	1147	740	633	410	1663	2007	423	1397	143	140
Cords/year	2.3	2.9	1.5	1.9	1.6	3.6	1.9	1.8	4.3	4.0	1.9	2.6
% Using wood	45.0	48.0	35.8	35.7	40.1	47.8	34.0	37.5	100.0	100.0	25.9	42.1
Age of house (yrs)	23.3	21.3	27.5	27.7	35.9	37.5	14.3	13.4	27.0	23.1	28.8	25.5
Size of house (ft^2)	1450	1460	1590	1660	1660	1850	1300	1250	1410	1550	1380	1410
Age of household head (yrs)	46.4	46.7	48.0	47.7	52.9	52.7	43.3	45.2	44.2	45.4	51.4	52.9
Education of household head (yrs)	12.9	13.2	13.0	13.6	12.9	13.3	13.0	13.2	12.6	12.9	12.5	12.2
Income of household ($)	18200	22500	18800	25970	19700	25100	17500	20600	18300	22600	15000	20900
No. of members in household	2.8	2.7	2.9	2.8	2.6	2.5	2.7	2.5	3.3	3.0	2.7	2.5
Day thermostat setting (°F)	66.1	62.7	66.4	62.3	66.0	63.0	65.6	62.7	67.4	62.8	68.1	65.3
Evening thermostat setting (°F)	67.9	69.0	67.8	69.0	67.4	68.3	67.7	68.5	69.6	70.2	69.1	69.8
Night thermostat setting (°F)	61.3	62.5	61.9	61.7	60.5	61.8	61.3	62.7	60.2	63.1	63.4	65.1

Compared to average households that use something other than wood for the primary fuel, wood users have houses of average age and size, the household heads are of average age and education, and the households have average incomes. What stands out is that wood using households have larger families. One can speculate that this observation is due to the fact that wood users do so to save money on energy in order to feed, clothe, and educate the children and/or because more family members help to keep the wood burning technology operating.

In comparison to households that use electricity as the primary heating fuel, households that use wood as the primary fuel have older and larger homes, larger families, and slightly more income.*

The final results presented in this subsection (Tables 3.11 and 3.12) provide information on the demographics of associated housing stock. The former table indicates that on a per unit basis, mobile homes use the most wood, followed by single family detached houses, and that wood use for all categories is increasing over time. The latter table indicates that older homes dominate wood use. As we shall see in the next section, older homes are related to older heating systems, and when new

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*Worth mentioning are changes in thermostat settings over time. No one fuel type stands out as being different but it appears as though day time settings have dropped over time and evening settings have increased slightly. Our hypothesis is that fewer people are home during the day because of the increased female work force participation, so that daytime settings can be lowered. On the other hand, there appears to be some take back of this energy saving in the evening. We have an intuitive feeling that wood use should be affected by changing lifestyles, but the data do not shed much light on the topic. For example, electricity may be used more to keep houses at a stable but low temperature during a winter day when the house is unoccupied. If time required to haul wood around is available only in the evening, households may decide to use wood exclusively in the evening and displace the electrical heat. It would be interesting to explore these kinds of behaviors in future work.

heating systems are installed, they tend to be wood stoves and furnaces as much as anything else.

Table 3.11. Selected regional survey responses by housing type

	PNWRES79/PNWRES83							
	Single family detached		Single family attached 2-4 units		Multiple unit, 5+		Mobile home	
Frequency*	2627	3354	648	407	389	243	366	653
Cords/year	2.4	2.9	1.8	2.5	0.3	0.5	3.3	3.4
% Using wood	50.1	64.5	37.7	34.4	3.9	5.8	19.9	39.8
Age of house (yrs)	27.7	26.1	17.2	11.0	17.6	8.5	7.2	9.3
Size of house (ft^2)	1600	1690	1400	1060	825	760	960	1000
Age of household head (yrs)	48.2	47.3	42.8	41.2	39.3	41.5	48.8	53.3
Education of household head (yrs)	12.9	13.4	13.2	12.6	13.3	13.2	12.2	12.0
Income of household ($)**	19600	25400	18800	17800	12800	15500	13800	16000
No. of members in household	3.0	2.9	2.7	2.6	1.8	1.8	2.6	2.3
Day thermostat setting (°F)	66.5	62.8	66.0	62.7	64.0	63.1	66.4	62.2
Evening thermostat setting (°F)	67.9	68.9	67.8	69.0	67.5	67.8	68.5	70.1
Night thermostat setting (°F)	61.2	62.6	62.1	63.0	60.8	63.0	61.5	61.5

*Responses were not available for 46 households surveyed in PNWRES83.

**PNWRES79 collected responses for 14 income levels; PNWRES83 collected responses for 16 income levels; and there are no natural aggregation levels for the two surveys. Values in current dollars. See Appendix A for additional information related to the similarities and differences between the regional surveys.

Table 3.12. Selected regional survey responses by age of house

Age of house	PNWRES79/PNWRES83 < 1 year		1-4 years		5-9 years		10-14 years		15-19 years		>20 years	
Frequency*	79	9	613	433	471	717	353	444	261	276	1518	969
Cords/year	1.9	1.5	2.0	3.3	2.5	2.8	2.2	2.5	2.0	5.5	2.4	2.6
% Using wood	40.5	66.7	49.4	60.5	45.6	63.7	47.6	59.9	54.0	64.1	41.8	61.3
Age of house (yrs)	0	0	2.3	2.8	7.0	6.8	12.0	11.6	17.0	16.7	41.2	43.4
Size of house (ft^2)	1280	1320	1470	1400	1580	1580	1560	1500	1680	1600	1490	1750
Age of household head (yrs)	38.0	33.5	40.0	42.9	45.2	45.7	47.1	49.7	48.9	50.8	51.4	54.2
Education of household head (yrs)	13.2	14.2	13.4	13.6	13.3	13.7	13.2	13.3	13.2	13.0	12.8	13.5
Income of household ($)	21100	28100	20700	23400	20400	26400	20800	25600	21600	26700	17700	24300
No. of members in household	3.1	3.7	3.1	2.8	3.1	2.9	2.9	2.6	3.0	2.7	2.7	2.5
Day thermostat setting (°F)	64.5	68.4	65.9	61.1	66.4	62.8	66.5	63.0	65.4	61.5	66.6	63.8
Evening thermostat setting (°F)	67.2	68.9	68.1	68.9	67.8	68.8	68.1	69.6	67.8	68.9	67.9	69.4
Night thermostat setting (°F)	62.2	64.7	62.2	61.9	61.6	62.6	61.4	62.3	62.1	60.6	60.9	62.4

*Responses were not available for 735 households surveyed in PNWRES79 and for 1855 houses surveyed in PNWRES83.

As Tables 3.11 and 3.12 show, a large number of homes surveyed are 20 years old and older. The heating systems of many of these systems will require replacement soon. Whether these homes will install new wood burning equipment depends on a number of factors, such as electricity and other fuel prices, household income, household size, price of wood burning equipment, regulations on wood stove efficiency, and the perceived convenience of wood. Whether the trend will continue toward wood, with system replacements leading the way, is an important issue. The next section begins to explore this question.

4. TRENDS IN WOOD USE IN THE PACIFIC NORTHWEST

Section 3 provides ample evidence that wood use has grown considerably in the Pacific Northwest in recent years. An important question is whether or not wood use will continue to grow, or level off or even decline in the near future. This section probes answers to this question through the use of descriptive statistics about: housing characteristics; fuel switching; heating system replacements; fuels for new houses; potentials for electricity and wood space heating; and potential swings in electricity and wood demand.

As the data presented in Section 3 indicate, single family homes, both detached and attached, provide by far the largest market for wood space heating. Trends toward more wood use in these housing types would suggest that wood consumption will continue to grow. Data presented in Table 4.1 indicate that this might be the case. First, from 1979 to 1983, single family detached and attached homes have increased their use of wood, as evidenced by the overall use of wood rising from 10% to 21% in that time period. Over 83% of the wood users are single family detached homes. Again, we see that gains in wood use have come at the expense of natural gas and fuel oil.

Also, Table 4.1 indicates that single family detached homes are continuing to dominate the electricity market, too. The evidence indicates that the single family detached home space heating market is becoming dominated by two fuels, wood and electricity.

An important topic to explore is how wood has made its in-roads into the space heating market. The next four tables provide information on this topic. First, from Table 4.2, we can see that households in

Table 4.1. Primary space heating fuel by housing type (%)

	PNWRES79					PNWRES83				
Primary fuel	SFD*	SFA**	Mobile*	MF†	Overall	SFD	SFA	Mobile	MF	Overall
Electricity	47	22	12	19	44	50	16	15	20	45
Wood	83	8	9	1	10	85	5	10	0	21
Natural Gas	76	15	4	5	26	83	9	5	4	21
Fuel Oil	83	10	3	4	16	95	3	2	1	10
Other	63	14	19	5	3	65	1	33	1	3
Subtotal	65	17	8	11	100	70	10	11	10	100
N					(4030)					(4703)

*Single family detached
**Single family attached
†Multiple family, 5+ units

existing homes rarely switched from wood to another fuel based on historical data collected during a period of rising electricity prices. Only 4 - 6% of households that changed primary space heating fuels in 1979 and 1983 switched from wood to another fuel. In 1979, fuel oil appears to have been the fuel of least choice, followed by electricity and natural gas. By 1983, most households that changed fuel type were switching from electricity to wood. This observation is probably due to the fact that by 1983, there were many less fuel oil and natural gas households as a percentage of potential fuel switchers.

Table 4.3 provides more detailed data on the directions of fuel switching. For background, approximately 5% of the PNWRES79 housing units switched fuels compared to 8.5% of the PNWRES83 units within one year of the survey. From Table 4.3 we can see that 57% of the households that changed fuel type switched to wood, with a net switch of

Table 4.2. Former fuels for households switching primary space heating fuels within one year of survey

	PNWRES79	PNWRES83
N	4030	4703
No switch	3827	4301
Switched from*	203	402
Natural gas (NG)	(18)	(17)
Fuel oil (FO)	(41)	(28)
Electricity (EL)	(27)	(44)
Wood (WD)	(4)	(6)
Other (OTH)	(8)	(5)

*Numbers in parentheses refer to percent of all who switched.

