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FACTORS INFLUENCING COUNTY LEVEL
HOUSEHOLD FUELWOOD USE

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KENNETH EDWARD SKOG

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of the requirements for

PH.D. degree in FORESTRY

Robert S. Manthy
Major professor

ROBERT S. MANTHY

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FACTORS INFLUENCING COUNTY LEVEL
HOUSEHOLD FUELWOOD USE

by
Kenneth Edward Skog

A DISSERTATION

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ABSTRACT

FACTORS INFLUENCING COUNTY LEVEL
HOUSEHOLD FUELWOOD USE

By
Kenneth E. Skog

This study explains household fuelwood consumption behavior at the county level by linking it to economic and demographic conditions in counties. Using this link, counties are identified where potential fuelwood use problems and benefits are greatest. A probit equation estimates household probability of wood use (percent woodburners in a county) based on county heating degree days, household income, nonwood fuel price, fuelwood price, percent forest land, population density, and fraction of households using various types of heating equipment. A linear-in-parameters equation estimates average wood consumed by a woodburner based on county heating degree days, household income, percent forest land, and price of nonwood fuel divided by fuelwood price. Parameters are estimated using fuelwood use data for individual households from a 1980-81 nationwide survey.

The probit equation predicts percentage of woodburners well over a wide range of county conditions. The wood consumption equation overpredicts for counties with high income and high population density (over 6000 persons per

Kenneth Edward Skog

square mile).

The model shows average woodburning per household over all households decreases with increasing population density, and the influence of county economic characteristics varies with density. Elasticity with respect to relative nonwood fuel price (divided by wood price) is positive, but decreases as relative price increases. Relative nonwood fuel price elasticity is lowest where woodburning is greatest -- in counties with low density and high relative prices.

Elasticity with respect to income is negative for higher density and lower income counties. This is caused by rapidly falling average wood use per woodburner as income increases (more households use fireplaces rather than stoves) even though participation increases. Elasticity is positive for low density/higher income counties. In these counties participation also rises with income, but amounts burned per woodburner decrease relatively little; overall, average amount burned increases with income.

Certain states have a high proportion of their fuelwood consumption in counties where the fuelwood use per unit forest is high. The following have 70% or more of their consumption in counties where consumption is .15 cords/acre of forest or more: Connecticut, Indiana, Iowa, Maryland,

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**Massachusetts, Nebraska, New Jersey, Ohio, Rhode Island,
and Washington.**

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I. INTRODUCTION

In 1981, an estimated 42 million cords of fuelwood were burned for home heating--an amount equal to one-fourth the amount going into all other wood products.¹ This large use presents potential forest management and marketing problems and opportunities for certain local areas. It is the purpose of this study to determine local areas of heavy fuelwood use by linking local economic characteristics of households and areas to fuelwood consumption. Using this link we can estimate local fuelwood use from local characteristics. We can also use the link to suggest how local consumption may change as economic conditions change. "Local areas" refers to individual counties in a state.

The Problem

Fuelwood use poses potential problems and opportunities for certain local areas. Fuelwood for home heating consumes roughly one-half as much roundwood as pulpwood

¹Kenneth E. Skog and Irene A. Watterson. 1984. Residential fuelwood use in the United States. Journal of Forestry 82(12):742-747 (December).

(roundwood and chips).² In certain areas high fuelwood consumption poses problems or opportunities, including:

- Avoidable competition between pulpwood and fuelwood users
- Air pollution health hazard from woodburning stoves
- Damage to ecosystems from improper harvesting
- An opportunity to increase the rate and quality of tree growth by thinning
- An opportunity to increase local employment and income
- An opportunity to decrease local export of dollars outside an area to buy nonwood heating fuels.

These problems and opportunities can be better dealt with by business and government if, for local areas, they know current fuelwood consumption and the likely change in consumption as economic conditions change.

Local use could be determined by surveys in each county of the U.S. But this study uses an alternative method to estimate local consumption by linking economic characteristics of households to much less detailed survey data on consumption.

Fuelwood Use Problems. Without knowing amounts or locations of fuelwood use, many authors have speculated on the impact of heavy fuelwood use. The exception is direct evidence of air pollution impacts. In Oregon, wood stove

²Ibid. p. 746.

particulate emissions increased from 1,000 tons/year in 1970 to 7,000 tons/year in 1983. Other Oregon industry is held to 4,000 tons/year by the Federal Clean Air Act of 1970.³ As a result, a new state law will require stoves sold after 1986 to meet clean burning standards. Pollution has also prompted restrictions on burning in Missoula, Montana, and in Aspen and Vail, Colorado. Recent surveys also show heavy woodburning in rural areas outside the already identified problem areas in the Northwest and New England.^{4,5}

Unlike direct evidence of air pollution, evidence of competition between pulpwood and fuelwood cutters is sketchy. Some foresters have warned that high prices for fuelwood would encourage harvest of trees without regard to their possible higher value as pulpwood or sawlogs.^{6,7} Some see expanded possibilities for fuelwood to be removed along with pulpwood, sawlogs and veneer logs in coordinated

³E. Carlson. 1983. Smoke from wood becomes big polluter in Northern U.S. Wall Street Journal. October 4.

⁴Skog and Watterson. 1984. Residential fuelwood use in the United States. p. 743.

⁵USDOE Energy Information Administration. 1983. Residential energy consumption survey: consumption and expenditures, April 1981 through 1982, part 2: regional data. DOE/EIA-0321/2 (81), p. 207-211.

⁶Michael Harris. 1980. The Boom in wood use: promise or peril. American Forests 86(9):57-60, (September).

⁷W. K. Murphey et al. 1981. Some implications of using wood as fuel. Southern Journal of Applied Forestry 5(1):16-19 (February).

operations.⁸ Others focus on expanded opportunities for economical timber stand improvement by removing poor quality trees for fuel.^{9,10} Local relationships between traditional timber markets and fuelwood markets will depend on key local conditions and public or private programs for constructive use of fuelwood harvests.

Researchers speculate that ecological consequences of fuelwood harvesting will range from beneficial to tragic. Heavy cutting and gathering may cause nutrient loss, soil disturbance, regeneration of different plant species, fire hazard, erosion/leaching, and/or improved or damaged wildlife habitat.¹¹

Heaviest cutting, using whole tree harvesting, is most likely with integrated operations where some roundwood is chipped to fuel industrial boilers or split into pieces and sold as residential fuelwood. Usually household cutting is not as severe, but to the extent that a household cuts all dead trees or all live trees or all logging waste from a

⁸Robert Seidl. 1980. Energy From Wood: A new dimension in utilization. TAPPI 63(1):26-29 (January).

⁹D.B. Field. 1982. Economic benefits from harvesting in forest management. pp. 67-81. In Proceedings of fuelwood management and utilization seminar, Nov. 9-11, 1982 (East Lansing, MI: Michigan State University Dept. of Forestry) p. 67.

¹⁰Arlyn W. Perkey. 1981. The New England fuelwood project. American Forests 87(8):13-15 (August).

¹¹R. I. Van Hook et al. 1982. Environmental effects of harvesting forests for energy. Forest Ecology and Management 4:79-94.

site, certain animals will suffer from a habitat change.^{12,13} Over many years fuelwood cutting and collecting will cause slow changes as millions of acres are harvested.

Fuelwood Use Opportunities. Heavy fuelwood use provides an opportunity to thin stands and thereby increase timber quality and growth. In New England, federal funds have been used to pay foresters to supervise fuelwood removal in certain privately owned stands.¹⁴ The program requires a stand to yield 5 cords of fuelwood per acre. At this removal level, the 42 million cords used nationwide in 1980-81 could have treated 8.4 million acres of the 187 million acres of private nonindustrial forest land. In Georgia and North Carolina, the Tennessee Valley Authority, in partnership with farm cooperatives, buys scrub timber from farmers, converts it to fuelwood and distributes it in 35-pound bundles to Atlanta retail stores.¹⁵

¹²Louise M. Tritton and Thomas C. Siccarra. 1977. The fallacy of playing pick-up-sticks fuelwood. Connecticut Woodlands 42(4):17 (Winter).

¹³John D. Gill. 1982. Wildlife and other multiple use considerations. pp. 106-109. In proceedings of fuelwood management and utilization seminar, Nov. 9-11, 1982 (East Lansing, MI: Michigan State University, Dept. of Forestry).

¹⁴Perkey. 1981. The New England fuelwood project. p. 13-15.

¹⁵Leslie Henderson. 1981. Greenbacks from green junk. American Forests 87(4):12-15 (April).

Foresters currently influence practices for only a small fraction of fuelwood harvests. Only 12% of households that cut from land they own select trees to cut based on advice from a forester.¹⁶ Households cutting from their own land removed 7.9 million cords in 1981. Households cut a total of 30 million cords and vendors cut about 12 million cords.¹⁷

Fuelwood harvesting and burning contributes immediately to a local economy by providing jobs, dollar income and expenditure, and by decreasing dollars sent out of the area to pay for nonwood fuel. In the long run, cutting fuelwood for timber stand improvement can produce more high valued forest products. These contributions are offset somewhat by loss of local employment and income for those selling nonwood fuels.

To the extent that fuelwood demand drives up timber prices, there is a risk that increased fuelwood use could reduce production of high-value-added products--lumber and paper--which contribute more dollars per cubic foot of roundwood to an economy than fuelwood.¹⁸ Economic

¹⁶Kenneth E. Skog and Irene A. Watterson. 1983. Residential fuelwood use in the United States: 1980-81. USDA Forest Service, Forest Products Laboratory, National Technical Information Service, ADA 131724. (Springfield, VA) p. 42.

¹⁷Ibid. p. 38.

¹⁸Field. 1982. Economic benefits from harvesting in forest management. p. 73.

advantages of fuelwood use are also reduced by the increased health and financial costs of chain saw accidents, wood stove related house fires and air pollution.¹⁹

Objective of the Study

The objective of this study is to predict near term household fuelwood consumption behavior at the county level by linking it to economic and demographic conditions in a county. These predictions are made in order to aid identification of counties having higher intensity fuelwood use and are therefore more likely to have fuelwood use related problems and benefits.

How Data Limitations Influence the Study

County fuelwood problems and opportunities could be pinpointed using surveys of several hundred households in each U.S. county but this method is costly. Instead, this study relies on the National Residential Fuelwood Use Survey of 5,569 households.²⁰ This survey was insufficient to estimate fuelwood use directly for individual counties. To use this limited data for county estimates additional knowledge must be used about the

¹⁹Curtis C. Travis, Elizabeth L. Etnier and H. Robert Meyer. 1985. Health risks of residential wood heat. Environmental Management. 9(3):209-216.

²⁰Skog and Watterson. 1983. Residential fuelwood use in the United States. p. C-3.

economic behavior of households. County estimates may be made by combining the limited data and a hypothesis about how household behavior is uniformly affected by economic factors. The following section discusses means to link household behavior to economic factors.

II. METHODS TO PREDICT LOCAL FUELWOOD CONSUMPTION

Literature helpful in linking household and area economic conditions to fuelwood use includes (1) theory and methods in household consumption economics, including methods used in residential energy demand models and (2) empirical findings from fuelwood use surveys.

Household Consumption Modeling

The theoretical basis for empirical models of aggregate household consumption has a weakness. Neoclassical economic theory explains that individual household consumption is the result of a household's choosing products so as to maximize utility subject to an income constraint. But this theory is not sufficient when economists want to justify a model of consumption for a group (aggregate) of households. Historically, empirical models of aggregate household consumption have been theoretically justified by stating that they model the "average household" by linking average consumption to average household income and prices.²¹ Unfortunately, it has been shown that even if every consumer in a group

²¹A. Brown and Angus S. Deaton. 1972. Surveys in applied economics: models of consumer behavior. Economic Journal 328(82):1145-1235 (December), p. 1168.

behaves according to theory, the relation of average consumption to average income and prices may, itself, not conform to theory of "average" utility maximization subject to an "average" income constraint.²²

Despite this theoretical weakness, data limitations have "forced" construction of many models of aggregate household consumption on the premise that they can still yield useful insights into household behavior. Some of these models for residential energy consumption are discussed next to learn what economic factors they find influence energy use. Following that, two theoretically justifiable models are discussed. These models require data on individual households. The second of these models will be used to predict county fuelwood consumption for this study.

Models of Aggregate Household Consumption. Hartman reviews 19 residential energy demand models that explain three consumer decisions spanning the economic long run.²³

- Should a home heating device be purchased?
- What characteristics and fuel should the device have?
- How much fuel should be used in the device?

²²Ibid.

²³Raymond S. Hartman. 1978. A Critical review of single and interfuel substitution residential energy demand models. Massachusetts Institute of Technology Energy Research Lab Tech. Report MIT-EL-78-003. (Cambridge, MA) 121 p.

In the short run equipment is fixed and the consumer only decides how much fuel to use. Hartman's models explain, to varying degrees, demand for energy-using appliances, and demand for fuels. Certain models cover only use of single fuels such as electricity or gas. Most use pooled time-series, cross-sectional data aggregated by state. The dependent variable is state per capita or per household fuel use. In some cases demand for appliances is modeled separately. Explanatory variables include own fuel price, substitute fuel prices, income, climate, housing characteristics (e.g., rooms per house), degree of urbanization, and other demographic characteristics of households. Certain models explain the level of appliance stock separately using variables such as own fuel price, substitute fuel prices, income, and cost to buy and maintain equipment.

Long run and short run behavior are most clearly separated where appliance stock and demand per appliance are modeled separately. In these cases, short run and long run price and income elasticities can be computed separately. Many models assume year to year demand for appliances is always in market equilibrium, others assume that demand lags behind theoretical equilibrium (dynamic partial adjustment).

Hartman judges superior those models which (1) have separate equations for stock level and stock utilization

and (2) allow partial adjustment of stock demand toward theoretical market equilibrium each period.

Hartman also examines five models which predict use of several fuels at once. These models show how cross price elasticities vary. Like the single fuel models they vary in degree of data aggregation, treatment of long run versus short run and sophistication in behavioral assumptions. One detailed and flexible model by Lin, Hirst and Cohn found elasticities for fuel market shares that suggest rising natural gas or fuel oil price will shift consumption to other fuels while rising electricity price will only decrease electricity use without notably increasing use of other fuels (Table 1).²⁴

Table 1.--Fuel share elasticity with respect to price for selected residential fuels

Fuel	Cross fuel		
	Electricity	Natural gas	Fuel oil
Electricity	-2.6	.4	1.4
Natural gas	.4	-1.6	.03
Fuel oil	.03	3.5	-1.1

This model suggests that similar price changes in various fuels have different effects on consumption of alternative fuels.

²⁴Ibid. p. 82.

The models Hartman reviews are usually linear-in-parameters with parameters often multiplying nonlinear transformations of one or more variables (e.g., log-linear or log-log forms).

The residential energy models Hartman reviews do not include fuelwood. One simple aggregate demand model for fuelwood, proposed by Lipfert, estimates the density of wood smoke pollution by relating average wood burning per household in New England counties to county climate (heating degree days) and population density.²⁵ His model is

$$W = 3.09 - .32 \ln D \quad (1)$$

where W = standard cords of wood used per
household per 10,000 heating degree
days in a county,

D = persons per square mile in a county.

This model predicts that wood use density peaks at a suburban population density of about 5,000 per square mile (about 3 households per acre). He notes population density could be a good predictor because it is a good proxy for other factors influencing wood use including percent urbanization, percent land in forests, retail price of wood, and perhaps family income.

²⁵Fredrich W. Lipfert and Jennifer L. Dungan. 1983.
Residential fuelwood use in the United States.
Science. 219 (25 March 83):1425-1426.

Models of Individual Household Consumption. The major theoretical weakness of aggregate models, linking average demand to average economic factors, can be removed by modeling behavior of individual households. But doing so makes predicting consumption for small areas problematic. We would need to know individual characteristics for many households in an area in order to make estimates or projections. As with aggregate models, models of individual household energy demand should account for decisions about (1) which kind of fuel to use and (2) how much fuel to use.

Hardie and Scodari develop a theoretical model of individual household fuelwood use and Hardie and Hassan develop a related empirical model. The model used in this study is a theoretical and empirical variation of these models.^{26,27}

Hardie and Scodari explain the fuelwood use of a single household in county i , Q_i , using the equation

$$Q_i = D_i \cdot q_i \quad (2)$$

where D_i is 1 with probability p_i , the probability of their burning any fuelwood, zero otherwise, and q_i is the

²⁶Ian W. Hardie and Paul F. Scodari. 1982. A model of residential demand for fuelwood. Univ. of Maryland Dept. of Agriculture and Resource Economics Scientific Paper A-3310. (College Park, MD) 61 p.

²⁷Ian W. Hardie and Aziz A. Hassan. 1984. An analysis of residential demand for fuelwood in the United States. Unpublished report to USDA Forest Service Northeast Forest Experiment Station, Broomall, PA. 59 p.

amount of wood used if the household burns wood. The total wood used by a group of m households would be

$$\sum_{i=1}^m Q_i = \sum_{i=1}^m D_i q_i \quad (3)$$

To explain the probability of a household burning wood, p , we first assume (1) utility gained from home heating is "weakly separable" from utility gained by using other products and (2) a representative utility function plus a random error can explain any household's utility gain from home heating. If a household's utility, U , is weakly separable into components for home heating, $U_1(q_1)$ and other items, $U_2(q_2)$, then total utility, U , may be expressed as:

$$U = U(U_1(q_1), U_2(q_2))$$

and we may assert that demand for home heating is not influenced by quantities and prices of nonheating products used.²⁸ If we assume utility from home heating for a household has a fixed "representative household" component and a random component, then we may explain the probability of fuelwood use, p , as follows.

