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Residential fuelwood consumption in the Missoula Montana urban area 1984-2000

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Residential Fuelwood Consumption in the

Missoula, Montana Urban Area 1984-2000

by

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The use of fuelwood as a residential space heating fuel increased dramatically during the second half of the 1970's. Residential fuelwood consumption in Montana was estimated to have tripled between 1974 and 1981. In the Missoula area, residential fuelwood consumption increased from an estimated 15,040 cords in 1977 to 31,800 cords in 1980. In Missoula that increase was met with growing concern about the reduction in air quality during wintertime inversion periods thought to be associated with the release of particulates from residential wood burning appliances. This concern prompted the Missoula City-County Health Department to impose regulations on wood burning, making it illegal to burn wood, except in special circumstances, when the ambient air contains a particulate level of more than 150 micrograms per cubic meter.

Despite the concern over levels of residential wood burning, there is little information on past levels of wood burning and no studies of possible future levels of residential fuelwood consumption. This study provides projections of future residential fuelwood consumption by using two different modelling techniques to forecast residential fuelwood consumption in the Missoula urban area from 1984 to 2000. The first method involves the econometric estimation of a forecasting demand equation using estimated historic levels of fuelwood consumption in the Missoula area. The second method uses a modified version of WOODSTOV-2, a simulation model for forecasting residential wood-energy use in New England, written by Norman Marshall at Dartmouth College. Both methods produce similar results, with growth in residential fuelwood consumption continuing until the end of the 1980's, peaking at approximately 18 percent above current levels, followed by a slow decrease in residential fuelwood consumption for the remainder of this century.

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CHAPTER ONE

INTRODUCTION TO THE PROBLEM

INTRODUCTION

During the mid and late 1970s many households returned to wood as a primary or supplementary home heating fuel. This reversed a long term decline in residential fuelwood use. Wood combined with coal had gone from being the primary heating fuels in the first half of the twentieth century to an insignificant source of heat by 1970. In 1950 nearly 45 percent of the nation's housing units were heated by coal or wood. By 1960 this percentage had dropped to 16.4, and further dropped to 4 percent in 1970 [DOE/EIA 1979]. The decline in wood and coal as a primary residential heating fuel was offset by the increase in natural gas and electricity as the primary residential space heating fuel. The proportion of housing units using natural gas or electricity as their primary heating fuel increased from 29 percent in 1950 to 73 percent in 1982 [DOE/EIA RECS 1983]. Table 1.1 illustrates the relative shares of fuel types used for residential space heating, and their trend since 1950.

Clearly wood, until the mid 1970s, was steadily declining as the primary heating fuel, and by 1970 was, at least nationwide, of little significance. Although new homes were still built with fireplaces, wood was not considered the primary heating fuel, as other heating systems were in place, and wood was only an alternative. In many if not most cases wood was burned for enjoyment or aesthetic purposes, and any heat gained could be considered as a positive side effect. Even if wood was burned in a conscious effort to heat one's home, burning in an open fireplace probably provided little or no net heat due to the very low efficiency of standard masonry fireplaces, ranging from negative to not more than 10 percent efficiency [DOE/CS 1980].

Table 1.1

National Primary Heating Fuel in Occupied Housing Units 1950 - 1982 (percentage)

Year	Natural Gas	Electricity	Wood
1950	26.6	2.5	10.0
1960	43.1	2.2	4.2
1970	55.2	7.7	1.2
1973	55.5	10.4	.9
1974	55.7	11.9	.9
1975	56.4	12.7	1.2
1976	55.7	13.7	1.3
1977	55.2	14.8	1.6
1981	55.6	17.1	6.4
1982	57.0	16.0	7.0

Source:Residential Energy Consumption Survey
Housing Characteristics 1980 [DOE/EIA RECS 1982]
Annual Report to Congress 1979, [DOE/EIA 1979]

For Missoula, survey results indicate that even as late as 1977, most wood burning occured in open fireplaces and specifically for aesthetic purposes. The 1977 Missoula survey found that of those who burned wood 91 percent had a fireplace, and only 16 percent owned a much more efficient wood heating stove, and only 43 percent of those who burned claimed to use their wood burning facility for primary or secondary heat [Otis 1977].

While the use of wood declined as a primary home heating fuel, from 1950 through the mid 1970s, the real price of the two main heating fuels, natural gas and electricity remained constant or actually declined. In the late 1970s, the real price of natural gas, the predominate space heating fuel, in urban Montana , rose dramatically, doubling in real price from 1975 to 1981 [MPC 1983]. For the same period, the price which the natural gas consumers see on their utility bill, the nominal price, quadrupled. In areas of the country where natural gas filled a large share of space heating fuel needs, this price increase is most likely a major stimulus for the return to wood as a primary or secondary home heating fuel. The resurgence of residential wood use was particularly noticeable in areas of the country that have relatively easy access to wood. Areas with the most significant increase in wood use, New England, the Pacific Northwest, the Upper Lake States, and the Southeast, are all heavily forested [Marshall 1981].

This suggests that urban Western Montana should also have experienced an increase in residential wood burning during the late 1970s, with natural gas being a major space heating fuel, and relatively easy access to wood. Since there are no consumption estimates for the period prior to 1976 it is assumed that wood use in the Missoula area followed the national pattern and was on the decrease untill the mid 1970s. By the time the first wood burning survey was conducted in the winter of 1976-77, there had already been a noticeable increase in the number of homes burning wood and the total amount burned. This increase in residential wood burning was evident in the quality of the wintertime air, which during inversions has a high particulate count tied, in part, to increased residential wood burning. It has been estimated that the percentage of contributions from fireplace and woodstove emissions to Missoula's wintertime total suspended particulates level increased from 21 percent in 1974 to 49 percent in 1980 [Church 1980]. The quality of wintertime air and its possibly links to wood burning is mentioned because it was the possibly health effects from air pollution that prompted the Missoula County Health Department wood burning surveys. These surveys provide the only reliable estimates of residential wood consumption for the Missoula area. The air quality issue is also important because such existing and proposed regulations on burning, aimed at improving winter air quality, will most likely affect future levels of residential wood burning. Estimating the effects of regulation on future levels of burning would be very difficult. What this thesis will attempt to do is forecast future levels of residential wood burning in the Missoula area given no regulations.

The Health Department surveys contain some simple 2 to 3 year wood use forecasts calculated by extrapolating the number of new wood burners and multiplying by a constant utilization rate. However the surveys give no indication of the possible quantity of burning 5, 10 or 20 years from now. Is the increase in wood burning likely to maintain the pace of the late 1970s? Probably not. But what increase, if any, can be expected. Or has wood burning hit a peak and begun a period of decline?

These are important questions when restrictions on burning and regulation of wood stove emissions are the subject of discussion and controversy. The speed and implementation of regulatory action may depend on the perceived severity of the problem in the years ahead.

Thus there seems to be a need for some sort of empirical estimates of the quantity of wood that will be burned in the residential sector in the remaining years of this century.

PURPOSE AND METHODOLOGY

The purpose of this thesis is to forecast residential fuelwood consumption, for the period 1984 to 2000, for the Missoula urban area. These forecasts will be based on historical relationships and will not consider the possible effects of wood burning regulations on future levels of burning. Two methods will be used in developing the forecasts. The first method is to develop a residential wood use time series for the Missoula area and use econometric techniques to estimate a demand equation, and use this equation for wood use forecasts. The second forecasting method is a simulation model, which derives wood use as a function of fuel cost savings, and has flexibility in allowing non-economic factors associated with wood burning to be modeled. Both models are based on the assumption that the vast majority of residential wood burning will be undertaken for the purpose of space heating, and the major stimulus to investing in wood heating is the perceived dollar savings associated with displacing conventional fuels with wood fuel for space heating.

CHAPTER TWO

PREVIOUS RESIDENTIAL FUELWOOD CONSUMPTION STUDIES

Attempting to derive empirical estimates for residential wood demand encounters many difficulties. Unlike other residential energy sources, wood is decentralized with few established large suppliers and no meaningful established market price. The results are a lack of readily available consumption or price data. Because of this, consumption series have to be created from other available data and the price of wood is usually left out of residential wood demand models.

Despite the difficulties, there have been attempts to model and forecast the demand for residential fuelwood consumption. The methods used ranged from trend extrapolations to full optimization models. Only one available forecast method relied on an econometric estimation from an estimated historical data series.

NATIONAL SURVEYS AND ESTIMATES

Estimates of recent levels of residential wood burning nationwide are available from national surveys including the Residential Energy Consumption Surveys from the U.S. Department of Energy [DOE/EIA 1984] and the U.S. Forest Service [Skogs 1983]. The annual Residential Energy Consumption Survey conducted by the Department of Energy is useful in providing information on the percentage of homes heating with wood-fuel, and past trends in residential fuelwood use. The most comprehensive survey of national fuelwood use was conducted during the 1980-81 burning season by the Forests Service Products Laboratory in

Madison Wisconsin. This survey not only estimated total residential wood use, but also allocated fuelwood consumption by geographic and socio-economic variables.

The Department of Energy along with estimating wood consumption on a yearly basis by surveys also estimated historical residential wood use. The historical estimates are contained in Estimates of U.S. Wood Energy Consumption from 1949 - 1981 [DOE/EIA 1982]. Residential fuelwood consumption estimates are derived for every state for the years 1960 to 1981 and are based on historical wood appliance sales and the specific characteristics of each state.

NATIONAL FORECAST MODELS

Most residential energy demand forecast models note that wood has become more important in the past ten years but do not attempt to incorporate fuelwood consumption projections into the model. One model that does incorporate wood consumption forecasts is the Energy Information Administration's HOME Residential Energy Demand Model [DOE/EIA 1984]. The historical wood consumption used for estimating a demand equation came from Estimates of U.S. Wood Energy Consumption from 1949 - 1981, as described above. Consumption is divided into four geographic regions and wood consumption is estimated on a logistic curve with wood consumption as a function of an upper limit on wood consumption, average weighted fuel prices, and wood consumption in the previous period. The resulting four equations are used to forecast residential wood-energy consumption in the four geographic regions.

Other less empirical forecast models have been developed to project residential wood use. Included are wood use forecasts by the Forest Service (1980), Office of Technology Assessment (1980), Solar Energy Research Institute (1980), and independent reports for the Department of Energy by Booze, Allen and Hamilton, Inc. (1979), and Bradburg, Over, Scnieder, and Art (1979) [Marshall 1981]. Because of the lack of historical estimates of fuelwood demand, the above mentioned models rely on existing wood use trends, population trends, conventional fuel prices, potential wood supply, and wood appliance sales as an indication of wood demand. Wood appliance sales are particularly important to several of the forecasts. The wood burning appliance industry has historically been limited to a few domestic manufactures whose sales records could be compiled to form a total United States sales figure, and from this an inventory of wood burning appliances can be calculated assuming that the average wood stove lasts ten years. All the stoves sold within the last ten years were assumed to be the total inventory of stoves being used at any given time. The stove industry also provides estimates of future sales, although it is not known how these projections were derived. It is possible that these projections are simply trend extrapolations modified by each year's sales figures. After a wood burning appliance inventory is calculated, the next step in the typical estimation procedure is to decide on the average amount of wood burned in each stove. In general this was accomplished by using various surveys from around the country and finding a national average, which multiplied by both the number of wood burning appliances, and a factor, 1 / percentage of wood burned in wood stoves, gives a value for total residential wood consumption. This process is carried out with industry predictions for future wood stove sales in order to forecast residential fuelwood consumption. This was the basic procedure of the Booze, Allen, and Hamilton model. The Office of Technology Assessment, and Forest Service projections added to the analysis by including variables such as improved burning efficiency, competition for forest residue, population trends, and price of both wood and conventional fuel. Because of the different assumptions the projected value of residential wood consumption in the year 2000 varies by a factor of ten. Of interest is that only one projection, the Solar Energy Research Institute study predicted that residential wood use would peak before the end of the century [Marshall 1981].

MONTANA ESTIMATES

Historic estimates of residential wood use in Montana come from Estimates of U.S. Wood Energy Consumption from 1949 - 1981, and are based on the principal of using wood stove sales to estimate historical residential fuelwood consumption [DOE/EIA 1982]. From the total amount of national residential wood burning, wood use for Montana was established by considering heating degree days, typical housing, availability of wood, the mix of urban and rural residences, and the percent of primary and secondary burners. Montana was represented by Chicago for typical housing characteristics, with an average heating requirement of 15,288 btus per heating degree day. This estimate of btus per heating degree day is assumed to be representative of the typical house floor size and insulation levels. But the figure of

15,288 may be a little high for Montana since this figure multiplied times the average annual heating degree days for say Missoula, 7931 [WSUN 1980], would produce an annual average heating requirement in excess of 120 million Btus, which is higher than any estimates made for this area. This indicates that Montana homes are possibly better insulated than the estimating procedure assumes, and thus wood use estimates should be biased to the high side.

The most current estimate of Montana fuelwood consumption comes from a 1984 statewide residential survey conducted for the Montana Department of Natural Resources by Economic Consultants Northwest Inc. The survey results estimate fuelwood consumption in Montana to be 300,000 cord in 1984, with 50 percent of the households in the state burning on average 2.6 cords [ECO NW 1984].

MONTANA FORECASTS

A simulation model was used to forecast residential wood use in Montana and Montana Power's service area. The model was developed by Economic Consultants Organization Northwest Inc. in work prepared for the Montana Department of Natural Resources [ECO NW 1984]. The model is in principle based on the WOODSTOV-2 residential wood-energy demand model developed by Norman Marshall at Dartmouth College [Marshall 1981]. The ECO NW model contains far fewer interactions than does WOODSTOV-2 and is claimed to be preferable on this basis. Interestingly , Montana residential wood use forecasts calculated by the author using the WOODSTOV-2 model were nearly identical to forecasts made with the ECO NW model, and were include in the report.

Before deciding to use a simulation approach to forecast wood use, ECO NW attempted to develop an econometric model, using Montana wood consumption estimates from Estimates of U.S. Wood Energy Consumption from 1949-1981 [DOE/EIA 1982], conventional fuel prices, heating degree days, percentage of forested land, and income. Statistical analysis revealed weighted conventional fuel prices to be the only significant variable. Price of wood was not include in the equation because establishing a statewide price for residential firewood proved to be difficult, with the only conclusion being that the price of wood had remained fairly constant in real terms the past 20 years [Finney].

Despite the presence of only one variable, weighted conventional fuel prices, the model did have considerable explanatory power. The drawback to the model was the unrealistic sensitivity of quantity of wood use to minor changes in the prices of electricity and or natural gas. Small yearly changes in projected gas or electric prices produced yearly wood use increases or decreases up to 45 percent over the previous year [Finney]. This practical problem, along with the theoretical problem of having no price variable for the good in the demand equation led ECO Northwest to abandon the econometric approach.

Montana Power Company has attempted to predict future values of residential fuelwood consumption for the 250,000 households in their service area in the state. Their projections indicate substantial growth in wood use, from current levels of less than 300,000 cords to more than 450,000 cords in 1994 [Finney].

MISSOULA AREA ESTIMATES

Residential fuelwood consumption in the Missoula area has been estimated by three Missoula City-County Health Department surveys. The first survey was conducted in the winter of 1976-77, and estimated fuelwood consumption to be 15,040 cords [Otis 1978]. The second survey estimated fuelwood use to be 31,800 cords during the winter of 1979-80 [Church 1980]. Finally, the most recent survey estimated an upper limit of 34,000 cords burned in 1982-83 [Steffell 1983].