Table 4.3. Direction of fuel switching to different primary space heating fuels - number of respondents

	To									
	PNWRES79 (N=203)					PNWRES83 (N=402)				
From	NG	FO	EL	WD	OTH	NG	FO	EL	WD	OTH
Natural Gas	-	1	11	25	0	2	0	7	59	1
Fuel Oil	18	-	23	40	1	34	2	16	58	2
Electricity	3	3	2	44	4	0	12	22	142	1
Wood	1	2	6	1	1	5	1	5	10	5
Other	2	2	6	6	0	1	0	3	14	0

52%.* By 1983, these figures rose to 70% and 66%, respectively. Of those switching from electricity, 81% went to wood in 1979 as compared to 92% in 1983. Electricity only lost a net 4% in 1979 but that figure rose to 31% in 1983.

These observations all suggest that recent trends in fuel switching have been to wood. Most interesting are the observations that the number of homes switching from electricity to wood is rising. Natural gas and fuel oil are still losing units, too, albeit at a somewhat steady pace. Inroads of wood into the electricity market, if continued, should be studied very carefully by BPA.

Tables 4.4a and b present information suggesting that a majority of fuel switching is done when new heating systems are installed. This is not an unexpected observation, but it is important because additional research should focus on predicting the behavior of households that possess old heating systems. To elaborate, a large number of homes were 20 years old or older in 1979 and 1983. Between 26% and 32% of these older homes installed new primary space heating systems within the last four years, as indicated by the reported age of their heating systems. By 1983, the majority of households were installing new wood systems and the market for electric conversions shrunk precipitously, from 33% to 15% of newly installed heating systems. Combining results from Tables 4.2, 4.3. and 4.4a and b, we find that in 1979 58% of the fuel switchings can be traced to heating system conversions as compared to 22% in 1983.

*Net switch is defined as (the number of houses switching to wood - the number of households switching away from wood) divided by the total number of fuel switchers.

Thus, the primary heating system replacement decision is a key one with respect to the growth of wood use in the Pacific Northwest.

Table 4.4a. Heating system installations within the past four years for houses at least 20 years old

	PNWRES79 (N=4030)	PNWRES83 (N=4703)
Percent of housing stock at least 20 years old (i.e., "old")	46	34
Percent of "old" housing stock installing heating systems (i.e., changing stock)*	26	32
Percent of changing stock installing electrical systems	33	15
Percent of changing stock installing wood burning systems**	38	50

*The new heating system uses a fuel different from the fuel used by the old system.
**All wood burning devices could be included here, However, the thrust of the questions points to wood burning systems to be used as primary space heating systems.

Table 4.4b. Heating system installations in households that switched primary space heating fuel within one year of survey

	PNWRES79	PNWRES83
Former primary fuel different from current primary fuel = a	203	402
Heating system <1 year old = b	117	123
Current supplemental fuel same as former primary fuel = c	49	96
Heating system conversions (b-c)/ switches (a) * 100%	33.5	6.7
Heating system conversions (b-c)/ new heating systems (b) * 100%	58.1	22.0

Significantly, wood is gaining in both new and existing housing. The previous paragraph documents inroads into the older home market; Table 4.5 indicates that wood is gaining in the new home market, too. In 1979, electricity was the primary space heating fuel of choice, with wood garnering only 12% of the new home market. But by 1983, the proportion of new homes installing electric primary fuel systems declined 16 percentage points and wood installations doubled. In fact, by 1983 over 80% of all new homes had either electricity or wood as their primary space heating fuels.

Table 4.5. Primary space heating fuels for single family houses built in last four years

	PNWRES79	PNWRES83
N	(4030)	(4703)
Houses built last four years ("new" houses)	(313)	(517)
Percent of "new" houses using electricity as primary fuel	71	55
Percent of "new" houses using wood as primary fuel	12	25

Just how much potential for wood heat exists in the Pacific Northwest housing stock? Observations up to this point indicate the evolving "electricity-wood" dual fuel market. If large potentials exist for wood, a large swing from electricity could materialize in the near future. Table 4.6 presents data which suggest that the potential for wood use in the existing housing stock is great. By 1983, fully 48% of the housing stock were burning wood. Equipment was in place in nearly half of these houses (21% overall) with the capability of burning wood as the primary space heating fuel. Electric heat is available to the highest proportion of households (60%), and natural gas and fuel oil are [illegible] less significant. Thus, any major shifts to wood would probably come at the expense of electricity. On the other hand, any major shifts from wood could only be absorbed by electricity. Thus, a situation is evolving where there could be potentially large swings in the residential demand for electricity, directly driven by the demand for wood.

Our data does not permit the estimation of a regression line that represents the relationship between the demands for electricity and wood. However, we can predict energy savings, post hoc, for the extreme

Table 4.6. Fuels currently used for space heating (percent of stock)

	PNWRES79 (N=4030)			PNWRES83 (N=4703)		
	As primary fuel	As suppl. fuel	Total* market potential	As primary fuel	As suppl. fuel	Total* market potential
Electricity	44	13	57	45	15	60
Wood	10	34	44	21	27	48
Natural gas	26	2	28	21	3	24
Fuel oil	16	1	17	10	3	13
Other	3	3	6	3	1	4

*Total market potential is most likely only a lower bound on the percentage of homes that could quickly switch to the fuel as a primary fuel: heating equipment for the heating fuel is "on line" (that is, operational); we presume that other fuels are available for uses other than heating, although we cannot assess the extent of their availability; conversion from nonheating use to heating use is more likely to occur where the fuel is already "in the house." For example, electricity might have an upper bound, total market potential of 100%.

cases: (1) no wood demand, all electric demand and (2) heavy wood demand, minimum electric demand. The difference between the extreme cases is the range of uncertainty, relative to the actual energy savings achieved by all residential energy using customers.

We used the three evaluation data sets to predict savings for all-electric use customers and heavy wood use customers. After selecting the all-electric and heavy wood customers,* we estimated separate energy savings regression models for these customers. We retained variables with coefficients that were significant at the .10 level; next, we computed predicted savings for each customer of the entire sample by multiplying observed values by coefficients. The results of this process are shown in Table 4.7.

In each program, all-electric customers underestimate the savings of the entire sample; heavy wood customers overestimate savings. The range of uncertainty is 27.4% of actual savings for the PILOT sample, 62.9% for the INTERIM82 sample, and 33.2% for the INTERIM83 sample. A positive value for uncertainty means that demand has declined; a negative value means that demand has increased. An alternative representation of the range of uncertainty is located in Appendix B.

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*All electric customers (1) use only electricity for space heating, (2) have no heating equipment for other fuels, and (3) do not burn wood. Heavy wood customers (1) use wood as the primary space heating fuel, and (2) have a wood furnace.

Table 4.7. The range of uncertainty based on predicted savings for all-electric (no wood) use and heavy wood use customers*

	Electricity		Wood	
	Electricity only	All houses	All houses	Heavy wood users
1981 (N)	(89)	(372)	(372)	(95)
Preprogram NAC	29120	27230	27230	21740
Actual savings	4040	3610	3610	2930
Predicted savings†		3530	4520	
Uncertainty (%)		2.2	-25.2	
Range		27.4		
1982 (N)	(239)	(810)	(810)	(229)
Preprogram NAC	26940	25340	25340	22020
Actual savings	3330	3210	3210	3620
Predicted savings†		2220	4240	
Uncertainty (%)		30.8	-32.1	
Range		62.9		
1983 (N)	(237)	(851)	(851)	(240)
Preprogram NAC	25530	23540	23540	19690
Actual savings	2320	1780	1780	1160
Predicted savings†		1700	2290	
Uncertainty (%)		4.5	-28.7	
Range		33.2		

*Estimated over both participants and nonparticipants, expressed as kWh/year.

†Regression:

Actual savings (DNAC) for houses = $b_0 + b_1X_1 + \ldots b_kX_k$, (1)

where $X_1 \ldots X_k$ are observed values and $b_0 \ldots b_k$ are parameter estimates of the model, and where X = (PRENAC, household size, thermostat setting in the evening, program participant, income, house size, age of household head).

Computation:

Predicted Savings (PSAV) for all houses = Intercept + Coefficient$_1$ * X_1 + ...coefficient$_k$ * X_k, (2)

where $X_1 \ldots X_k$ are observed values of the significant parameter estimates of (1) and Intercept, Coefficient$_1$...Coefficient$_k$ are parameter estimates of (1) used as constants in (2).

Uncertainty (for all houses) =

[(actual savings - predicted savings)/ actual savings] * 100%. (3)

5. CORRELATES OF WOOD USE

5.1 INTRODUCTION

The purpose of this section is to expand upon work presented in the previous sections on levels and trends of wood use in the Pacific Northwest. Specifically, work reported here addresses important correlates to wood use. That is, through the use of mathematical models, we explore relationships between decisions related to wood use and demographic descriptors, housing characteristics, electricity prices, electricity use, and a selected set of homeowner attitudes.

Developing models to capture and explain wood-using behavior by households is a difficult task because wood use behavior is complex. This section begins with a brief discussion on wood use behavior and decision making in order to provide an appreciation of the complexity of the task facing a modeler of wood use behavior. Instead of modeling all aspects of wood use behavior together, we have chosen to break up the problem into four distinct modeling areas. Each modeling area will be discussed with respect to the decision making ideas presented before. This section concludes by synthesizing the results from all four modeling areas with significant observations about determinants of wood use.

5.2 WOOD USE AND DECISION MAKING

Wood use by households in the Pacific Northwest results from a complex set of goals, decisions, and exogenous factors. Goals associated with wood use include cutting costs for space heating, satisfying needs to pursue conservationist and/or rural ethics, attaining independence from utilities, and acquiring some occasional luxury, asthetic and/or comfort benefits from burning wood. Households will organize their behavior with respect to fuel use to satisfy these goals in conjunction with satisfying a host of other goals salient in their lives.