Let

$$U_{1n} = \bar{U}_1 + e_{1n} \quad (5)$$

²⁸Angus Deaton and John Muellbauer. 1980. Economics of Consumer Behavior. (Cambridge Univ. Press) p. 127-8.

be the utility consumer n obtains from burning wood plus, possibly, another fuel. Let

$$U_{2n} = \bar{U}_2 + e_{2n} \quad (6)$$

be the the utility consumer n obtains from burning a nonwood fuel only. Terms $\bar{U}_1$ and $\bar{U}_2$ are representative consumer utilities where

$$\bar{U}_{in} = \bar{U}_i(y_n, p_n, a_n), \quad i = 1 \text{ or } 2 \quad (7)$$

and

y = consumer income

p = heating fuel prices (vector)

a = other household characteristics (vector)

Terms e_{1n} and e_{2n} are random differences between the representative consumer and consumer n . A household chooses to burn wood if

$$\bar{U}_{1n} + e_{1n} > \bar{U}_{2n} + e_{2n} \quad (8)$$

or

$$\bar{U}_{1n} - \bar{U}_{2n} > -e_{1n} + e_{2n} \quad (9)$$

Let

$$\bar{U}_{12n} = \bar{U}_{1n} - \bar{U}_{2n}$$

and

$$e_{12n} = -e_{1n} + e_{2n}$$

Since e_{12n} is a random variable, woodburning is chosen with probability

$$p_n = \text{Prob} [e_{12n} < \bar{U}_{12n}] \quad (10)$$

An empirical model can be formed using theoretical equation (10) and data on individual households, provided

values of $\bar{U}_{12n}$ can be computed, and an assumption is made about the distribution of e_{12n} . If e_{12n} has a normal distribution and $\bar{U}_{12n}$ is a linear-in-parameters function of prices, household income, and other household characteristics, then a probit function is formed. If e_{12n} has a Weibell distribution, a logit function is formed.^{29,30} Hardie and Scodari suggest $\bar{U}_{1n}$ and $\bar{U}_{2n}$ and thus $\bar{U}_{12n}$ and p_n should be determined by factors which influence nonwood heating costs:

- type and price of nonwood heating fuel(s) used
- type of heating appliances in the house
- maintained indoor temperature
- climate
- amount of insulation
- house size
- type and location of house,

by factors which influence wood fuel heating costs:

- cost to own and maintain a wood heater
- purpose of woodburning: heating or enjoyment
- access to a wood supply

²⁹John A. Hausman and D.A. Wise. 1978. A Conditional probit model for qualitative choice: Discrete decisions recognizing interdependence and heterogeneous preferences. Econometrica 46(2):403-406.

³⁰Raymond S. Hartman. 1979. A generalized logit formulation of individual choice. Massachusetts Institute of Technology Energy Research Lab Working Paper MIT-EL-79-010WP. (Cambridge, MA) 28 p.

-occupations of household members (influences time cost for wood cutting)

and by factors determining a household's tastes and preferences:

-household income

-age of head of household

-education

-family size

-number of employed household members.

Hardie and Hassan prepare a probit model based on this theory which is discussed later.³¹

Hardie and Scodari develop a theory of (1) how much wood a household would burn (q_i in equation (2)), (2) how much they would purchase or cut themselves and (3) how much nonwood fuel they would use.³² Fuelwood consumption may be modeled without reference to prices for nonhome-heating products consumed because we assume weak separability of home heating utility. Their theoretical fuelwood use equation is:

$$Q_w = q_w(P_f, P_e, P_w, P_c, P_h, C; k)$$

(11)

where

P_f = price of nonwood fuel used (natural gas, fuel oil, propane)

³¹Hardie and Hassan. 1984. An analysis of residential demand for fuelwood.

³²Hardie and Scodari. 1982. A model of residential demand for fuelwood.

P_e = price of electricity

P_w = price of wood purchased

P_c = price of coal

P_h = value of household labor per hour while
harvesting wood

C = last season's heating bill

k = nonwood heating fuel used.

Hardie and Hassan prepare several regional probit models for equation (10), the probability of burning, and a specially adjusted ordinary least squares (OLS) regression model for equation (11), amount burned.³³ Probit models for each of 5 census regions predict probability of burning wood based on

- house area heated (sq. ft.)
- heating degree days (under 50° f)
- family size
- firewood price (\$/cord)
- nonwood fuel price (\$/MMBtu)
- household income (1000 \$)
- type of heating equipment used; wall or floor
furnace, radiators, central warm air, electric wall
units, gas or oil heaters, portable heaters

An OLS regression predicts amount burned using a sample

³³Hardie and Hassan. 1984. An analysis of residential demand for fuelwood.

bias correction procedure developed by Heckman³⁴, ³⁵ and variables for

- the ratio of firewood price to nonwood fuel price
- house area heated
- heating degree days
- family size
- household income
- kind of nonwood fuel used (i.e., electricity, oil, gas, LP gas)
- whether or not firewood was purchased.

A regression to predict wood use for any household may be biased, if a correction is not made, because the regression is fit only on data for woodburning households. Binary variables were also included in the OLS regression for each of 5 census regions (regional shift variables).

Hardie's model predicts probability of woodburning and average use given the characteristics of a single household. If we have characteristics of a large random sample of households in an area we can predict total use using equation (3) for each household. But in making

³⁴James J. Heckman. 1976. The common structure of statistical models of truncation, sample selection and limited dependent variables and a simple estimation for such models. Annals of Economic and Social Measurement 5(4):153-61.

³⁵James J. Heckman. 1979. Sample selection bias as a specification error. Econometrica 47(1):153-61.

regional estimates Hardie and Hassan instead use average characteristics of households by region to predict probability of woodburning, and average characteristics over the whole U.S. to predict average wood use. In order to use Hardie's model correctly to predict county level fuelwood use we would need characteristics of a representative group of households in each county. These data are not readily available. Hardie's model could use average household characteristics from each county but the average may not reflect well the distribution of individual household characteristics in the county.

A Model of County Level Fuelwood Consumption

As an alternative to Hardie's empirical model, consider the following two equation model that explicitly links average household characteristics in a county to (1) the probability of woodburning, p_i , and (2) the average amount burned per woodburning household, q_i . Using these two equations we may compute wood burned per county as follows:

$$Q_i = p_i \cdot q_i \cdot N_i \quad (12)$$

where

Q_i = the quantity of wood burned in county i ,

p_i = the percentage of households burning wood
in county i ,

q_i = the quantity burned by an average
woodburning household in county i

N_i = the number of households in county i .

To form the equation for p_i , we assume (1) a household with average characteristics in a county has an average likelihood for burning wood among all households in the county, (2) these average households have utility for home heating which is weakly separable from utility for other products consumed and (3) the utility from heating for these average households may be modeled by an equation with two components--one component giving the value of utility of a representative average household and a component giving the difference in utility between the representative average household and the average household in a particular county. The representative average household's utility is expressed as a function of county characteristics and county level averages of household characteristics.

To form the equation for q_i --the amount burned per woodburning household--we assume (1) the average amount burned by woodburning households in a county can be expressed as a function of average woodburner characteristics in the county, and (2) the average characteristics of woodburners in a county are highly correlated with the average characteristics for all households in the county.

An Equation to Predict Percent Woodburners. The assumptions above for predicting percent of woodburners,

p_i , allows use of the household utility theory expressed in equations (4) through (10). The differences in formulation here are that (1) utility is for a representative average household in a county not a representative individual household and (2) utility of the representative average household is dependent on average county characteristics not individual household characteristics. In order to explain the equation to estimate percent of woodburning households in a county the household utility hypothesis is restated for an average household in a county:

$$\text{Let } U_{1i} = \bar{U}_1(X_{1i}) + e_{1i} \text{ and} \quad (13)$$

$$U_{2i} = \bar{U}_2(X_{2i}) + e_{2i} \quad (14)$$

where U_{1i} = the utility of burning wood for the average household in county i,

U_{2i} = the utility of not burning wood for the average household in county i,

$\bar{U}_1(X_{1i})$ = the utility for a representative average household for burning wood in a county based on average characteristics, X_{1i} , of households in county i.

$U_2(X_{2i})$ = the utility for a representative average household for net burning wood in a county based on average characteristics, X_{2i} , of households in county i .

e_{1i} , e_{2i} = differences between a representative average household and an average household in a particular county, i .

Assume U_1 and U_2 are linear-in-parameters functions of X_{1i} and X_{2i} , and assume e_{1i} and e_{2i} have random normal distributions.

Our hypothesis is that the probability that the average household will burn wood is the probability that U_{1i} exceeds U_{2i} . That is;

$$\begin{aligned} \text{Prob (burning)} &= \text{Prob } (U_{1i} - U_{2i}) \\ &= \text{Prob } (U_{1i}(X_{1i}) + e_{1i} - U_{2i}(X_{2i}) - e_{2i}) \\ &= \text{Prob } (U_{1i}(X_{1i}) - U_{2i}(X_{2i}) - e_{1i} + e_{2i}) \quad (15) \end{aligned}$$

If e_{1i} and e_{2i} are normally distributed so is $e_{1i} - e_{2i}$.

A necessary condition for e_{1i} and e_{2i} to be normally distributed random variables is that $U_{1i}(X_{1i})$ and $U_{2i}(X_{2i})$ must account for all variables that influence utility and that the manner of the influence be properly specified by the form of the equations.

Equation (15) may be converted into an explicit probit model by first specifying the form of $\bar{U}_{1i}(X_{1i}) - \bar{U}_{2i}(X_{2i})$.

$$\begin{aligned} \text{Let } f_i &= \bar{U}_{1i}(X_{1i}) - \bar{U}_{2i}(X_{2i}) \\ &= \sum_{j=1}^n a_j z_{ji} \end{aligned} \quad (16)$$

where z_{ji} = a vector of n variables
 X_{1i} and X_{2i} .

The probit model, expressing the probability that f_i will exceed $e_{1i} - e_{2i}$ for an average household in a particular county i is given by the cumulative normal distribution function:

$$P_i = \int_{-\infty}^{f_i} \frac{1}{\sqrt{2\pi}} \exp(-x^2/2) dx \quad (17)$$

where f_i is given by equation (16). The parameters a_j in equation (16) are estimated by a maximum likelihood procedure which uses data on individual households, and their county characteristics; z_{ji} , from the National Residential Fuelwood Use Survey.³⁶ The survey gave data on 5569 households, indicating whether or not they burned wood and, if so, the amount burned during the 1980-81 heating season. Data on the households respective counties was obtained primarily from the 1980 Census of Population

³⁶Skog and Watterson. 1983. Residential fuelwood use in the United States.

and Housing. County fuelwood price estimates came from the National Residential Fuelwood Use Survey and nonwood fuel prices came from the Los Alamos National Laboratory.³⁷ See the Appendix for an explanation of data characteristics and sources.

An Equation to Predict Amount Burned by Woodburners.

To estimate average amount burned by woodburners in a particular county it would be best if we knew the average characteristics of woodburners to use as predictors. Unfortunately we only have average characteristics over all households in each county. There are two ways average county characteristics could work well as predictors of wood use by woodburners. First, a variable may work well if it indicates the economic environment equally well for burners and nonburners, and if, second, the average value of the variable for burners is highly correlated with the average value for nonburners. These guides are used to form the equation to predict amount burned.

³⁷Los Alamos National Laboratory. 1980 Residential fuel price database for solar heating market analysis. Unpublished data for 280 U.S. regions obtained from Fred Roach. Los Alamos, NM (1982).

III. MODEL SPECIFICATION AND PARAMETER ESTIMATION

Model specification is the procedure by which (1) the independent variables are identified and (2) the mathematical linkage between independent and dependent variables is specified. The procedure of parameter estimation identifies the values of numerical constants in the equations of the model.

A Probit Equation to Estimate Percent of Woodburners

To specify a probit equation for p_i (equation (17)) we seek county level variables, z_j , for equation (16) which determine the utility of burning wood, and not burning wood. Following the theoretical model of Hardie and Scodari we seek factors which influence

- nonwood heating costs,
- fuelwood heating costs, and
- household tastes and preferences.

Consider for inclusion factors identified as important by previous empirical work. Hardie and Hassan included, as determinants of heating costs; square foot area heated, heating degree days, number of household members, price of wood fuel and type of nonwood heating equipment used.³⁸

³⁸Hardie and Hassan. 1984. An analysis of residential demand for fuelwood.

To account for variation in tastes and preferences they constructed separate probit equations for each of 5 census regions. A second empirical model by Lipfert predicted average household fuelwood use in a county based on heating degree days, which has a major influence on heating costs, and logarithm of population density, which is related to the cost of heating with wood.³⁹ Population density is linked to cost of wood burning in so far as households in high density areas have greater difficulty in finding, cutting and hauling wood, or have greater costs in buying wood; and greater inconvenience in tending a fire. Thus, households in high density areas are less likely to burn wood. The survey by Skog and Watterson confirms urban households are less likely to burn wood than rural households; 23% versus 45% respectively.⁴⁰ Another factor which influences cost of woodburning, in addition to population density, is access to forest land for households or vendors to cut wood. The model presented here uses percent forest land in a county as one measure of costliness of obtaining wood.

Using the guidance of these previous studies, 19 variables denoting county characteristics were selected for a probit equation to predict percentage of woodburners

³⁹Lipfert. 1983. Residential fuelwood use in the United States. p. 1425.

⁴⁰Skog and Watterson. 1984. Residential fuelwood use in the United States. p. 743.

in a county (Table 2). These include eight dummy (0, 1) variables to denote when a county is in one of 9 regions. Dummy variables account for regional differences in costs and tastes not accounted for by the other 11 variables. Certain variables are taken from the Hardie and Hassan model and used in the form of county averages: heating degree days, average nonwood fuel price, fuelwood price, and fraction of households using each of 6 types of nonwood heating equipment (5 variables). Median household income was included as a chief determinant of tastes. Median number of household members was initially included but discarded since its coefficient was not significantly different from zero.

A second probit equation was formed to allow for the possibility that the influence of 4 variables--heating degree days, household income, nonwood fuel price and wood price--is not strictly proportional to the value of the variable. These four variables were squared and included in the second probit equation (Table 3). Parameters were estimated using a maximum likelihood technique for probit models.⁴¹ Parameter estimates, statistics to test if parameters are significantly different from zero, and elasticities of woodburning probability with respect to model variables are shown in Tables 2 and 3.

⁴¹Institute for Research on Poverty. 1984. Probit - version 6. An unpublished computer program. (Madison: University of Wisconsin).

Table 2--Variables and parameter estimates for probit equation 1 which excludes squared terms

County Variable (Z _j)	Mean value	Coefficient (a _j)	Ratio of coef. to standard deviation ₁	Elasticity at mean values of Z _j
Constant	----	-.33153	-.89	---
Heating degree days	4616.	.00019	6.20	.68
Median household income	17.19	.04955	6.70*	1.06
Average nonwood fuel price	9.11	.01938	1.56**	.22
Average fuelwood price	76.	-.01492	-7.48*	-1.41
Percent forest land	25.51	.00596	5.54*	.19
Log of population density	5.85	-.71848	3.82*	-.57
Fraction of households using: ²				
Steam radiators	16.98	-.01257	-3.26*	-.26
Ducted hot air system	48.86	-.00717	-2.11*	-.43
Electric wall heaters	8.14	-.00643	-1.09**	-.06
Ductless furnace	5.97	-.00655	-1.39**	-.05
Gas or oil room heater	10.98	-.00793	-1.50**	-.11
Regional dummy variables ³				
Pacific Northwest	.03	.58734	4.04*	
Northern Rocky Mountains	.01	-.27642	-1.33**	
Southern Rocky Mountains	.15	.11426	8.46*	
Lake States		.0		
Central States	.19	-.1110	-1.66*	
Mid Atlantic	.20	-.26849	2.75*	
North East	.05	.49440	3.76*	

Table 2 (cont'd.)

County Variable (Z_j)	Mean Value	Coefficient (a_j)	Ratio of coef. to standard deviation ¹	Elasticity at mean values of Z_j
South Central	.15	.16257	2.12*	
South East		.0		

¹* Indicates the coefficient is significant at the 95% confidence level.
 ** Indicates the coefficient is significant at the 90% confidence level.
 *** Indicates the coefficient is significant at the 85% confidence level.

²Deleted category is fraction of households with electric heat pumps, fireplaces, wood stoves, portable room heaters or no heating equipment.

³Regions are U.S. Forest Service Timber Regions shown in: USDA Forest Service. 1982. An analysis of the timber situation in the United States. Forest Res. Rept. 23. Washington, D.C. p. 335.

Table 3--Variables and parameter estimates for probit equation 2 which includes squared terms

County Variable (Z _j)	Coefficient (a _j)	Ratio of coef. to standard deviation ₁	Chi- square statistic ₂	Elasticity at mean values of Z _j
Constant	.19012	.33		
Heating degree days	.00022		40.8*	.47
--squared	-.11488 E-7			
Median household income	-.04562		42.0*	.51
--squared	.00232			
Average nonwood fuel price	.19333		16.0*	.37
--squared	-.00806			
Average fuelwood price	-.40993		61.1*	-.94
--squared	.00018			
Percent forest land	.00489	4.43*		-.15
Log of population density	-.07592	3.99*		.55
Fraction of households using: ³				
Steam radiators	-.00992	-2.48*		-.21
Ducted hot air system	-.00236	-.64		-.14
Electric wall heaters	-.00368	-.59		-.04
Ductless furnace	-.00158	-.32		-.12
Gas or oil room heaters	-.00826	1.52**		.11
Regional dummy variables				
Pacific Northwest	.60437	4.08*		
Northern Rocky Mountains	-.22485	-1.07***		
Southern Rocky Mountains	.81261	4.93*		

Table 3--(cont'd.)

County Variable (Z_j)	Coefficient (a_j)	Ratio of coef. to standard deviation ¹	Chi- square statistic ²	Elasticity at mean values of Z_j
Lake States	.0			
Central States	-.18582	-2.52*		
Mid Atlantic	.18082	2.80*		
North East	.50410	3.83*		
South Central	.12636	1.61**		
Southeast	.0			

¹*Indicates coefficient is significant at 95% level of confidence.

**Indicates coefficient is significant at 90% level of confidence.

***Indicates coefficient is significant at 85% level of confidence.

²*Indicates quadratic expression is significant at 95% level of confidence.

³Deleted category is fraction of households with electric heat pumps, fireplaces, wood stoves, portable room heaters, or no heating equipment.

A Linear-in-Parameters Equation to Estimate Amount Burned
by Woodburners

To specify an equation for amount burned by woodburners in a county, q_i in equation (12), we seek county level variables, X_j ($j = 1 \dots m$) which influence amount burned. By using county level variables to predict individual household fuelwood use we lose the greater predictive power of individual household characteristics such as kind of nonwood fuel used. But we gain a direct link between county level characteristics and county fuelwood use. County variables used should describe the economic environment of burners accurately.

Previous studies suggest certain variables account for variation in fuel use. Lin, Hirst and Cohn, in their state level aggregate model use prices of all three fossil fuels to predict demand for residential heating fuels.⁴² Lipfert, in a county level aggregate model, uses county population density as a proxy for the influence of fuel prices, access to forests, and family income.⁴³ The only other variable in Lipfert's model is heating degree days. Hardie and Scodari suggest a theoretical model of individual household fuelwood use which uses prices of wood and of each nonwood fuel, the value of household

⁴²Hartman. 1978. A review of residential energy demand models. p. 82.