SUMMARY

From this brief overview of wood use surveys and models created to explain and forecast the quantity of residential wood use it can be seen that there is no clearly accepted theoretical framework. From the viewpoint of economic theory, many of the models have the undesirable feature of not including the price of fuelwood in the demand equation. Historic wood consumption data contains few directly estimated observations, and even these are subject to considerable error, since consumption must be estimated by survey techniques. The lack of reliable fuelwood consumption and price data has forced many of the projections to have a powerful subjective component. As a result models with similar inputs draw distinctly different conclusions. In Montana specifically, there is no common agreement on the magnitude of future growth in residential wood use, or if there will be any growth at all. Models have predicted increased wood use of up to 60 percent in the next 15 years [ECO NW 1984, Finney], while on the other hand persons who have devoted considerable time researching wood use speculate that there will be little or no future growth in residential fuelwood consumption in Montana [Keegan 1983].

CHAPTER THREE

DATA AND PRELIMINARY ANALYSIS

ESTIMATING FUELWOOD CONSUMPTION IN MISSOULA

Residential wood use experienced a period of steady decline from 1960 until 1974, followed by large increases until 1980, and a slowed increase since 1980. In Missoula that increase was evident in the doubling of estimated cords burned between the 1977 survey and the 1980 survey. Estimates for the state of Montana show a tripling in residential wood burning, from 111,000 cords in 1974 to 333,000 cords in 1981 [DOE/EIA 1982]. Since the 1977 survey provides the earliest estimates of the quantity of residential burning in Missoula, a time series of cords burned in Missoula had to be created using Missoula and statewide wood use estimates.

ESTIMATING PAST FUELWOOD CONSUMPTION IN MISSOULA

Figures for Missoula area residential wood burning are a combination of Missoula survey results and statewide estimates. The two Missoula-County Health Department surveys are for the 1976-77 burning season and the 1979-80 burning season. Statewide estimates are _Estimates of U.S. Wood-Energy Consumption from 1949 - 1981_ [DOE/EIA 1982], and provide statewide estimations of residential fuelwood consumption from 1960 to 1981. The survey estimate of wood use in Missoula for 1976-77 is 15,020 cords, while the average D.O.E. statewide estimate for 1976-77 is 169,500 cords. In 1979-80 those values are 31,836 cords in Missoula, and 301,500 cords statewide.

Calculating the ratio of Missoula use to state use:

1976-77	1979-80
$\frac{15,020}{169,500} = 8.86\%$	$\frac{31,836}{301,500} = 10.56\%$

Where: Numerators are from Missoula wood surveys, 1977, 1980
Denominators are two year averages of Montana estimates

From these two observations wood use in Missoula was assumed to represent 10 percent of statewide residential wood burning for the entire period of the statewide estimates, 1960 to 1979. Values for 1980 and 1983 are from the two most recent Missoula surveys, with 1981 and 1982 values estimated from these surveys. These twenty-four observations for residential wood use in Missoula, are neither directly measured data nor, in most cases, even directly estimated values. However since residential fuelwood measurements will always be subject to considerable error, and given little survey estimated data to go by, these estimates are felt to represent a "best guess" at the historic levels of wood burning in the Missoula area. Table 3.1 shows the values for residential wood burning derived by the above procedure. Use per household is calculated from total use by dividing total use by the number of households in the Missoula urban area. This gives a value for the average number of cords burned for both wood burning and non wood burning households combined. Appendix I shows the estimated data for Montana consumption, Missoula household population data, and how the Missoula area consumption series was calculated.

Table 3.1

Estimated Residential Fuelwood Consumption,
Missoula Urban Area 1960 - 1983

YEAR	TOTAL WOOD USE (cords)	USE PER HOUSEHOLD (cords)
1960	22,900	2.00
1961	21,200	1.77
1962	20,000	1.60
1963	18,800	1.45
1964	18,600	1.38
1965	17,600	1.26
1966	16,100	1.11
1967	15,100	1.01
1968	14,600	.95
1969	14,000	.88
1970	13,500	.82
1971	12,500	.73
1972	12,200	.68
1973	11,100	.59
1974	11,100	.57
1975	14,800	.73
1976	15,400	.72
1977	18,500	.82
1978	23,300	.97
1979	28,900	1.18
1980	31,800	1.28
1981	32,500	1.29
1982	33,300	1.31
1983	34,000	1.32

Fuel Prices

The values in Table 3.1 show that wood use experienced very rapid growth in the late 1970's. When looking for explanations for this increase, the most logical reason, and the reason most commonly cited, is the increase in home heating fuels, namely natural gas, during this period. Natural gas, the major home heating fuel in this part of the country, experienced more than a doubling in real price from $1.94 per million per btu in 1974 to $4.16 per million btu in 1981 [MPC 1983].

Add to this real price increase, inflation rates during the period and the consumer was witnessing nominal price increases of up to 30% per year. At a time when wood was easy to collect, and there was minimum public awareness of the hazards of wood smoke, it is not surprising that households would turn to wood as a perceived less costly home heating fuel.

The explanatory power of natural gas prices on increased wood burning can be demonstrated with statistical analysis, particularly when considering the period of increasing wood use during the late 1970's. A simple regression equation with use per household as the dependent variable and real gas price lagged one year can explain 86 percent of the increase for the period 1973 to 1981. Real gas price alone offers less explanatory power for the entire period, 1960 to 1983, but other factors such as the introduction of clean and convenient home heating fuels to a greater percentage of the Montana households during the 1960's may have been more important in converting from wood heat then was the price of those fuels. When the above regression procedure is applied to the entire period, 1960 to 1983, the lagged price of natural gas by itself can explain very little of the variation in wood use.

The other conventional fuel that is becoming more prominent as a space heating fuel is electricity. In 1960 1.3 percent of Montana households employed electricity as the primary space heating fuel, and that figure increased to 16.1 percent in 1984 [ECO NW 1984]. Nationwide, 11 percent of new homes constructed between 1960 and 1964 use electricity as the main heating fuel. This increased to 21 percent of new homes constructed between 1965 and 1969, 36 percent of new homes constructed between 1970 and 1974, and 50 percent of new homes constructed after 1975 [DOE/EIA RECS 1982]. This increase in the all electric home is possibly due to the changing housing location patterns, with more new homes being constructed on the outskirts of the urban areas where a natural gas distribution network may not yet exist. Missoula records show that the majority of new homes constructed since 1960 have been located outside the city limits [Missoula Planning Board 1975].

The increase in the percentage of electrically heated homes, creates a large group of homeowners whose space heating fuel costs are much higher than those heating with natural gas. Using some simple calculations for heating costs based on fuel prices, heating efficiencies, and heating requirements, the difference in electricity costs versus natural gas costs was $1011 in 1970. The difference decreased to $746 in 1975, and the gap diminished still further to $381 in 1980. Although the costs of heating with electricity relative to natural gas have been decreasing, the differences are substantial, and show that the owner of an electrically heated home would have a strong incentive to seek less costly alternative forms of heating.

Unlike the price of natural gas, the real price of electricity decreased from 1960 to 1983. In 1960 the real price of electricity was $.062 per kwh, decreasing to $.034 per kwh in 1980, and then rising slightly to $.039 per kwh in 1983 [MPC 1983]. During the period of greatest increase in wood use, 1974 to 1981, the real price of electricity fell 17 percent. For the entire 23 year period the real price of a kilowatt-hour of electricity fell 37 percent.

Although the real price of electricity was falling during the period of most rapid increase in fuelwood use, the nominal price of electricity was increasing. Until individual's perception of these increases adjusted to the high inflation rates of the late 1970's, the nearly doubling of nominal electricity prices from 1974 to 1981 could well have been a major concern to owners of electrically heated homes. Assuming average heating requirements, an increase of $.01 per kwh in the price of electricity raises total heating costs $249. Considering that the nominal price of electricity increased approximately $.02 from 1974 to 1981, it is not difficult to understand how this increase could have been met with alarm from owners of electrically heated homes, even though this increase was, in fact, due entirely to high inflation rates.

Real fuelwood prices have remained fairly constant for the period 1960 to 1983. These prices were established for purchased cords of fuelwood by averaging the advertised prices for cords of firewood in the November and December volumes of the local newspaper, the Missoulian for the years 1960 to 1983. The average real advertised price of a cord of firewood was 51 dollars for the 24 years with a range of approximately plus or minus 15 dollars. By using the average advertised price of fuelwood in the analysis this author is assuming that purchased fuelwood or the opportunity of gathering firewood is represented by the advertised price. This ignores the recreational aspect of gathering firewood, which would make the perceived cost of self gathered wood much less than the advertised price. Unit prices for natural gas, electricity, and wood are presented in Appendix II, while Table 3.2 and Figure 3.1 show the efficiency weighted real costs of electricity, natural gas and wood in dollars per million btu.

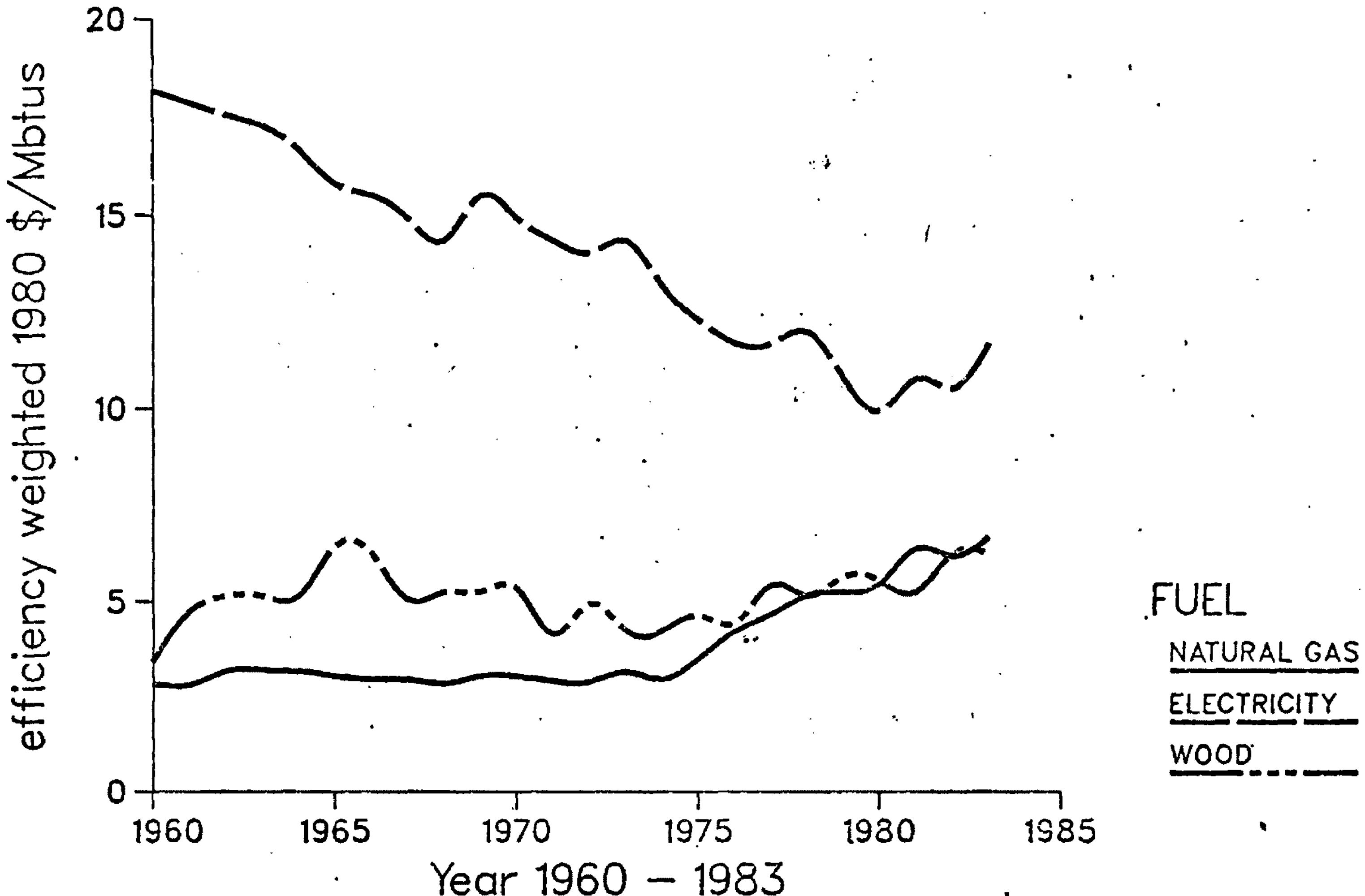
Table 3.2

Efficiency Weighted Real Price of Natural Gas, Electricity and Fuelwood 1960 -1983 (1980 $ / Mbtu)

Year	Natural Gas	Electricity	Wood
1960	2.86	18.16	3.43
1961	2.83	17.87	4.75
1962	3.20	17.57	5.15
1963	3.23	17.29	5.15
1964	3.18	16.70	5.15
1965	3.05	15.82	6.46
1966	2.97	15.52	6.26
1967	2.97	14.94	5.05
1968	2.86	14.36	5.25
1969	3.06	15.52	5.25
1970	3.05	14.94	5.35
1971	2.92	14.36	4.14
1972	2.91	14.06	4.95
1973	3.17	14.36	4.24
1974	2.98	13.18	4.24
1975	3.52	12.30	4.65
1976	4.23	11.72	4.44
1977	4.69	11.72	5.45
1978	5.18	12.01	5.15
1979	5.26	10.80	5.66
1980	5.48	9.96	5.55
1981	6.40	10.80	5.25
1982	6.20	10.55	6.26
1983	6.69	11.72	6.26

Source: Montana Power Company for natural gas and electricity prices [MPC 1983].
Missoulian classified section for wood prices. [Missoulian 1960 - 1983].
Efficiency weights; natural gas (65 %),electricity (100%), wood (55%).

FIGURE 3.1
RESIDENTAIL SPACE HEATING ENERGY COSTS
1960 – 1983, MISSOULA URBAN AREA



Source: Table 2.2

Figure 3.1

Even though the real price of electricity was decreasing over the past two decades, electricity still was and is the most expensive fuel on a dollar per million btu basis. In real dollars per million btu for 1983, wood is the least expensive at $3.44, next natural gas at $4.56, and most costly, electricity at $11.87. These prices however exaggerate the final heating costs as electricity is close to 100 percent efficient, while wood and gas are in the 50 to 65 percent range. Assuming 1983 prices, 65 percent efficiency for natural gas and 55 percent for wood, the costs of a million btus are $7.02 for gas and $6.25 for wood, compared to the $11.87 for electricity. Wood fuel costs surpass natural gas costs on an efficiency weighted dollar per Mbtu basis, assuming the above combustion efficiencies, when wood costs are equal to or greater than $70 per cord. For wood to be as expensive as electricity, with the same assumptions, a cord would have to cost at least a $117. The above examples are based on wood burning efficiency of 55 percent, which would represent a properly operated, good quality woodstove. However, fireplaces and many stoves do not operate with 55 percent burning efficiency. For a closed fireplace or poor quality woodstove 25 percent efficiency may be more realistic. At this lower efficiency the 1983 advertised purchased price of wood is $13.78 per Mbtu. To compete with natural gas and electricity at the costs presented above wood burned at 25 percent efficiency would have to cost no more than $32 per cord to be equal cost with natural gas and $53 per cord to be equal cost with electricity. Even lower burning efficiency, as in an open fireplace, would require that wood be in the $10 to $25 range to have equal cost to natural gas or electricity.