Many factors influence wood use decisions, with the importance of any factor differing across households. Important factors include the real and perceived cost of wood and competing fuels, the availability of wood and other fuels, and the capital cost and efficiency of wood burning systems and other heating systems. Wood also has other intangible factors associated with it: it is inconvenient to gather and use in the wood burning system; wood burning is less safe than electricity; and it is dirtier to use than electricity. Finally, wood burning may not be very practical in urban areas and in buildings with multiple units.

In modeling wood use, it is prudent to hypothesize the underlying decision processes and then develop models which are based on these assumptions. The decision making process can be represented by a model that is very simple or quite complex depending on how comprehensive one wants to be. A simple model may just include a decision on the number of cords to use in a year. A complex model would include decisions to switch primary heating fuels, to install new or additional heating equipment, on how much electricity and/or other fuels to use, and about how warm to keep the house by time of day. Decisions on conservation program participation, where to live, and those concerning lifestyle and career choices may also have important, albeit indirect, effects on wood use behavior.

The six data sets used in the modeling exercises reported herein represent a very rich resource. Many households are represented over time from all over the Pacific Northwest. However, the data sets do not provide the information required to determine how households go about making wood use decisions. The data are not extensive enough to estimate complex decision process models. Instead, we have adopted an approach where several different simple models are designed, estimated, and analyzed. Each represents a piece of the complex decision process. By weight of evidence, we hope, the accumulation of observations and conclusions from the simple models will provide strong indications about the most important determinants of wood use behavior in the Pacific Northwest.

5.3 WOOD USE DISCRETE CHOICE MODELS

The models in this subsection were designed under the assumption that wood use decision making in existing households can be viewed as the synthesis of broad policy-like decisions and basic daily behavior decisions. The policy decisions address whether or not to use wood at all, and if so, whether to use wood as the primary or supplemental sources for space heat. These decisions drive daily and seasonal behavior about when to use wood, how much to burn each day, and how to allocate responsibility among household members for maintaining the preferred wood heat output (e.g., who should bring wood in from outside).

This subsection focuses on the determinants of the policy decisions. Two modeling approaches are followed. One assumes a nesting of wood use decisions (Fig. 2). The first decision involves whether to use wood at all. The second decision is whether to use wood as the primary or supplemental fuel, given the household has decided to use wood.

With respect to our goal of examining wood use behavior, this model appears to capture robustly the important aspects of such policy decisions.

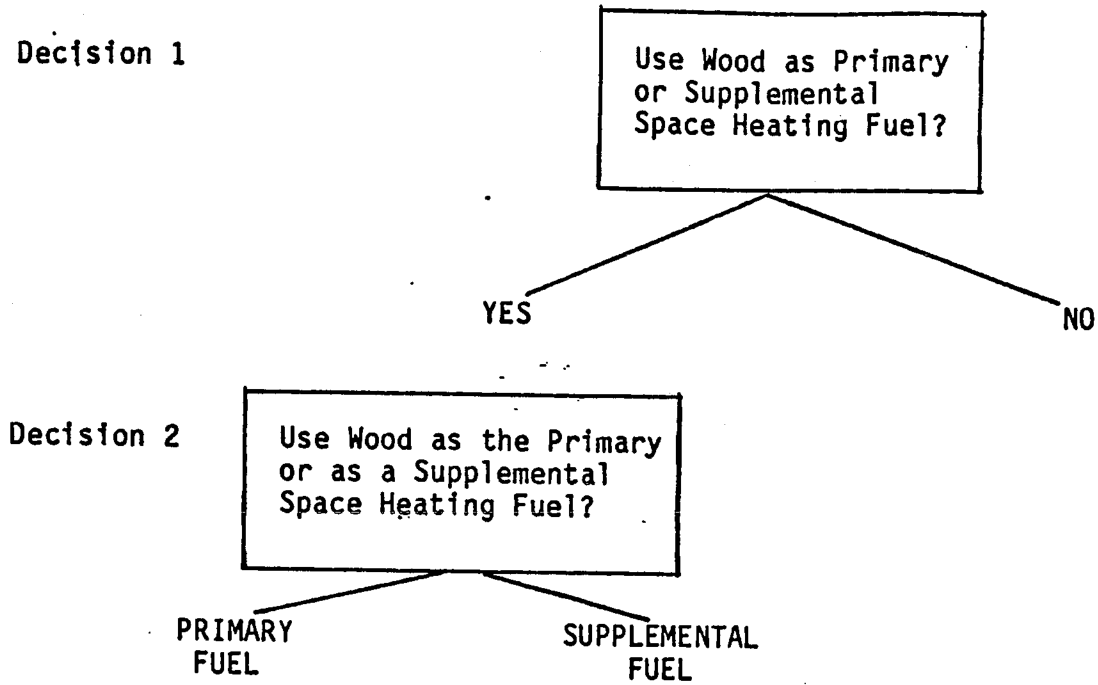

Figure 2. Nested model of wood use decision making.

However, many other decision models could have been hypothesized. For example, in reality, households may first decide whether electricity will be their main fuel. Natural gas and fuel oil use decisions may also occur before wood is considered. Appendix C reports some modeling results along these lines. The last part of this subsection describes results of a model which simply assumes that households make the decision whether to use wood as the main fuel or use any of the other main fuel options (Fig. 3).

All six data sets were used in these modeling exercises. The regional data sets--PNWRES79, PNWRES83, and ROS-M--provide the foundation for models representative of all potential wood users in the Pacific Northwest. Developing models with data that cover an extensive period of time will help us understand if the major wood use correlates are

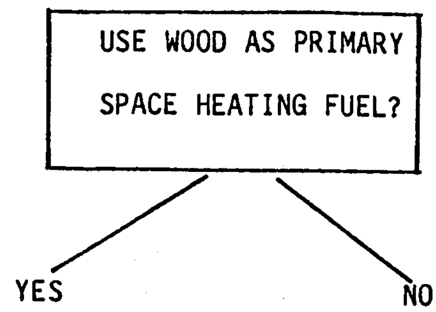

Figure 3. Simple wood use decision model.

changing. The evaluation data sets are also used - PILOT, INTERIM82, INTERIM83 - to provide insights into whether households in active conservation program areas have different or similar wood use correlates.

All of the models described in this subsection were developed using data from a subset of the households contained in the survey populations. Specifically, the models were estimated over single family detached, owner-occupied homes that reported main fuels as either electricity, natural gas, fuel oil or wood. This sample represents most of the households in the surveys (see Section 3), almost all of the wood users, and avoids complications of trying to model owner vs. renter decisions and decisions about more exotic space heating fuels (i.e., solar). SAS procedure PROC LOGIST was used to estimate the models (SAS 1985).

The results estimated over the three regional data sets are presented first (first-stage decison, Table 5.1 and second-stage decision, Table 5.2). The two choices in the first stage decision are: the household reported that wood is currently used for either the primary fuel or supplemental fuel; wood is not used as either the primary or supplemental fuel. Independent variables include standard demographic and house characteristics, an instrumental variable that represents an

Table 5.1. Discrete choice model: household uses or does not use wood (beta coefficients)

Dependent variable: 1 = Wood is primary or supplemental fuel
0 = No wood is used

Independent variable	conditions survey N (=1, =0)	Model: Natural gas NA PNWRES79 (472, 286)	Natural gas NA PNWRES83 (884, 368)	Nat. gas available PNWRES79 (628, 582)	Nat. gas available PNWRES83 (429, 345)	-- ROS-M (90, 73)
Intercept		.18	.17	-.17	.11	1.42
Income ($)		-.0000027	--	.000021***	.000018*	-.000016
Age head household (yrs)		-.012**	--	-.0071	-.0079	.0053
Education head household (yrs)		--	.0041	--	-.028	N/A
Age of house (yrs)		.023	.02*	-.0084	--	--
Size of house (sq.ft.) (rooms for ROS-M)		.00035	.00052***	.00052***	.00036***	-.043
Age of main heating system (yrs)		-.07	-.085	-.0096	-.032	N/A
Number of household members		.19	.099**	-.0038	.11*	.091
Conservation program participation (1=yes, 0=no)		N/A	-.104	N/A	-.14	N/A
Urban (=1)		-.56	N/A	--	N/A	N/A
Instrumental variable		-.42	-.14	.089	.103	-.012
Comfort of wood heat†		N/A	N/A	N/A	N/A	-.42***
Ease of using wood†		N/A	N/A	N/A	N/A	-.12
Inconvenient to gather wood†		N/A	N/A	N/A	N/A	.33**
Cost of delivered wood†		N/A	N/A	N/A	N/A	-.19*
Fraction predicted correctly		.65***	.68***	.67***	.68***	.77***

*significant at 0.10

**significant at 0.05

***significant at 0.01

†See Appendix A for definitions.

Table 5.2. Discrete choice model: household uses wood as primary or supplemental space heating fuel (beta coefficients)

Dependent variable: 1 = Wood is primary fuel
0 = Wood is used as supplemental fuel

Independent variable	conditions survey N (=1, =0)	Natural gas NA PNWRES79 (157, 316)	Natural gas NA PNWRES83 (556, 328)	Nat. gas available PNWRES79 (114, 513)	Nat. gas available PNWRES83 (167, 266)	-- ROS-M (59, 32)
Intercept		1.02	2.89***	2.99***	3.01***	.40
Income ($)		-.000027***	-.0000093*	-.00002***	-.000027**	-.000012
Age head household (yrs)		--	-.0092	-.02**	--	--
Education head household (yrs)		-.069	-.096***	-.11*	-.087**	N/A
Age of house (yrs)		.036***	.029***	.028***	.013**	.018
Size of house (sq.ft.) (rooms for ROSM)		-.00053**	-.00033***	-.00019***	-.00027***	.061
Age of main heating system (yrs)		-.12***	-.15***	-.20***	-.156***	N/A
Number of household members		.32***	--	--	--	.43**
Conservation program participation (1=yes, 0=no)		N/A	-.80***	N/A	-.58**	N/A
Urban (=1)		-.71***	N/A	-.90***	N/A	N/A
Community issue - crime		N/A	N/A	N/A	N/A	-.32
Inconvenience of wood		N/A	N/A	N/A	N/A	-.17
Distance to gather wood		N/A	N/A	N/A	N/A	.30*
Availability of conventional space heating fuel		N/A	N/A	N/A	N/A	.099
Fraction predicted correctly		.79***	.79***	.85***	.81***	.75***

*significant at 0.10

**significant at 0.05

***significant at 0.01

input from the second stage decision,* and, for the ROS-M models, some selected attitudes related to wood use. Missing are variables on electricity and wood prices and equipment prices.