⁴³Lipfert. 1983. Residential fuelwood use in the United States. p. 1425.

labor to harvest and haul fuelwood, last season's heating bill and type of nonwood fuel used.⁴⁴ Hardie and Hassan, in their empirical model of individual household fuelwood use, use relative price of nonwood fuel to wood fuel, area of the house that is heated, heating degree days, family size, income, kind of nonwood fuel and whether or not fuelwood was purchased.⁴⁵

Based on these previous studies five county variables were selected for use in the equation for fuelwood consumed by woodburners:

- median household income,
- heating degree days,
- percent forest land
- price of nonwood fuel divided by price of wood fuel,
- population density

The price of nonwood fuel, contained in the price ratio, is the average price per MMBtu heat output for electricity, fuel oil and natural gas in the county weighted by the percentage of households using each fuel in the county according to the 1980 Census of Housing. (See Appendix for an explanation of equipment efficiency adjustments). Individual prices for nonwood fuels were not used in order to simplify the model. It is assumed that consumers

⁴⁴Hardie and Scodari. 1982. A model for residential demand for fuelwood. p. 36.

⁴⁵Hardie and Hassan. 1984. An analysis of residential demand for fuelwood in the United States. p. 32.

will exhibit rational economic behavior in that nonwood fuels of different types with the same price per unit of heat output will give a household the same incentive to burn wood.

Since Lipfert's model found a strong association between population density and woodburning it is included here. Certain influences associated with population density are included separately - income, percent forest and fuel prices. Including these variables will help to determine the influence of density alone.

Household income, while not included in Hardies' models, is included here as a proxy for area of house heated and family size.

Since 72% of fuelwood is harvested by households rather than purchased from vendors, ease of access to forest land was included as an influence in the model by using percent forest land in the county. No distinction is made between public and private forest, a potentially important influence on access.

One concern in using county wide variables covering all households is that they may not represent the average woodburner well. Of the five county variables chosen for the model percent forest land and heating degree days are likely to be nearly the same for woodburners and nonwoodburners. Median household income for a county tends to be lower than for woodburners alone. Higher income

households more often burn wood. Population density for a county tends to be higher than the population density nearest the average woodburner. This is because woodburners tend to live in more rural areas than nonwoodburners. The county average price of nonwood fuel divided by the price of fuelwood is likely to be higher for woodburners than for nonwoodburners. The fact that certain county averages are not the averages for woodburners will not cause difficulties in our equation if the variation in county averages from one county to another is the same as variation in woodburner averages from one county to another. That is, we assume countywide averages are highly correlated to county averages for woodburners.

Three equations were formed using the selected variables:

$$X_1 = \ln \text{ INC } = \ln(\text{median household income})$$

$$X_2 = \ln \text{ HDD } = \ln(\text{heating degree days})$$

$$X_3 = \ln \text{ FOR } = \ln(\text{percent forest land})$$

$$X_4 = \ln \text{ REL } = \ln(\text{price of nonwood fuel divided by} \\ \text{price of wood fuel})$$

$$X_5 = \ln \text{ PD } = \ln(\text{population density})$$

$$Q_w = \ln(\text{amount burned by household})$$

$$e = \text{error term}$$

$$Q_w = \sum_{j=1}^4 a_j x_j + e \quad (18)$$

$$Q_w = \sum_{j=1}^4 \left(\sum_{k=1}^4 a_{jk} x_5^k \right) x_j + e \quad (19)$$

$$Q_w = \left(\sum_{k=1}^4 a_{1k} x_5^k \right) x_1 + \left(\sum_{k=1}^4 a_{2k} x_5^k \right) (x_1)^2 +$$

$$\left(\sum_{k=1}^4 a_{3k} x_5^k \right) (x_1)^3 + \left(\sum_{k=1}^4 a_{4k} x_5^k \right) x_2 +$$

$$\left(\sum_{k=1}^4 a_{5k} x_5^k \right) (x_2)^2 + \left(\sum_{k=1}^4 a_{6k} x_5^k \right) x_3 +$$

$$\left(\sum_{k=1}^4 a_{7k} x_5^k \right) (x_3)^2 + \left(\sum_{k=1}^4 a_{8k} x_5^k \right) x_4 +$$

$$\begin{aligned}
 &4 \\
 &(\sum_{k=1}^4 a_{9k} X_5^k)(X_4)^2 + e \quad (20)
 \end{aligned}$$

Equations (18)-(20) are formed using natural logarithms of variables because error term estimates were more nearly normally distributed than linear equations tested, and because coefficients represent the elasticity of wood use with respect to independent variables. Equation (18) uses only four variables leaving out $\ln(\text{population density})$. Equations (19) and (20) allow elasticities of wood use with respect to X_1 - X_4 to vary with $\ln(\text{population density})$. Equation (20), in addition to allowing variation in elasticity depending on $\ln(\text{population density})$, allows variation in elasticity depending on the value of each predictor variable.

Although equations (19) and (20) are quite flexible, they make the simplifying assumption that the influence of each predictor variable is independent of the influence of other predictor variables, except for the influence of $\ln(\text{population density})$.

Parameters in equations (18), (19) and (20) were determined using ordinary least squares regression and data from the National Residential Fuelwood Use Survey. Dependent variables, Q_w , are amounts burned by individual households throughout the U.S. Independent variables are

county characteristics for those individual households.

A test is needed for equations (18)-(20) to see if their parameter estimates are biased as a result of their being fit on data for woodburners only. Equation (12) estimates total woodburning in a county by multiplying probit equation estimates of percent burners times amount burned from equations (18), (19) or (20). The probit models are fit on data from both woodburning and nonwoodburning households. Equations (18)-(20) are fit on data from woodburners only. Counties with a high proportion of woodburners are over represented in the determination of parameters for equations (18)-(20). The effect of the over representation, or sample selection bias, on parameters in equations (18)-(20) can be tested by including an instrumental variable LAMBDA in equations (18)-(20) and determining if it has a coefficient significantly different from zero.

LAMBDA for a household in county j is given by

$$\text{LAMBDA}_j = \frac{f(\sum a_i Z_{ij})}{F(\sum a_i Z_{ij})} \quad (21)$$

where f is the standard normal distribution function and F is the cumulative standard normal distribution function.⁴⁶ Z_{ij} and a_i are variables and parameters respectively from the probit model to predict probability

⁴⁶Hardie and Hassan. 1984. An Analysis of residential demand for fuelwood.

of woodburning by households in county j (equation (16)).

The coefficient for LAMBDA, when it is included in equation (20), is not significantly different from zero at the 82% confidence level. As a result LAMBDA was not used to estimate parameters for equation (20). The coefficients for LAMBDA in equations (18) and (19) are significantly different from zero above the 83% confidence level. LAMBDA is excluded from equations (18) and (19) so differences between their predictions and those of equation (20) are not due to use of LAMBDA.

Parameter estimates for equations (18)-(20) are shown in table 4. Parameters in equations (18)-(20) were estimated in order of greatest contribution in accounting for variance in Q_w . Parameters were estimated for successive terms until the inclusion of an additional term would not explain at least .01% of the variance not yet accounted for. Parameters for equation (19) were estimated before those of equation (20). Estimation for equation (20) began by retaining terms included in equation (19) (but not their coefficients). This procedure was used in order to conduct an F-test of the significance of additional terms contained in equations (19) and (20). The F-tests of the increased variance accounted for between equations (18) and (19), and between equations (19) and (20) are significant at the 99.99% confidence level.

Table 4.--Terms and parameter estimates for equations (18), (19) and (20) which predict amount of fuelwood used by a household.

Term in equation	Equation parameters (a_{ij})		
	(18)	(19)	(20)
(1n INC)	-1.0895	-8.1198E-1	-1.8261
(1n PD) (1n INC)			
(1n PD) ² (1n INC)		5.5712E-3	-3.7750E-3
(1n PD) ³ (1n INC)			
(1n PD) ⁴ (1n INC)		-1.7073E-4	2.9245E-4
(1n INC) ²			
(1n PD) (1n INC) ²			
(1n PD) ² (1n INC) ²			
(1n PD) ³ (1n INC) ²			
(1n PD) ⁴ (1n INC) ²			
(1n INC) ³			7.0609E-2
(1n PD) (1n INC) ³			
(1n PD) ² (1n INC) ³			
(1n PD) ³ (1n INC) ³			
(1n PD) ⁴ (1n INC) ³			-2.0205E-5
(1n HDD)	4.507E-1	3.4132E-1	5.8973E-1
(1n PD) (1n HDD)		-6.7259E-3	-1.2630E-2
(1n PD) ² (1n HDD)			
(1n PD) ³ (1n HDD)		2.6907E-4	4.9210E-4
(1n PD) ⁴ (1n HDD)		1.1787E-5	-6.8437E-5
(1n HDD) ²			
(1n PD) (1n HDD) ²			
(1n PD) ² (1n HDD) ²			
(1n PD) ³ (1n HDD) ²			
(1n PD) ⁴ (1n HDD) ²			
(1n FOR)	1.969E-1	2.7496E-1	1.9432E-1
(1n PD) (1n FOR)		-8.0520E-2	-2.6608E-3
(1n PD) ² (1n FOR)		1.0170E-2	-9.7183E-3
(1n PD) ³ (1n FOR)			
(1n PD) ⁴ (1n FOR)		-4.6857E-5	1.0058E-4

Table 4 (cont'd).

Term in equation	Equation parameters (a_{ij})		
	(18)	(19)	(20)
(1n FOR) ²			-8.5907E-3
(1n PD) (1n FOR) ²			
(1n PD) ² (1n FOR) ²			2.0060E-3
(1n PD) ³ (1n FOR) ²			
(1n PD) ⁴ (1n FOR) ²			-2.0894E-5
(1n REL)	3.6316E-1	1.3950E-1	7.9131E-1
(1n PD) (1n REL)		7.0600E-3	
(1n PD) ² (1n REL)			-2.7318E-3
(1n PD) ³ (1n REL)			
(1n PD) ⁴ (1n REL)		-2.8198E-5	1.0003E-4
(1n REL) ²			1.3998E-1
(1n PD) 1n REL) ²			
(1n PD) ² 1n REL) ²			
(1n PD) ³ 1n REL) ²			
(1n PD) ⁴ 1n REL) ²			
R ²	.381	.413	.442
Standard error	.703	.685	.676

The adjusted coefficient of determination (R^2), indicating the fraction of variance in natural logarithm of fuelwood use accounted for by an equation is relatively high--.44 for equation (20). This is high for a model using cross-section data. The models by Hardie and Hassan using individual household characteristics as predictors obtained R^2 values of .20 to .24.⁴⁷

Equations (18)-(20) estimate Q_{wi} which is $\ln$ (amount burned) for an average woodburner in county i . Call this estimate $\bar{Q}_{wi}$.

$$Q_{wi} = \bar{Q}_{wi} + e$$

Amount burned by the average woodburner in a county, q_i , is estimated by

$$q_i = \exp(\bar{Q}_{wi}) \exp(SE^2/2)$$

where SE is the standard error in estimating $\bar{Q}_{wi}$. Values for SE for equations (18)-(20) are given in Table 4. Since SE is only an estimate, an adjustment was made to the initial estimates of q_i and Q_i . Recall that

$$Q_i = p_i q_i N_i \text{ (see equation (12))}$$

An adjustment factor k was computed for Models I-III such that total U.S. woodburning estimated by the model equals the survey estimate for 1980-81 -- 40.5 million cords.

$$k \sum_{i=1}^m p_i q_i N_i = 40.5$$

⁴⁷Ibid. p. 32-43.

where m is the number of counties in the U.S. For Model III, $k = .98508$.

$$q'_i = kq_i$$

$$Q'_i = kQ_i$$

where q'_i and Q'_i are adjusted estimates for amount burned by the average woodburner and total amount burned in county i respectively.

IV. VALIDATION OF THE MODEL

Forrester and Senge describe validation as the process of establishing confidence in the soundness and usefulness of a model.⁴⁸ Its objective is to convince potential users that the model is a useful basis for decision making. The fact that there may be several audiences may complicate validation because each audience has its own objectives and criteria for evaluating the model. For scientists, a model is useful if it (1) gives insight into the workings of a real system, (2) makes correct predictions or (3) stimulates questions for future research. For public leaders, and their analysts, a model is useful if it (1) explains the causes of problems and (2) provides a basis for designing policies to alleviate problems.⁴⁹

The validation steps taken here are an effort to satisfy the validation interests primarily of scientists. Forrester and Senge suggest specific validation tests for

⁴⁸Jay W. Forrester and Peter M. Senge. 1978. Tests for building confidence in system dynamics models. Massachusetts Institute of Technology Alfred P. Sloan School of Management System Dynamics Group paper D-2926-4. (Cambridge, MA) p. 5.

⁴⁹Ibid.

models constructed from a system dynamics perspective. Rather than adapt their tests of model structure, behavior and policy consequences to the two equation model in this study, certain general validation tests suggested by Kaplan are used here.⁵⁰ Kaplan suggests that theories are validated by evaluating how they meet norms of (1) correspondence (to the real world), (2) coherence (in a larger body of knowledge) and (3) pragmatism (performing useful functions for the scientific enterprise).

Correspondence between a model and the real world is demonstrated, in part, when the model makes predictions which are fulfilled. The correspondence is more convincing if the model operates well under a heterogeneous range of conditions. Kaplan concludes his explanation of correspondence by noting that "what counts in the validation of a theory [by correspondence], . . ., is the convergence of data brought to bear upon it, the concatenation of evidence . . ."⁵¹

The notion of concatenation of evidence suggests the coherence criteria--the model should fit into established theory. Coherence also favors a theory or model which is simple to explain and which has a mechanism for determining behavior which is simple. When developing

⁵⁰Abraham Kaplan. 1964. The Conduct of Inquiry.
(Scranton, PA: Chandler Publ. Co.) pp. 312-322.

⁵¹Ibid. p. 314.

models Kaplan asserts "We are to introduce a complicating factor only if we have reason to expect error from its omission . . .".⁵²

The pragmatic norm for validation suggests theories and models should do useful work. Useful work may include success in "practical" applications, such as using a fuelwood use model to efficiently target resources to improve forest management in counties using the most fuelwood. But this kind of useful work is neither necessary nor sufficient to validate a model or theory. The pragmatic norm is most related to the work the model does for science itself. How does it guide or stimulate ongoing inquiry? What new questions does it raise? Does it serve to explain prior observations better? Does it systematize or unify knowledge?⁵³

Validation by Correspondence

One way to examine the validity of our two equation model is to compare its predictions to results of surveys. We first compare percent burners and amount burned, as predicted by equations developed here, to results from the National Residential Fuelwood Use Survey. Comparisons are made between estimates for households in different income groups, different heating degree day groups and other

⁵²Ibid. p. 318.

⁵³Ibid. p. 319-322.

groups. The objective is to use a wide range of subgroups to discern the equations ability to predict over a wide range of county conditions. Table 5 shows how households are subdivided into approximately equal size groups (number of households) based on county characteristics. Table 6 compares predictions of probit equations 1 and 2 to survey results. Table 7 compares equation estimates of amount burned by woodburners to survey results. Table 8 compares predicted average amounts burned over all households, as computed by combining probit equation 2 and each amount equation, to survey results. Probit equation 2 was chosen to pair with each amount equation because results in table 6 suggest it predicts better than probit equation 1.

Percent woodburners is predicted best by probit equation 2 which includes squared terms (table 3). For probit equation 2 predictions for various subgroups differ from survey results by 7% or less except for one fuelwood price category, one relative nonwood fuel price category, one "percent forest land" category and one "percent homeowners" category. The probit equation underpredicts the most for counties with low percent forest land (-10.9%). It overpredicts the most for counties with low median income (5.8%).

Predictions of amounts burned by equations (18)-(20) show greater percent differences from survey estimates than predictions made by the probit models (Tables 6 and 7).

Table 5.--Values of selected county characteristics which divide households into four roughly equal size groups, 1980-81

County Characteristic	Units	Quartile upper limit		
		1	2	3
Median income	(\$1000 dollars)	14.70	17.08	18.94
Heating degree days		2673	5064	6328
Nonwood fuel Price	(\$/MMBtu)	7.12	8.95	10.80
Price of fuelwood	(\$/cord)	55	68	94
Nonwood fuel price divided by price of wood	(cords/ MMBtu)	.099	.120	.146
Percents forest Land		3	15	45
Population density	(persons/ sq. mile)	97	417	1508
Percent rural population		2.5	13.4	44.4
Percent homeowners		59.4	66.5	73.3

Table 6.--Survey and probit equation estimates of average percent woodburners for subgroups of counties, 1980-81

County characteristic and quartile of households	<u>Percent of households burning wood</u>		<u>Percentage difference between survey and equation estimates</u>		
	<u>Probit equation</u>				
	Survey	1	2	1	2
Average	27.8	27.9	27.3	.4	-1.8
Median income					
1	29.3	27.2	27.6	-7.2	5.8
2	27.2	28.7	27.3	5.5	.4
3	24.4	25.8	24.7	5.7	1.2
4	30.2	29.8	29.5	-1.3	2.3
Heating degree days					
1	22.9	23.1	21.5	.9	-6.1
2	34.6	33.4	34.0	-3.5	-1.7
3	23.6	22.8	23.1	3.4	-2.1
4	29.4	32.1	30.3	9.2	3.1

Table 6 (cont'd.)

County characteristic and quartile of households	Percent of households burning wood		Percentage difference between survey and equation estimates	
	Probit equation			
	Survey	1 2	1 2	
<u>Non wood fuel price</u>				
1	23.1	24.9	22.9	7.8
2	26.7	27.3	27.0	2.2
3	32.5	30.3	30.9	-6.8
4	28.6	29.0	28.1	1.4
				-1.7
<u>Price of fuelwood</u>				
1	32.4	32.7	33.5	.9
2	23.5	23.1	21.8	1.7
3	33.7	35.0	33.4	3.9
4	21.1	21.0	20.5	- .5
				-2.8
				3.4
				-7.2
				- .9
				-2.8
<u>Nonwood fuel price divided by price of wood</u>				
1	24.6	25.6	24.3	4.1
2	23.3	22.6	21.6	3.0
3	28.8	29.1	28.4	1.0
4	34.1	34.2	34.8	.3
				-1.2
				-7.3
				-1.4
				2.1

Table 6 (cont'd.)