HEATING WITH WOOD

In the preceding discussion on relative fuel prices wood does not appear to be cheaper than natural gas before 1978. There are however several factors, other than the straight market price of the fuels, which contribute to making perceived wood heating costs cheaper than the conventional alternatives. To start with, the number of btus required to heat a home must be considered. It was estimated that in 1980 the average Missoula house required 96.5 million btu for space heating purposes [Neilson 1983]. Assuming that there has been some conservation trends towards more energy efficient homes, and accounting for arguments claiming this value is too high because it neglects solar gain (Montana DNRC), a value of 85 Mbtu will be used for discussion purposes. This space heating requirement figure, and projected decreases in it due to conservation are very important variables in the wood simulation models that will be presented in chapter five.

With an average btu requirement of 85 million, and obviously some houses higher, every dollar or more saved per million btu can add up to significant amount of savings for an entire year. Consider electricity at $11.87 per Mbtu versus wood at $6.25. Multiplied by the yearly requirement of 85 Mbtu, electricity costs are $1009 per year, while wood is only $531. Natural gas costs calculated in the same manner would be $597 per year. On the basis of these calculations a house with average space heating requirements will save at least $578 per year on their fuel bill by burning purchased fuelwood if their alternative is electricity, and $66 dollars per year if their alternative is natural gas. These savings are based on the advertised price of purchased fuelwood, and savings will be greater if the fuelwood used is gathered at a very low perceived cost. Savings will be equal to the cost of the displaced conventional fuels if the perceived cost of gathering firewood is zero. However there are peculiarities of wood burning that can alter these savings in either direction.

For two houses with equal space heating requirements, the household with the wood stove will use a fewer number of total Btus than will the house that heats with a central furnace [Marshall 1981]. Three reasons account for this difference. First, with wood the fire burns down when unattended at night, or during the daytime when the occupants are out, unlike a thermostatically controlled central heating system. Second, wood heat is not distributed to all rooms equally, with unoccupied rooms being colder than they would be in a house with central heating. Third, in the rooms that are heated, there is a thermal gradient with more heat concentrated near the center of the room and less near the walls and windows where heat loss occurs. The degree to which these factors decrease the total btu requirements is difficult to quantify, and depend on individual burning habits and on what percentage of total heating needs wood provides. If only a small percentage of total heating needs are met by wood heat than the number of btus displaced by wood will be significantly larger than the number of btus provided by the wood. However as a greater percentage of heating needs are met by wood the ratio of displaced btus to wood provided btus decreases. When wood heat provides 100 percent of the heat, as in the case of a central wood furnace, then displaced btus and wood provided btus are equal.

Not only does the percentage of heat provided by wood affect the btu displacement properties, but it also directly effects the savings by altering the amount of conventional fuel still needed to adequately meet heating requirements. Most wood burners do not provide all of their heat with wood. According to the most recent Missoula survey the average wood burner consumed approximately 2.75 cords [Steffell 1983], which at 18 million btus per cord [Neilson 1983], burned at 55 percent efficiency, would yield 27.225 million Btu. If the average house requires 85 Mbtu, then 2.75 cords represents 32 percent of total Btu requirements. As was pointed out earlier, in typical use, wood displaces more heat than it provides, so that these 2.75 cords provide 32 percent of the total heating requirements on an even btu for btu tradeoff, but since the tradeoff isn't even, the wood heat displaces more than 32 percent of the total heat load. This means that less than 68 percent (100 percent minus 32 percent) of total heating requirements must be provided for by conventional fuels.

The percent of total heat provided by wood and the displacement factor, along with the fuel prices and efficiencies, and total heat requirement will determine the yearly fuel bill savings or dis-savings from burning wood. If a positive savings accrues from wood burning, then the total savings will be a function of how much conventional heat is displaced by wood heat. Intuitively this is obvious. If a million Btus of wood heat is cheaper than a million Btus of conventional heat, then the more wood heat you use the less conventional heat you need and the lower the total fuel bill.

Calculating a savings or dis-savings from wood burning depends on more than just the relative fuel costs. One very important factor which has been left out of the discussion so far is that fuel costs aren't the only costs in space heating. The heating unit itself, whether it is a conventional fuel heating system or a wood burning appliance must also be paid for. Usually a conventional heating system comes with the house, and the consumer does not have the choice of heating system. The consumer's choice lies in the decision to invest in wood burning capacity. The cost comparison to the consumer is the yearly wood burning equipment costs plus the cost of wood versus the conventional fuel costs. The consumer usually wouldn't consider the cost of the conventional heating system because those costs are sunk costs and are hidden in house payments. Besides it is generally necessary that the household have a conventional heat source, unless the sole heat source is wood, which is claimed by a small percentage of households. However a consumer whose conventional heating system is in need of replacement could theoretically weigh the total costs of conventional heat to the total cost of wood heat, and make a decision based on lowest yearly costs.

CHAPTER FOUR

ECONOMETRIC ESTIMATION AND FORECASTS

This chapter is devoted to the development of an econometric demand equation useful in explaining historical trends and capable of forecasting resonable future levels of residential fuelwood consumption in the Missoula area. There are few guidelines defining what "reasonable" means here other than that wood use will probably continue to increase in the near future, but not at the same rate as experienced in the late 1970's, and will not grow to levels that would represent the same percentage increases as growth in the 1974 to 1980 period.

DEVELOPING THE MODEL

From the standpoint of economic theory, the demand equation should include the price of the good, the price of substitutes, income, taste, related variables, and the number of consumers in the market. All of these factors are expected to play a role in the demand for residential fuelwood consumption, but only some of these variables are measurable in a precise fashion. It becomes necessary to leave out of the model some potentially important variables, and include others that are only crudely estimated.

In determining the amount of residential fuelwood consumption, the price of the good is the price of a cord of wood. In this case a market price for wood was established by scanning the classified advertising section of the Missoulian for November and December, 1960 to 1983, for the most common price, defined as a price that is advertised by two or more different suppliers. The price is for a delivered full cord, advertised as such, not as pickup loads or some other vague measurement converted to cords. Wood prices were presented in the preceding chapter.

Conventional heating fuels, natural gas and electricity, represent the substitutes for wood fuel. Historical and forecasted natural gas and electricity prices were supplied by the Montana Power Company, which serves the Missoula area. Natural gas and electricity prices were weighted by saturation rates and efficiency to create a price variable labeled average weighted energy price (AWEP). The weighting procedure is shown below.

$$AWEP = \sum_{i=1}^{2} P_i * Saturation_i * 1/Efficiency_i$$

Where:
P = real price per Mbtu of natural gas, electricity
Saturation = percent of homes using fuel as primary heat source
Efficiency = thermal efficiency of natural gas, electricity

Income was entered in the equation along with average weighted fuel price, as a single variable AWEP/INCOME , where income is real per capita income for Montana Power Company's service area. If INCOME is entered as a separate variable then neither AWEP or INCOME are significant in the estimated equation. AWEP, however is significant when entered as a single variable without INCOME. When entered in this manner income has the effect of emphasizing the increase in fuel prices when income growth is stagnant or slow, as in the late 1970's and of reducing the effect of fuel price increases when income also is growing. Growth in real per capita income is particularly important for forecasting purposes, in preventing wood use forecasts from climbing to unrealistic levels, by keeping ever increasing fuel prices a constant or even declining percentage of per capita income. For forecasting, real per capita income growth is set optimistically at 2.9% annually [MPC 1983, BEA 1980].

Total wood consumption for Missoula is a combination of survey results and statewide estimates as explained in the previous section. They depend on the assumption that the ratio of Missoula wood use to statewide use was constant for the 1960 to 1981 period.

In the estimating procedure, fuelwood consumption is normalized with respect to the number of households in the Missoula area. Housing units in the Missoula urban area are estimates by the Missoula Planning Board, and the annual growth in the housing stock is set at 1 percent for the period 1984 to 2000 [Steffell 1983]. The resulting variable "Total Wood Use/Households" should not be confused with what is presented in most wood burning surveys as the "average number of cords burned per household", where only households burning wood are considered. The variable in this model incorporates no saturation levels for wood burning households. In Missoula, surveys indicate that the current wood burning saturation level is close to 50 percent [Steffell 1983]. Thus a doubling of the value of Total Wood Use/Households would approximate the average number of cords burned per wood burning household.

The estimating equation consists of wood use per households as a function of the cost of wood, the cost of natural gas and electricity, per capita income, and wood use per household the previous year, where cost is the price per million btu times 1 / efficiency of the fuel.

$$\frac{\text{Wood use}}{\text{Households}_t} = f(\text{Pwood, Pelec., Pgas, Income, } \frac{\text{Wood Use}}{\text{Households}_{t-1}})$$

The choice of a lag adjustment in the reduced form consumption model is motivated by the limitations of the data and past experiences of static consumption models forecasting implausible fuelwood consumption changes given only slight variations in projected conventional fuel prices. The theory behind this form of model is that individuals reside in a house with a given type of heating appliance of a given efficiency and are limited in their ability to respond immediately to a price change. Use of this typical lag procedure is a common practice in energy forecasting, and makes the assumption that energy use habits, in this case fuelwood consumption, will not vary dramatically from year to year. This argument is less persuasive with fuelwood than with conventional space heating fuels because the typical wood burner, who has both a wood and conventional heating source, can burn a large quantity of wood in one year and then none the next year. However, given that most fuelwood is not purchased, but obtained by the user, and once obtained involves considerable time splitting, carrying and tending, any such dramatic year-to-year fuel switches would involve dramatic changes in behavior, habit, and time use. The lag adjustment assumption is more plausible when considering wood burning households as a whole. The Energy Information Administration's HOME residential energy demand model includes an equation for wood use projections which is of the same form as above, with wood use a function of conventional fuel prices and wood use the previous period [DOE/EIA 1984]. Though it is a common practice in energy demand modeling, the inclusion of the lagged dependent variable leads to theoretical problems in estimation which cannot be completely remedied.

ESTIMATING THE EQUATION

The variables were converted to their natural logarithms and ordinary least squares regression procedure was applied to these variables to obtain the following results.

$$\ln USEPHH_t = \underset{(1.77)}{2.47} + \underset{(.26)}{.53} \ln AWEPRAT - \underset{(.11)}{.067} \ln WOODRAT + \underset{(.085)}{.87} \ln USEPHH_{t-1}$$

R squared = .94

Where:

- USEPHH = Total Wood Use / Households
- AWEPRAT = Average Weighted Energy Price / Per Capita Income
- WOODRAT = Wood Price / Per Capita Income
- t = time subscript
- ln = natural logarithm
- number in parenthesis are standard errors

With the lagged endogenous variable used as an explanatory variable, the result is not surprisingly an equation with a high R squared. The sign of the conventional energy price variable is theoretically correct, and significant, as it is expected that wood use per household should increase as conventional energy prices relative to per capita income increases. The wood price variable is however, highly insignificant, implying that the market price of wood has not been an important factor affecting variations in the amount of wood burned. The reasons for market price not being an influence on past variations in the quantity of wood burning, and changing circumstances that may bring about an increased importance of the in the market price of wood are discussed in chapter six.

FORECASTING FUELWOOD CONSUMPTION

For forecasting purposes the wood price variable was dropped from the equation because of the its lack of statistical significance, making future values of wood use per household a function of projected natural gas and electricity prices, efficiencies and saturations, projected growth in real per capita income, and use per household the previous year. The equation was estimated using the Cochrane-Orcutt regression procedure in the SORITEC econometric software package [SORITEC 1982]. In this instance the Cochrane-Orcutt technique reduces to the application of ordinary least squares to a data series transformed by the first order serial correlation coefficient. This was done in order to correct for the presumed presence of serial autocorrelation created by the presence of the lagged dependent variable. Tests for the presence of autocorrelation, the Durbin-Waston statistic and regression of the error term on lagged error terms, are not appropriate for models containing the lagged dependent variable as an explanatory variable , or when the sample size is less than 30 [Koutsoyiannis 1977]. Correcting for autocorrelation however, does not cure the bias due to the presence of the lagged dependent variable in small samples. Techniques developed to cure the problem of biased coefficients have not been very successful in practice, particularly with a small sample size. Despite theoretical problems in estimation the demand equation including the lagged dependent variable is considered by this author to be preferable.

$$\ln USEPHH_t = \underset{(1.52)}{2.0876} + \underset{(.24)}{.5243} \ln AWEPRAT + \underset{(.096)}{.7757} \ln USEPHH_{t-1}$$

R squared = .94

Where:
USEPHH = Total Wood Use / Households
AWEPRAT = Average Weighted Energy Price / Per Capita Income
t = time subscript
ln = natural logarithm
values in parenthesis are standard errors

The above demand equation for fuelwood consumption per household was used to forecast consumption per household and these forecasts were multiplied by the projected number of households in the Missoula area to forecast total number of cords consumed by residential burners.

The results are presented in both tabular and graphic form. Fuelwood consumption per household is forecasted to continue increasing until 1986, when it peaks at 1.56 cords per household, followed by continually declining use to the year 2000, when use per household is lower than current levels, at 1.22 cords per household. The forecasted increase in total wood use is even greater in the immediate future than use per household due to the growth in the number of potential wood burning households. Total wood use peaks once in 1987 at 41,530 cords, and peaks again for the last time in 1990, at 41,490 cords. Total wood use declines after 1990, as growth in the housing stock is not large enough to counter the decrease in use per household after 1990. Since housing stock is still growing at 1 percent per year, meaning there are more potential wood burners, total wood use declines more slowly than use per household to 36,970 cords being burned in 2000. Table 4.1, and Figures 4.1 and 4.2 show forecasted fuelwood consumption and consumption per household 1984 to 2000.

Table 4.1

Forecasted Residential Fuelwood Consumption,
Missoula Urban Area 1984 - 2000

Year	Total Wood Use (cords)	Use per Household (cords)
1984	34,430	1.33
1985	38,770	1.48
1986	41,340	1.56
1987	41,530	1.55
1988	40,790	1.51
1989	40,790	1.50
1990	41,490	1.51
1991	41,260	1.48
1992	40,670	1.45
1993	39,940	1.41
1994	39,230	1.37
1995	38,740	1.34
1996	37,900	1.30
1997	38,050	1.29
1998	37,620	1.26
1999	37,270	1.24
2000	36,970	1.22

Residential fuelwood consumption and fuelwood consumption per household are forecasted to continue increasing through the 1980's, and then slowly decline during the 1990's, so that by the year 2000 wood use is only slightly higher than current levels.