The results presented in Table 5.1 offer five major observations and a few more insights. One, income is basically positively related to wood use. However, this observation is not consistent over time in sign and magnitude. And, as we shall see, income is also often negatively related to wood use (e.g., Table 5.2). Overall, we believe that in some sense, wood is an inferior good with respect to fuels such as electricity and natural gas, fuels which do not require personal labor for use. Thus, in models where wood as a primary fuel is a choice, then we would expect income to be negatively related to wood use. However, in models such as Table 5.1 where wood can be chosen as either a primary or supplemental fuel, then income could be positively related to wood use because wood could then represent a luxury good (e.g., for fireplace use).

Two, the size of the house is positively related to wood use. Larger houses have more space heating needs, and it is possible that wood would be more frequently used to save money based on the homeowner's perception that use of wood is cheaper than electricity, oil or gas. Three, the age of the heating system is negatively, but insignificantly, related to wood use. As we found in the previous section, a high proportion of all

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*The instrumental variable (IV) is defined as $IV=a+b_1x_1+b_2x_2...b_nx_n$ where x_1 to x_n represent variables in the second decision logistic regression and b_1 to b_n the coefficients; a is the intercept. It is supposed to capture the interdependence of the two decisions (to use or not use wood, to use wood as primary or supplemental fuel). An IV coefficient close to 1.0 signifies high interdependence, a coefficient close to zero or negative indicates independence. The results of Tables 5.1 and 5.2 indicate they are very independent choices.

households are installing new wood burning systems, typically wood stoves, for primary space heating. Thus, SFDs with new main heating systems, should, all things being equal, be more likely to have wood systems than SFDs with old main heating systems.

Fourth, the number of individuals in a household is positively related to wood use. This observation points to two hypotheses, that households with larger family sizes have more need to save money and that larger households can better absorb and allocate the labor involved with wood use. Fifth, the availability of natural gas does not appear to significantly affect the wood use decision as evidenced by coefficients of similar signs and magnitudes. We will find these observations present in many of the remaining models discussed in this section.

A couple of additional observations may also be made, although support for them is tenuous. One, it appears that wood use is related to rural location. This makes sense because wood is more available in rural areas, easier to store on larger lots, and creates less environmental problems to burn in low density areas. Two, conservation program participation is negatively related to wood use. A very tentative conclusion is that program participants, in an effort to save money, have chosen conservation instead of wood use.

From the ROS-M model, we can see that a few attitude variables are significantly related to wood use. Most significant is the comfort of wood as a space heating fuel. Those unconcerned with space heating comfort are unlikely to use any wood. Thus, comfort is an important factor in wood use decision making. If the household perceives that the inconvenience of gathering wood is not important in deciding whether to use wood, then the household is more likely to use wood. Lastly, if cost of wood is an important consideration, then the household is more likely to use wood; we assume households are thinking wood is cheap.

Insights from the wood primary fuel or wood supplemental fuel models show some support for the above insights (Table 5.2, second-stage decisions). Specifically, the two choices are: wood is used as the primary space heating fuel; and wood is used as the supplemental space heating fuel. Only households reporting wood use were included in the sample. The same sets of independent variables were used in the models, except that the instrumental variable was not needed.

The results of Table 5.2 indicate that income is negatively associated with use of wood as a primary fuel, again suggesting that wood is perceived as an inferior good for primary heating purposes. Education of the head of the household is also negatively related to this dependent variable, which is not unexpected given that income and education are typically positively correlated (r=.33). As found above, age of the heating system is negatively correlated with use of wood as a primary fuel and number of individuals in the household is positively related. In addition, the coefficients for the urbanicity and conservation program participation variables carry the same signs as in Table 5.1 but are stronger predictors.

A few new observations may be made. One, the age of the house is positively related to use of wood as a primary fuel. When combined with the observation that the size of the house is positively related to wood use, one can conclude that older houses, which on average are larger than newer houses, are likely to use more wood.

Two, only one attitude variable shows any significance. This one relates to the households' perception about the distance to gather wood.

The sign of the coefficient indicates that those unconcerned about distance are more likely to use wood as a main heating fuel.

Some similar conclusions and observations can be seen in the results of the two-stage wood use (Fig. 2) model when estimated over data from the evaluation data sets. Additional insights are possible because these data sets contain variables pertaining to electricity prices, annual long-run heating degree days (HDD), and pre-retrofit electricity use from billing histories.

With respect to the first stage wood use decision (i.e., use wood at all, Table 5.3), the results suggest similar observations: the number of household members and the size of the house are both positively related to wood use. The results also indicate, however, that income is positively related to wood use. This observation represents negative evidence for the inferior good hypothesis. We believe, though, that the presence of the preprogram electricity use variable is highly correlated with income and this may account for the change in sign (as compared to Table 5.1).

As expected, the electricity price variables are positively related to wood use, thus suggesting that wood use will increase as the price of electricity increases. Wood use is also positively correlated with HDD. This observation suggests that wood is used more often in very cold climates to supplement other systems. However, this observation may also be an artifact that households in the colder climates tend to be located in the rural areas east of the Cascades. Also as expected, pre-retrofit electricity use is negatively related to wood use.

There are no fresh observations regarding the second stage models, use of wood as a primary fuel (Table 5.4). Coefficients for the education, electricity prices, house age, number of household members, preprogram electricity use, house size, and income variables remain the same (as compared to Table 5.2). HDD is less significant once the wood use decision has been made. As with the models reported in the previous tables, the observations are robust over time.

Table 5.3. Discrete choice model: household uses or does not use wood - Evaluation data sets† (beta coefficients)

Dependent variable: 1 = Wood is primary or supplemental fuel
0 = No wood is used

Independent variable	conditions survey N (=1, =0)	PILOT (197 104)	INTERIM82 (394 260)	INTERIM83 (414 255)
Intercept		-3.25***	-2.44**	-1.69*
Education head household (yrs)		.12*	--	--
Electricity price (1980-1981) (¢/kWh)		98.84**	--	--
Electricity price (1982-1983) (¢/kWh)		--	25.6	67.3**
Electricity price (1983-1984) (¢/kWh)		--	46.8	--
Annual long run HDD		.00012***	.00011***	.00015***
Number household members		.16	.19	.12
Preprogram electricity use (kWh/yr)		-.000036	-.000047	-.000064***
Size house (ft^2)		.00022	.00039***	.00039***
Income ($)		.000029**	.0000054	.0000064
Age house (yrs)		--	-.02***	-.016***
Age head of household (yrs)		N/A	--	-.0065
Instrumental variable		.16	.09	.13
Fraction predicted correctly		.73***	.69***	.70***

*significant at 0.10

**significant at 0.05

***significant at 0.01

†Both participants and nonparticipants included. Where appropriate, preprogram data were used.

Table 5.4. Discrete choice model: household uses wood as primary or supplemental space heating fuel - Evaluation data sets (beta coefficients)

Dependent variable: 1 = Wood is primary fuel
0 = Wood is supplemental fuel

Independent variable - survey conditions N (=1, =0)	PILOT (91 105)	INTERIM82 (214 274)	INTERIM83 (167 247)
Intercept	.68	-.34	-2.58
Education head household (yrs)	-.11	-.079*	-.068
Electricity price (1980-1981) (¢/kWh)	70.21**	-49.9	--
Electricity price (1982-1983) (¢/kWh)	--	127.0***	36.8**
Electricity price (1983-1984) (¢/kWh)	--	--	124.68***
Age of house (yrs)	.02***	--	.012*
Number household members	.23**	.30***	.34***
Preprogram electricity use (kWh/yr)	-.00010***	-.000010***	--
Size house (ft^2)	.00044	.00022	--
Income ($)	.000016**	--	.0000089
Annual long run HDD	--	-.0000092	.000022
Age head of household (yrs)	--	-.015*	-.032***
Fraction predicted correctly	.78***	.77***	.81***

*significant at 0.10

**significant at 0.05

***significant at 0.01

A simple wood-as-primary-fuel model was explored (Fig. 3) as an alternative to the assumptions made in the two stage model (Fig. 2). In these models, the two choices are: wood is the primary fuel; and wood is not the primary fuel. The model was estimated only over the regional data sets because they contain houses that use something other than wood and electricity for the main space heating fuel.

The results do not offer any unique insights nor contradict any previous conclusions (Table 5.5). The standard demographic variables all carry the same signs and are just as robust over time. If anything, the conservation program participation variable is even more negatively related to wood use. The attitude variables did not perform well nor did any of the signs offer any interesting observations.

In summary, the results reported in this subsection are robust over data sets and over time. Wood appears to be an inferior good. Increases in electricity prices will spur its use, and easy access to wood and a large family help overcome nonmonetary barriers to its use. The results also suggest that conservation program participants may view conservation and wood use as an either/or proposition, but this conclusion must be considered to be very tentative.

5.4 TWO-STAGE-LEAST-SQUARES MODELS OF ELECTRICITY AND WOOD USE

The previous subsection addressed the policy decision aspects of wood use. This subsection addresses the daily-type decisions made about wood use. The approach is to model wood use and electricity use as simultaneous decisions. This approach has some face validity because decisions to use more of one will directly affect decisions to use less of the other. Thus, econometrically, electricity and wood use may be viewed as endogenous variables. We chose to use two-stage-least-squares (using SAS) to estimate the equations because no logical evidence suggests that correlations between error terms would warrant more sophisticated techniques.