County characteristic and quartile of households	<u>Percent of households burning wood</u>		<u>Percentage difference between survey and equation estimates</u>	
	<u>Probit equation</u>			
	Survey	1 2	1 2	
<u>Percent forest land</u>				
1	19.2	17.9	17.1	-6.8 -10.9
2	25.5	26.9	25.9	5.5 1.6
3	28.0	28.1	28.0	.4 .0
4	38.8	39.0	38.4	.5 -1.0
<u>Population density</u>				
1	35.5	37.7	36.7	6.2 3.4
2	31.9	31.8	30.9	-.3 -3.1
3	26.7	26.3	26.0	-1.5 -2.6
4	16.3	15.8	15.5	-3.1 -4.9
<u>Percent rural population</u>				
1	15.9	16.2	15.7	1.9 -1.3
2	25.6	25.7	25.2	.4 -1.6
3	30.6	31.8	30.4	3.9 -.7
4	38.4	38.0	37.9	-1.0 -1.3

Table 6 (cont'd.)

County characteristic and quartile of households	<u>Percent of households burning wood</u>		<u>Percentage difference between survey and equation estimates</u>	
	Survey	<u>Probit equation</u>	1	2
<u>Percent home owners</u>				
1	19.0	17.6	-7.4	-8.9
2	26.0	27.4	5.4	2.3
3	30.8	31.5	2.3	-1.9
4	34.6	35.1	1.4	2.6
<u>Region</u>				
Northwest	55.1	58.3	5.8	5.4
N. Rocky Mnts.	41.6	38.0	-8.7	-7.2
S. Rocky Mnts.	29.0	30.6	5.5	-1.4
Lake States	28.3	29.5	4.2	.7
Central States	25.2	25.4	.7	.0
Mid Atlantic	20.5	20.0	.6	-4.9
North East	34.1	35.9	5.3	4.1
South Central	26.8	26.4	-1.5	-4.1
South East	31.2	29.6	-5.1	-5.1

Table 7.--Survey and equation estimates of average amount burned per woodburning household for subgroups of counties, 1980-81

County characteristic and quartile of households	Amount burned				Percentage difference between survey and equation estimates		
	Equation						
	Survey	(18)	(19)	(20)	(18)	(19)	(20)
Average	1.83	1.83	1.83	1.83	0	0	0
Median income							
1	2.60	2.54	2.47	2.32	-2.3	-5.0	-10.8
2	2.06	1.88	1.96	1.97	-8.7	-4.9	- 4.4
3	1.40	1.52	1.53	1.56	8.6	9.3	11.1
4	1.24	1.36	1.33	1.46	9.7	7.3	17.7
Heating degree days							
1	.97	1.19	1.30	1.11	22.7	34.0	14.4
2	2.08	2.20	2.27	2.20	5.8	9.1	5.8
3	1.74	1.87	1.65	1.70	7.5	5.2	-2.3
4	2.25	2.04	2.08	2.29	9.3	-7.6	1.8

Table 7 (cont'd.)

County characteristic and quartile of households	Amount burned			Percentage difference between survey and equation estimates			
	Equation						
	Survey	(18)	(19)	(20)	(18)	(19)	(20)
------(cords)-----							
<u>Nonwood fuel price</u>							
1	1.57	1.58	1.62	1.62	.6	3.2	3.2
2	1.79	1.68	1.74	1.74	6.1	-2.8	-2.8
3	1.79	1.90	1.93	1.93	6.1	7.8	7.8
4	2.12	2.14	2.01	2.02	.9	-5.2	-4.7
<u>Price of fuelwood</u>							
1	2.24	2.33	2.51	2.41	4.0	12.0	7.6
2	1.42	1.53	1.51	1.39	7.7	6.3	-2.1
3	2.32	2.19	2.26	2.47	5.6	-2.6	6.4
4	.83	1.28	1.04	1.05	54.2	25.3	26.5
<u>Nonwood fuel price divided by price of wood</u>							
1	1.15	1.27	1.27	1.31	10.4	10.4	13.9
2	1.78	1.71	1.57	1.61	3.9	-11.8	-9.6
3	2.01	2.01	2.03	2.07	.0	1.0	3.0
4	2.21	2.33	2.44	2.32	3.9	10.4	5.0

Table 8.--Survey and combined equation estimates of average amount burned per household for subgroups of counties, 1980-81

County characteristic and quartile of households	Amount burned			Percentage difference between Model and survey			
	Model ¹						
	Survey	I	II	III	I	II	III
Average	.507	.507	.507	.507	.0	.0	.0
Median income							
1	.762	.740	.736	.689	-2.9	-3.4	-9.6
2	.561	.531	.547	.551	-5.3	-2.5	-1.8
3	.342	.369	.365	.370	7.9	6.7	8.2
4	.374	.387	.379	.418	3.5	1.3	11.8
Heating degree days							
1	.222	.257	.271	.229	15.8	22.1	3.2
2	.719	.734	.734	.707	2.1	2.1	-1.7
3	.412	.418	.398	.409	-1.5	3.4	-.7
4	.660	.617	.622	.682	-6.5	-5.8	3.3

Table 8 (cont'd.)

County characteristic and quartile of households	Amount burned				Percentage difference between Model and survey		
	Model ¹						
	Survey	I	II	III	I	II	III
------(cords)-----							
<u>Nonwood fuel price</u>							
1	.363	.341	.348	.350	6.1	-4.1	-3.6
2	.477	.454	.468	.463	4.8	-1.9	-2.9
3	.583	.590	.590	.583	1.2	1.2	.0
4	.607	.646	.624	.634	6.4	1.5	4.4
<u>Price of fuelwood</u>							
1	.726	.768	.784	.746	5.8	8.0	2.8
2	.334	.346	.335	.314	3.6	.3	-6.0
3	.781	.701	.707	.768	-10.2	-9.5	1.7
4	.175	.219	.208	.208	25.1	18.9	18.9
<u>Nonwood fuel price divided by price of wood</u>							
1	.283	.284	.290	.300	.4	2.5	6.0
2	.416	.351	.345	.355	-15.6	-17.1	14.7
3	.580	.573	.574	.589	-1.2	1.0	1.6
4	.754	.823	.821	.786	9.2	8.9	4.2

Table 8 (cont'd.)

County characteristic and quartile of households	Amount burned			Percentage difference between Model and survey			
	Model ¹						
	Survey	I	II	III	I	II	III
------(cords)-----							
<u>Percent forest land</u>							
1	.214	.188	.186	.285	-12.1	-13.1	-13.6
2	.352	.353	.372	.360	.3	5.7	2.3
3	.520	.535	.521	.514	2.9	.2	-1.2
4	.965	.969	.965	.985	.4	.0	2.1
<u>Population density</u>							
1	.915	.891	.924	.917	-4.8	1.0	.2
2	.653	.576	.596	.606	-11.8	- 8.7	- 7.2
3	.300	.382	.365	.363	27.3	21.7	21.0
4	.131	.201	.146	.143	-53.4	11.5	9.2
<u>Percent rural population</u>							
1	.125	.186	.140	.137	49.0	12.0	9.6
2	.267	.347	.334	.329	30.0	25.1	23.2
3	.569	.549	.577	.585	-3.5	-2.1	2.8
4	1.032	.952	.984	.983	-7.8	-4.7	-4.7

Table 8 (cont'd.)

County characteristic and quartile of households	Amount burned			Percentage difference between Model and survey			
	Model ¹			I	II	III	
	Survey	I	II				III
------(cords)-----							
Percent homeowners							
1	.199	.251	.217	.205	26.1	9.0	3.0
2	.363	.435	.425	.425	19.8	17.1	17.1
3	.613	.557	.581	.589	-9.1	-5.2	-3.9
4	.826	.789	.809	.813	-4.5	-2.1	-1.6
Region							
Northwest	1.265	1.170	1.248	1.350	-7.5	-1.3	6.7
N. Rocky Mtns.	1.005	.905	1.096	1.228	-10.0	9.1	22.2
S. Rocky Mtns.	.263	.293	.323	.328	11.4	22.8	24.7
Lake States	.653	.562	.563	.611	-13.9	-13.8	-6.4
Central States	.495	.456	.452	.439	-7.9	-8.7	-11.3
Mid Atlantic	.381	.372	.343	.367	-2.4	-10.0	-3.7
North East	.780	.832	.777	.849	6.7	.4	8.8
South Central	.499	.502	.514	.450	.6	3.0	-9.8
South East	.580	.671	.652	.617	15.7	12.4	6.4

¹Model I combines probit equation 2 with amount equation (18). Model II combines probit equation 2 with amount equation (19). Model III combines probit equation 2 with amount equation (20).

Discussion is focused on equation (20) since it provides the best fit of the amount data (multiple $R^2 = .44$). For equation (20), 23 categories (of 54) have differences from the survey of more than 7%. Five categories have differences of 17% or more:

- Highest income counties are predicted 18% to high,
- Highest fuelwood price counties are predicted 27% to high,
- Highest population density counties are predicted 30-36% to high,
- Next to lowest percent rural households group is predicted 37% to high,
- next to lowest percent homeowners group is predicted 17% to high,
- the two Rocky Mountain regions are predicted 44% and 26% to high respectively.

Certain patterns appear in comparing amount burned predictions to survey estimates. Equation (20) underestimates for low income groups and overestimates for high income groups. Also, predictions across income groups become worse as we move from equation (18) to equation (20). The greater flexibility of equations (19) and (20) does not improve predictions across income groups. Equation (20) also underpredicts for low percent forest counties and overpredicts for high percent forest counties (Table 7). Predictions for households in counties with low

population density are good, but are high for high density counties. Even though the influence of factors in equation (20) can change with population density, the change is not enough to prevent overestimates at high population density. It is possible that equation (20) is not flexible enough at high population density, or it is possible the combined influence of two or more factors, at high densities, decreases woodburning. For example, at high densities, high income and high fuelwood price may combine to cause very low fuelwood consumption. In equation (20), a move to a higher fuelwood price drives down fuelwood use by the same percentage regardless of income.

Based on comparisons in Table 7 it appears equation (20) predicts amounts best for those counties with "near median" characteristics. Overestimates are most common and are greatest for high density counties and high income counties.

The errors in predicting amount per woodburner are offset somewhat when a probit equation is combined with an amount equation to predict average amount used per household over all households in a county. Three models were formed by pairing probit equation 2 (Table 3) with amount equations (18) through (20) respectively (Table 4). The combined equations in Model III provide moderately better predictions at high population densities, on average, than does equation (20), and slightly better

predictions across income groups (Table 8). Predictions tend to be good for counties with "near median" characteristics. Model III predictions for 16 categories (of 54) differ from survey results by more than 7%. Six categories differ by 17% or more.

Because of the importance of population density in determining fuelwood use a more detailed comparison of survey and Model III results was made for higher density counties (Table 9). For Model III, overpredictions of average amount burned becomes larger as density increases beyond 6000 persons per square mile. For counties with 1508-6000 persons per square mile predictions average 7.8% too high. For counties with 6000-13087 persons per square mile predictions average 44% too high, and for counties over 13087 persons per square mile predictions average 160% too high. Six and one half percent of households live in counties with 6000 persons per square mile or more. Model III overpredicts their fuelwood use by an average of 68 percent. Model III predicts well, on average, for counties under 6000 persons per square mile. It overpredicts by only 1.4% on average.

The forgoing correspondence tests cannot indicate how well the equations will predict for individual counties. Essentially these comparisons are a qualitative test of the hypothesis that the equations predict well across a wide range of county conditions. The hypothesis is false for

Table 9.--Survey and equation estimates of percent burners, average fuelwood use by woodburners, and average household fuelwood use, by population density of counties, 1980-81.

County population density	Number of households in counties	Percentage burners		Average amount burned by woodburners		Average Amount burned over all households	
		Survey	Probit Equation 2	Survey	Equation (20)	Survey	Model III
(persons per square mile)	(millions)	------(Cords)-----					
0-98	19.9	35.5	36.7	2.58	2.68	.915	.917
98-417	19.9	31.9	30.9	2.04	2.12	.652	.605
417-1508	19.9	26.7	26.0	1.12	1.52	.301	.365
1508-6000	14.8		18.7	.83	1.06	.165	.178
6000-13087	2.3	7.6	8.4	.72	1.03	.055	.079
13087-28511	1.0	5.0	6.9	.12	.50	.006	.027
28511-34000	1.2	1.5	3.4	.87	.84	.012	.025
34000 or more	.7	3.5	3.5	.17	.38	.006	.011

prediction of amounts burned in counties with high income, or high density and for the two Rocky Mountain regions. Predictions for these counties are too high on average.

To obtain an idea about the likely accuracy of individual county estimates it would be best if we could compare independent county estimates with model estimates. Such estimates are not available for 1980-81. As a substitute several state level estimates are compared to our model estimates. Unfortunately state level survey estimates vary widely in accuracy. So, the confidence we can place in comparisons is limited.

Comparing model estimates of amount burned to 9 state survey estimates for 1980-81 shows our model "underestimates" by 20% or more in 4 states and "overestimates" by 20% or more in 1 state (Table 10). Comparison of model estimates to state survey estimates for other years shows our model usually "underestimates" total consumption. If we place confidence in the individual state surveys we would expect the individual county estimates would be underestimates in many cases. Many state estimates are probably too high based on the fact that the resurvey conducted for the National Residential Fuelwood Use Survey found households overestimated by an average of 18% on the initial survey.⁵⁴ The state

⁵⁴Skog and Watterson. 1983. Residential fuelwood use in the United States. p. c-10.

Table 10.--Total residential fuelwood consumption by state as estimated by the National Residential Fuelwood use Survey of 1980-81, by Model III and by other surveys

STATE	Residential fuelwood use survey 1980-81 ¹	Estimate by Model III 1980-81	Other survey results			
			1979-80	1980-81	1981-82	1982-83
----- (million cords) -----						
Alabama	.76	1.05				
Arizona		.29				
Arkansas	.85	.53				
California	1.84	1.90				
Colorado	.39	.76				
Connecticut	.44	.71	.91			.66
Delaware		.07				
D.C.		.01				
Florida	.62	.65				
Georgia	.73	.97		1.70		
Idaho	.39	.44	.37			
Illinois	1.58	1.09				1.70
Indiana	.86	.96				
Iowa		.55				
Kansas		.26				
Kentucky		.87				
Louisiana		.42				

Table 10 (cont'd.)

STATE	Residential fuelwood use survey 1980-81 ¹	Estimate by Model III 1980-81	Other survey results			
			1979-80	1980-81	1981-82	1982-83
----- (million cords) -----						
Maine	.84	.75				
Maryland	.49	.52		.94		
Massachusetts	1.07	1.21				
Michigan	1.79	1.68			2.86	
Minnesota	.96	.92	1.31			
Mississippi		.64				
Missouri	1.23	.82			1.79	
Montana	.26	.32	.29			
Nebraska		.21				
Nevada		.26				
New Hampshire	.46	.50	.39	.50		
New Jersey	.41	.75		1.00		
New Mexico	.23	.31				
New York	2.12	1.92		3.39		
North Carolina	1.92	2.05				
North Dakota	.14	.17				
Ohio	2.09	1.98			2.07	
Oklahoma	.57	.36				
Oregon	1.55	1.44	1.21			
Pennsylvania	2.20	1.89		3.10		

Table 10 (cont'd.)

STATE	Residential fuelwood use survey 1980-81 ₁	Estimate by Model III 1980-81	Other survey results			
			1979-80	1980-81	1981-82	1982-83
----- (million cords) -----						
Rhode Island		.20				.21
South Carolina	.61	.84		.58		
South Dakota	.22	.18				
Tennessee	1.47	1.42				
Texas	1.32	.99				
Utah		.30				
Vermont	.41	.33	.37		.50	
Virginia	1.76	1.96				
Washington	1.67	1.99	1.21			
West Virginia	.64	.61				

Table 10 (cont'd.)

STATE	Residential fuelwood use survey 1980-81 ₁	Estimate by Model III 1980-81	Other survey results			
			1979-80	1980-81	1981-82	1982-83
------(million cords)-----						
Wisconsin	1.28	1.18	1.97	1.35		
Wyoming	.14	.19				

1Relative Standard error of estimate varies from 15 to 50%.

2Source of state estimates unless otherwise noted is: USDOE Energy Information Administration. 1984. Estimates of U.S. wood energy consumption, 1980-1983. DOE/EIA-0341(83). p. 29.

Other sources:

State of Connecticut, Office of Policy and Management - Energy Division. 1984.

Residential wood energy users survey. Unpublished report. p. 12.

Terrence G. Esvelt and Marle L. Roberts. 1980. The use of wood for residential space heating in the Pacific Northwest. Presented at Solwest 80, August 6, Vancouver, BC. Estimates for OR, WA, ID, MT for 1979-80.

Dwight R. McCurdy and John H. Burde. 1984. Highlights of wood for energy in Illinois, 1982-83. Dept. of Forestry, Southern Illinois Univ., Carbondale. p. 5.

Minnesota Dept. of Natural Resources - Forestry. 1981. Minnesota residential fuelwood demand, 1979-80. Unpublished report. St. Paul (October).

surveys generally did not conduct resurveys or other checks to verify respondent estimates.

The conclusions to be drawn from the correspondence tests that compare estimates for groups of counties include:

- probit equation 2 predicts average percentage of burners fairly well over a wide range of county conditions,
- equation (20) overpredicts average amount burned by woodburners for counties with high incomes and high population density, and underpredicts for counties with low income,
- Model III overpredicts average fuelwood use by 68% for counties with population density above 6000 per square mile. Model III predicts fairly well for counties with densities under 6000 persons per square mile. The specification of equation (20) needs to be improved to predict wood use at high densities.

From comparisons of state level estimates we conclude that Model III under estimates total fuelwood use in states and counties if independent state survey results are correct.

Validation by Coherence

Coherence among findings on what influences wood use behavior. How well does Model III agree with previous findings concerning the fuelwood use behavior of households? Three previous studies have evaluated the way various factors influence fuelwood use behavior.^{55, 56, 57} The elasticities of variables from these previous studies have signs which match the signs of elasticities for equations developed here (Table 11).

The elasticities of the probability of woodburning from probit equation 2 are compared to elasticities from Hardie's probit equation for individual households. Signs of elasticities match for variables found in both equations. Hardie does not include income in his model but uses "area heated" which is highly correlated with income. The elasticity for area heated is positive as is our elasticity for income in probit equation 2.

The elasticities for amount burned by woodburners from equation (20) are compared to elasticities from Hardie's amount equation for individual households. Elasticity

⁵⁵Lipfert. 1983. Residential fuelwood use in the United States.