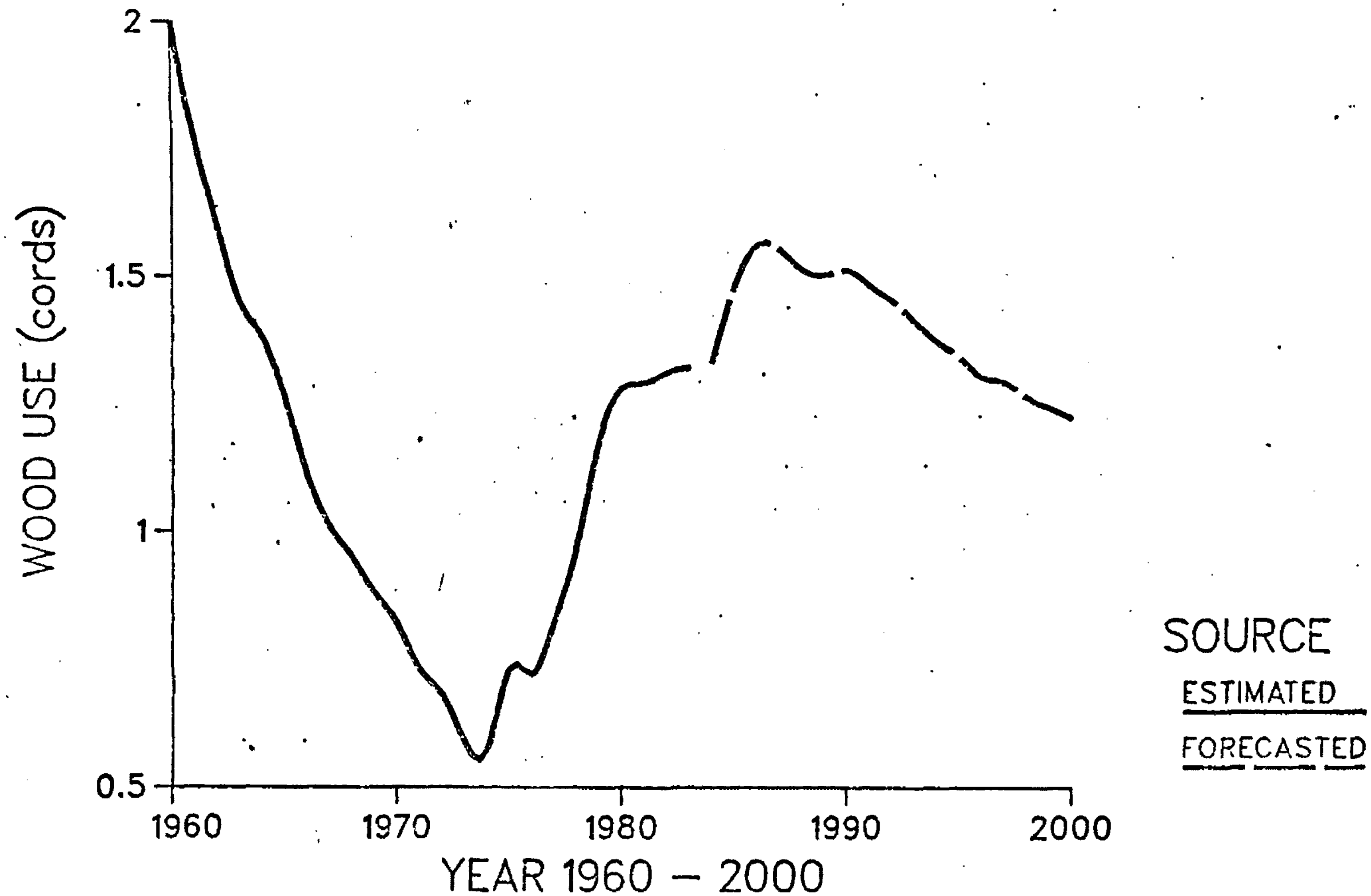
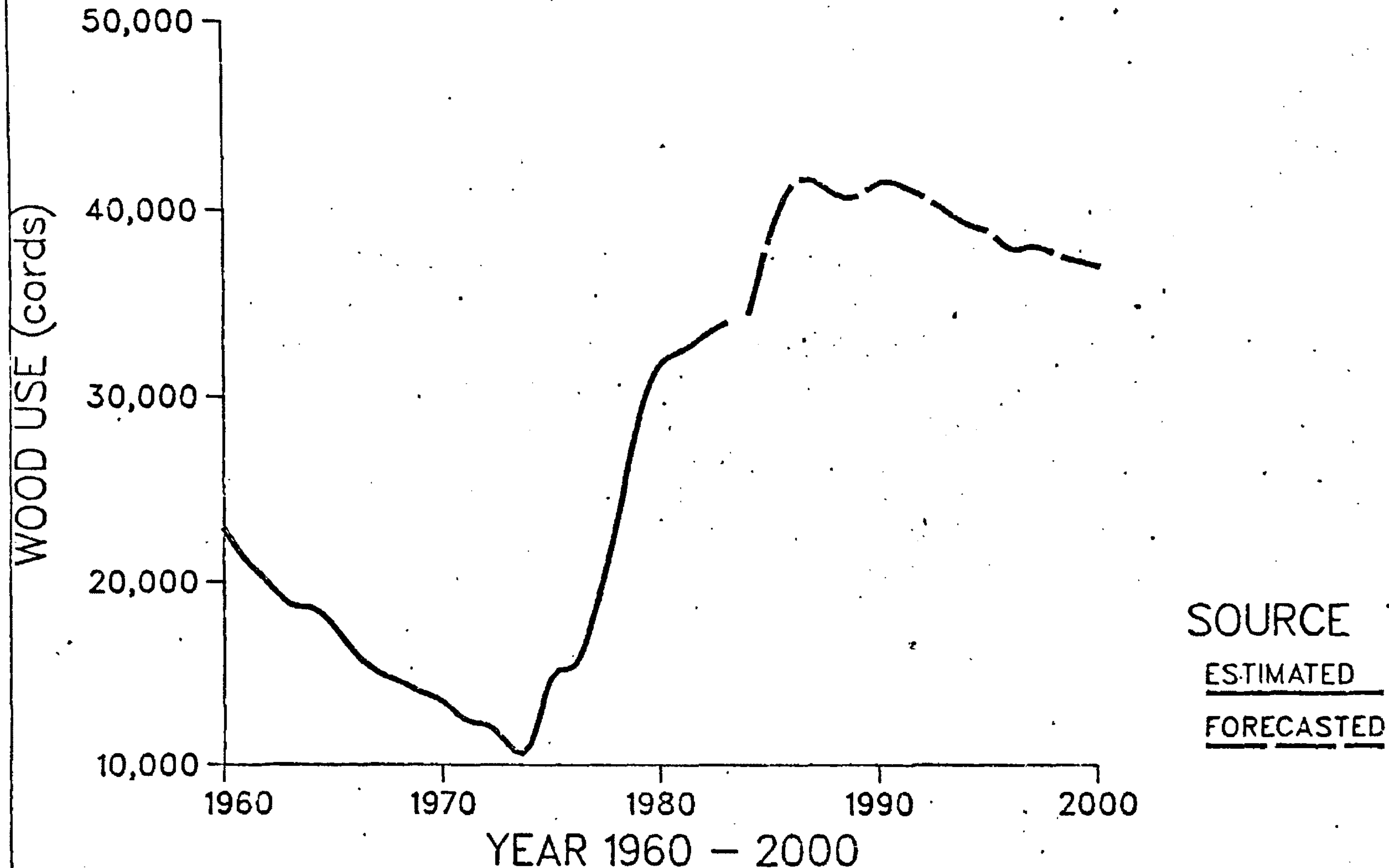


FIGURE 4.1
RESIDENTIAL FUELWOOD CONSUMPTION PER HOUSEHOLD
1960 – 2000, MISSOULA URBAN AREA

Figure 4.1

FIGURE 4.2
RESIDENTIAL FUELWOOD CONSUMPTION
1960 – 2000, MISSOULA URBAN AREA



Source: Table 2.1, Table 4.1

Figure 4.2

CHAPTER FIVE

SIMULATION ESTIMATION AND PROJECTIONS

This section explains and presents the results of the wood use simulation model that will be used to project residential fuelwood consumption in the Missoula area, for the period 1984 to 2000. The model is in essence a type of structural demand model in that both appliance stock and utilization rates are considered. The simulation, in theory, requires no historical time series for wood use, which for Missoula were estimated proportions of an estimate, and are of questionable quality.

EXPLANATION OF THE MODEL

The simulation model used for projecting is a modified version of WOODSTOV-2, developed by Norman Marshall at Dartmouth College. The model was written in DYNAMO simulation language, and the parameters set for the New England states area for the forecast period 1970 to 2000. Since the University of Montana's computer system did not have the DYNAMO compiler, the model was first converted to BASIC and run with the New England parameters to insure the conversion from DYNAMO to BASIC preserved the workings of the model.

WOODSTOV-2 uses a modeling method, system dynamics, that is relatively insensitive to individual parameter errors, so that projections aren't as sensitive to an individual parameter, which may be difficult to accurately measure. The equations of the model are calculated five times for every year of simulation, using interpolated values of input parameters and endogenous parameters. Either the time period being estimated or conditions in the previous period, are used to determine the interpolated parameter values needed to solve the equations calculating wood use in the current period. These newly calculated values are then in turn carried forward to be used in the calculation of the next time period.

The basic premise of the model is that existing households will convert to wood heat, or new households will be built equipped to heat with wood, based on a payback period of the wood capacity equipment. Payback period is a function of fuel cost savings and wood capacity installation costs. Wood burning capacity is not assumed to be used to its full capabilities, as most households which burn wood still rely on a conventional heat source for part of their heating needs. How much this capacity is used is based on the possible fuel cost savings if 100 percent of heating requirements were provided by wood. For a simulation run the needed inputs are energy prices, and efficiencies for both conventional fuels and wood, saturations for conventional fuels, household heating requirement, and wood burning equipment installation costs.

The inputs listed above obviously are required to determine conventional fuel costs, wood costs, and payback period. They differ in their reliability as data series, and in their importance to the model. As it turns out, the values for household heating requirements play the most important role in simulating wood use. Unfortunately there is no firm evidence as to what those values should be. A 1980 estimate concluded the average house in the Missoula area required 96.5 Mbtus per year [Neilson 1983]. The Montana Department of Natural Resources provided values for the entire state approximately 20 Mbtus lower, with the difference being attributed to solar gain. What this lower value does is shrink the average fuel cost savings, and since the model operates on the absolute level of fuel cost savings and not on the savings relative to heating requirements, the fraction of households investing in wood capacity decreases. Future heating requirements become a very crucial assumption in the simulation projections. Conservation goals, like Northwest Power Planning Council's 33 percent reduction in space heating requirements by the year 2002 [NWPPC 1983], if incorporated in the model, would be a powerful factor decreasing simulated values of future fuelwood consumption.

The sequence of equations in the simulation begin by first calculating the cost of providing 100 percent of the heating needs with conventional fuels using electricity and gas prices, efficiencies, saturations and household heating requirements. Next, wood costs, derived the same way as conventional fuel costs, are subtracted from conventional fuel costs to derive average fuel cost savings from burning wood. Wood heating capacity utilization is a function of total possible fuel cost savings, and is multiplied times average potential fuel cost savings to account for wood suppling only part of the heating needs. This provides perceived fuel cost savings, which the model forces to be a small positive value even if they are negative. The next step is to create a wood equipment payback period by dividing wood installation costs by positive fuel cost savings. Wood installation costs are a function of capacity installed and a set of pre-determined installation costs.

Payback period becomes the driving variable in the model, as the derived payback period determines the fraction of existing households that will invest in wood burning capacity in the simulation period. The maximum fraction is set a 20 percent of the existing households investing per year for a payback period of two years or less, and no wood capacity installations occurring for payback periods greater than 10 years, the assumed average normal lifetime of a wood stove. Between 2 and 10 years a linear relationship is assumed for the fraction deciding to invest in wood burning capacity from payback period. The installation of wood burning capacity in new households is a direct function of average fuel cost savings. With a $1000 average savings the number of new households with wood capacity is expected to be 50 percent. It must be pointed out that for Missoula, at least, there is no empirical evidence to testify to the validity of these relationships between savings and wood capacity aquisition, and slight changes in these assumed relationships will cause major changes in the simulated wood use values.

ADJUSTING THE PARAMETERS OF THE MODEL FOR MISSOULA

Since there is no method to empirically establish the relationships in the model specifically for the Missoula area, the next step is to calibrate the model to reflect the estimated conditions in Missoula. The approach to this task will be first to assume that the estimated time series for wood use, used in the econometric projections, is the best guess at past trends and levels.

Using housing stock values, and informed guesses as to the percentage of homes burning wood, the average amount burned, average capacity installed, and average capacity utilization, a starting point for the simulation model can be established. Given energy price and housing stocks that are known to have existed, the model can simulate the 1960 to 1983 period, and hopefully reproduce the declining and then rapidly increasing pattern of wood use that is assumed to have occurred.

The simulation run for 1960 to 1984 does reproduce the decline until the early 1970's followed by increasing wood use for the rest of the period. The disparity between the simulation and assumed pattern of wood use is the slower growth of wood use in the late 1970's for the simulation. The decline in wood use from 1960 to 1973 is similar except that the simulated wood use reaches a low point earlier in 1970, but maintains the low levels through 1974. Simulated wood use decreases to 11,093 cords in 1970, rises slowly to 12,643 cords in 1974, and then increases more rapidly to 18,051 cords in 1977, 25,243 cords in 1980, and 32,396 cords in 1983.

The simulated wood use values presented in table 5.1 were generated solely by the equations utilizing average fuel cost savings and wood installation costs. Difficult to quantify variables, inconvenience costs, pollution regulation, ethics of wood burning, were not explicitly included in the simulation run. Changes in fuelwood consumption are assumed by the model to be a function of wood price, conventional fuel prices and wood installation prices only. Knowing this the discrepancy between estimated wood use and simulated wood use can be narrowed. It should be noted that the assumption being made is that the change in behavior, accounting for the discrepancy, occurs during the increasing period of 1974 to 1981, and not during the decreasing period, 1960 to 1974.

Table 5.1

Simulated Wood Use versus Estimated Wood Use
Missoula Urban Area, 1960 - 1983 (cords)

Year	Estimated Use	Simulated Use
1960	22,900	23,014
1961	21,200	22,331
1962	20,000	21,150
1963	18,800	19,819
1964	18,600	18,577
1965	17,600	17,251
1966	16,100	15,460
1967	15,100	13,776
1968	14,600	12,370
1969	14,000	11,452
1970	13,500	11,093
1971	12,500	11,261
1972	12,200	11,547
1973	11,100	11,924
1974	11,100	12,643
1975	14,800	13,653
1976	15,400	15,702
1977	18,500	18,051
1978	23,300	20,722
1979	28,900	23,266
1980	31,800	25,243
1981	32,500	27,051
1982	33,300	29,423
1983	34,000	32,397

The opposite assumption could be made, in which case the simulation model would be adjusted so that the simulation increases from 1974 to 1981 mimicked estimated increases, but simulated decreases wouldn't resemble the estimated decreases for the 1960 to 1974 period. This second approach is difficult if fuelwood consumption is assumed to have decreased from 22,000 cords in 1960 to 11,100 cords in 1974. If the simulation is adjusted to backcast this magnitude of decrease then the increase in fuelwood consumption from 1974 to 1981 will be smaller than what the surveys in Missoula estimated. If the simulation is adjusted to accurately simulate the growth in fuelwood consumption from 1974 to 1981 then the assumption must be made that either wood use was considerably lower than 22,000 cords in 1960 or that the survey estimated 15,040 cords consumed in 1976-77 underestimated actual fuelwood consumption. This author's choice for the final simulation projections is to adjust the model so that the fuelwood consumption is simulated to decrease from approximately 22,000 cords in 1960 to 11,000 cords in 1974. This choice leads to the assumption that factors other than those incorporated in the simulation model were, in part, responsible for the increase in fuelwood consumption from 1974 to 1981.