Specifically, each model contains two equations. The dependent variable for the first equation is preretrofit electricity use; for the

Table 5.5. Discrete choice model: household uses wood or other fuel as primary space heating fuel (beta coefficients)

Dependent variable: 1 = Wood is primary fuel
0 = Wood is not primary fuel

	Model†					
	Natural gas NA		Nat. gas available		--	--
Independent variable / conditions survey N (=1, =0)	PNWRES79 (157, 601)	PNWRES83 (556, 696)	PNWRES79 (114, 1096)	PNWRES83 (166, 608)	ROS-M (59, 104)	ROS-M (59, 104)
Intercept	-.28	1.16**	1.5	1.11	.66	1.56
Income ($)	-.000018**	-.0000062	-.0000014***	-.000013*	-.000017	-.00002
Age head household (yrs)	-.013*	-.0035	-.019***	-.0059	-.024*	-.012
Education head household (yrs)	-.026	-.047*	-.105*	-.076*	N/A	N/A
Age of house (yrs)	.031***	.028***	.022***	.012***	.0058	.0068
Size of house (sq.ft.) (rooms for ROS-M)	-.00043**	.000052	-.000018***	.000084	-.0017	--
Age of main heating system (yrs)	-.17***	-.15***	-.25**	-.16***	N/A	N/A
Number of household members	.25***	.063	.048*	.10	.21	.18
Conservation program participant (1=yes, 0=no)	N/A	-.52***	N/A	-.70***	N/A	N/A
Urban, Rural (1,0)	-.64***	N/A	-.77***	N/A	N/A	N/A
Community issue - crime	N/A	N/A	N/A	N/A	-.16	-.21
Cost of delivered wood	N/A	N/A	N/A	N/A	--	-.13
Cost of conventional fuel	N/A	N/A	N/A	N/A	--	-.087
Inconvenience of gathering wood	N/A	N/A	N/A	N/A	--	.07
Comfort of wood heat	N/A	N/A	N/A	N/A	--	-.29*
Cost of wood heat equipment	N/A	N/A	N/A	N/A	--	-.097
Fraction predicted correctly	.76***	.76***	.84***	.79***	.67**	.75***

*significant at 0.10

**significant at 0.05

***significant at 0.01

†All models are limited to main fuels equal to electricity, natural gas, wood or fuel oil; single family, owner occupied homes.

second equation it is cords (i.e., preretrofit wood use). Independent variables include the standard demographic and house characteristics in addition to the endogenous variable. Also included are a small set of attitude responses and information on thermostat settings. The models were estimated over single family detached, owner-occupied houses that had wood burning equipment installed. The models were only estimated using the evaluation data sets because preretrofit electricity use was required.

The results indicate that electricity and wood use decisions are not strongly related (Tables 5.6 and 5.7); the coefficients of the endogenous variables are not strongly significant (e.g., the cords/year variable in Table 5.6 for the Pilot data set is insignificant). Indeed, a close inspection of the signs suggests that the two behaviors may not be substitutions for one or the other but in some sense are complementary. When more electricity is needed, then more wood is needed and vice versa. This observation is partially supported by our earlier observations that larger households in colder climates will use more wood, and presumably, use more electricity, too. Possibly if the models were estimated separately for houses east and west of the Cascades a substitution relationship would have appeared.

With respect to the electricity equation (Table 5.6), many of the coefficients perform as we have already seen. Income is positively related to electricity use and electricity prices are negatively related. As might be expected electricity use increases with family and house size. The only attitude variable that is highly significant relates to the household's perception of its ability to conserve more energy. If no more energy can be saved, then electricity use is less, which is a very reasonable finding. A slightly signficant attitude variable relates to comfort attainable at 68°F. Those uncomfortable at this temperature will require more energy for space heating, and the sign of the coefficient bears this out.

Table 5.6. Two-stage-least-squares model - preretrofit electricity use (beta coefficients)

Dependent variable: preretrofit electricity use (kWh/yr)

Independent variable	conditions survey	limited to homes with wood use capability PILOT	INTERIM82	INTERIM83
	N	(167)	(287)	(275)
Intercept		24240.2*	255094***	33781***
Cords/year		-1796.	201	537.7**
Electricity price (1981-1982) (¢/kWh)		-297623	-332277**	--
Electricity price (1982-1983) (¢/kWh)		--	-93814	-523332***
Income ($)		.24***	.10***	.086**
Number of household members		2339***	1367***	1694***
Age house (yrs)		-12.8	--	--
Education of head of household (yrs)		-569.7*	--	--
Size of house (ft^2)		1.50**	1.3*	2.4***
Thermostat setting (evening)(°F)		107.9	--	-140.6
Comfort difficult at <68°F (agree, disagree)		N/A	513.8*	520.4
Reduce heating temp. when away (agree, disagree)		N/A	283.3	--
Can't save any more energy (agree, disagree)		N/A	-736.6**	-430.5
Years residing in house		--	--	135.4*
R^2		.32***	.22***	.24***

*significant at 0.10

**significant at 0.05

***significant at 0.01

Table 5.7. Two-stage-least-squares model - cords used in past year (beta coefficients)

Dependent variable: cords used in last year

Independent variable	conditions survey N	limited to homes with wood use capability PILOT (167)	INTERIM82 (287)	INTERIM83 (275)
Intercept		11.5***	-.51	-1.4
Preretrofit electricity use (kWh/yr)		-.0001***	.00011	.000026
Size house (ft^2)		.00028**	-.00068	-.00094
Education head of household (yrs)		-.099	.11	.24
Thermostat setting (day) (°F)		-.032	-.03	-.1
Thermostat setting (night) (°F)		-.06**	--	.06
Number of household members		.54***	--	--
Years residing in house		--	-.24***	-.18***
Age of household head (yrs)		N/A	.14***	.13***
Age of house (yrs)		--	.014	
Reduce temp. when away (agree, disagree)		N/A	--	.59*
Income ($)		--	--	.000029
R^2		.22***	.06**	.07**

*significant at 0.10
**significant at 0.05
***significant at 0.01

The results for the cords equation are disappointing. The R^2s are low, even if they are statistically significant. Not many of the independent variables are significant. Also, the signs of some coefficients are not stable across time. For example, house size is positively and significantly related to cords in the PILOT model but negatively and insignificantly related to cords in the INTERIM models. The electricity use endogenous variable displays similar behavior.

Only years in residence and age of the household head are significant across time. The first shows a negative relationship with wood use; possibly these families may be too set in their ways to retrofit their homes for extensive wood use. The age variable shows a positive relationship, which tends to contradict the previous conclusion. However, the age variable may be picking up some influence from the income variable. In general, the cords models may suffer because survey responses to "cords used" questions are unreliable.

5.5 DISCRETE CHOICE MODELS OF FUEL SWITCHING BEHAVIOR

The discrete choice models of wood use presented in Subsection 5.2 are static. This is because the models describe wood use decisions that need not have been made in the previous year or within the past few years. However, there is an important dynamic component to wood use. Results presented in Section 4 suggest that major shifts from electricity to wood have occurred recently and such shifts can potentially significantly impact electricity demand and estimates of energy saved from BPA conservation programs. Thus there is a need to examine the correlates of fuel switching behavior separately from our explorations of fuel choices over time.

This subsection presents and analyzes models of fuel switching behavior. The two-choices are: the household switched primary fuels during the last year; and the household did not switch primary fuel. The sample is limited to single family detached, owner-occupied houses which used electricity or natural gas for primary fuel in the previous or current year. The study is limited to households potentially switching from these two primary fuels because data presented in Section 4 indicate that few houses switched away from wood and the surveys contained too few houses using fuel oil.

Both regional and evaluation data sets were used in this exercise. The regional data sets used were the PNWRES79 and PNWRES83; the ROS-M data set does not provide adequate information from which to reliably determine fuel switchers. Models were developed for both electricity and natural gas primary fuel users under conditions where natural gas is availabile (Table 5.8).

Table 5.8. Discrete choice model: household did or did not switch primary fuel last year (beta coefficients)

Dependent variable: 1 = Switch primary fuel last year; 0 = Did not switch primary fuel

Independent variable	survey	PNWRES79			PNWRES83		
	conditions	NG NA former fuel=elec.	NG avail. former fuel=elec.	NG avail. former fuel=NG	NG NA former fuel=elec.	NG avail. former fuel=elec.	NG avail. former fuel=NG
	N (=1, =0)	(22, 445)	(15, 279)	(28, 582)	(89, 582)	(20, 256)	(29, 274)
Intercept		-.38	-3.07	3.49	-1.83*	-2.61	1.13
Income ($)		-.000049	.000024	.000037	.000012	-.000037	-.000027
Age head of household (yrs)		-.03	-.0078	-.017	.017	-.00068	-.0054
Education head of household (yrs)		.073	-.019	-.15	.047	.02	-.0019
Age of house (yrs)		.033***	.03***	.018*	.027***	.024**	.016*
Size of house (sq. ft.)		-.0001	-.00038	.00018	-.00028	.00025	.00019
Age of primary heating system (yrs)		-1.15***	-.16**	-.75***	-.56***	-.27***	-.43***
Number of household members		.37**	.104	-.52**	.20*	.53***	-.18
Urban, rural (1,0)		-.37	-.0022	-.57	N/A	N/A	N/A
Conservation program participation (1=yes, 0=no)		N/A	N/A	N/A	.22	-.55	-.33
Fraction predicted correctly		.90***	.73*	.91***	.90***	.83***	.92***

*significant at 0.10
**significant at 0.05
***significant at 0.01

The results do not offer too many surprises. Most important is the age of the primary heating system. The negative coefficient indicates that the newer the system, the more likely the household switched fuels. The conclusion is that fuel switches will occur most often when the primary heating system needs to be replaced, a conclusion strongly supported in Section 4. Tracking the ages of the stock of fuel systems in the Pacific Northwest will provide information on the potential for fuel switching behavior.

The next most important correlate of fuel switching behavior is the age of the house. The older the house, the more likely the house was to switch fuels. This finding is not surprising because house age can be directly related to the age of the heating system and therefore the need to replace the heating system.