⁵⁶Frederich W. Lipfert et al. 1984. Empirical analysis of residential wood burning impacts. An unpublished report for the Office of Policy Analysis, U.S. Environmental Protection Agency (Washington, D.C.) 36 p.

⁵⁷Hardie and Hassan. 1984. An analysis of residential demand for fuelwood.

Table 11.--A comparison of signs of elasticities of fuelwood use from previous studies and from probit equation 2, amount equation (20) and Model III.

Variable	Percentage of households burning wood		Amount burned per woodburner		Amount burned over all households	
	Previous finding ₁	Probit equation 2	Previous finding ₂	Equation (20) ₃	Previous finding ₄	Model III ₃
Income		+	-	-/+		-/+
Heating degree days						
	+	+	+	+	+	+
Nonwood fuel price	+	+				
Fuelwood price	-	-				
Percent forest land		+		+	+	+
Nonwood fuel price divided by price of wood			+	+		+
Population density		+		-	-	-

Table 11 (cont'd.)

Variable	Percentage of households burning wood		Amount burned per woodburner		Amount burned over all households	
	Previous finding ₁	Probit equation ₂	Previous finding ₂	Equation (20) ₃	Previous finding ₄	Model III ₃
Heating equipment used						
Steam radiators	-	-				
Ducted hot air	-	-				
Electric wall heaters	-	-				
Gas or oil room heater	-	-				

¹Hardie and Hassan. 1984. An analysis of demand for fuelwood. pp. 23-27. The Sign is shown that is found for most regions. For the North Central region the elasticity was negative for heating degree days and positive for electric heating.

²Ibid. p. 32, 37.

³Elasticity with respect to income is positive for higher income, lower density counties. See Tables 14 & 15.

⁴Lipfert et al. 1984. Empirical analysis of residential woodburning impacts. p. 29.

signs match with the partial exception of income elasticity discussed below. Elasticities for equation (20) vary with population density and are shown in Table 12. Elasticities of amounts burned by woodburners are short term demand elasticities indicating how much fuelwood demand would change in the absense of entry and exit of households to woodburning. Short term demand elasticities are positive for heating degree days and for relative price of nonwood fuel both for Hardie's equation and equation (20). Hardie initially included income but found it had an insignificant coefficient, so, he excluded it from his amount equation. He retained the "area heated" variable which has a negative elasticity. Our proxy for "area heated" in equation (20) is income. Equation (20) has a negative elasticity for income for most combinations of income and population density. For these combinations wood is like an "inferior good" (less is used as income increases). But for higher income low density counties income elasticity is positive indicating fuelwood is a "normal good" (Table 12).

Income elasticities of fuelwood use for the average woodburner vary from small positive values to negative values over income groups and population groups largely because of differences in the type of woodburning equipment the average woodburner is most likely to use and differences in woodburning purpose. In low density counties the average woodburner uses a stove and burns wood

Table 12.--Elasticities of average amount burned by woodburners with respect to selected variables, for counties with various population densities.

Population density	County variable				
	Population density	Income (1000 dollars)	Heating degree days	Percent forest land	Relative price
		14.7 17.1 18.9	2673 5064 6328	3.1 15. 45.	.099 .120 .146
(persons per square mile)					
EQUATION (18)					
Any		-1.09	.45	.12	.36
EQUATION (19)					
1.65		- .81	.34	.27	.14
98		- .77	.33	.10	.25
417		- .83	.37	.10	.36
1808		- .95	.41	.10	.42
22026		-1.96	.66	.02	.56
EQUATION (20)					
1.65		0.18 .01	.15 .59	.59 .59	.17 .15 .13 .14 .20 .25
98		-.27 -.10	.03 .55	.55 .55	.09 .15 .19 .13 .18 .23
417		-.50 -.38	-.29 .53	.53 .53	.04 .16 .24 .17 .23 .28
1808		-.71 -.64	-.59 .51	.51 .51	.03 .16 .24 .25 .30 .36
22026		-2.01-2.32	-2.54 .27	.27 .27	.16 .11 .07 .87 .92 .98

to provide much of his space heat. As we move to higher density counties the average woodburner is more likely to have a fireplace rather than a stove and is more likely to heat just part of his house or burn wood just for pleasure.

In low density counties income elasticity moves from slightly negative to slightly positive. The move from negative to positive elasticity may be due to one or more factors: (1) higher income households may have larger houses to heat, (2) they may be more likely to heat entirely with wood, or (3) they may view greater woodburning as part of a life style to be desired.

In higher density counties with low income the average woodburner is fairly likely to own a stove and burn wood for space heating. But, as average income increases, the average woodburner is more likely to use a fireplace just for pleasure. So as we move from low income to high income counties wood use by the average household goes down (income elasticity is negative).

Equations (19) and (20) indicate that short term demand elasticities vary considerably with population density. For example, in higher density counties amount burned decreases much more rapidly in response to higher income. This might be interpreted as a greater sensitivity to inconvenience of wood use in high density areas. Unlike the increased response to changing income at high density, households decrease their response to heating degree day

changes at higher density. And, as we might expect, colder weather will increase a rural household's wood use more than an urban household's use.

The short term response of households to change in forest availability (percent forest land) is greater for highly forested, middle density counties. Response is lowest for counties with little forest. These findings suggest increased access to forest land may increase average woodburning by the greatest percentage in highly forested, moderately populated rural counties.

The short term response of woodburning households to increasing relative price of nonwood fuel increases sharply as county population density increases above 1800 persons per square mile. Even though woodburners in high density areas are responsive to relative nonwood fuel price changes, they are even more responsive to changes in income. In high density areas if income increases as fast as relative nonwood fuel price, fuelwood use by woodburners will decrease. But, in middle and upper income low density areas equal percentage increases in income and relative nonwood fuel price will cause an increase in woodburning.

When probit equation 2 and equation (20) are combined as Model III both the entry/exit decisions and amount to burn decisions are included. Elasticities of amounts burned for Model III are long term fuelwood demand elasticities (Table 13).

Table 13.--Elasticity of average amount burned by over all households with respect to selected variables, for counties with various population densities.

	County variable			
Population density	Income (1000 dollars)	Heating degree days	Percent forest land	Relative price
	14.7	17.1	18.9	
	2673	5064	6328	3.1
				15. 45.
				.099 .120 .146

MODEL III

1.65	-.41	.21	.65	.99	1.17	1.19	1.09	.19	.23	.35	.78	.67	.43
98	-.41	.15	.63	.99	1.24	1.28	1.17	.10	.25	.47	.89	.75	.45
417	-.46	-.01	.44	.80	1.26	1.31	1.19	.06	.26	.53	.99	.83	.51
1808	-.65	-.33	.05	.36	1.26	1.31	1.19	.06	.26	.54	1.17	1.00	.65
8103	-.89	-.67	-.38	-.13	1.23	1.29	1.16	.08	.26	.52	1.37	1.19	.83
22026	-1.47	-1.44	-1.36	-1.25	1.11	1.18	1.05	.19	.23	.41	1.82	1.46	1.24

The differences between short term and long term elasticities are smallest for percent forest land. This is due to the low entry/exit elasticity of .15 from probit equation 2 (Table 3). The small difference in elasticities implies that increasing access to forests/fuelwood will have the greatest influence on households that already burn wood.

A change in household income has varying effects on the entry/exit and amount to burn decisions. The elasticity for entry/exit is .51 (at an income of \$17,190); but for amount burned it varies at least from .15 to -2.54 (Table 12). The net long term elasticity is positive for most combinations of income and population density. Only at high densities or low incomes does overall woodburning decline with greater income.

To the extent that annual heating degree days for an area do not persist at levels far from the mean, the main effect of changes in heating degree days will be to change the amount burned by woodburners. This degree of change is indicated by the short term elasticity which is .5 to .6 except at high population densities. If winter becomes persistently colder or warmer in an area the long term demand elasticity would be 1.1 to 1.3 (Table 13).

Long term elasticity with respect to relative price of nonwood fuel moves from less than one to greater than one as density increases. The elasticity is also much higher at lower relative prices where wood does not have as much price advantage. This means that increases in woodburning will be low in response to relative price increases to the extent that they occur in areas where wood already has a price advantage or where population density is low.

When comparing the long term response of households to equal percentage increases in income and relative price at higher population densities, we find that the increase due to increased relative price exceeds the decrease due to increased income. This means that overall wood use is likely to increase in densely populated areas as relative prices increase unless income increases at a faster percentage rate than relative price.

Coherence between findings on what population density results in the most woodburning per square mile. Lipfert et al. constructed two single equation models to predict fuelwood use in individual counties.^{58,59} One purpose of these models was to estimate at what population density pollution from woodburning is greatest. His second, more detailed model, based on the same data as Model III

⁵⁸Lipfert et al. 1983. Residential fuelwood use in the United States.

⁵⁹Lipfert et al. 1984. Empirical analysis of residential woodburning impacts.

estimated that wood use intensity is greatest at about 6000 persons per square mile (445 cords/sq. mi.). Model III estimates the highest wood use per square mile would be at 163,000 persons/sq. mi. This density is greater than for Manhattan (62,099 persons per sq. mi.). The estimate by Model III is too high given the finding in Table 8 that Model III overpredicts substantially for densities above 6000 persons per square mile.

Lipfert's model gives a more realistic level of maximum use but does so by using a more rigid single equation model. Model III's more flexible form allows data from lower density counties to dominate determination of parameters in a way that causes overpredictions for the relatively few high density counties. In Model III, the weight of observations in high density counties is not sufficient to cause the regression procedures to calculate parameters that predict wood use well at high densities.

Validation by Pragmatic Uses

How well does the model serve to guide or stimulate inquiry about fuelwood use behavior? This modeling effort raises a number of questions and conjectures worth further consideration in efforts to predict fuelwood use behavior. First, a household's fundamental view of the value of woodburning may differ depending on life styles predominant in various population density-income classes. Households in low density areas with middle to high incomes view

fuelwood as a normal good. They want to use more of it as they become more affluent. Low income low density households and high density households consider some use of fuelwood to be desirable as they become more affluent, but, the desirable amount to be used goes down with increasing income.

Second, Model III suggests availability of forest land increases fuelwood use. But we do not know what availability characteristics of forest land would cause more or less fuelwood use. What are the influences of public vs. private ownership, size of ownership, species, and management activities?

Third, the probit equation in Model III predicts well, but the amount equation predicts amounts burned poorly for some counties. Can aggregate fuelwood use be predicted well with any equation using aggregate county characteristics, or are equations predicting individual household use needed for accuracy?

There are a number of ways an aggregate model might be improved.

- Use separate probit models to estimate the likelihood of use by oil, natural gas electricity and "other" fuel users
- Use separate equations to predict amount burned by woodburners who use oil, natural gas, electricity or "other" fuels.

- Change the amount burned equation to allow greater change in the influence of variables at high population densities.
- Change the amount burned equation to allow for a varying influence of income depending on both relative price of nonwood fuel and population density.

The model developed here is pragmatic for researchers to the extent that the foregoing suggestions lead to better empirical models. The model will be pragmatic for local state or national officials to the extent that they use predictions of county fuelwood use given in the next section.

V. IDENTIFYING COUNTIES WITH HIGH INTENSITY FUELWOOD USE

Model III was used to estimate intensity of fuelwood use in each county in the continental U.S. Five measures of use intensity were used to rank counties. Tables 14-17 show the 10 counties in each of 9 regions which have the highest intensity use according to the following measures:

- percent woodburners
- amount burned per woodburning household
- average amount burned over all households
- amount burned per square mile of county.

Information on population density of counties is included in the listings to show if a county has over 6000 persons per square mile and is therefore likely to have its wood use overpredicted.

Counties ranking high in a particular intensity of use have certain characteristics in common. For example, counties with a high percentage of burners have small populations, low population density, high heating degree days for their region, substantial forest land and high relative price for nonwood fuel. It is somewhat surprising that these counties have low median incomes (except in the Pacific Northwest), since table 2 indicates percentage of burners increases with higher county income. In most

regions nonincome factors are most important in determining percent users in high use counties. The percentage of burners for the top 10 counties in each region ranges from a high of 86% in Mineral, Colorado to a low of 46% in Shannon, Missouri and Hampshire, West Virginia (Table 14).

Counties with high amount burned per woodburning household are similar to those with a high percentage of woodburners. Forty-two of the 90 high percent user counties are also high amount burned counties. The high amount burned counties have more uniformly low income, more uniformly high percent forest land and more uniformly low population density. Amount burned per woodburner for the top 10 counties in each region ranges from a high of 6.01 cords in Hinsdale, Colorado to a low of 3.56 cords in Okanogan, Washington (Table 15).

Counties with high use per household over all households are similar to those with high use under the previous two measures. In fact, fifty nine of the 90 counties with high use over all households are also on one of the previous two lists. Counties with high amount burned over all households are more uniformly low in population density than the previous two sets of counties. As for the preceding lists, they have low income, colder climate, substantial forest land and high relative price for nonwood fuel. Amounts of fuelwood used

TABLE 14.-- TEN COUNTIES IN EACH REGION WITH THE HIGHEST ESTIMATED PERCENTAGE OF WOODBURNERS, 1981

REGION	STATE	COUNTY	NUMBER OF HHOLDS	PCT. WOOD USERS	WOOD			WOOD PER SQ. MI.	WOOD PER SQ. MI.	MEDIAN HHOLD INCOME	HEATING DEGREE DAYS	PCT. FOREST LAND	NONWOOD		WOOD FUEL PRICE	RELA- TIVE PRICE	PERSONS PER SQ. MI.	LAND AREA
					WOOD BURNER	WOOD PER HHOLD	WOOD PER SQ. MI.						FUEL PRICE	FUEL PRICE				
-----CORDS----- (\$1000) (\$ PER (\$/CORD) (SQ. MI.)																		
NW	WA	SKAMANIA	2.9	73.	4.03	2.95	5.	6.	19.5	6864.	86.	7.38	84.	0.088	4.7	1672.		
NW	OR	GRANT	3.0	72.	4.50	3.22	2.	4.	15.2	6704.	53.	11.01	84.	0.131	1.8	4530.		
NW	WA	FERRY	2.0	71.	4.22	2.99	3.	4.	14.7	6454.	72.	9.19	84.	0.109	2.6	2202.		
NW	OR	KLAMATH	21.8	70.	3.93	2.76	10.	16.	15.4	7759.	63.	8.64	73.	0.118	9.9	5970.		
NW	WA	SNOHOMISH	120.8	69.	2.90	2.01	116.	223.	20.8	6864.	52.	14.12	71.	0.199	161.0	2098.		
NW	OR	CLACKAMAS	84.5	68.	2.37	1.61	72.	99.	21.2	4666.	73.	10.16	73.	0.140	128.4	1884.		
NW	OR	DOUGLAS	33.4	67.	3.00	2.02	13.	16.	16.7	4779.	85.	10.61	76.	0.139	18.5	5063.		
NW	WA	PEND OREILLE	3.0	67.	4.05	2.71	6.	7.	12.3	6454.	82.	8.75	84.	0.104	6.1	1402.		
NW	WA	STEVENS	9.9	67.	3.49	2.33	9.	13.	14.8	6454.	69.	8.84	81.	0.109	11.7	2481.		
NW	OR	LAKE	2.8	66.	4.12	2.73	1.	4.	15.5	6413.	23.	8.58	77.	0.111	0.9	8231.		
-----CORDS----- (\$1000) (\$ PER (\$/CORD) (SQ. MI.)																		
NRM	ID	VALLEY	2.1	66.	5.72	3.79	2.	3.	15.8	7822.	62.	9.80	50.	0.196	1.5	3676.		
NRM	ID	BOISE	1.1	64.	5.68	3.65	2.	3.	15.5	7822.	62.	9.68	50.	0.194	1.6	1910.		
NRM	ID	ADAMS	1.2	64.	5.45	3.50	3.	5.	14.8	7822.	62.	10.00	50.	0.200	2.4	1371.		
NRM	MT	MINERAL	1.3	62.	4.78	2.97	3.	6.	16.1	7218.	52.	9.32	50.	0.186	3.0	1222.		
NRM	ID	CAMAS	0.3	61.	6.53	3.95	1.	2.	13.2	7822.	62.	10.15	50.	0.203	0.8	1054.		
NRM	MT	LINCOLN	6.1	59.	4.41	2.60	4.	8.	15.7	7218.	52.	8.82	50.	0.175	4.8	3714.		
NRM	MT	SANDERS	3.1	58.	4.98	2.90	3.	6.	12.6	7218.	52.	9.12	50.	0.182	3.1	2778.		
NRM	ID	IDAHO	5.2	58.	5.18	3.01	2.	3.	14.5	7822.	62.	7.19	51.	0.142	1.7	8516.		
NRM	ID	CLEARWATER	3.6	58.	4.54	2.62	4.	6.	17.3	7822.	62.	7.22	51.	0.141	4.1	2521.		
NRM	ID	ELMORE	6.8	55.	4.70	2.60	6.	9.	13.3	7822.	62.	9.45	52.	0.182	7.1	3048.		
-----CORDS----- (\$1000) (\$ PER (\$/CORD) (SQ. MI.)																		
SRM	CO	MINERAL	0.3	86.	5.99	5.14	2.	5.	15.3	8084.	35.	12.70	60.	0.212	0.9	921.		
SRM	CO	HINSDALE	0.2	85.	6.01	5.11	1.	2.	15.5	7204.	35.	12.37	60.	0.206	0.4	1054.		
SRM	CO	PARK	1.9	85.	4.52	3.84	3.	10.	18.1	6342.	35.	12.71	60.	0.212	2.5	2162.		
SRM	CO	SAN MIGUEL	1.3	84.	4.95	4.16	4.	12.	13.6	7204.	35.	12.36	60.	0.206	2.5	1283.		
SRM	NV	ESMERALDA	0.3	84.	3.93	3.30	0.	3.	17.4	4899.	11.	10.84	60.	0.181	0.2	3570.		
SRM	UT	DAGGETT	0.2	83.	3.79	3.15	1.	19.	16.5	7715.	6.	8.14	60.	0.136	1.1	682.		
SRM	CO	DOUGLAS	7.8	83.	2.01	1.66	15.	1532.	28.4	6342.	1.	7.99	70.	0.115	29.8	843.		
SRM	CO	OURAY	0.7	82.	4.71	3.85	5.	15.	14.2	7204.	35.	12.75	60.	0.212	3.6	540.		
SRM	CO	SAN JUAN	0.3	82.	4.97	4.06	3.	9.	14.7	7204.	35.	12.34	60.	0.206	2.1	391.		
SRM	NM	CATRON	1.0	82.	4.34	3.54	0.	7.	10.3	5293.	7.	10.84	60.	0.181	0.4	6897.		