Since the model calculates wood use based solely on economic considerations, an explanation for the unrealisticly slow increase in simulated wood use is that factors other than real fuel cost savings were promoting fuelwood consumption in the 1974 to 1981 period. The only fuel costs savings adjustment that could be incorporated into the model is that the cost of wood capacity installation decreased dramatically after 1973, a speculation easily proven false. Even though it possibly was cheaper to heat with wood, if the wood was not purchased, than with conventional fuels, during the 1960's households chose to use wood in decreasing numbers. There can be little argument that heating with natural gas or electricity is more convenient than heating with wood. This inconvenience may be part of that decrease in the 1960 to 1974 period, as gas and electricity became available to most households. A homeowner in the 1960's might very well have grown up in a household which heated with wood, and became aware of the inconvenience associated with it. The homeowners of the late seventies and early eighties on the other hand grew up in a house heated with conventional fuels and hadn't formed a negative association with wood heat. This individual then became a prime candidate for investment in wood capacity, placing relatively lower value on the inconvenience of wood heat and higher value on reducing utility bills and gaining independence from the utility.

A national wood use survey showed that the majority of wood burning households were headeded by persons in the 30 to 44 year old age category [Skogs 1983]. Other common features of the wood burning population was a college education, middle class income, and residing in a single family dwelling [Skogs 1983]. The age finding lends evidence to the assumption of newer, younger homeowners, constituting the majority of wood burners, having a romantic vision of wood heat and tending to discount the inconvenience costs. The increased numbers of young homeowners during the 1970's, created by the post war baby boom, is a likely reason for part of the increase in residential fuelwood consumption. In many cases wood burning was not in response to economic hardship created by high conventional heating costs forcing the household to switch to wood. Households with income of $40,000 or more were four times as likely to burn wood as a household with income of $10,000 or less [Skogs 1983]. The assumption being made by this author is that investment in wood burning capacity was made in great numbers when the economics only indicated a modest increase in the number of wood burners. This is not to say that the fuel price increases (natural gas) in the 1974 to 1981 period were not substantial, but that the response to those increases was weighted towards investment in wood heating, versus other possible responses such as more insulation, turning down the thermostat, or investing in new more efficient conventional heating equipment.

The description of wood burning given above, could be interpreted as describing wood burning as a fad. Indeed, having a wood stove in the living room, getting out to cut your own wood, being self sufficient, did seem to be a popular notion in the 1970's. Combining this "back to nature" attitude with increasing nominal fuel price increases and a large supply of easily accessible firewood, and little concern about the contribution of residential burning to air pollution, helped put a positive value on the "ethics of wood burning". This attitude may have been more important in explaining the rapid escalation of wood burning in the late 1970's than was the actual dollar savings available by heating with wood. The self gathering of firewood may very well have been essential to realize any positive dollar gain from wood burning. A study by Peter Neilson for the U.M. Environmental Studies Department, entitled The Economics of Woodburning in Missoula, Montana, found that persons who purchased wood realized a positive savings only if their alternative heat was electric baseboard heat and they burned more than six cords [Neilson 1983]. Neilson's study also calculated the costs of self gathering of firewood, and if these formulas were applied to estimates of round trip distance for wood gathering [Steffel 1983], the results would be that many individuals who gather their own wood are not saving much versus purchased firewood. Calculation of the costs and savings or dis-savings of wood burning lead to a persuasive argument, if unprovable, that positive "ethics of wood burning" played a large role in the resurgence of wood as an alternative residential space heating fuel.

Projections with the WOODSTOV simulation model can be initiated in two ways. The first method is to simulate the entire period, 1960 to 2000, and consider the 1984 to 2000 period as forecasts. To do this the model has to be adjusted to inflate wood use for the 1974 to 1983 period, as the model underestimates the increase in wood use from 1974 to 1983, the period in which there are three years with survey estimates. Wood usage can be increased in the simulation by modifying a variable which, in effect causes wood investment to be more fashionable than would be indicated by the fuel cost savings wood use relationship established in the first 14 years, or 70 estimations, of the simulation. The fraction of households investing in wood capacity from the incorporated fuel cost savings factors included in the model is multiplied times a variable greater than one for the time span 1976 to 1984, with the largest wood use boost occurring in 1980. After 1980, the variable declines through 1984. In this manner wood use is increased in 1980 to 30,572 cords, slightly below the survey estimated wood use that year, of 31,800 cords. This does not however generate values for households with wood capacity, wood use per household, or average stove capacity similar to survey estimated values for 1980. Table 5.2 shows simulated wood use for the entire period, 1960 to 2000, with inflated values of fuelwood consumption from 1976 to 1984.

A second way to initiate a simulation projection is to put in the initial values, which would be in 1983, and start the simulation from that point. The model still needs to be calibrated by simulating a previous period to approximate known or estimated values. The projection simulation can be greatly altered by changing the calibration period, thus changing the relationship between wood capacity investment and fuel cost savings. In essence, the decision of what period to use for calibration is based on a judgement as to which period will best represent conditions in the projecting period.

The term calibration as it is being used here refers to the adjustment of the model so that it produces wood use values somewhat similar to the assumed historical values obtained by surveys and statewide estimations. Appendix I explains how these estimates for the Missoula area were derived. The equations in the model that are adjusted include the relationships between market penetration and wood installation costs, between market penetration and inconvenience costs, and the cost of self cut wood. This was done for the time span 1974 to 1981, when the simulation, without including a variable boosting fuelwood consumption, underestimates wood use. The model can be calibrated to produce realistic wood use growth by ignoring market penetration on wood installation, lowering the effects of market penetration on inconvenience costs, and providing a steady low cost supply of self cut wood.

Table 5.2

Simulated Residential Fuelwood Consumption
Missoula Urban Area 1960 - 2000 (cords)
* Inflated Fuelwood Consumption 1976-1984

YEAR	SIMULATED WOOD USE
1960	23,014
1961	22,331
1962	21,150
1963	19,819
1964	18,577
1965	17,251
1966	15,460
1967	13,778
1968	12,370
1969	11,452
1970	11,093
1971	11,261
1972	11,549
1973	12,003
1974	13,037
1975	14,885
1976	17,829
1977	21,468
1978	25,168
1979	28,398
1980	30,572
1981	32,229
1982	34,203
1983	36,502
1984	38,908
1985	39,929
1986	40,567
1987	40,734
1988	40,440
1989	40,014
1990	39,634
1991	39,279
1992	38,909
1993	39,262
1994	39,511
1995	39,662
1996	39,725
1997	38,980
1998	38,335
1999	37,776
2000	37,284

PROJECTION SCENARIOS

Because the period of declining fuelwood consumption followed by the increasing period of fuelwood consumption cannot both be accurately simulated with the same relationship between fuel cost savings and investment in fuelwood capacity the simulation projections will be made with two different scenarios. The scenarios are based on which time span best represents the relationship between household investment in wood capacity, and the payback period for investment in wood capacity.

The assumption of the first scenario is that the relationship between the payback period for wood capacity investment and investment in wood burning capacity calibrated for the period of greatest growth in fuelwood consumption, 1974 to 1983, will continue for the rest of the century. Households response to increasing fuel prices will be weighted towards investing in wood burning capacity, investing more heavily as the gap between wood costs and conventional fuel cost increases. Included in this scenario is the assumption that wood use will not become unfashionable behavior, nor will regulation make wood burning impractical. Basically it assumes that the motivations to invest in wood burning capacity will continue at the same magnitude as they have the last 10 years. Included in this is the assumption that there will be a continuing supply of easily accessible wood that individuals can gather at a low perceived immediate cost. This scenario is expected to produce the highest projections of wood use, and what might be considered a highest possible forecast, for any foreseeable circumstances in the Missoula area.

The second scenario assumes that part of the wood use growth since 1974 was due, in part, to the "trendiness" of wood heating. To calibrate the model for this scenario wood use is assumed accurately simulated for the period 1960 to 1983, and the underestimation from 1974 to 1983 is attributed to factors other than the relationship of fuel cost saving to wood capacity investment incorporated in the model. The simulation forecasts with this scenario are expected to be lower than the other scenario, and would represent a future attitude towards wood burning which does not view it as the fashionable, lowest cost, least inconvenient form of alternative energy. This is not to say that households will not still invest in wood capacity, only that the economics of burning wood will probably have to be more than marginal before a commitment to wood is made.

PROJECTED FUELWOOD CONSUMPTION

The results of the two simulation forecasts are presented in Table 5.3, and Figure 5.1. Both forecasts are made with base price conventional energy price forecasts, 20 percent decrease in average heating requirements, 1 percent household growth rate, and no pollution related regulation. Future fuelwood consumption projected under the conditions of Scenario 1 is significantly higher than future fuelwood consumption projected under the conditions of Scenario 2. Projected levels of fuelwood consumption are approximately 14 percent higher with Scenario 1, and the decline in total consumption is delayed untill the mid 1990's versus peak fuelwood consumption in 1988 in Scenario 2.

Table 5.3

Simulation Projections of Residential Fuelwood Consumption, Missoula Urban Area 1984 - 2000

Scenario 1: Wood use relative to fuel prices is based on behavior evident in the period 1974 - 1983.

Scenario 2: Wood use relative to fuel prices is based on behavior evident in the period 1960 - 1983.

YEAR	SCENARIO 1 (cords)	SCENARIO 2 (cords)
1984	36,852	35,667
1985	39,151	37,831
1986	40,935	39,227
1987	42,149	40,004
1988	42,606	40,054
1989	43,110	39,808
1990	43,267	39,542
1991	43,317	39,260
1992	43,282	38,920
1993	44,029	39,314
1994	44,636	39,590
1995	45,120	39,756
1996	45,495	39,828
1997	44,907	39,085
1998	44,357	38,440
1999	43,631	37,880
2000	43,320	37,386

FIGURE 5.1
SIMULATION PROJECTIONS OF RESIDENTIAL FUELWOOD CONSUMPTION 1984 – 2000, MISSOULA URBAN AREA

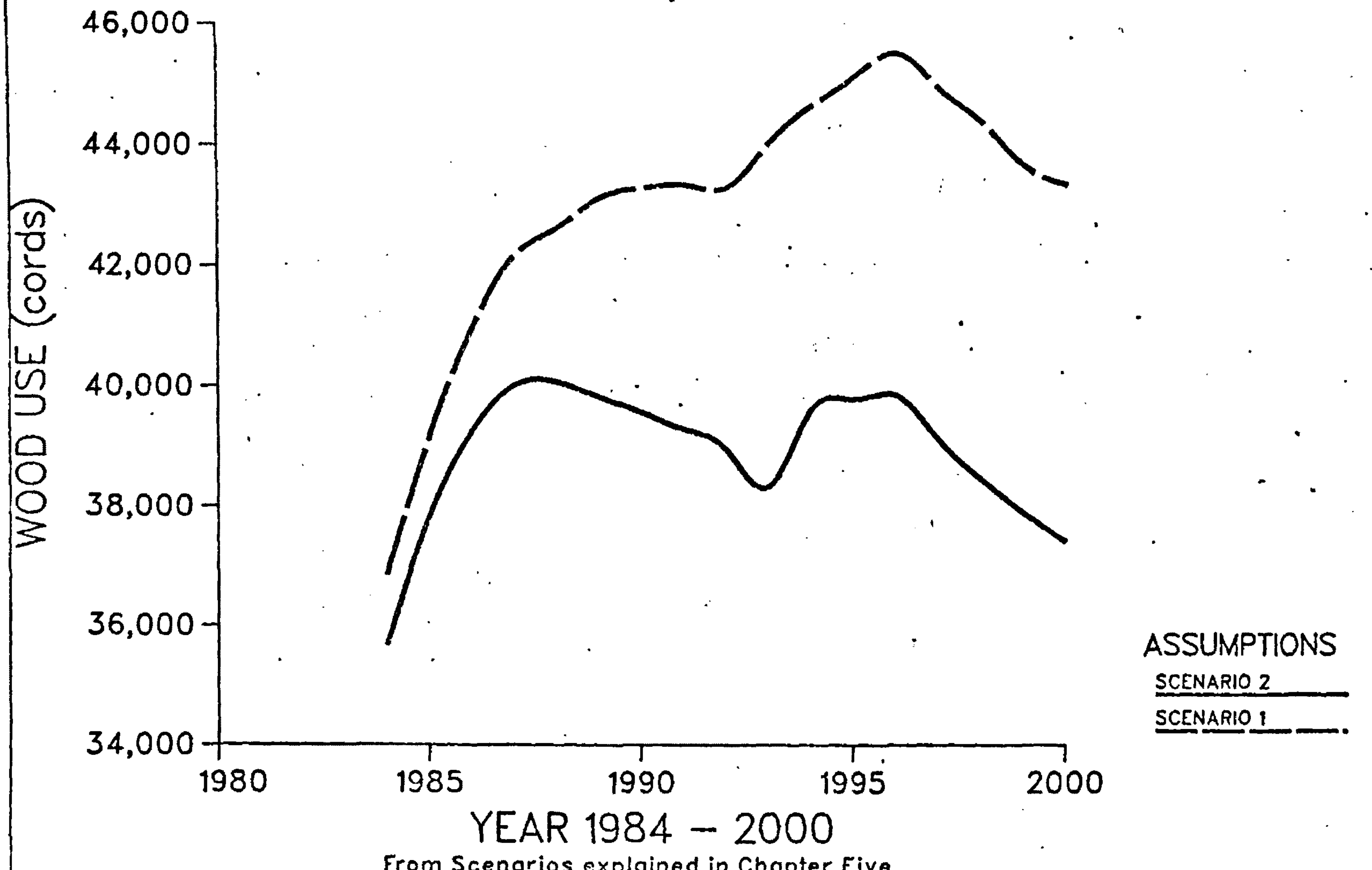


Figure 5.1

CHAPTER SIX

CONCLUSIONS AND COMMENTS

SUMMARY OF THE FINDINGS

Trying to develop models to estimate and project residential wood demand encounters problems and limitations that make it hard to work within a theoretically sound framework. The greatest hindrance is the lack of reliable data concerning levels of past residential wood use, residential wood prices, and the actual economic costs of using wood as a fuel. It is also most certainly true that the decision to burn wood involves much more than the simple economics of whether or not burning will save dollars on the total heating expenditures. Personal opinions of wood burning are important. Is it too inconvenient, or too polluting? Is gaining a measure of independence from the utility companies important? Is wood heat preferable to conventional heat? All these can be factors that lead an individual to burn or not burn despite contrasting economics.

The estimations in this thesis approached residential wood burning from an economic standpoint, assuming that households burn wood primarily for functional space heating purposes and that it is the dollar saving associated with wood heating that motivates the conversion to, and increased utilization of, wood heat. The costs of heating are represented by the price of conventional fuels relative to income in the econometric estimation, and the price of conventional fuels, price of wood, heating requirements, and wood capacity installation costs in the simulation model.

Three Missoula Health Department surveys provide estimations of the quantity of of wood use in the Missoula area for the years 1976, 1980 and 1983. Residential wood use estimates for the state of Montana, for the years 1960 to 1981 are from Estimates of U.S. Wood-Energy Consumption from 1949-1981, published by the U.S. Department of Energy [DOE/EIA 1982]. From these two data sets a residential wood use series for Missoula was created for the period 1960 to 1983, and this data series was used in the econometric estimation, and in the simulation forecasting procedure.