The only other significant variable is the number of members in the household. The coefficient is positive for electrically-heated homes that switched fuels. Since most households that switched fuels went to wood, this finding is consistent with previous findings that wood users tend to have larger households. The coefficients are negative for natural gas users, which is inconsistent with our hypothesis. However, it could be that some natural gas users switched to electricity instead of wood (see Table 4.3).

None of the other variables possess significant coefficients. However, a few other tentative observations may be made. First, rural households appear more likely to switch than urban households. The availability of wood may be a factor in this case. Income appears not to be important, suggesting fuel switching and heating system replacement decisions are made as a matter of course. Supporting this hypothesis are observations that house size and education and age of the head of the household are also insignificant.

The results from the evaluation data sets are somewhat different (Table 5.9). Instead of carrying a positive sign, the age of house variable carries a negative sign across time and when natural gas is or is not available. Thus, in the evaluation samples, newer houses are correlated with fuel switching. It is possible that owners of older houses opted instead to participate in the conservation program in order to save money instead of switching fuels. And indeed, the results of the next subsection support this hypothesis.

The evaluation data sets contain some variables not contained in the regional data sets. One example is preretrofit electricity use, which is negatively correlated with fuel switching. Since these are all electrically heated homes, it is possible that households with major space heating needs could not envision meeting those needs wholly with wood. Somewhat tempering this observation is the fact that the size of house coefficients are positive, but insignificant.

The electricity price variable coefficients are difficult to interpret. One would expect the coefficients to be uniformly positive, indicating that increases in electricity prices would drive households to switch to other fuels. What we find is a mixture of positive and negative signs on mostly significant coefficients. One interpretation centers on the difference between natural gas availability and unavailability. In the former case, electricity prices are generally negatively related to fuel switching which could mean that natural gas prices may have risen even more. In the latter case where electricity is not competing with natural gas, electricity price increases have a direct

Table 5.9. Discrete choice model: household did or did not switch primary fuels - evaluation data sets (beta coefficients)

Dependent variable: 1 = Switch primary fuel last year
0 = Did not switch primary fuel

survey	INTERIM82	INTERIM83	INTERIM82	INTERIM83
conditions	Nat. gas not available		Nat. gas available	
N (=1,=0)	(53, 419)	(31, 329)	(5, 63)	(5, 63)
Intercept	-4.3**	-3.42	24.0*	31.6
Electricity price (1981-1982) (¢/kWh)	--	-215.6**	--	238.9
Electricity price (1982-1983) (¢/kWh)	134.7***	401.3***	-463.7**	-843.***
Age head of household (yrs)	-.02*	-.045**	-.11*	-.10*
Size of house (sq.ft.)	.00037	.00046	.0011	.0015
Education head of household (yrs)	-.076	-.17*	.12	-.083
Long-run HDD	.000037	.00014*	-.00012	.000066
Income ($)	-.0000014	-.000026*	.000001	.000038
Age of house (yrs)	-.025*	-.072**	-.29	-.22
Number of household members	--	-.17	--	.56
Preretrofit electricity use (kWh/yr)	-.000029	-.00015***	-.00029**	-.00047
Fraction predicted correctly	.75***	.85***	.91*	.95**

*significant at 0.10
**significant at 0.05
***significant at 0.01

effect on switching behavior and the generally positive coefficients support this hypothesis.

The only other variable which is significant and possesses a stable coefficient sign is the variable for the age of household head. The negative coefficient suggests that younger households may be more willing to adopt wood as their primary fuel and, physically, may be more able to do so. Other variables such as education, long-run HDD, income and number of members in the household did not perform well.

To summarize the findings in this subsection, it appears that fuel switching has only a few significant correlates. First, it will occur most often when the heating system needs to be replaced. Second, households with fewer barriers to wood use are more likely to switch. Barriers include wood availability and household labor to support wood use. Electricity prices appear to be important, but their importance must be viewed in comparison to the availability and cost of competing fuels such as natural gas.

5.6 DISCRETE CHOICE MODELS OF CONSERVATION PROGRAM PARTICIPATION

Deciding whether or not to participate in a conservation program may seem, at first, to be unrelated to decisions about wood use. However, as hinted at in the previous subsections, some evidence suggests that households decide to reduce fuel expenditures either by substituting wood for the relatively expensive electricity or natural gas, or by concentrating on energy conservation. Thus decisions to participate may in fact have some relevance to future wood use.

In this subsection we explore the possible relationships between conservation program participation and wood use through the development and analysis of conservation participation discrete choice models. Only the evaluation data sets are used and the samples are limited to single family detached, owner-occupied dwellings which have electricity or wood as the primary heating fuel.

The logistic regressions were run with an assortment of independent variables, but we shall concentrate our analysis on variables related to wood use (Table 5.10). Most important is the coefficient associated with cords of wood used in the previous year. The negative coefficient

Table 5.10. Discrete choice model: household did or did not participate in a conservation program (beta coefficients)†

Dependent variable: 1 = Conservation program participant
0 = Nonparticipant

Independent variables	Survey	PILOT	INTERIM82	INTERIM83
	Conditions	Primary fuel = electricity or wood		
	N (=1,=0)	(145, 154)	(367, 287)	(254, 287)
Intercept		-3.29***	5.84***	7.43***
Cords/year		-.076	-.035**	-.039**
Education head of household (yrs)		.11*	-.022	-.015
Age of house (yrs)		-.0083	.18***	.022***
Number of household members		.17*	-.022	-.08
Age head of household (yrs)		N/A	-.03***	-.038***
Long-run HDD		.000078*	-.000073**	-.00013***
Preprogram electricity use (kWh/yr)		.000042**	.000054***	.000015
Size of house (sq.ft.)		.00012	-.00072***	-.00046***
Income ($)		.000009	-.000021***	-.0000031
Electricity price (1980-81) (¢/kWh)		202.***	--	--
Electricity price (1981-82) (¢/kWh)		-154.1***	-193.6***	77.5*
Electricity price (1982-83) (¢/kWh)		--	184.1***	-187.2***
Electricity price (1983-84) (¢/kWh)		--	-119.4***	9.7
Fraction predicted correctly		.73***	.77***	.72***

†Electricity prices observed in time after a survey was given are included in the models to represent price expectations.
*significant at 0.10
**significant at 0.05
***significant of 0.01

suggests that wood users, indeed, were not as interested in energy conservation through BPA programs. A possibility does exist, though, that wood users may have "do it yourself" personalities and may have independently installed conservation measures in their homes. Their decision to use wood resulted in saving money and therefore the need to save money from conservation is lessened.

As a corollary, pre-program electricity use is positively correlated with program participation, suggesting the need to save money through conservation. As we observed in the previous section, the actual electricity prices are mostly significant but are rather hard to interpret. A priori, one would expect prices to be positively related to program participation. However, in the PILOT model and the INTERIM82 model we find negative coefficients. A possible explanation is that utilities with lower prices experienced higher percentage price changes, thus providing more impetus to seek conservation program services.

Other variables provide additional interesting interpretations. For example, smaller houses are more likely to participate than larger houses, younger families are more likely to participate than older families, and households in colder climates are less likely to participate than households in warmer climates. Income, education and size of the household are generally insignificant, which is interesting because the groups were only matched to the extent of being SFD, owner-occupied with electric heat. Interpretations of these variables when using the assumption that households either use wood or participate in conservation are similar to those made in previous section.

In summary, the results suggest that there is a relationship between wood use and conservation program participation. According to our hypothesis, households will either switch to wood or participate in a conservation program to save energy and/or money. The logistic regression results support this hypothesis. Nevertheless, changes in electricity prices could overwhelm electricity users, and force them to use more wood. In the near-term it appears that with stable electricity prices, our hypothesis may hold up. However, pressures to increase prices in the near term could indeed lead to more wood use. A possible recommendation to BPA would be to conduct surveys directed at understanding non-participants' wood use decision making and reasons for not participating in conservation programs.

6. DISCUSSION

6.1 SUMMARY

This report explores wood use in the Pacific Northwest. Six data bases representing regional residential wood users and wood users that were part of ORNL conservation program evaluations were used in the analysis. Descriptive statistics concerning wood use indicated that wood as the primary space heating fuel rose from 10% of all housing units in 1979 to 21% of all housing units in 1983. Of households switching fuels, wood was chosen a net 52% in 1979 and a net 66% in 1983. By 1983, almost all new heating system installations that involved switching fuels were wood burning systems. A large fraction of new homes, 25% in 1983, were choosing wood as their primary fuel.

The residential sector in the Pacific Northwest is becoming a two-fuel space heating market (Sections 3 and 4). By 1983, fully 48% of the households were burning wood for heating, aesthetic or other reasons, compared to 60% for electricity and only 24% and 14% for natural gas and fuel oil, respectively. Nearly half of the wood burners (21% overall) had equipment in place to use wood as the primary source of heat. With respect to net electricity demands, households switching to wood from electricity would decrease their annual electricity demand by approximately 23%, and to electricity from wood would increase their electricity demand by 33%. If natural gas and fuel oil continue to lose market shares, the possibility for large short-term swings in residential electricity demand will become greater, and these potential swings are directly related to decisions by households on wood use.

In Section 5, we explored determinants of wood use. Modeling exercises consistently suggested the importance of six key determinants.

- The size of the household is positively related to wood use.
- Wood use is more prevalent in rural areas.
- Income is negatively related to wood use, suggesting that wood may be an inferior good.
- The size of the house is positively related to wood use.
- Electricity price increases which dampen demand for electricity seem to indirectly increase demand for wood.
- Conservation program participation is negatively related to wood use.

With respect to the last observation, we have hypothesized that households may view saving energy as an "either/or" decision--either use wood or participate in a conservation program.

In deference to the trends in wood use reported in Sections 3 and 4, the correlates may indicate that wood use has at least peaked in the Pacific Northwest. This is because trends of the correlates mostly point toward less wood use. For example, nationally the trends are toward smaller family sizes. More single adult households and families headed by one parent may result both in less demand for SFDs, which are the main users of wood, and, in smaller families with less available household labor for maintaining wood burning activities.