TABLE 14.--(CONT'D.)

REGION	STATE	COUNTY	NUMBER OF HHOLDS	PCT. WOOD USERS	WOOD PER BURNER	WOOD HHOLD	WOOD PER SQ. MI.	WOOD PER SQ. MI.	WOOD PER SQ. MI.	HEATING DEGREE DAYS	PCT. FOREST LAND	NONWOOD FUEL PRICE	WOOD FUEL PRICE	RELA- TIVE PRICE	PERSONS PER SQ. MI.	LAND AREA
-----CORDS-----																
			(1000S)									(\$ PER MMBTU)	(\$ /CORD)			(SQ. MI.)
LS	MN	COOK	1.6	56.	5.38	3.03	4.	6.	14.6	9002.	63.	10.92	68.	0.161	3.0	1346.
LS	WI	FLORENCE	1.5	54.	4.95	2.69	8.	10.	11.9	8189.	84.	10.75	68.	0.158	8.6	487.
LS	MN	ITASCA	15.1	54.	4.30	2.33	13.	18.	16.2	9039.	76.	9.83	69.	0.142	16.4	2633.
LS	WI	FOREST	3.0	54.	5.05	2.74	8.	10.	11.2	8189.	82.	10.76	68.	0.158	9.0	1007.
LS	ND	BILLINGS	0.4	54.	3.04	1.64	1.	53.	20.3	7817.	1.	11.38	68.	0.167	1.0	1139.
LS	MI	OSCODA	2.6	54.	4.99	2.67	12.	14.	11.2	8346.	85.	10.84	68.	0.159	12.2	563.
LS	WI	SAWYER	4.7	53.	5.12	2.70	10.	13.	11.1	8649.	77.	10.83	68.	0.159	10.2	1259.
LS	MN	CASS	7.5	53.	5.17	2.72	10.	15.	10.9	9039.	67.	10.89	68.	0.160	10.5	1998.
LS	WI	BAYFIELD	5.1	52.	5.06	2.65	9.	11.	11.8	8649.	83.	10.72	68.	0.158	9.5	1460.
LS	WI	MENOMINEE	0.8	52.	4.45	2.32	5.	9.	13.4	8189.	59.	10.74	68.	0.158	9.4	360.
CS	KY	LESLIE	4.5	50.	4.13	2.08	23.	25.	9.4	4594.	94.	12.27	54.	0.227	36.4	409.
CS	OH	GEAUGA	22.9	50.	2.38	1.19	67.	257.	24.4	6532.	26.	10.13	54.	0.187	183.0	407.
CS	KY	OWSLEY	1.9	49.	5.53	2.71	25.	30.	6.7	4594.	84.	12.07	54.	0.224	29.0	197.
CS	KY	CUMBERLAND	2.6	48.	4.25	2.04	17.	27.	8.5	4559.	65.	11.85	54.	0.219	23.5	310.
CS	IN	BROWN	4.4	48.	3.09	1.48	21.	32.	16.5	5008.	64.	11.80	54.	0.219	38.6	319.
CS	KY	MC CREARY	4.9	47.	4.76	2.26	26.	31.	7.5	4594.	84.	11.57	54.	0.214	37.4	418.
CS	MO	REYNOLDS	2.7	47.	3.82	1.81	6.	7.	10.3	4282.	81.	9.83	54.	0.182	8.9	817.
CS	KY	BREATHITT	5.2	47.	3.97	1.88	20.	22.	9.4	4594.	88.	11.15	54.	0.206	34.4	494.
CS	OH	VINTON	3.9	47.	3.65	1.71	16.	23.	11.9	5748.	72.	9.74	54.	0.180	28.2	411.
CS	MO	SHANNON	2.8	46.	4.19	1.94	5.	7.	9.0	4282.	75.	9.88	54.	0.183	7.9	999.
MA	WV	WEBSTER	4.1	52.	4.36	2.28	17.	19.	9.8	6487.	90.	11.34	79.	0.143	22.2	551.
MA	WV	POCAHONTAS	3.6	52.	4.05	2.12	8.	10.	12.4	6487.	83.	11.07	79.	0.140	10.5	943.
MA	PA	FOREST	1.9	51.	4.19	2.14	10.	11.	12.7	7111.	92.	10.64	79.	0.135	12.1	419.
MA	PA	SULLIVAN	2.2	51.	4.26	2.17	10.	12.	12.5	7493.	82.	11.14	79.	0.141	13.3	478.
MA	NY	LEWIS	8.1	51.	4.19	2.12	13.	19.	14.5	9050.	69.	11.02	81.	0.136	19.4	1291.
MA	NY	HAMILTON	1.9	49.	5.10	2.49	3.	8.	12.3	9050.	34.	11.13	79.	0.141	2.9	1735.
MA	PA	PIKE	7.1	47.	3.57	1.68	22.	28.	14.7	7224.	79.	10.75	79.	0.136	33.7	542.
MA	PA	POTTER	6.1	47.	3.96	1.86	10.	12.	13.0	7111.	85.	10.77	82.	0.132	16.2	1092.
MA	MD	HOWARD	40.0	47.	1.51	0.70	112.	374.	27.6	5064.	30.	9.59	92.	0.104	472.4	251.
MA	WV	HAMPSHIRE	5.1	46.	3.49	1.62	13.	17.	11.9	5643.	78.	11.21	79.	0.142	23.3	639.

TABLE 14.--(CONT'D.)

REGION	STATE	COUNTY	NUMBER OF HHOLDS	PCT. WOOD USERS	WOOD PER BURNER	WOOD PER HHOLD	WOOD PER SQ.MI.	WOOD PER SQ.MI. FOREST	MEDIAN HHOLD INCOME	HEATING DEGREE DAYS	PCT. FOREST LAND	NONWOOD FUEL PRICE	WOOD FUEL PRICE	RELA- TIVE PRICE	PERSONS PER SQ.MI.	LAND AREA
			(1000S)				CORDS-----			(\$1000)			(\$ PER MMBTU)			(SQ.MI.)
NE	ME	PISCATAQUIS	6.3	68.	5.49	3.75	6.	7.	12.3	9421.	87.	11.68	89.	0.132	4.5	3892.
NE	ME	SOMERSET	15.4	64.	5.04	3.23	13.	14.	11.8	9421.	90.	11.85	89.	0.133	11.6	3894.
NE	VT	ESSEX	2.2	62.	4.47	2.76	9.	10.	12.4	7687.	93.	11.10	88.	0.126	9.5	663.
NE	ME	WASHINGTON	12.3	60.	4.65	2.77	13.	15.	10.4	7579.	88.	11.50	89.	0.130	13.7	2554.
NE	ME	AROOSTOOK	29.4	58.	4.78	2.79	12.	14.	12.4	9421.	86.	11.29	90.	0.126	13.4	6821.
NE	NH	CARROLL	11.1	58.	3.88	2.25	27.	31.	13.6	7488.	86.	12.61	88.	0.143	29.8	938.
NE	ME	OXFORD	17.5	58.	4.14	2.40	20.	23.	13.0	8065.	88.	11.88	89.	0.133	23.5	2080.
NE	VT	ORANGE	7.7	58.	3.78	2.19	24.	32.	12.9	7687.	76.	11.13	88.	0.126	33.0	690.
NE	ME	WALDO	9.9	58.	3.94	2.27	30.	40.	11.6	7579.	76.	11.99	89.	0.135	38.5	737.
NE	VT	WINDHAM	13.9	57.	3.80	2.16	38.	45.	13.7	8224.	85.	11.13	90.	0.124	47.1	784.
SC	TN	HANCOCK	2.4	73.	5.34	3.87	40.	58.	6.7	4198.	68.	10.49	40.	0.262	29.9	230.
SC	AR	NEWTON	2.7	73.	4.71	3.42	11.	12.	7.8	3945.	91.	8.37	40.	0.209	9.4	822.
SC	TN	FENTRESS	5.0	72.	4.49	3.23	33.	41.	8.2	4360.	80.	9.75	40.	0.244	29.8	498.
SC	TN	VAN BUREN	1.6	72.	3.99	2.86	18.	24.	11.4	4360.	76.	11.72	40.	0.293	18.6	254.
SC	TN	MORGAN	5.4	71.	3.77	2.67	27.	35.	10.9	4360.	78.	10.59	40.	0.264	30.8	539.
SC	TN	GRUNDY	4.5	70.	3.89	2.74	35.	42.	10.5	4360.	82.	11.11	40.	0.278	38.5	358.
SC	TN	WAYNE	4.8	69.	3.40	2.35	15.	19.	11.7	3961.	78.	9.22	40.	0.230	18.9	739.
SC	TN	MEIGS	2.5	69.	3.07	2.13	28.	45.	14.1	4198.	62.	10.41	40.	0.260	38.9	191.
SC	TN	POLK	4.6	69.	3.44	2.37	25.	34.	12.1	4198.	74.	10.47	40.	0.262	31.3	434.
SC	TN	BLEDSoE	3.0	69.	3.79	2.61	19.	29.	10.6	4360.	66.	10.54	40.	0.264	23.5	404.
SE	VA	CRAIG	1.5	70.	4.21	2.94	13.	16.	13.6	5055.	81.	12.15	43.	0.282	11.8	336.
SE	VA	HIGHLAND	1.1	69.	4.45	3.09	8.	11.	13.6	5055.	74.	12.42	43.	0.289	7.1	416.
SE	VA	BLAND	2.1	68.	4.11	2.80	16.	22.	13.9	5238.	74.	12.71	43.	0.296	17.2	369.
SE	VA	FAIRFAX	205.6	67.	1.24	0.83	430.	1101.	30.0	5104.	39.	10.24	58.	0.175	1496.0	399.
SE	VA	ALLEGHANY	4.8	67.	3.61	2.41	26.	30.	15.9	5055.	87.	11.33	43.	0.263	32.3	444.
SE	VA	BATH	1.9	66.	4.23	2.80	10.	12.	13.3	5055.	86.	11.61	43.	0.270	10.9	540.
SE	VA	BOTETOURT	8.0	66.	3.48	2.29	34.	48.	17.1	5055.	70.	12.45	43.	0.289	42.5	548.
SE	VA	BUCHANAN	11.8	65.	3.60	2.33	54.	65.	15.4	5238.	83.	13.03	44.	0.295	74.8	508.
SE	NC	AVERY	4.9	65.	4.05	2.62	52.	64.	11.1	5328.	81.	11.64	43.	0.271	58.8	245.
SE	VA	DICKENSON	6.5	64.	3.83	2.47	48.	59.	13.5	5238.	82.	12.98	43.	0.302	59.7	332.

TABLE 15.-- TEN COUNTIES IN EACH REGION WITH THE HIGHEST ESTIMATED FUELWOOD USE PER WOODBURNING HOUSEHOLD, 1981

REGION	STATE	COUNTY	NUMBER OF HHOLDS	PCT. WOOD USERS	WOOD PER BURNER	WOOD PER HHOLD	WOOD PER SQ.MI.	WOOD PER SQ.MI. FOREST	MEDIAN HHOLD INCOME	HEATING DEGREE DAYS	PCT. FOREST LAND	NONWOOD FUEL PRICE	WOOD FUEL PRICE	RELAT- TIVE PRICE	PERSONS PER SQ.MI.	LAND AREA
			(1000S)						(\$1000)			(\$ PER MMBTU)	(\$/CORD)			(SQ.MI.)
-----CORDS-----																
NW	OR	WHEELER	0.6	65.	5.16	3.36	1.	4.	10.1	6413.	29.	11.03	84.	0.131	0.9	1707.
NW	OR	GRANT	3.0	72.	4.50	3.22	2.	4.	15.2	6704.	53.	11.01	84.	0.131	1.8	4530.
NW	WA	FERRY	2.0	71.	4.22	2.99	3.	4.	14.7	6454.	72.	9.19	84.	0.109	2.6	2202.
NW	OR	WALLOWA	2.8	66.	4.22	2.78	2.	7.	13.6	6704.	35.	11.02	84.	0.131	2.3	3178.
NW	OR	LAKE	2.8	66.	4.12	2.73	1.	4.	15.5	6413.	23.	8.58	77.	0.111	0.9	8231.
NW	WA	PEND OREILLE	3.0	67.	4.05	2.71	6.	7.	12.3	6454.	82.	8.75	84.	0.104	6.1	1402.
NW	WA	SKAMANIA	2.9	73.	4.03	2.95	5.	6.	19.5	6864.	86.	7.38	84.	0.088	4.7	1672.
NW	OR	KLAMATH	21.8	70.	3.93	2.76	10.	16.	15.4	7759.	63.	8.64	73.	0.118	9.9	5970.
NW	OR	BAKER	6.2	64.	3.73	2.38	5.	17.	13.3	6704.	29.	10.08	73.	0.137	5.3	3068.
NW	WA	OKANOGAN	11.5	60.	3.56	2.15	5.	12.	13.8	6529.	38.	8.85	82.	0.108	5.8	5301.
-----CORDS-----																
NRM	ID	CAMAS	0.3	61.	6.53	3.95	1.	2.	13.2	7822.	62.	10.15	50.	0.203	0.8	1054.
NRM	ID	CLARK	0.3	52.	5.79	3.04	0.	3.	11.5	7395.	14.	10.46	50.	0.209	0.5	1751.
NRM	ID	VALLEY	2.1	66.	5.72	3.79	2.	3.	15.8	7822.	62.	9.80	50.	0.196	1.5	3676.
NRM	ID	BOISE	1.1	64.	5.68	3.65	2.	3.	15.5	7822.	62.	9.68	50.	0.194	1.6	1910.
NRM	ID	CUSTER	1.2	55.	5.54	3.03	1.	5.	11.7	7822.	14.	9.64	50.	0.193	0.7	4829.
NRM	ID	ADAMS	1.2	64.	5.45	3.50	3.	5.	14.8	7822.	62.	10.00	50.	0.200	2.4	1371.
NRM	ID	IDAHO	5.2	58.	5.18	3.01	2.	3.	14.5	7822.	62.	7.19	51.	0.142	1.7	8516.
NRM	ID	OWYHEE	2.6	48.	5.11	2.47	1.	6.	10.6	6735.	14.	9.90	50.	0.198	1.1	7641.
NRM	MT	GARFIELD	0.6	54.	5.01	2.70	0.	6.	11.9	7936.	6.	8.92	50.	0.178	0.4	4455.
NRM	MT	GRANITE	1.0	52.	5.00	2.59	2.	3.	12.7	7218.	52.	6.63	50.	0.133	1.6	1733.
-----CORDS-----																
SRM	CO	HINSDALE	0.2	85.	6.01	5.11	1.	2.	15.5	7204.	35.	12.37	60.	0.206	0.4	1054.
SRM	CO	MINERAL	0.3	86.	5.99	5.14	2.	5.	15.3	8084.	35.	12.70	60.	0.212	0.9	921.
SRM	CO	SAGUACHE	1.3	78.	5.87	4.55	2.	6.	9.8	8084.	35.	7.64	60.	0.127	1.3	3144.
SRM	NV	EUREKA	0.4	75.	5.65	4.21	0.	4.	13.2	6328.	11.	17.39	60.	0.290	0.3	4182.
SRM	NV	LINCOLN	1.3	61.	5.06	3.07	0.	3.	14.3	4899.	11.	20.49	60.	0.342	0.3	10649.
SRM	CO	SAN JUAN	0.3	82.	4.97	4.06	3.	9.	14.7	7204.	35.	12.34	60.	0.206	2.1	391.
SRM	CO	SAN MIGUEL	1.3	84.	4.95	4.16	4.	12.	13.6	7204.	35.	12.36	60.	0.206	2.5	1283.
SRM	CO	CONAJOS	2.4	70.	4.86	3.38	6.	18.	9.2	8084.	35.	6.60	60.	0.110	6.2	1268.
SRM	CO	OURAY	0.7	82.	4.71	3.85	5.	15.	14.2	7204.	35.	12.75	60.	0.212	3.6	540.
SRM	CO	CUSTER	0.6	79.	4.70	3.72	3.	8.	12.1	5639.	35.	13.30	60.	0.222	2.1	737.

TABLE 15.--(CONT'D.)