Inputs common to both estimation methods are Montana Power's base case projections for electricity and natural gas price, and a 1 percent growth rate in the Missoula area housing stock. The simulation estimation in addition assumes 20 percent increase in home heating efficiency between now and the year 2000, improved efficiency in gas and wood burning appliances, and no increase in the real price of wood in the next 16 years.

The conclusions derived by an econometric approach is that residential wood use in the Missoula area will continue to increase for the remainder of this decade, but at a considerably slower rate than during the late 1970's. Sometime around the end of the 1980's residential wood use will peak and slowly decline for the remainder of the century. Wood use per household is forecasted to decrease rapidly, after 1990. When this downward trend is multiplied by steady assumed growth in the number of households the net result is a slow decline in total residential wood use.

Residential wood use projections derived from the simulation model have a similar time profile compared to the econometric results. Wood use continues to grow untill the late 1980's and then slowly declines. But some calibrations of the simulation model produce significantly higher future wood burning levels than those produced by the econometric approach.

IMPORTANT ASSUMPTIONS OF THE FORECASTS

In both the econometric and simulation forecasts, the decline in residential wood consumption is tied to the relative decline in conventional fuel costs. The assumption of the econometric model is that wood consumption will decrease as the the ratio of real natural gas and electricity costs to real per capita income decreases. Four factors could alter this ratio; the price of natural natural gas and electricity, the growth in real per capita income, improved efficiency in natural gas heating, and a change in saturation levels of homes heated by natural gas or electricity. The simulation model assumes that the decrease in wood consumption is caused by an increase in the payback period on wood capacity investment. The price of natural gas, electricity and wood, the heating efficiencies of natural gas and wood, saturation of natural gas and electricity, home heating requirements (conservation), and the cost of wood capacity installation will all work to change the payback period. In both the econometric forecasts and the simulation projections future levels of residential fuelwood consumption will be increased if higher natural gas and electricity price forecast are used rather than the base case forecasts. Using Montana Power

Company's high case forecast of natural gas and electricity prices will increase peak fuelwood consumption forecasts by approximately 25 percent, but the same increasing and then decreasing pattern of fuelwood consumption will still exist.

Table 6.1, and Figure 6.1 shows forecasted and projected residential fuelwood consumption in the Missoula urban area from 1984 to 2000. The projections presented are the lower of the two simulation projections. The lower projection was chosen because factors not included in the simulation, increased wood prices, pollution regulations, inconvenience of wood heat all have the potential to decrease future levels of residential wood burning. Given these factors plus evidence from the two most recent surveys of little or no growth in residential fuelwood consumption, causes this author to judge the lower projections to be more plausible.

Future Fuelwood Supply and Price

Many other variables could play an important role in changing these projections. One of these is the price of firewood , which was not included in the econometric analysis because of its lack of statistical significance. Firewood price was established by looking in the classified section of the Missoulian for the advertised price for a cord of wood. In most cases there was more than one advertisement with the same price for one split delivered cord, and this price was assigned as the market price for that year. When converted to real dollars the average price for the entire period, 1960 to 1983 was approximately $51.

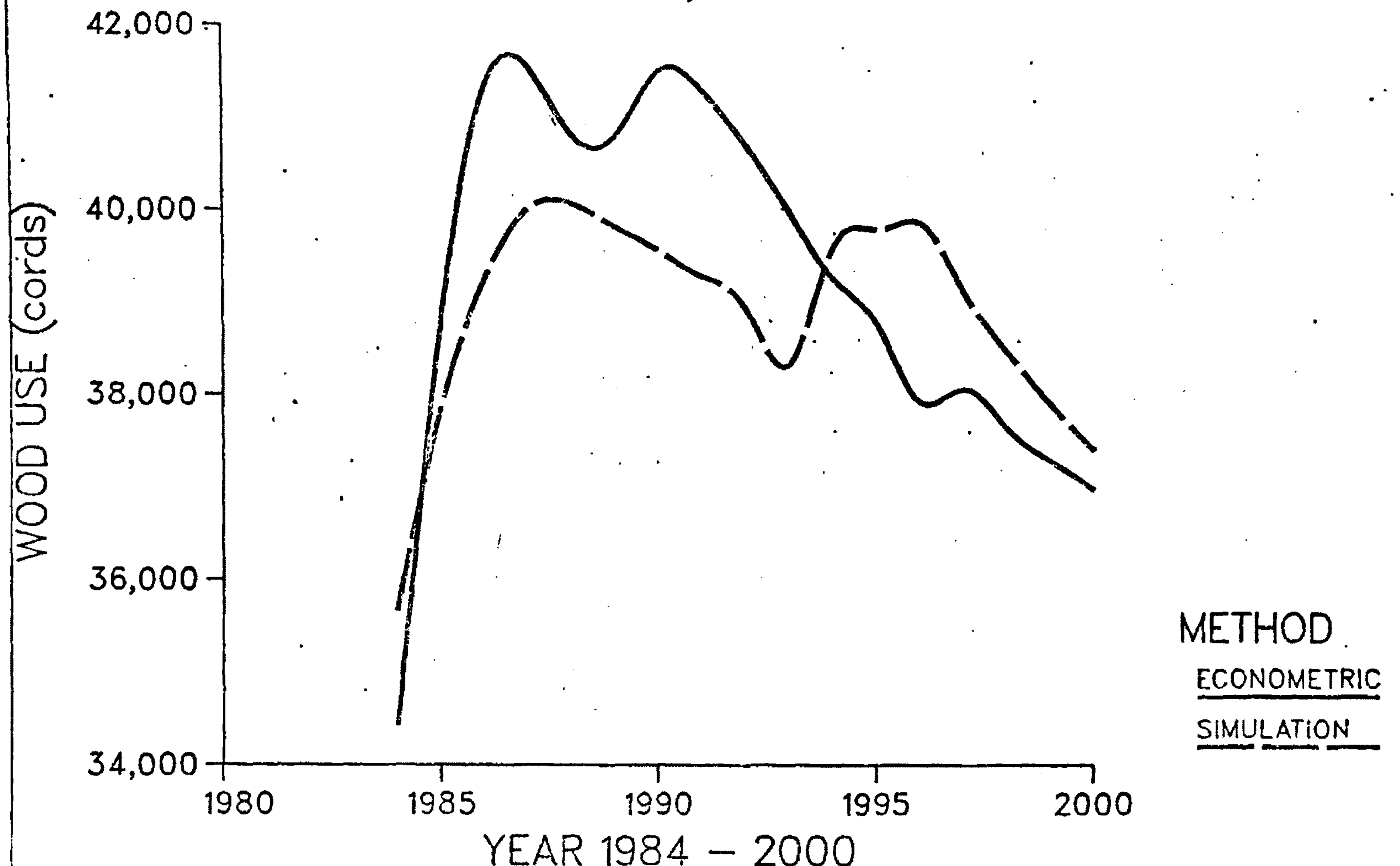
Table 6.1

Econometric Forecasts and Simulation Projections
of Residential Fuelwood Consumption
Missoula Urban Area 1984-2000

YEAR	ECONOMETRIC (cords)	SIMULATION (cords)
1984	34,430	35,670
1985	38,770	37,830
1986	41,340	39,230
1987	41,530	40,000
1988	40,790	40,050
1989	40,790	39,800
1990	41,490	39,540
1991	41,260	39,260
1992	40,670	38,920
1993	39,940	39,310
1994	39,230	39,590
1995	38,740	39,760
1996	37,900	39,830
1997	38,050	39,090
1998	37,620	38,440
1999	37,270	37,880
2000	36,970	37,390

Although wood price was included in only the simulation model, both the price of wood and the availability could become important factors. Analysis by the Bureau of Business and Economics Research at the University of Montana indicates that competition for forest residue may increase sharply in the near future. This could effect both purchasers of wood and the self gatherer. The following statement by the Bureau indicates their opinion of the potential firewood supply in western Montana.

FIGURE 6.1
FORECASTS AND PROJECTIONS OF RESIDENTIAL FUELWOOD CONSUMPTION 1984 – 2000, MISSOULA URBAN AREA



Forecasts: econometric Projections: simulation

Figure 6.1

> The supply of timber physically available to the home firewooder with only a chainsaw and pickup will become greatly reduced in some areas. As the firewooder finds that wood is becoming more difficult to gather, he will become more willing to pay for it. Whatever the reason, more and more commercialization is coming and home fuelwood is going to become more expensive, especially in heavy use areas.
>
> [Keegan 1983]

Another important factor that could alter the quantity of residential wood burning is possible regulations imposed on wood burning, regulations that are being enforced with fines beginning in the 1984-85 burning season. The effects of such regulations, aimed at improving air quality could be two-fold. One response is that wood burners find the regulations an inconvenience and added expense, prompting them to abandon wood burning entirely because the savings available are no longer worth the effort. On the other hand, regulations in Missoula and other places have created the incentive for the production of cleaner burner stoves, which besides being cleaner are also more efficient. Although these newer stoves are more expensive initially, they have the advantage of being allowed to burn during alerts and using considerably less wood. The efficiency, increased convenience and non-polluting nature of these stoves could bring more households into the wood burning group.

The assumptions of this study are that wood burners are in large part motivated by the potential savings associated with wood heating , and as long as conditions continue so that investment in wood heating is perceived as being a good investment, residential wood use in Missoula will not drastically decline. However the period of rapid growth in wood use, starting with the resurgence of wood burning in the mid 1970's, is not expected to continue, and only modest growth will occur for the remainder of the 1980's, followed by a slow decline in residential fuelwood consumption during the 1990's.

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Appendix I

Calculation of Fuelwood Consumption
Missoula Urban Area 1960 - 1983

Year	Montana Estimates (000 tons)	Montana Estimates (000 cords)	Missoula Estimates (cords)	Missoula Households	Missoula Consumption Per Household (cords)
1960	276	229	22,900	11,500	2.00
1961	255	212	21,200	11,993	1.77
1962	241	200	20,000	12,485	1.60
1963	226	188	18,800	12,978	1.45
1964	224	186	18,600	13,470	1.38
1965	212	176	17,600	13,962	1.26
1966	194	161	16,100	14,455	1.11
1967	182	151	15,100	14,948	1.01
1968	176	146	14,600	15,440	.95
1969	169	140	14,000	15,933	.88
1970	162	135	13,500	16,425	.82
1971	151	125	12,500	17,172	.73
1972	147	122	12,200	17,919	.68
1973	134	111	11,100	18,666	.59
1974	134	111	11,100	19,413	.57
1975	178	148	14,800	20,359	.73
1976	185	154	15,400	21,306	.72
1977	223	185	18,500	22,629	.82
1978	281	233	23,300	23,952	.97
1979	349	289	28,900	24,431	1.18
1980	378	314	31,800*	24,919	1.28
1981	401	333	32,500*	25,169	1.29
1982	...	...	33,300*	25,421	1.31
1983	...	...	34,000*	25,675	1.32

Where:

Montana estimates (000 tons) are from Estimates of U.S. Wood-Energy Consumption from 1949-1981, [DOE/EIA 1982].

Conversion to cords based on 17.2 Mbtus per ton and 20.7 Mbtus per cord, [DOE/EIA 1982].

Missoula area assumed to represent 10% of statewide consumption except, * where Missoula consumption is from 1980 and 1983 surveys, and estimated guesses 1981 and 1982.

Missoula housing stock from Missoula City-County Planning Board, 1960,1970,1975,1980,1983, and linear interpolation between, [Missoula Planning Board 1975], [Steffell 1980].

Appendix II

Unit Fuel Prices (1980 $), and
Saturations (% of homes using fuel for primary heating)

Year	Natural Gas ($/000 cu. ft.)	Saturation (%)	Electricity ($/kwh)	Saturation (%)	Wood ($/cord)
1960	1.86	61.0	.062	1.30	34
1961	1.84	61.9	.061	1.56	47
1962	2.08	62.7	.060	1.82	51*
1963	2.10	63.6	.059	2.08	51*
1964	2.07	64.4	.057	2.34	51*
1965	2.03	65.3	.054	2.60	64
1966	1.98	66.1	.053	2.86	62
1967	1.93	67.0	.051	3.12	50
1968	1.86	67.8	.049	3.38	52
1969	1.99	68.7	.053	3.64	52
1970	1.98	69.5	.051	3.90	53
1971	1.90	68.6	.049	5.10	41
1972	1.89	67.8	.048	6.30	49
1973	2.06	66.9	.049	7.50	42
1974	1.94	66.0	.045	8.70	42
1975	2.29	65.2	.042	9.90	46
1976	2.75	64.3	.040	11.00	44
1977	3.05	63.4	.040	12.20	54
1978	3.37	62.5	.041	13.40	51
1979	3.39	61.7	.037	14.60	56
1980	3.56	60.8	.034	15.80	55
1981	4.16	60.5	.037	15.90	52
1982	4.03	60.0	.037	16.00	62
1983	4.35	60.0	.039	16.10	62

Where:

Natural gas and electricity prices supplied by the Montana Power Company, [MPC 1983].

Wood prices are from Missoulian classified advertising section 1960 - 1983, except * where prices were unavailable and were defined as the average price for the decade.

Saturations are from Forecasts of Montana Residential Fuelwood Consumption,[ECO NW 1984], for 1960,1970,1980,1984, with linear interpolation between.

APPENDIX III

Important Forecasting Variables

Year	Nat. Gas ($/Mbtu)	Efficiency (%)	Saturation (%)	Electricity ($/kwh)	Efficiency (%)	Saturation (%)
1984	4.28	.60	.60	.058	1.00	.161
1985	4.58	.60	.60	.065	1.00	.163
1986	4.60	.60	.60	.062	1.00	.166
1987	4.38	.60	.60	.058	1.00	.168
1988	4.54	.60	.60	.050	1.00	.171
1989	4.82	.60	.60	.051	1.00	.173
1990	5.13	.60	.60	.050	1.00	.176
1991	5.26	.60	.60	.048	1.00	.178
1992	5.41	.60	.60	.046	1.00	.181
1993	5.51	.60	.60	.045	1.00	.183
1994	5.61	.60	.60	.044	1.00	.185
1995	5.72	.60	.60	.043	1.00	.188
1996	5.83	.60	.60	.043	1.00	.190
1997	5.94	.60	.60	.051	1.00	.193
1998	6.07	.60	.60	.047	1.00	.195
1999	6.20	.60	.60	.046	1.00	.197
2000	6.34	.60	.60	.045	1.00	.200

Where: Nat. Gas and Electricity are unit prices for natural gas and electricity. [MPC 1983]

Efficiency and Saturation are heating efficiencies and percentage of households heating with natural gas and electricity.

Year	AWEP ($/Mbtu)	Wood ($/cord)	Efficiency (%)	Households	Income ($ per capita)
1984	7.02	65	50.00	25,932	5515.0
1985	7.68	65	51.25	26,191	5690.0
1986	7.62	65	52.50	26,453	5979.6
1987	7.24	65	53.75	26,717	6218.5
1988	7.10	65	55.00	26,984	6381.9
1989	7.40	65	56.25	27,254	6505.4
1990	7.71	65	57.50	27,527	6589.4
1991	7.76	65	58.75	27,802	6901.3
1992	7.85	65	60.00	28,081	7149.9
1993	7.92	65	60.00	28,361	7338.3
1994	7.99	65	60.00	28,645	7490.1
1995	8.09	65	60.00	28,931	7598.7
1996	8.22	65	60.00	29,221	7934.9
1997	8.82	65	61.25	29,513	8213.0
1998	8.77	65	62.50	29,808	8432.9
1999	8.90	65	63.75	30,106	8602.0
2000	8.98	65	65.00	30,407	8733.3

Where: AWEP is average weighted energy costs calculated as:

$$AWEP = \sum_{i=1}^{2} * Price_i * Saturation_i * 1/Efficiency_i$$

Wood is the price for a cord of firewood, and Efficiency is the heating efficiency of wood.