In addition, relative incomes are rising, in part because of the low rate of inflation and in part because of the growth of the national economy. Indications are that at least the non-forestry elements of the Pacific Northwest economy have enjoyed similar growth. However, the forestry industry may be such a large force in the Pacific Northwest economy that gains in income from other sectors may be canceled by losses of income in this sector. Increasing income would tend to increase demand for wood as a supplemental fuel but would be more than offset by decreases in wood primary fuel demand.

Other important correlates include the construction of smaller new single-family housing units, both because of price and the reduced availability of land, and, second, the recent stabilization of electricity prices in the BPA service area. The latter trends may be the most important determinant of the potential peaking of wood use, and additional work should strive to better specify price and cross-price elasticities for electricity and wood. This task is particularly important given recent discussions within BPA concerning new electricity price increases.

Continued inroads by BPA residential conservation programs may also stem the growth of wood use. In the next couple of years, given stable electricity prices, we may witness a reverse in fuel switching from wood to electricity among conservation program participants, because the perceived costs of using wood (including labor costs) may become greater than costs for using electricity.

One correlate which is not conclusive is the ruralness factor. Nationally, population appears to be decentralizing from the standard metropolitan regions. While the rural ethic is an important factor in the Pacific Northwest, it is not clear whether the region is also decentralizing from its 79% urbanicity reported in PNWRES79. Given the slump in the forestry industry, it is possible that urbanization is continuing as displaced workers seek employment in the larger labor markets. The decentralization-urbanization issue probably warrants additional study.

6.2. RECOMMENDATIONS

We have several recommendations for BPA concerning future work to track and understand future wood use behavior in the residential sector.

Most obviously, BPA could direct attention in two areas: household decisions to replace old primary heating systems and decisions being made in the new home market concerning heating fuels. In the former area, BPA could survey households reporting the purchase of new heating equipment. We recommend data be collected on electricity, natural gas, fuel oil and wood price expectations, the costs of new systems for each fuel, maintenance expectations, availability of wood, household demographics, possible conditions on switching to electricity if electrical equipment was not chosen (e.g., how high would wood prices have to rise before switching to electricity), and attitudes about the fuels. A similar survey could be made of new home buyers.

In addition to such surveys, we recommend that BPA keep close track of wood use and incorporate wood using topics into its planning processes. With respect to the former, BPA could begin a panel study consisting of representative households. The households would be trained on how to guage cords used per heating system and reimbursed for their record keeping efforts.

With respect to conservation program planning and evaluation, we recommend that BPA take care to separate what might be termed real electricity savings from virtual savings attributable to conservation programs. As we saw in Sections 3 and 4, recent program participants who switched to wood tended to inflate estimates of program saving. Also we found that actual savings reported for wood users were smaller than those reported for electricity users. However, if wood users switched to electricity, the actual program savings would be much greater if preretrofit wood use is taken into consideration.

Improved methods such as the one presented in Section 4 could help BPA estimate actual and virtual electricity energy savings, where virtual conservation is defined as energy savings potential of energy conservation measures installed in houses that do not use only electricity for space heating. These estimates could then form the basis from which to calculate the benefits to BPA of virtual conservation. One specific benefit would be to dampen increases in electricity demand resulting from large swings away from wood which might result from decreases in electricity prices, reductions in the supply of wood, regional regulations against wood burning intended to reduce pollution, etc. Dampening electricity demand increases could save money by reducing the need for back-up power sources and for new plants and significantly reduce uncertainty about the possible magnitudes of future electricity demand. Indeed, work presented in Appendix B suggests that the range of demand uncertainty can be reduced by over 40 average megawatts, given a fully-weatherized housing stock.

We recommend that BPA consider explictly representing wood in its conservation supply curves. Based on forecasts of wood use in housing stock untreated by conservation programs, the supply curve conservation potential estimates should include savings from wood heat participants as if they did use wood. This would eliminate double counting of wood use from both reduced use of electricity and reduced savings from wood. However, this solution is only as sound as are the forecasting model, and the forecasting model may misforecast wood use because it does not incorporate conservation program participation decisions. This is an important problem because in Section 5 we found that wood use is negatively correlated with program participation. Because the BPA conservation forecasting and planning is so complex (see Tonn, et al. 1986) any changes to the process to incorporate wood use issues must be studied very carefully, and adjustments must be made in a consistent fashion in both supply curves and forecasting models.

Our final recommendations concern additional studies that BPA should consider conducting on a regular basis. First, data should be collected on the wood market including near-term wood supplies and the cost of delivered wood and wood heat systems and efficiencies. Second, inasmuch as nonparticipants of conservation programs appear to use more wood than participants, a special survey of nonparticipants might give indications about future levels of wood use and reasons for nonparticipation. Third, data should be collected on heating system installations in old and new households and on wood use in a representative sample of Pacific Northwest households and BPA conservation program participants and nonparticipants.

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APPENDIX A. SELECTED SURVEY QUESTIONS

The six survey data sets used in this study (see Section 2) were developed from five survey questionnaires which were designed and administered by three different survey research companies. Differences across surveys are unavoidable; therefore, we were very deliberate in choosing what should have evoked comparable responses, despite subtle differences in phrasing or in the range of responses.

The following selected survey questions show similarities and differences in questions across surveys.

Questions regarding PRIMARY HEATING FUEL:

PNWRES79, Q15	PILOT, Q10	PNWRES83, Q48 SURVEY83, Q48	INTERIM82, Q10 INTERIM83, Q10	ROS-M, Q8
Which fuel is used by the main heating equipment for your (house) (apartment)? That is, the fuel that heats most rooms or the largest space.	What is the one main fuel used for heating your residence?	Would you please turn to Exhibit #48 and indicate which one of the fuels listed is used most of the time to heat your house.	Which one fuel was used most of the time to heat your home last winter (1982-83)? What is the main fuel you currently use to heat your home?	What system do you use most of the time for heating your home (circle one primary choice)? [There was no direct question about fuel.]

Questions regarding SUPPLEMENTAL SPACE HEATING FUEL:

PNWRES79, Q33	PILOT, Q12	PNWRES83, Q61 SURVEY83, Q61	INTERIM82, Q14 INTERIM83, Q13	ROS-M, Q9
Which fuel is used most by this additional equipment? [If "yes" to Q31: Have any of these types of equipment been used during the past 12 months in your home in addition to your main equipment? Respondent give "additional type in Q32.]	What type of additional fuel, if any, do you use to help heat your home?	Please look at Exhibit #61 and indicate which fuels you use for heating this home in addition to the fuel used most of the time. Please indicate all of the fuels used. [If "yes" to Q60: Do you use any other fuels to heat your home in addition to the fuel you use most of the time?]	What type of additional fuel did you use to help heat your home in the winter of 1982-83 (last winter)? What type of additional fuel do you use to help heat your home?	What other system do you use to heat your home, if any? (Circle one secondary choice.) [Again, there was no direct question about fuel.]

Questions regarding FORMER PRIMARY HEATING FUEL:

PNWRES79, Q16/Q17	PILOT,	PNWRES83, Q54/Q56 SURVEY83, Q54/Q56	INTERIM82, Q13 INTERIM83, Q12	ROS-M, Q8
During the past 12 months, did you make any changes in the fuel you use for your main heating equipment? What fuel did you use before you made the change?	[Not asked]	Since September 1981 have you changed the fuel type you use most of the time to heat this house (apartment)? [Q55 asked when.] Please look at Exhibit #56 and indicate which fuel was used most of the time to heat this home before September 1981?	Which one fuel was used most of the time to heat your home in the winter of 1981-82? [If "no" to Q12: Is the main fuel you used last winter the same main fuel you used to heat your home in the winter of 1981-82 (the winter before last).] Which one fuel was used most of the time to heat your home last winter (1982-83)?	[Not asked]

Questions regarding WOOD Heating ISSUES:

PNWRES79	PILOT	PNWRES83 SURVEY83	INTERIM82 INTERIM83	ROS-M, Q34
[Not asked].	[Not asked]	[Not asked]	[Not asked]	Listed below are issues that some people think are important to consider when deciding whether or not to heat with wood. Please indicate how important each issue is, or would be, for you. (Circle the number of your answer).

[The following ten issues were listed:

- the cost of delivered wood.
- the cost of conventional space heating fuels.
- the distance traveled to gather wood.
- the availability of conventional space heating fuel.
- the inconvenience of gathering your own wood.
- the need to heat the entire house.
- the cleaning and maintenance of a wood stove.
- the ease and convenience of using your wood stove or insert.
- the comfort of wood heat.
- the cost of buying and installing wood burning equipment.

The categories of responses were

1. very important
2. somewhat important
3. not important
4. don't know]

Questions regarding ATTITUDES toward ENERGY CONSERVATION

PNWRES79	PILOT	PNWRES83 SURVEY83	INTERIM82, Q32 INTERIM83, Q28	ROS-M
[Not asked]	[Not asked]	[Not asked]	For each statement I read, tell me if you strongly agree, agree, disagree, or strongly disagree. Do you feel that...	[Not asked]

- o In the winter it is difficult to be comfortable when the temperature in your house is 68°F or less.
- o Reducing the temperature on the hot water heater from 140° to 120° saves enough energy to make it worth doing.
- o The main reason to conserve energy is to save money.
- o During the winter, when no one will be home for two hours or more, turning down the temperature is worthwhile.
- o It's hard to get around to making your home more energy efficient.
- o People have a right to use as much energy as they want and can pay for.
- o The price you first pay for an appliance is more important than the energy savings.
- o I only use electricity when it's really needed; there's no way I could cut down.