REGION	STATE	COUNTY	NUMBER OF HHOLDS	PCT. WOOD USERS	WOOD PER BURNER	WOOD HHOLD	WOOD PER SQ. MI.	WOOD PER SQ. MI. FOREST	MEDIAN HHOLD INCOME	HEATING DEGREE DAYS	PCT. FOREST LAND	NONWOOD FUEL PRICE	WOOD FUEL PRICE	RELAT- TIVE PRICE	PERSONS PER SQ. MI.	LAND AREA
			(1000S)						(\$1000)			(\$ PER MMBTU)	(\$/CORD)			(SQ. MI.)
LS	MI	KEEWENAW	0.8	47.	6.61	3.08	5.	9.	9.1	9341.	55.	11.08	68.	0.163	3.7	538.
LS	WI	IRON	2.7	51.	5.57	2.83	10.	13.	9.9	8773.	78.	10.67	68.	0.157	9.0	747.
LS	MN	COOK	1.6	56.	5.38	3.03	4.	6.	14.6	9002.	63.	10.92	68.	0.161	3.0	1346.
LS	MN	LAKE OF THE WO	1.4	49.	5.29	2.60	3.	7.	11.8	9039.	43.	9.02	68.	0.133	2.9	1311.
LS	MN	CLEARWATER	3.0	50.	5.27	2.65	8.	17.	10.1	9116.	47.	10.88	68.	0.160	8.8	1000.
LS	MI	LAKE	3.0	52.	5.20	2.70	14.	18.	9.1	7434.	81.	10.73	68.	0.158	13.5	571.
LS	MN	CASS	7.5	53.	5.17	2.72	10.	15.	10.9	9039.	67.	10.89	68.	0.160	10.5	1998.
LS	MI	MONTMORENCY	2.8	51.	5.13	2.60	13.	16.	10.3	8346.	83.	10.61	68.	0.156	13.5	555.
LS	WI	SAWYER	4.7	53.	5.12	2.70	10.	13.	11.1	8649.	77.	10.83	68.	0.159	10.2	1259.
LS	MI	ONTONAGON	3.6	52.	5.07	2.61	7.	9.	13.2	9341.	79.	10.00	68.	0.147	7.5	1316.
CS	KY	OWSLEY	1.9	49.	5.53	2.71	25.	30.	6.7	4594.	84.	12.07	54.	0.224	29.0	197.
CS	KY	MC CREARY	4.9	47.	4.76	2.26	26.	31.	7.5	4594.	84.	11.57	54.	0.214	37.4	418.
CS	KY	JACKSON	4.1	45.	4.74	2.14	26.	36.	7.4	4594.	71.	12.03	54.	0.223	35.6	337.
CS	KY	WOLFE	2.3	45.	4.49	2.03	20.	29.	7.8	4594.	70.	11.57	54.	0.214	29.5	227.
CS	KY	CLINTON	3.2	39.	4.39	1.70	29.	54.	7.2	4559.	53.	11.36	54.	0.210	49.1	190.
CS	KY	MORGAN	4.1	46.	4.37	1.99	22.	30.	8.1	4594.	73.	11.40	54.	0.211	32.8	369.
CS	KY	LEE	2.6	44.	4.33	1.89	24.	29.	8.4	4594.	82.	11.90	54.	0.220	36.9	210.
CS	KY	CUMBERLAND	2.6	48.	4.25	2.04	17.	27.	8.5	4559.	65.	11.85	54.	0.219	23.5	310.
CS	MO	OREGON	3.9	41.	4.23	1.72	9.	14.	7.9	4282.	63.	9.46	54.	0.175	13.1	784.
CS	KY	WAYNE	5.8	45.	4.22	1.89	25.	38.	8.4	4594.	66.	12.41	54.	0.228	38.7	440.
MA	NV	HAMILTON	1.9	49.	5.10	2.49	3.	8.	12.3	9050.	34.	11.13	79.	0.141	2.9	1735.
MA	WV	WEBSTER	4.1	52.	4.36	2.28	17.	19.	9.8	6487.	90.	11.34	79.	0.143	22.2	551.
MA	PA	SULLIVAN	2.2	51.	4.26	2.17	10.	12.	12.5	7493.	82.	11.14	79.	0.141	13.3	478.
MA	PA	FOREST	1.9	51.	4.19	2.14	10.	11.	12.7	7111.	92.	10.64	79.	0.135	12.1	419.
MA	NV	LEWIS	8.1	51.	4.19	2.12	13.	19.	14.5	9050.	69.	11.02	81.	0.136	19.4	1291.
MA	WV	POCAHONTAS	3.6	52.	4.05	2.12	8.	10.	12.4	6487.	83.	11.07	79.	0.140	10.5	943.
MA	PA	POTTER	6.1	47.	3.96	1.86	10.	12.	13.0	7111.	85.	10.77	82.	0.132	16.2	1092.
MA	NV	FRANKLIN	15.1	39.	3.94	1.55	14.	23.	12.3	8186.	61.	11.24	85.	0.132	26.8	1674.
MA	PA	CAMERON	2.6	45.	3.90	1.74	11.	12.	14.1	7165.	94.	10.86	86.	0.126	16.6	401.
MA	WV	PENDLETON	2.8	46.	3.80	1.77	7.	11.	11.0	5643.	68.	11.00	79.	0.139	11.4	695.

TABLE 15.--(CONT'D.)

REGION	STATE	COUNTY	NUMBER OF HHOLDS	PCT. WOOD USERS	WOOD PER BURNER	WOOD PER HHOLD	WOOD PER SQ. MI.	WOOD PER SQ. MI. FOREST	MEDIAN HHOLD INCOME	HEATING DEGREE DAYS	PCT. FOREST LAND	NONWOOD FUEL PRICE	WOOD FUEL PRICE	RELA- TIVE PRICE	PERSONS PER SQ. MI.	LAND AREA
-----CORDS----- (\$1000) (\$ PER (\$/CORD) (SQ. MI.)																
NE	ME	PISCATAQUIS	6.3	68.	5.49	3.75	6.	7.	12.3	9421.	87.	11.68	89.	0.132	4.5	3892.
NE	ME	SOMERSET	15.4	64.	5.04	3.23	13.	14.	11.8	9421.	90.	11.85	89.	0.133	11.6	3894.
NE	ME	AROOSTOOK	29.4	58.	4.78	2.79	12.	14.	12.4	9421.	86.	11.29	90.	0.126	13.4	6821.
NE	ME	WASHINGTON	12.3	60.	4.65	2.77	13.	15.	10.4	7579.	88.	11.50	89.	0.130	13.7	2554.
NE	VT	ESSEX	2.2	62.	4.47	2.76	9.	10.	12.4	7687.	93.	11.10	88.	0.126	9.5	663.
NE	NH	COOS	13.0	55.	4.36	2.37	17.	20.	13.7	8925.	86.	11.82	90.	0.132	19.3	1820.
NE	ME	OXFORD	17.5	58.	4.14	2.40	20.	23.	13.0	8065.	88.	11.88	89.	0.133	23.5	2080.
NE	ME	HANCOCK	15.5	57.	4.06	2.30	23.	26.	12.1	7579.	88.	11.82	89.	0.133	27.2	1536.
NE	NH	GRAFTON	23.3	56.	4.00	2.24	30.	38.	14.5	8925.	80.	12.14	90.	0.136	38.0	1732.
NE	ME	WALDO	9.9	58.	3.94	2.27	30.	40.	11.6	7579.	76.	11.99	89.	0.135	38.5	737.
SC	TN	HANCOCK	2.4	73.	5.34	3.87	40.	58.	6.7	4198.	68.	10.49	40.	0.262	29.9	230.
SC	AR	NEWTON	2.7	73.	4.71	3.42	11.	12.	7.8	3945.	91.	8.37	40.	0.209	9.4	822.
SC	AR	SEARCY	3.2	68.	4.56	3.11	15.	21.	7.6	3858.	73.	8.84	40.	0.221	13.3	664.
SC	TN	FENTRESS	5.0	72.	4.49	3.23	33.	41.	8.2	4360.	80.	9.75	40.	0.244	29.8	498.
SC	AR	STONE	3.3	68.	4.29	2.93	16.	19.	8.2	3858.	82.	8.76	40.	0.219	14.8	608.
SC	TN	PICKETT	1.6	68.	4.21	2.84	29.	50.	9.0	4360.	58.	11.36	40.	0.284	27.6	158.
SC	MS	KEMPER	3.2	60.	4.07	2.45	11.	15.	9.0	2950.	71.	13.53	40.	0.338	13.4	757.
SC	TN	VAN BUREN	1.6	72.	3.99	2.86	18.	24.	11.4	4360.	76.	11.72	40.	0.293	18.6	254.
SC	TN	CLAY	2.7	67.	3.91	2.60	30.	52.	8.9	3961.	58.	10.89	40.	0.272	32.9	233.
SC	TN	GRUNDY	4.5	70.	3.89	2.74	35.	42.	10.5	4360.	82.	11.11	40.	0.278	38.5	358.
SE	VA	HIGHLAND	1.1	69.	4.45	3.09	8.	11.	13.6	5055.	74.	12.42	43.	0.289	7.1	416.
SE	NC	CHEROKEE	6.9	64.	4.32	2.76	42.	47.	9.7	4706.	89.	11.85	43.	0.276	41.9	452.
SE	VA	BATH	1.9	66.	4.23	2.80	10.	12.	13.3	5055.	86.	11.61	43.	0.270	10.9	540.
SE	VA	CRAIG	1.5	70.	4.21	2.94	13.	16.	13.6	5055.	81.	12.15	43.	0.282	11.8	336.
SE	NC	CLAY	2.4	64.	4.21	2.68	31.	38.	10.3	4706.	82.	12.06	43.	0.280	31.7	209.
SE	VA	LEE	8.9	60.	4.15	2.50	51.	89.	10.4	5238.	57.	13.69	43.	0.318	59.3	438.
SE	VA	BLAND	2.1	68.	4.11	2.80	16.	22.	13.9	5238.	74.	12.71	43.	0.296	17.2	369.
SE	NC	MADISON	5.8	61.	4.10	2.50	32.	44.	9.5	4706.	74.	10.82	43.	0.252	37.4	450.
SE	VA	SCOTT	8.7	60.	4.05	2.44	40.	59.	10.9	5238.	67.	13.03	46.	0.284	46.5	539.
SE	NC	AVERY	4.9	65.	4.05	2.62	52.	64.	11.1	5328.	81.	11.64	43.	0.271	58.8	245.

per household for counties on this list range from 5.14 cords for Mineral Colorado to 1.69 for Traher, West Virginia (Table 16).

Counties with high fuelwood use per square mile, as calculated by Model III are the most densely populated counties in their regions. To the extent that these counties have population densities greater than 6000 persons per square mile the Model III estimates of use per square mile are probably too high. But there are only 9 such counties among the top 90 counties. We can be more confident of the estimates for the remaining 81 counties (Table 17). The major cities in counties with highest use per square mile are shown in Table 18.

Identifying counties with high use per square mile does not identify cities with highest use per square mile. Some high use cities will be in large counties with lower average use per square mile. We would have to compute use per square mile in cities separately for each city using Model III. The accuracy of Model III in predicting city use intensity is dependent on the degree to which predictions of the model are independent of the county land area. We have implicitly assumed Model III holds for counties of varying size. No attempt is made to use Model III to predict individual city use, in part, because city land areas are much smaller than county areas used to fit parameters for Model III.

TABLE 16.-- TEN COUNTIES IN EACH REGION WITH THE HIGHEST ESTIMATED AVERAGE FUELWOOD USE OVER ALL HOUSEHOLDS, 1981

REGION	STATE	COUNTY	NUMBER OF HHOLDS	PCT. WOOD USERS	WOOD PER BURNER	WOOD PER HHOLD	WOOD PER SQ.MI.	WOOD PER SQ.MI. FOREST	MEDIAN HHOLD INCOME	HEATING DEGREE DAYS	PCT. FOREST LAND	NONWOOD FUEL PRICE	WOOD FUEL PRICE	RELAT- TIVE PRICE	PERSONS PER SQ.MI.	LAND AREA
-----CORDS----- (\$1000) (\$ PER (\$/CORD) (SQ.MI.)																
NW	OR	WHEELER	0.6	65.	5.16	3.36	1.	4.	10.1	6413.	29.	11.03	84.	0.131	0.9	1707.
NW	OR	GRANT	3.0	72.	4.50	3.22	2.	4.	15.2	6704.	53.	11.01	84.	0.131	1.8	4530.
NW	WA	FERRY	2.0	71.	4.22	2.99	3.	4.	14.7	6454.	72.	9.19	84.	0.109	2.6	2202.
NW	WA	SKAMANIA	2.9	73.	4.03	2.95	5.	6.	19.5	8864.	86.	7.38	84.	0.088	4.7	1672.
NW	OR	WALLOWA	2.8	66.	4.22	2.78	2.	7.	13.6	6704.	35.	11.02	84.	0.131	2.3	3178.
NW	OR	KLAMATH	21.8	70.	3.93	2.76	10.	16.	15.4	7759.	63.	8.64	73.	0.118	9.9	5970.
NW	OR	LAKE	2.8	66.	4.12	2.73	1.	4.	15.5	6413.	23.	8.58	77.	0.111	0.9	8231.
NW	WA	PEND OREILLE	3.0	67.	4.05	2.71	6.	7.	12.3	6454.	82.	8.75	84.	0.104	6.1	1402.
NW	OR	BAKER	6.2	64.	3.73	2.38	5.	17.	13.3	6704.	29.	10.08	73.	0.137	5.3	3068.
NW	WA	STEVENS	9.9	67.	3.49	2.33	9.	13.	14.8	6454.	69.	8.84	81.	0.109	11.7	2481.
NRM	ID	CAMAS	0.3	61.	6.53	3.95	1.	2.	13.2	7822.	62.	10.15	50.	0.203	0.8	1054.
NRM	ID	VALLEY	2.1	66.	5.72	3.79	2.	3.	15.8	7822.	62.	9.80	50.	0.196	1.5	3676.
NRM	ID	BOISE	1.1	64.	5.68	3.65	2.	3.	15.5	7822.	62.	9.68	50.	0.194	1.6	1910.
NRM	ID	ADAMS	1.2	64.	5.45	3.50	3.	5.	14.8	7822.	62.	10.00	50.	0.200	2.4	1371.
NRM	ID	CLARK	0.3	52.	5.79	3.04	0.	3.	11.5	7395.	14.	10.46	50.	0.209	0.5	1751.
NRM	ID	CUSTER	1.2	55.	5.54	3.03	1.	5.	11.7	7822.	14.	9.64	50.	0.193	0.7	4929.
NRM	ID	IDAHO	5.2	58.	5.18	3.01	2.	3.	14.5	7822.	62.	7.19	51.	0.142	1.7	8516.
NRM	MT	MINERAL	1.3	62.	4.78	2.97	3.	6.	16.1	7218.	52.	9.32	50.	0.186	3.0	1222.
NRM	MT	SANDERS	3.1	58.	4.98	2.90	3.	6.	12.6	7218.	52.	9.12	50.	0.182	3.1	2778.
NRM	MT	GARFIELD	0.6	54.	5.01	2.70	0.	6.	11.9	7936.	6.	8.92	50.	0.178	0.4	4455.
SRM	CO	MINERAL	0.3	86.	5.99	5.14	2.	5.	15.3	8084.	35.	12.70	60.	0.212	0.9	921.
SRM	CO	HINSDALE	0.2	85.	6.01	5.11	1.	2.	15.5	7204.	35.	12.37	60.	0.206	0.4	1054.
SRM	CO	SAGUACHE	1.3	78.	5.87	4.55	2.	6.	9.9	8084.	35.	7.64	60.	0.127	1.3	3144.
SRM	NV	EUREKA	0.4	75.	5.65	4.21	0.	4.	13.2	6328.	11.	17.39	60.	0.290	0.3	4182.
SRM	CO	SAN MIGUEL	1.3	84.	4.95	4.16	4.	12.	13.6	7204.	35.	12.36	60.	0.206	2.5	1283.
SRM	CO	SAN JUAN	0.3	82.	4.97	4.06	3.	9.	14.7	7204.	35.	12.34	60.	0.208	2.1	391.
SRM	CO	OURAY	0.7	82.	4.71	3.85	5.	15.	14.2	7204.	35.	12.75	60.	0.212	3.6	540.
SRM	CO	PARK	1.9	85.	4.52	3.84	3.	10.	18.1	6342.	35.	12.71	60.	0.212	2.5	2162.
SRM	CO	CUSTER	0.6	79.	4.70	3.72	3.	8.	12.1	5639.	35.	13.30	60.	0.222	2.1	737.
SRM	CO	ARCHULETA	1.3	81.	4.50	3.64	3.	10.	13.1	7204.	35.	9.01	60.	0.150	2.7	1364.

TABLE 16.--(CONT'D.)

REGION	STATE	COUNTY	NUMBER OF HHOLDS	PCT. WOOD USERS	WOOD PER BURNER	WOOD PER HHOLD	WOOD PER SQ.MI.	WOOD PER SQ.MI. FOREST	MEDIAN HHOLD INCOME	HEATING DEGREE DAYS	PCT. FOREST LAND	NONWOOD FUEL PRICE	WOOD FUEL PRICE	RELA- TIVE PRICE	PERSONS PER SQ.MI.	LAND AREA
(1000S)																
-----CORDS-----																
(\$1000)																
(\$ PER (\$/CORD) MMBTU)																
(\$/SQ.MI.)																
LS	MI	KeweenaW	0.8	47.	6.61	3.08	5.	9.	9.1	9341.	55.	11.08	68.	0.163	3.7	538.
LS	MN	COOK	1.6	56.	5.38	3.03	4.	6.	14.6	9002.	63.	10.92	68.	0.161	3.0	1346.
LS	WI	IRON	2.7	51.	5.57	2.83	10.	13.	9.9	8773.	78.	10.67	68.	0.157	9.0	747.
LS	WI	FOREST	3.0	54.	5.05	2.74	8.	10.	11.2	8189.	82.	10.76	68.	0.158	9.0	1007.
LS	MN	CASS	7.5	53.	5.17	2.72	10.	15.	10.9	9039.	67.	10.89	68.	0.160	10.5	1998.
LS	WI	SAWYER	4.7	53.	5.12	2.70	10.	13.	11.1	8649.	77.	10.83	68.	0.159	10.2	1259.
LS	MI	LAKE	3.0	52.	5.20	2.70	14.	18.	9.1	7434.	81.	10.73	68.	0.158	13.5	571.
LS	WI	FLORENCE	1.5	54.	4.95	2.69	8.	10.	11.9	8189.	84.	10.75	68.	0.158	8.6	487.
LS	MI	OSCODA	2.6	54.	4.99	2.67	12.	14.	11.2	8346.	85.	10.84	68.	0.159	12.2	563.
LS	WI	BAYFIELD	5.1	52.	5.06	2.65	9.	11.	11.8	8649.	83.	10.72	68.	0.158	9.5	1460.
CS	KY	OWSLEY	1.9	49.	5.53	2.71	25.	30.	6.7	4594.	84.	12.07	54.	0.224	29.0	197.
CS	KY	MC CREARY	4.9	47.	4.76	2.26	26.	31.	7.5	4594.	84.	11.57	54.	0.214	37.4	418.
CS	KY	JACKSON	4.1	45.	4.74	2.14	26.	36.	7.4	4594.	71.	12.03	54.	0.223	35.6	337.
CS	KY	LESLIE	4.5	50.	4.13	2.08	23.	25.	9.4	4594.	94.	12.27	54.	0.227	36.4	409.
CS	KY	CUMBERLAND	2.6	48.	4.25	2.04	17.	27.	8.5	4559.	65.	11.85	54.	0.219	23.5	310.
CS	KY	WOLFE	2.3	45.	4.49	2.03	20.	29.	7.8	4594.	70.	11.57	54.	0.214	29.5	227.
CS	KY	MORGAN	4.1	46.	4.37	1.99	22.	30.	8.1	4594.	73.	11.40	54.	0.211	32.8	369.
CS	MO	SHANNON	2.8	46.	4.19	1.94	5.	7.	9.0	4282.	75.	9.88	54.	0.183	7.9	999.
CS	KY	WAYNE	5.8	45.	4.22	1.89	25.	38.	8.4	4594.	66.	12.41	54.	0.228	38.7	440.
CS	KY	LEE	2.6	44.	4.33	1.89	24.	29.	8.4	4594.	82.	11.90	54.	0.220	36.9	210.
MA	NY	HAMILTON	1.9	49.	5.10	2.49	3.	8.	12.3	9050.	34.	11.13	79.	0.141	2.9	1735.
MA	WV	WEBSTER	4.1	52.	4.36	2.28	17.	19.	9.8	6487.	90.	11.34	79.	0.143	22.2	551.
MA	PA	SULLIVAN	2.2	51.	4.26	2.17	10.	12.	12.5	7493.	82.	11.14	79.	0.141	13.3	478.
MA	PA	FOREST	1.9	51.	4.19	2.14	10.	11.	12.7	7111.	92.	10.64	79.	0.135	12.1	419.
MA	NY	LEWIS	8.1	51.	4.19	2.12	13.	19.	14.5	9050.	69.	11.02	81.	0.136	19.4	1291.
MA	WV	POCAHONTAS	3.6	52.	4.05	2.12	8.	10.	12.4	6487.	83.	11.07	79.	0.140	10.5	943.
MA	PA	POTTER	6.1	47.	3.96	1.86	10.	12.	13.0	7111.	85.	10.77	82.	0.132	16.2	1092.
MA	WV	PENDLETON	2.8	46.	3.80	1.77	7.	11.	11.0	5643.	68.	11.00	79.	0.139	11.4	695.
MA	PA	CAMERON	2.6	45.	3.90	1.74	11.	12.	14.1	7165.	94.	10.86	86.	0.126	16.6	401.
MA	WV	TUCKER	3.1	45.	3.80	1.69	13.	16.	11.5	6487.	78.	10.13	79.	0.128	20.6	421.