Households is the number of households in the Missoula area.

Income is per capita income for the Montana Power Company's service area. [MPC 1983].

APPENDIX IV

Simulation Model Documentation

```
00001   REM           WOODSTOV-2 Residential Wood-Energy
00002   REM           Consumption Model
00003   REM           Norman Marshall, original author
00004   REM           Dartmouth College, 1981
00005   REM           Conversion to BASIC and other modifications;
00006   REM           William Johnson, Univ. of Mont., 1984.
00007
00008
00009
00010   LET DT = 0.2 ' TIME PERIOD FOR CALCULATIONS
00011
00050   DIM FCIWCDAT(15),GPHDAT(15),OPHDAT(15),OPFDAT(15),EPHDAT(15)
00055   DIM GEFDAT(15),HRHDAT(15),FCFEDAT(15),FCFGDAT(15),OEDAT(15)
00056   DIM WEDAT(15),EEDAT(15),EPIWCDAT(15)
00060   DIM WPHDAT(15),ETPDAT(15),TPDAT(15),HGFDAT(15),EWBENHDAT(15)
00065   DIM EWDEWCDAT(15),EWBEWCDAT(15),TABVAL(15),ESCWPDAT(15)
00067   DIM TH(210),H(210),HWC(210),CU(210),HRH(210),SC(210),AC(210)
00068   DIM APC(210),PPPT(210),WP(210),BWP(210),ESCWP(210),WC(210)
00069   DIM WE(210),EC(210),EE(210),EP(210),GC(210),GEF(210),GP(210)
00070   DIM OC(210),OE(210),OP(210),CFC(210),FCFE(210),FCFG(210)
00071   DIM FCS(210),CIW(210),CIWC(210),EPCIW(210),PFCS(210),APTC(210)
00072   DIM AFCS(210),PPFCS(210),ECCU(210),EPRCU(210),HRWC(210),NH(210)
00073   DIM TCF(210),WIC(210),NWIC(210),EMPWIC(210),EPRWIC(210),PBP(210)
00074   DIM FHIWC(210),FCIWC(210),EWBEWC(210),EPIWC(210),HIWC(210)
00075   DIM FXHWC(210),FCINH(210),EWBENH(210),EPINH(210),FRWC(210)
00076   DIM HGF(210),DSC(210),ISC(210),CFI(210),NHWC(210),PCNS(210)
00077   DIM ERPCNS(210),CAPC(210),K(210),AWU(210),AHPW(210),WUPD(210)
00078   DIM YEAR(210),FIR(210),ESDHPW(210),TP(210),EPRP(210),ETP(210)
00079   DIM WCS(210),HPW(210),DHPW(210),WU(210),FHDW(210),NALTS(210)
00080
00095   GOTO 8000  ' READ ALL TABULAR DATA INTO DAT VARIABLES
00096
00097   REM    SET INITIAL CONDITIONS
00098
00099   LET K = 1
00100   LET TH(K) = 22.919E+03
00104   LET IFHWC = .44
00108   LET H(K) = TH(K) * ( 1-IFHWC )
00112   LET HWC(K) = TH(K) * IFHWC
00116   LET CU(K) = .86
00120   LET HRH(K) = .9125E+08
00124   LET ACFI = .4
00128   LET SC(K) = TH(K) * IFHWC * HRH(K) * ACFI
00136   LET IPTC = 41
00137   LET ICOC = 425
00140   LET APC(K) = IPTC
```

```
00144   LET WUPHI = 3.5
00148   LET PPPT(K) = APC(K) * WUPHI * TH(K) * IFHWC
00149   LET AP = 3E+06
00150   LET YEAR(K) = 1983
00151
00152   FOR K = 1 TO 86
00153
00154   TH(K) = H(K) + HWC(K)
00156   LET AC(K) = SC(K)/HWC(K)
00157
00160   GOTO 1300  ' FUEL LOOP INTERPOLATED VALUES
00161
00162   REM   FUEL COST CALCULATIONS
00163
00165   LET WP(K) = BWP(K) * ESCWP(K)
00168   LET ECW = 19E+06  ' ENERGY IN A CORD OF WOOD
00171   LET WC(K) = (HRH(K)/WE(K)) * (WP(K)/ECW)
00172
00174   LET EKWHE = 3413
00177   LET EC(K) = (HRH(K)/EE(K)) * (EP(K)/EKWHE)
00178
00179   LET ETCFG = 1E+06  ' ENERGY IN A THOUSAND CU. FT. OF GAS
00181   LET GC(K) = (HRH(K)/GEF(K)) * (GP(K)/ETCFG)
00182
00183   LET EGO = 136E+03
00185   LET OC(K) = (HRH(K)/OE(K)) * (OP(K)/EGO)
00186   LET Z = .45 * EC(K)
00187   LET CFC(K)=FCFG(K)*GC(K)+FCFE(K)*EC(K)+(1-FCFG(K)-FCFE(K))*Z
00189   LET AC(K) = SC(K)/HWC(K)
00190   LET FCS(K) = ( CFC(K) - WC(K) ) * ( AC(K)/HRH(K) )
00192   LET CIW(K) = CIWC(K) * EPCIW(K)
00194   LET PFCS(K) = FCS(K)
00196   IF K > 1 THEN 199
00197   LET AFCS(K) = PFCS(K)
00198   GOTO 200
00199   LET AFCS(K) = AFCS(K-1) + (PFCS(K) - AFCS(K-1)) * (DT/1)
00200
00206   IF AFCS(K) > .01 THEN 209
00207   LET PPFCS(K) = .01
00208   GOTO 212
00209   LET PPFCS(K) = AFCS(K)
00212
00214   GOTO 1140  '  HOUSEHOLDS WITH WOOD CAPACITY
00215
00216
00217   LET FCU = 1
00219   LET CU(K) = FCU * ECCU(K) * EPRCU(K)
00221   LET NLT = 10
00223   LET HRWC(K) = HWC(K)/(NLT * FRWC(K))
00224
00225   GOTO 1050 '  HH WITH WOOD CAP FIND TABULAR VALUES
```

```
00226
00227   REM   WOOD INSTALLATION COSTS AND PAYBACK PERIOD
00228
00230   LET TCF(K) = 0
00231   LET WIC(K) = NWIC(K) * EMPWIC(K) * EPRWIC(K)
00233   LET PBP(K) = WIC(K)/(PPFCS(K) * CFI(K) * (1 - TCF(K)))
00234   IF PBP(K) > 20 THEN 236
00235   GOTO 237
00236   LET PBP(K) = 20
00237   GOTO 800    ' MORE TABULAR VALUES HH WITHOUT WOOD CAP
00238   LET FHIWC(K) = FCIWC(K) * EWBEWC(K) * EPIWC(K)
00240   LET HIWC(K) = FHIWC(K) * H(K)
00243   LET FXHWC(K) = FCINH(K) * EWBENH(K) * EPINH(K)
00245   LET TH(K) = H(K) + HWC(K)
00247   LET NH(K) = HGF(K) * TH(K) * (1 - FXHWC(K))
00253   LET NHWC(K) = HGF(K) * TH(K) *FXHWC(K)
00254
00256   REM    STOVE CAPACITY RATE CALCULATIONS
00257
00260   LET DSC(K) = AC(K) * HRWC(K)
00264   LET ISC(K) = CFI(K) *HRH(K) * (HIWC(K) + NHWC(K))
00265
00275   GOTO 4180   ' POLLUTION CALCULATIONS
00276
00277   LET PCNS(K) = IPC * ETP(K) * ERPCNS(K)
00280   LET CAPC(K) =(PCNS(K)-APC(K))*(HIWC(K)+NHWC(K))/HWC(K)
00281
00282   REM   CALCULATION OF NEW LEVELS
00283
00284   LET YEAR(K+1) = YEAR(K) + DT
00286   LET APC(K+1) = APC(K) + ( DT * CAPC(K) )
00288
00290   LET SC(K+1) = SC(K) + ( DT * (ISC(K) - DSC(K)) )
00294   LET H(K+1) = H(K) + DT * (NH(K) - HIWC(K) + HRWC(K))
00295   LET HWC(K+1) = HWC(K) + DT*(NHWC(K)+HIWC(K)-HRWC(K))
00296   LET CU(K+1) = ECCU(K) *EPRCU(K)
00297   REM CALCULATION OF AUXILIARY OUTPUT
00299   LET WCS(K) = HIWC(K) + NHWC(K)
00300   LET WU(K) = SC(K) * CU(K)/WE(K)/ECW
00301   LET PPPT(K) = WU(K)*41
00302   LET WUPD(K) = WU(K)/24
00303   LET NALTS(K+1) = PPPT(K)/75000
00304   LET HPW(K) = SC(K) *CU(K) * WE(K)
00305   LET AHPW(K) = HPW(K)/HWC(K)
00306   LET DHPW(K) = HPW(K) * ESDHPW(K)
00308   LET FHDW(K) = DHPW(K)/(HRH(K) * TH(K))
00309   LET PPPT(K+1) = APTC(K) * WU(K) * EPRP(K)
00310   LET WCS(K) = HIWC(K) + NHWC(K)
00311   LET AWU(K) = WU(K)/HWC(K)
00312   NEXT K
00314   PRINT " YEAR ", " HOUSEHOLDS ", " HOUSEHOLDS "," NEW HOUSEHOLDS"
```

```
00315  PRINT "      ", " W/O WOOD   ", " WITH WOOD  "," WITH WOOD    "
00316  PRINT "      ", " CAPACITY   ", " CAPACITY   "," CAPACITY     "
00317  PRINT "      "
00318  FOR K = 1 TO 86 STEP 5
00319  PRINT YEAR(K),H(K),HWC(K),NHWC(K)
00320  NEXT K
00321
00323  PRINT "   "
00325  PRINT " YEAR ", " WOOD USE ", " AVERAGE ", " AVERAGE "
00326  PRINT "      ", " CORDS/YR. ", " WOOD USE ", " STOVE "
00327  PRINT "      ", "            ", " CORDS/YR/ ", " CAPACITY "
00328  PRINT "      ", "            ", " HOUSEHOLD ", " BTUS     "
00329  PRINT "    "
00330  FOR K = 1 TO 86 STEP 5
00331  PRINT YEAR(K),WU(K),AWU(K),AC(K)
00332  NEXT K
00333  PRINT "    "
00337  PRINT " YEAR ", " AVERAGE  ", " DISPLACED ", " FRACTION OF "
00338  PRINT "      ", " HEAT PRO- ", " HEAT PRO- ", " HEAT DIS-   "
00339  PRINT "      ", " VIDED BY,  ", " VIDED BY   ", " PLACED BY "
00340  PRINT "     ", " WOOD,BTUS  ", " WOOD, BTUS ", " WOOD       "
00341  PRINT "    "
00342  FOR K = 1 TO 86 STEP 5
00343  PRINT YEAR(K),AHPW(K),DHPW(K),FHDW(K)
00344  NEXT K
00346  PRINT " YEAR ", " FCS ", " CFC ", " PBP ", " NALTS "
00347  PRINT "    "
00348  FOR K = 1 TO 86 STEP 5
00349  PRINT YEAR(K),FCS(K),CFC(K),PBP(K),NALTS(K)
00350  NEXT K
00351  GOTO 30600
00352  FOR K = 1 TO 86 STEP 5
00353  PRINT YEAR(K),PP(K)
00354  NEXT K
00355  GOTO 30600
00358  PRINT " YEAR ", " HWC/TH ", " HRH ", " AC/HRH "
00359  PRINT "    "
00360  FOR K = 1 TO 86 STEP 5
00361  PRINT YEAR(K), HWC(K)/TH(K), HRH(K), AC(K)/HRH(K)
00362  NEXT K
00365  GOTO 30600
00400
00500
00600
00629
00700
00798  REM   HOUSEHOLDS WITHOUT WOOD CAPACITY
00799
00800  FOR I = 1 TO 14
00805  LET TABVAL(I) = HGFDAT(I)
00810  NEXT I
```

```
00815   LET X = YEAR(K)
00820   GOSUB 7000
00825   LET HGF(K) = Y
00830   FOR I = 1 TO 10
00835   LET TABVAL(I) = FCINHDAT(I)
00840   NEXT I
00845   LET X = AFCS(K)
00850   GOSUB 7000
00855   LET FCINH(K) = Y
00860   FOR I = 1 TO 14
00865   LET TABVAL(I) = EWBENHDAT(I)
00870   NEXT I
00875   LET X = YEAR(K)
00880   GOSUB 7000
00885   LET EWBENH(K) = Y
00890   FOR I = 1 TO 9
00895   LET TABVAL(I) = EPINHDAT(I)
00900   NEXT I
00905   LET X = PPPT(K)/AP
00910   GOSUB 7000
00915   LET EPINH(K) = Y
00920   FOR I = 1 TO 14
00925   LET TABVAL(I) = FCIWCDAT(I)
00930   NEXT I
00935   LET X = PBP(K)
00940   GOSUB 7000
00945   FCIWC(K) = Y
00946   GOTO 238
00950   FOR I = 1 TO 9
00955   LET TABVAL(I) = EMPWICDAT(I)
01000   NEXT I
01005   LET X = HWC(K)/TH(K)
01010   GOSUB 7000
01015   LET EMPWIC(K) = Y
01020   FOR I = 1 TO 9
01025   LET TABVAL(I) = NWICDAT(I)
01030   NEXT I
01035   LET X = CFI(K)
01040   GOSUB 7000
01045   LET NWIC(K) = Y
01046   GOTO 230
01050   FOR I = 1 TO 10
01055   LET TABVAL(I) = CFIDAT(I)
01060   NEXT I
01065   LET X = AFCS(K)
01070   GOSUB 7000
01075   LET CFI(K) = Y
01080   FOR I = 1 TO 14
01085   LET TABVAL(I) = EWBEWCDAT(I)
01090   NEXT I
01095   LET X = YEAR(K)
```

```
01100   GOSUB 7000
01105   LET EWBEWC(K) = Y
01110   FOR I = 1 TO 9
01115   LET TABVAL(I) = EPIWCDAT(I)
01120   NEXT I
01125   LET X = PPPT(K)/AP
01130   GOSUB 7000
01135   LET EPIWC(K) = Y
01136   GOTO 950
01137   REM  HOUSEHOLDS WITH WOOD CAPACITY
01138
01140   FOR I = 1 TO 9
01145   LET TABVAL(I) = EPRWICDAT(I)
01150   NEXT I
01155   LET X = PPPT(K)/AP
01160   GOSUB 7000
01165   LET EPRWIC(K) = Y
01170   FOR I = 1 TO 9
01175   LET TABVAL(I) = FRWCDAT(I)
01180   NEXT I
01185   LET X = CU(K)
01190   GOSUB 7000
01195   LET FRWC(K) = Y
01200   FOR I = 1 TO 10
01205   LET TABVAL(I) = ECCUDAT(I)
01210   NEXT I
01215   LET X = AFCS(K)
01220   GOSUB 7000
01225   LET ECCU(K) =Y
01230   FOR I = 1 TO 9
01235   LET TABVAL(I) = EPRCUDAT(I)
01240   NEXT I
01245   LET X = PPPT(K)/AP
01250   GOSUB 7000
01255   LET EPRCU(K) = Y
01257   GOTO 216
01260   FOR I = 1 TO 9