[respondents could also answer "uncertain"]

Questions regarding WOOD HEATING SYSTEM:

PNWRES79, Q19/Q32	PILOT, Q9/Q13	PNWRES83, Q51/Q64 SURVEY83, Q51/Q64	INTERIM82, Q17 INTERIM83, Q15	ROS-M, Q8/Q9
What one of these is the main heating equipment for your home? [Or] What additional type [of heating equipment] do you use most?	What type of heating equipment do you use most frequently? [Or] What heating equipment provides most of your heat from wood?	Please review Exhibit #51 and indicate which one of the types of equipment listed is used most of the time to heat your home. [If "wood" in Q48]. [Or] Please review Exhibit #64 and indicate which one of the types of equipment listed is used to provide additional heat for your home. [If "wood" in Q61].	What type of heating equipment provides most of your heat from wood? What type of heating equipment provides most of your heat from wood?	[See questions regarding PRIMARY SPACE HEATING FUEL and SUPPLEMENTAL SPACE HEATING FUEL, above].

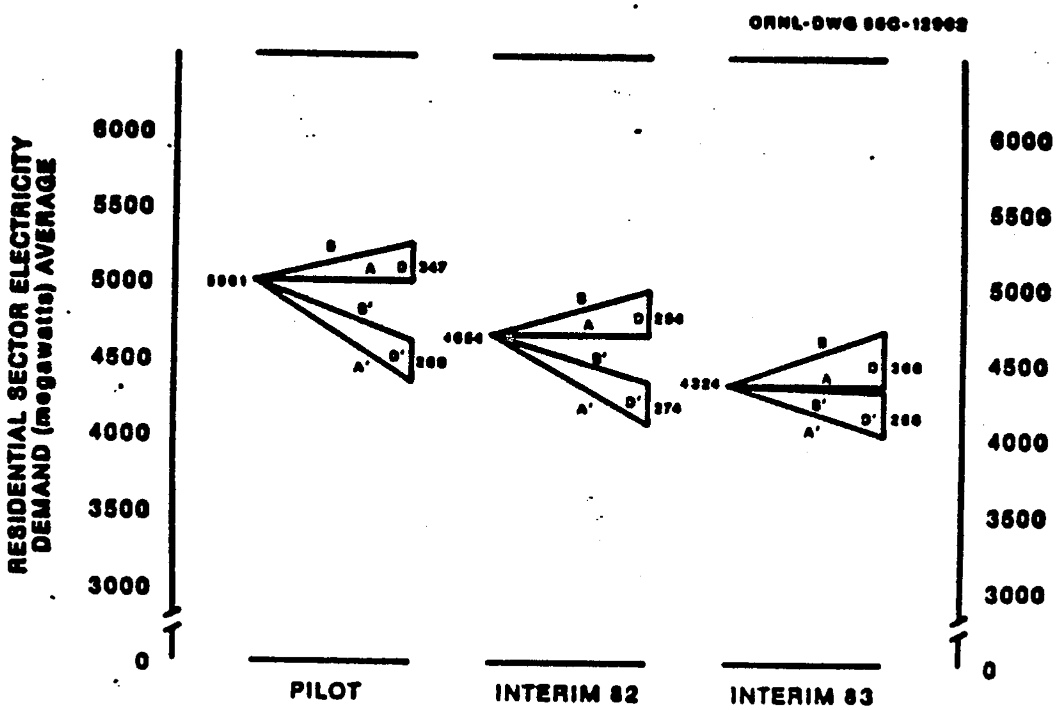
APPENDIX B. UNCERTAINTY IN ELECTRICITY DEMAND

In this Appendix, we present an alternative view to the discussion on pages 35-36, based on Table 4.7. Our purpose here is to illustrate the potential error (uncertainty) in projecting residential sector electricity demand on the premise that no wood is being used for space heating in the BPA region. In other words, we are concerned here with the differences in electricity demand under the following conditions: all-electric space heating and current mixed-fuel space heating.

In Fig. B1, we present electricity demand for the estimated 1.609 million households with permanent electrical space heating equipment in the BPA region, for each of the three evaluation data sets as indicated by their program references.

We developed two post hoc estimates of demand for each program (data set). (We assume that the evaluation data sets are representative samples of all electrically heated houses.) The top triangle shows electricity demand without the effect of conservation. Line A represents electricity demand for the current mixed-fuel space heating condition. Line B represents electricity demand for the all-electric space heating condition. The difference, line D, between these two conditions represents the range of uncertainty that exists concerning residential electricity demand for space heating. In other words, residential electricity demand could fluctuate by D as the population of homes switched heavily to wood and back to electricity to meet space heating needs. As results in the main body of the report indicate, such fluctuations could be significant and occur in time periods much shorter than periods required for new power resource construction. On the other hand, fluctuation away from electricity could also relatively quickly result in large amounts of idle power resources.

The bottom triangle shows electricity demand after weatherization. Lines A' and B' correspond to lines A and B. The difference, line D', between lines A' and B' represents the range of uncertainty in residential electricity demand for space heating given a weatherized housing stock.*



Line A represents mixed-fuels condition, no conservation measures installed. Line B represents all-electric condition, no conservation measures installed. Line D represents difference between line A and B. A', B' and D' represent similar numbers, except conservation measures have been installed.

Fig. B1. Residential sector electricity demand for program participants and nonparticipants for all-electric and mixed-fuels conditions

*For illustration only, we projected the proportions of participants/nonparticipants for each program to the entire BPA region. In other words, if possible, all households would have participated or not participated as represented by the evaluation data sets.

In each program, the projected demand (lines B and B') exceeds consumption (lines A and A') whenever the all-electric condition is imposed. Furthermore, in all cases, the uncertainty involved with the all-electric condition is reduced after accounting for conservation/weatherization effects. Specifically, the reduction in possible demand ranged from 20 average megawatts using the INTERIM82 data to 100 average megawatts using the INTERIM83 data. Thus in the weatherized cases, the risk to BPA of not meeting residential electricity demands or of finding itself with unproductive power resource capacity would be much reduced. Additionally, the lower magnitudes of aggregate demand in the weatherized cases would help BPA avoid undertaking new large-scale construction projects that entail enormous financial risks. Further research is required to determine the benefits to BPA of reducing uncertainty in demand.

APPENDIX C. OTHER DISCRETE CHOICE MODELS OF WOOD USE BEHAVIOR

In Section 5, two types of discrete choice models that encompass wood use decisions are presented. One posits wood use as first a choice of whether or not to use wood and second as a choice as to whether wood will be the primary or supplementary space heating fuel, given wood was chosen in the first step. A second model posits just a simple wood as primary fuel vs other primary fuel model.

As mentioned in Section 5, wood use decision making is quite complex. In this appendix we posit a third model, one which assumes that households consider other primary fuels before considering whether or not to use wood as the primary heating fuel. Only the PNWRES79 and PNWRES83 data sets are used and the sample was restricted to single family detached, owner occupied homes.

Generally, the model assumes that households follow a decision tree when arriving at their primary heating fuel choices. If natural gas is not available, then the decision tree has only two decision points: first, whether or not to use electricity as the primary heating fuel, and second, given a negative decision at the first node, whether to use wood or fuel oil as the primary space heating fuel. When natural gas is available, then the decision tree has three nodes, with the natural gas decision following the electricity decision but preceeding the wood/fuel oil decision.

The results (Table C.1) are not as interesting or as robust as those presented in Section 5. Basically, we find that the decisions in the decision tree are unrelated, as indicated by the insignificance of the instrumental variable coefficients. This model structure yields

Table C.1. Discrete choice model: Household choices of primary fuels

Dependent variable		1 = Electricity primary fuel 0 = Other		1 = Wood primary fuel 0 = Fuel oil		1 = Electricity primary fuel 0 = Other		1 = Natural gas primary fuel 0 = Fuel oil		1 = Wood primary fuel 0 = Fuel oil	
Independent variable	survey	PNWRES79	PNWRES83	PNWRES79	PNWRES83	PNWRES79	PNWRES83	PNWRES79	PNWRES83	PNWRES79	PNWRES83
	conditions	Natural gas not available				Natural gas available					
	N (=1,=0)	(458, 300)	(593, 659)	(170, 152)	(557, 103)	(292, 918)	(267, 507)	(609, 327)	(282, 256)	(118, 210)	(116, 59)
Intercept		2.03***	-.019	4.13***	4.66***	.87**	-.057	.006	-1.16	5.81***	7.49*
Income ($)		--	.0000021	-.000034**	-.0000085	-.000012*	--	-.0000091	.00001	-.00044***	-.000018
Age head of household (yrs)		--	--	-.032***	-.02*	--	.0099	--	--	-.037***	-.025*
Education head of household (yrs)		-.02	.067**	--	--	--	.014	.069*	.031	--	-.14
Age of house (yrs)		-.045***	-.046***	--	-.0097*	-.033***	-.029***	-.017***	-.006	-.016*	-.014
Size of house (sq.ft.)		-.000099	-.00015*	-.00038	-.000069	-.00019*	-.00031***	--	--	--	-.0001
Age main heating system (yrs)		-.029	.056*	-.17***	-.15***	-.084***	-.016	-.024	.07	-.23***	-.18***
Number of household members		-.126*	--	.27**	.077	-.012	-.063	.09	-.02	.20	--
Conservation program participant (1=yes, 0=no)		N/A	.61***	N/A	--	N/A	.81*	N/A	.71***	N/A	--
Urban-Rural (1,0)		.36*	N/A	-.88***	N/A	.40	N/A	.34	N/A	-1.41***	N/A
Instrumental variable		.019	-.18	--	--	-.39	-.092	-.07	-.014	--	--
Fraction predicted correctly		.75***	.72***	.88***	.89***	.74***	.69***	.63***	.69***	.94***	.91***

*significant at 0.10
**significant at 0.05
***significant at 0.01

equations which work well to predict the wood/fuel oil decisions, with income, urbanicity, and age of the household head all negatively related to wood use. As we found in the previous sections, new heating systems tend to be wood burning systems.

The equations involving electricity and natural gas provide a few interesting observations. First, use of electricy and natural gas is positively related to conservation program participation. Second, the age of the house is negatively related to the use of these fuels. What this observation indicates is that homes in the 5- to 15-year age range were equiped to use electricity or natural gas. We would expect that a model estimated with data collected five years from now would show a different result.

Overall, this modeling exercise did not provide any more useful observations than those presented in Section 5. Also, the decision model itself does not indicate that the models used in Section 5 are in any way inadequate.

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