01265   LET TABVAL(I) = FIRDAT(I)
01270   NEXT I
01275   LET X = HRWC(K)/(HIWC(K) + 1 )
01280   GOSUB 7000
01285   LET FIR(K) = Y
01297
01298   REM    FUEL COSTS
01299
01300   FOR I = 1 TO 14
01310   LET TABVAL(I) = HRHDAT(I)
01320   NEXT I
01330   LET X = YEAR(K)
01340   GOSUB 7000
01350   LET HRH(K) = Y
```

```
01360   FOR I = 1 TO 9
01370   LET TABVAL(I) = EPCIWDAT(I)
01380   NEXT I
01390   LET X = HWC(K)/TH(K)
01400   GOSUB 7000
01410   LET EPCIW(K) = Y
01420   FOR I = 1 TO 9
01430   LET TABVAL(I) = CIWCDAT(I)
01440   NEXT I
01450   LET X = AC(K)/HRH(K)
01460   GOSUB 7000
01470   LET CIWC(K) = Y
01480   FOR I = 1 TO 14
01490   LET TABVAL(I) = FCFEDAT(I)
01500   NEXT I
01510   LET X = YEAR(K)
01520   GOSUB 7000
01530   LET FCFE(K) = Y
01540   FOR I = 1 TO 14
01550   LET TABVAL(I) = FCFGDAT(I)
01560   NEXT I
01570   LET X = YEAR(K)
01580   GOSUB 7000
01590   LET FCFG(K) = Y
01600   FOR I = 1 TO 14
01610   LET TABVAL(I) = OEDAT(I)
01620   NEXT I
01630   LET X = YEAR(K)
01640   GOSUB 7000
01650   LET OE(K) = Y
01655   IF YEAR(K) > 1980 THEN 1720
01660   FOR I = 1 TO 14
01670   LET TABVAL(I) = OPHDAT(I)
01680   NEXT I
01690   LET X = YEAR(K)
01700   GOSUB 7000
01710   LET OP(K) = Y
01715   GOTO 1780
01720   FOR I = 1 TO 9
01730   LET TABVAL(I) = OPFDAT(I)
01740   NEXT I
01750   LET X = YEAR(K)
01760   GOSUB 7000
01770   LET OP(K) = Y
01780   FOR I = 1 TO 14
01790   LET TABVAL(I) = GEFDAT(I)
01800   NEXT I
01810   LET X = YEAR(K)
01820   GOSUB 7000
01830   LET GEF(K) = Y
01835   IF YEAR(K) > 1980 THEN 1900
```

```
01840   FOR I = 1 TO 14
01850   LET TABVAL(I) = GPHDAT(I)
01860   NEXT I
01870   LET X = YEAR(K)
01880   GOSUB 7000
01890   LET GP(K) = Y
01895   GOTO 1960
01900   FOR I = 1 TO 9
01910   LET TABVAL(I) = GPFDAT(I)
01920   NEXT I
01930   LET X = YEAR(K)
01940   GOSUB 7000
01950   LET GP(K) = Y
01960   FOR I = 1 TO 14
01970   LET TABVAL(I) = EEDAT(I)
01980   NEXT I
01990   LET X = YEAR(K)
02000   GOSUB 7000
02010   LET EE(K) = Y
02015   IF YEAR(K) > 1980 THEN 2080
02020   FOR I = 1 TO 14
02030   LET TABVAL(I) = EPHDAT(I)
02040   NEXT I
02050   LET X = YEAR(K)
02060   GOSUB 7000
02070   LET EP(K) = Y
02075   GOTO 3040
02080   FOR I = 1 TO 9
02090   LET TABVAL(I) = EPFDAT(I)
03000   NEXT I
03010   LET X = YEAR(K)
03020   GOSUB 7000
03030   LET EP(K) = Y
03040   FOR I = 1 TO 14
03050   LET TABVAL(I) = WEDAT(I)
03060   NEXT I
03070   LET X = YEAR(K)
03080   GOSUB 7000
03090   LET WE(K) = Y
03995   IF YEAR(K) > 1980 THEN 4060
04000   FOR I = 1 TO 14
04010   LET TABVAL(I) = WPHDAT(I)
04020   NEXT I
04030   LET X = YEAR(K)
04040   GOSUB 7000
04050   LET BWP(K) = Y
04055   GOTO 4115
04060   FOR I = 1 TO 9
04070   LET TABVAL(I) = WPFDAT(I)
04080   NEXT I
04090   LET X = YEAR(K)
```

```
04100   GOSUB 7000
04110   LET BWP(K) = Y
04115   FOR I = 1 TO 9
04120   LET TABVAL(I) = ESCWPDAT(I)
04125   NEXT I
04130   LET X = HWC(K)/TH(K)
04135   GOSUB 7000
04140   LET ESCWP(K) = Y
04145   FOR I = 1 TO 9
04150   LET TABVAL(I) = ESDHPWDAT(I)
04155   NEXT I
04160   LET X = AC(K)/HRH(K)
04165   GOSUB 7000
04170   LET ESDHPW(K) = Y
04172   GOTO 161
04176
04177   REM    POLLUTION MODULE
04179
04180   FOR I = 1 TO 14
04185   LET TABVAL(I) = ETPDAT(I)
04190   NEXT I
04200   LET X = YEAR(K)
04210   GOSUB 7000
04215   LET ETP(K) = Y
04220   FOR I = 1 TO 9
04225   LET TABVAL(I) = ERPCNSDAT(I)
04230   NEXT I
04235   LET X = PPPT(K)/AP
04240   GOSUB 7000
04245   LET ERPCNS(K) = Y
04250   FOR I = 1 TO 14
04255   LET TABVAL(I) = TPDAT(I)
04260   NEXT I
04265   LET X = YEAR(K)
04270   GOSUB 7000
04275   LET TP(K) = Y
04280   FOR I = 1 TO 9
04285   LET TABVAL(I) = EPRPDAT(I)
04290   NEXT I
04295   LET X = PPPT(K)/AP
04300   GOSUB 7000
04305   LET EPRP(K) = Y
04306   GOTO 277
04406
04506
06900
06998   REM  SUBROUTINE FOR CALCULATING Y VALUES
06999
07000
07003   LET XO = TABVAL(1)
07005   IF X < XO THEN 7300
```

```
07007    IF X > TABVAL(2) THEN 7308
07010    LET J = 1
07012    IF X > XO + TABVAL(3) THEN 7015
07013    GOTO 7200
07015    LET XO = XO + TABVAL(3)
07017    LET J = J+1
07019    GOTO 7012
07100    RETURN
07200    LET AD = ((TABVAL(J+3)-TABVAL(J+4))/TABVAL(3)) *(X-XO)
07205    LET Y = TABVAL(J+3) - AD
07210    GOTO 7100
07300    PRINT K, X, TABVAL(1), TABVAL(2), "VALUE TOO SMALL"
07301    GOTO 30600
07308    PRINT K, X, TABVAL(1), TABVAL(2), "VALUE TOO LARGE"
07310    GOTO 30600
07400
07900
08000    REM      HOUSEHOLDS WITHOUT WOOD CAPACITY
08100
08200    DATA 1960,2000,4,.0355,.0355,.0355,.0355,.0355,.0355,.0355
08210    DATA .01,.01,.01,.01
08300    FOR I = 1 TO 14
08400    READ HGFDAT(I)
08500    NEXT I
08600
08700    DATA -200,1000,200,.02,.05,.1,.2,.3,.4,.5
08800    FOR I = 1 TO 10
08900    READ FCINHDAT (I)
09000    NEXT I
09100
09200    DATA 1960,2000,4,1,1,1,1,1,1,1,1,1,1,1
09300    FOR I = 1 TO 14
09400    READ EWBENHDAT(I)
09500    NEXT I
09600
09700    DATA 0,5,1,1,1,1,1,1,1
09800    FOR I = 1 TO 9
09900    READ EPINHDAT(I)
10000    NEXT I
10100
10200    DATA 0,20,2,.2,.2,.15,.1,.05,0,0,0,0,0,0
10300    FOR I = 1 TO 14
10400    READ FCIWCDAT(I)
10500    NEXT I
10600
10700    DATA 0,1,.2,1,1,1,1,1,1
10800    FOR I = 1 TO 9
10900    READ EMPWICDAT(I)
11000    NEXT I
11100
11200    DATA 0,1,.2,200,300,400,600,1000,1500
```

```
11300   FOR I = 1 TO 9
11400   READ NWICDAT(I)
11500   NEXT I
11600
11700   DATA -200,1000,200,.2,.3,.4,.6,.8,.9,.95
11800   FOR I = 1 TO 10
11900   READ CFIDAT(I)
12000   NEXT I
12100
12200   DATA 1960,2000,4,1,1,1,1,1,1,1,1,1,1,1
12300   FOR I = 1 TO 14
12400   READ EWBEWCDAT(I)
12500   NEXT I
12600
12700   DATA 0,5,1,1,1,1,1,1,1
12800   FOR I = 1 TO 9
12900   READ EPIWCDAT(I)
13000   NEXT I
13100
13200   REM  HOUSEHOLDS WITH WOOD CAPACITY
13300
13400   DATA 0,5,1,1,1,1,1,1,1
13500   FOR I = 1 TO 9
13600   READ EPRWICDAT(I)
13700   NEXT I
13800
13900   DATA .5,1,.1,2,1.5,1.25,1,.75,.5
14000   FOR I = 1 TO 9
14100   READ FRWCDAT(I)
14200   NEXT I
14300
14400   DATA -200,1000,200,.5,.7,.85,.93,.96,.98,1
14500   FOR I = 1 TO 10
14600   READ ECCUDAT(I)
14700   NEXT I
14800
14900   DATA 0,5,1,1,1,1,1,1,1
15000   FOR I = 1 TO 9
15100   READ EPRCUDAT(I)
15200   NEXT I
15300
15400   DATA 0,2,.4,0,.2,.4,.6,.8,1
15500   FOR I = 1 TO 9
15600   READ FIRDAT(I)
15700   NEXT I
15800
15900   REM FUEL COSTS
16000
16100   DATA 0,1,.2,0,0,0,0,0,0
16200   FOR I = 1 TO 9
16300   READ CIWCDAT(I)
```

```
16400   NEXT I
16500
16600   DATA 0,1,.2,0,.05,.1,.15,.2,.25
16700   FOR I = 1 TO 9
16800   READ EPCIWDAT(I)
16900   NEXT I
17000
17100   DATA 1960,2000,4,120E+06,115E+06,110E+06,105E+06,100E+06,95E+06
17200   DATA 90E+06,85E+06,80E+06,75E+06,70E+06
17300   FOR I = 1 TO 14
17400   READ HRHDAT(I)
17500   NEXT I
17600
17700   DATA 1960,2000,4,.013,.0234,.0338,.063,.11,.158,.161,.171
17710   DATA .181,.190,.20
17800   FOR I = 1 TO 14
17900   READ FCFEDAT(I)
18000   NEXT I
18100
18200   DATA 1960,2000,4,.61,.644,.678,.678,.643,.608,.6,.6,.6,.6,.6
18300   FOR I = 1 TO 14
18400   READ FCFGDAT(I)
18500   NEXT I
18600
18700   DATA 1960,2000,4,.5,.5,.5,.5,.5,.5,.5,.5,.5,.5,.5
18800   FOR I = 1 TO 14
18900   READ OEDAT(I)
19000   NEXT I
19100
19200   DATA 1960,2000,4,0,0,0,0,0,0,0
19300   FOR I = 1 TO 10
19400   READ OPHDAT(I)
19500   NEXT I
19600
19700   DATA 1980,2005,5,0,0,0,0,0,0
19800   FOR I = 1 TO 9
19900   READ OPFDAT(I)
20000   NEXT I
20100
20200   DATA 1960,2000,4,.6,.6,.6,.6,.6,.6,.6,.65,.65,.65,.65
20300   FOR I = 1 TO 14
20400   READ GEFDAT(I)
20500   NEXT I
20600
20700   DATA 1960,1980,2,1.86,2.08,2.07,1.98,1.86,1.98,1.89,1.94,2.75
20800   DATA 3.37,3.56
20900   FOR I = 1 TO 14
21000   READ GPHDAT(I)
21100   NEXT I
21200
21300   DATA 1980,2000,4,3.56,4.28,4.59,5.41,5.83,6.34
```

```
21400   FOR I = 1 TO 9
21500   READ GPFDAT(I)
21600   NEXT I
21700
21800   DATA 1960,2000,4,1,1,1,1,1,1,1,1,1,1,1
21900   FOR I = 1 TO 14
22000   READ EEDAT(I)
22100   NEXT I
22200
22300   DATA 1960,1980,2,.062,.060,.057,.053,.049,.051,.048,.045,.040
22400   DATA .041,.034
22500   FOR I = 1 TO 14
22600   READ EPHDAT(I)
22700   NEXT I
22800
22900   DATA 1980,2000,4,.034,.058,.050,.046,.043,.045
23000   FOR I = 1 TO 9
23100   READ EPFDAT(I)
23200   NEXT I
23300
23400   DATA 1960,2000,4,.4,.45,.5,.5,.5,.5,.5,.55,.60,.60,.65
23500   FOR I = 1 TO 14
23600   READ WEDAT(I)
23700   NEXT I
23800
23900   DATA 1960,1980,2,34,51,51,62,52,53,49,42,44,51,55
24000   FOR I = 1 TO 14
24100   READ WPHDAT(I)
24200   NEXT I
24300
24400   DATA 1980,2000,4,55,65,65,65,65,65
24500   FOR I = 1 TO 9
24600   READ WPFDAT(I)
24700   NEXT I
24800
24900
25000   DATA 0,1,.2,.25,.25,.25,.25,.25,.25
25100   FOR I = 1 TO 9
25200   READ ESCWPDAT(I)
25300   NEXT I
25400
25500   DATA 0,1,.2,1.5,1.4,1.3,1.2,1.1,1
25600   FOR I = 1 TO 9
25700   READ ESDHPWDAT(I)
25800   NEXT I
25900
26000   REM     POLLUTION MODULE
26100
26200
26300   DATA 1960,2000,4,1,1,1,1,1,1,1,1,1,1,1
26400   FOR I = 1 TO 14
```

```
26500   READ ETPDAT(I)
26600   NEXT I
26700
26800   DATA 0,5,1,1,1,1,1,1,1
26900   FOR I = 1 TO 9
27000   READ ERPCNSDAT(I)
27100   NEXT I
27200
27300   DATA 1960,2000,4,0,0,0,0,0,0,0,0,0,0,0
27400   FOR I = 1 TO 14
27500   READ TPDAT(I)
27600   NEXT I
27700
27800   DATA 0,5,1,1,1,1,1,1,1
27900   FOR I = 1 TO 9
28000   READ EPRPDAT(I)
28100   NEXT I
28500
28505   GOTO 99
28600
30600   END
```

Note: For a complete explanation of WOODSTOV-2 equations and variables see;
Marshall, Norman. The Dynamics of Residential Wood-Energy in New England 1970 - 2000, RP no. 363, Resource Policy Center, Dartmouth College, Hanover, NH, October 1981.

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