TABLE 16.--(CONT'D.)

REGION	STATE	COUNTY	NUMBER OF HHOLDS	PCT. WOOD USERS	WOOD				WOOD PER SQ.MI. FOREST	MEDIAN HHOLD INCOME	HEATING DEGREE DAYS	PCT. FOREST LAND	NONWOOD		WOOD		RELA- TIVE PRICE	PERSONS PER SQ.MI.	LAND AREA			
					WOOD BURNER	WOOD HHOLD	WOOD PER SQ.MI.	FUEL PRICE					FUEL PRICE									
-----CORDS-----																			(\$ PER (\$/CORD)		(\$/SQ.MI.)	
(1000S)																						
NE	ME	PISCATAQUIS	6.3	68.	5.49	3.75	6.	7.	12.3	9421.	87.	11.68	89.	0.132	4.5	3892.						
NE	ME	SOMERSET	15.4	64.	5.04	3.23	13.	14.	11.8	9421.	90.	11.85	89.	0.133	11.6	3894.						
NE	ME	AROOSTOOK	29.4	58.	4.78	2.79	12.	14.	12.4	9421.	86.	11.29	90.	0.126	13.4	6821.						
NE	ME	WASHINGTON	12.3	60.	4.65	2.77	13.	15.	10.4	7579.	88.	11.50	89.	0.130	13.7	2554.						
NE	VT	ESSEX	2.2	62.	4.47	2.76	9.	10.	12.4	7687.	93.	11.10	88.	0.126	9.5	663.						
NE	ME	OXFORD	17.5	58.	4.14	2.40	20.	23.	13.0	8065.	88.	11.88	89.	0.133	23.5	2080.						
NE	NH	COOS	13.0	55.	4.36	2.37	17.	20.	13.7	8925.	86.	11.82	90.	0.132	19.3	1820.						
NE	ME	HANCOCK	15.5	57.	4.06	2.30	23.	26.	12.1	7579.	88.	11.82	89.	0.133	27.2	1536.						
NE	ME	WALDO	9.9	58.	3.94	2.27	30.	40.	11.6	7579.	76.	11.99	89.	0.135	38.5	737.						
NE	NH	CARROLL	11.1	58.	3.88	2.25	27.	31.	13.6	7488.	86.	12.61	88.	0.143	29.8	938.						
SC	TN	HANCOCK	2.4	73.	5.34	3.87	40.	58.	6.7	4198.	68.	10.49	40.	0.262	29.9	230.						
SC	AR	NEWTON	2.7	72.	4.71	3.42	11.	12.	7.8	3945.	91.	8.37	40.	0.209	9.4	822.						
SC	TN	FENTRESS	5.0	73.	4.49	3.23	33.	41.	8.2	4360.	80.	9.75	40.	0.244	29.8	498.						
SC	AR	SEARCY	3.2	68.	4.56	3.11	15.	21.	7.6	3858.	73.	8.84	40.	0.221	13.3	864.						
SC	AR	STONE	3.3	68.	4.29	2.93	16.	19.	8.2	3858.	82.	8.76	40.	0.219	14.8	608.						
SC	TN	VAN BUREN	1.6	72.	3.99	2.86	18.	24.	11.4	4360.	76.	11.72	40.	0.293	18.6	254.						
SC	TN	PICKETT	1.6	68.	4.21	2.84	29.	50.	9.0	4360.	58.	11.36	40.	0.284	27.6	158.						
SC	TN	GRUNDY	4.5	70.	3.89	2.74	35.	42.	10.5	4360.	82.	11.11	40.	0.278	38.5	358.						
SC	TN	MORGAN	5.4	71.	3.77	2.67	27.	35.	10.9	4360.	78.	10.59	40.	0.264	30.8	539.						
SC	TN	BLEDSE	3.0	69.	3.79	2.61	19.	29.	10.6	4360.	66.	10.54	40.	0.264	23.5	404.						
SE	VA	HIGHLAND	1.1	69.	4.45	3.09	8.	11.	13.6	5055.	74.	12.42	43.	0.289	7.1	416.						
SE	VA	CRAIG	1.5	70.	4.21	2.94	13.	16.	13.6	5055.	81.	12.15	43.	0.282	11.8	336.						
SE	VA	BATH	1.9	66.	4.23	2.80	10.	12.	13.3	5055.	86.	11.61	43.	0.270	10.9	540.						
SE	VA	BLAND	2.1	68.	4.11	2.80	16.	22.	13.9	5238.	74.	12.71	43.	0.296	17.2	369.						
SE	NC	CHEROKEE	6.9	64.	4.32	2.76	42.	47.	9.7	4706.	89.	11.85	43.	0.276	41.9	452.						
SE	NC	CLAY	2.4	64.	4.21	2.68	31.	38.	10.3	4706.	82.	12.06	43.	0.280	31.7	209.						
SE	NC	AVERY	4.9	65.	4.05	2.62	52.	64.	11.1	5328.	81.	11.64	43.	0.271	58.8	245.						
SE	VA	LEE	8.9	60.	4.15	2.50	51.	89.	10.4	5238.	57.	13.69	43.	0.318	59.3	438.						
SE	NC	MADISON	5.8	61.	4.10	2.50	32.	44.	9.5	4706.	74.	10.82	43.	0.252	37.4	450.						
SE	NC	GRAHAM	2.5	63.	3.97	2.49	21.	25.	11.3	4706.	83.	11.34	43.	0.264	24.7	292.						

TABLE 17.-- TEN COUNTIES IN EACH REGION WITH THE HIGHEST ESTIMATED FUELWOOD USE PER SQUARE MILE OF COUNTY, 1981

REGION	STATE	COUNTY	NUMBER OF HHOLDS	PCT. WOOD USERS	WOOD				MEDIAN HHOLD INCOME	HEATING DEGREE DAYS	PCT. FOREST LAND	NONWOOD		WOOD		RELAT- IVE PRICE	PERSONS PER SQ.MI.	LAND AREA
					WOOD PER BURNER	WOOD HHOLD	WOOD PER SQ.MI.	WOOD PER SQ.MI.				FUEL PRICE	FUEL PRICE					
			(1000S)		-----CORDS-----				(\$1000)			(\$ PER MMBTU)	(\$/CORD)				(SQ.MI.)	
NW	OR	MULTNOMAH	233.3	48.	1.74	0.83	457.	16.1	4666.	41.		10.20	66.	0.154	1330.1	423.		
NW	WA	KING	498.2	61.	1.95	1.19	279.	20.7	4574.	60.		12.01	67.	0.178	596.7	2128.		
NW	OR	WASHINGTON	91.1	64.	1.94	1.24	158.	21.6	4666.	54.		9.93	69.	0.144	343.3	716.		
NW	WA	PIERCE	174.5	57.	2.32	1.33	139.	17.2	4908.	55.		12.89	69.	0.187	289.8	1676.		
NW	WA	KITSAP	52.8	53.	1.91	1.01	135.	18.9	4574.	65.		8.15	74.	0.110	374.4	393.		
NW	WA	SNOHOMISH	120.8	69.	2.90	2.01	116.	20.8	6864.	52.		14.12	71.	0.199	161.0	2098.		
NW	WA	CLARK	68.9	52.	1.94	1.02	111.	19.0	4908.	56.		7.17	71.	0.102	306.6	627.		
NW	WA	SPOKANE	128.6	51.	2.13	1.09	80.	15.9	6454.	26.		7.59	69.	0.110	194.4	1758.		
NW	OR	MARION	74.5	54.	2.13	1.15	74.	16.1	4666.	45.		10.24	71.	0.144	175.6	1166.		
NW	WA	THURSTON	46.5	52.	2.12	1.11	72.	17.9	4574.	68.		7.55	74.	0.102	174.0	714.		
NRM	ID	CANYON	28.6	39.	2.87	1.13	56.	13.8	5476.	62.		9.49	52.	0.184	144.9	578.		
NRM	ID	ADA	63.3	34.	1.95	0.67	41.	17.5	5476.	14.		9.30	53.	0.177	165.9	1043.		
NRM	ID	KOOTENAI	21.3	42.	3.12	1.32	23.	15.2	6694.	62.		6.79	51.	0.132	47.8	1249.		
NRM	ID	BANNOCK	22.4	41.	2.66	1.09	22.	17.5	7908.	14.		8.69	52.	0.166	58.3	1122.		
NRM	ID	PAYETTE	5.6	42.	3.41	1.43	20.	11.7	5476.	62.		9.37	51.	0.184	39.1	402.		
NRM	MT	SILVER BOW	14.7	30.	3.21	0.95	19.	14.6	7960.	52.		5.80	53.	0.110	53.3	715.		
NRM	ID	NEZ PERCE	12.5	39.	2.76	1.07	16.	15.9	5104.	62.		7.51	53.	0.143	39.4	844.		
NRM	ID	BONNEVILLE	21.3	45.	2.85	1.28	15.	18.2	7908.	14.		8.80	52.	0.169	35.9	1836.		
NRM	ID	LATAH	10.3	42.	3.39	1.42	13.	14.0	6690.	62.		6.99	52.	0.135	26.4	1090.		
NRM	MT	MISSOULA	28.2	38.	3.21	1.22	13.	16.3	7218.	52.		6.20	52.	0.119	29.1	2612.		
SRM	CA	SAN FRANCISCO	299.9	12.	0.33	0.04	255.	15.9	2322.	1.		9.05	120.	0.075	1508.3	45.		
SRM	CA	SAN MATEO	225.3	34.	0.65	0.22	111.	23.2	2322.	15.		9.18	119.	0.077	1313.9	447.		
SRM	CA	ORANGE	687.1	27.	0.46	0.12	109.	22.6	1794.	14.		8.43	120.	0.070	2471.5	782.		
SRM	CO	JEFFERSON	129.8	44.	1.21	0.53	88.	24.0	6342.	1.		6.08	115.	0.053	474.8	783.		
SRM	CA	SACRAMENTO	300.2	29.	0.99	0.29	88.	17.4	3258.	14.		8.03	118.	0.068	803.5	975.		
SRM	UT	SALT LAKE	202.2	29.	1.13	0.33	87.	18.4	5767.	6.		4.88	120.	0.041	810.3	764.		
SRM	CA	ALAMEDA	427.4	22.	0.63	0.14	82.	18.7	2322.	1.		9.06	119.	0.076	1508.0	733.		
SRM	CO	BOULDER	68.2	44.	1.94	0.86	79.	19.8	6342.	35.		6.46	110.	0.059	253.5	748.		
SRM	CO	ARAPAHOE	105.9	46.	1.28	0.59	79.	23.9	6342.	1.		6.27	119.	0.053	368.4	797.		
SRM	CA	LOS ANGELES	2735.1	18.	0.62	0.11	76.	17.6	1794.	14.		8.08	119.	0.068	1837.7	4069.		

TABLE 17.--(CONT'D.)

REGION	STATE	COUNTY	NUMBER OF HHOLDS	PCT. WOOD USERS	WOOD PER BURNER	WOOD PER HHOLD	WOOD PER SQ.MI.	WOOD PER SQ.MI. FOREST	MEDIAN HHOLD INCOME	HEATING DEGREE DAYS	PCT. FOREST LAND	NONWOOD FUEL PRICE	WOOD FUEL PRICE	RELAT- TIVE PRICE	PERSONS PER SQ.MI.	LAND AREA
-----CORDS----- (\$1000) (\$ PER (\$/CORD) (SQ.MI.)																
(1000S)																
LS	WI	MILWAUKEE	364.5	16.	0.89	0.14	219.	21868.	18.1	6930.	1.	7.67	74.	0.104	4071.7	237.
LS	MI	WAYNE	824.9	16.	0.92	0.15	205.	2282.	18.6	6752.	9.	6.88	74.	0.093	3864.3	605.
LS	MN	RAMSEY	170.5	16.	1.00	0.15	170.	16954.	18.9	8172.	1.	7.09	74.	0.096	2966.4	155.
LS	MI	MACOMB	229.8	32.	1.10	0.35	169.	1129.	24.2	6752.	15.	7.09	74.	0.096	1447.1	480.
LS	MI	OAKLAND	356.1	35.	1.15	0.41	167.	1195.	25.3	6752.	14.	7.24	73.	0.099	1167.0	867.
LS	MN	HENNEPIN	366.0	19.	1.12	0.21	134.	6696.	20.1	8172.	2.	6.87	74.	0.093	1660.3	567.
LS	WI	WAUKESHA	88.5	42.	1.54	0.64	102.	787.	25.8	6930.	13.	8.21	73.	0.113	506.0	554.
LS	MN	ANOKA	60.9	35.	1.71	0.60	86.	618.	23.4	8172.	14.	7.28	74.	0.099	462.3	424.
LS	MI	GENESEE	154.9	24.	1.36	0.33	80.	726.	21.0	6752.	11.	6.23	73.	0.086	701.6	642.
LS	MI	MUSKEGON	54.6	29.	2.43	0.71	78.	159.	16.2	7434.	49.	6.99	72.	0.097	314.5	501.
CS	MO	ST LOUIS CITY	178.4	9.	1.22	0.11	313.	31304.	11.5	4978.	1.	6.53	55.	0.119	7427.6	61.
CS	OH	CUYAHOGA	563.3	18.	1.00	0.18	226.	22615.	18.0	6532.	1.	6.49	55.	0.118	3286.0	456.
CS	IL	DU PAGE	221.6	38.	0.79	0.30	201.	4019.	27.5	6331.	5.	6.02	55.	0.110	1990.4	331.
CS	OH	LUCAS	172.5	26.	1.50	0.39	199.	1657.	17.7	6497.	12.	8.19	55.	0.149	1375.3	343.
CS	OH	SUMMIT	189.9	27.	1.57	0.43	198.	763.	18.4	6532.	26.	6.64	55.	0.121	1285.5	408.
CS	MO	ST LOUIS	344.7	27.	1.02	0.28	193.	1070.	22.1	4978.	18.	6.78	55.	0.123	1951.7	499.
CS	OH	HAMILTON	322.4	18.	1.24	0.23	177.	1262.	17.4	5455.	14.	6.90	55.	0.126	2109.2	414.
CS	OH	FRANKLIN	323.1	23.	1.26	0.29	175.	3508.	17.1	5898.	5.	7.36	55.	0.134	1615.5	538.
CS	IN	MARION	285.1	21.	1.16	0.24	175.	3504.	17.4	5763.	5.	6.97	55.	0.127	1952.1	392.
CS	OH	LAKE	71.8	36.	1.56	0.56	173.	666.	22.4	6532.	26.	7.30	55.	0.133	921.2	231.
MA	NJ	HUDSON	208.1	8.	1.19	0.10	428.	1069.	14.4	5985.	40.	10.52	96.	0.110	11850.5	47.
MA	NY	NEW YORK	706.0	4.	0.33	0.01	351.	35062.	13.9	5407.	1.	11.57	96.	0.121	62099.3	23.
MA	NY	BROX	430.5	4.	0.84	0.03	317.	31678.	10.9	5407.	1.	11.33	96.	0.118	28511.5	41.
MA	NJ	ESSEX	300.8	10.	1.20	0.12	272.	679.	16.2	5985.	40.	10.44	96.	0.109	6547.0	130.
MA	NY	KINGS	829.3	3.	0.67	0.02	266.	26643.	11.9	5407.	1.	10.99	96.	0.114	31870.5	70.
MA	NJ	UNION	177.8	17.	0.88	0.15	259.	647.	21.6	5985.	40.	10.31	96.	0.107	4894.1	103.
MA	NJ	BERGEN	299.9	21.	0.89	0.19	239.	598.	24.1	5985.	40.	10.34	96.	0.108	3612.8	234.
MA	NY	WESTCHESTER	307.4	21.	1.37	0.29	199.	453.	22.7	6734.	44.	11.44	95.	0.120	1956.2	443.
MA	MD	BALTIMORE CITY	281.8	6.	0.83	0.05	192.	19159.	12.8	5064.	1.	8.85	96.	0.092	10086.9	78.
MA	NY	ROCKLAND	78.0	31.	1.38	0.42	187.	425.	25.6	6734.	44.	11.21	96.	0.117	1474.6	176.

TABLE 17.--(CONT'D.)

REGION	STATE	COUNTY	NUMBER OF HHOLDS	PCT. WOOD USERS	WOOD				WOOD PER SQ. MI.	MEDIAN HHOLD INCOME	HEATING DEGREE DAYS	PCT. FOREST LAND	NONWOOD		WOOD		RELAT- TIVE PRICE	PERSONS PER SQ. MI.	LAND AREA
					WOOD PER BURNER	WOOD PER HHOLD	WOOD PER SQ. MI.	WOOD PER HHOLD					FUEL PRICE	FUEL PRICE					
			(1000S)		-----CORDS-----					(\$1000)			(\$ PER MMBTU)	(\$/CORD)				(SQ. MI.)	
NE	MA	SUFFOLK	252.4	13.	1.05	0.13	600.	0.13	60020.	12.8	6220.	1.	11.62	92.	0.126	11609.7	56.		
NE	MA	MIDDLESEX	475.6	32.	1.58	0.51	293.	0.51	681.	20.4	6755.	43.	11.43	92.	0.125	1657.0	825.		
NE	MA	NORFOLK	207.8	35.	1.50	0.52	276.	0.52	627.	21.9	6220.	44.	11.85	92.	0.129	1539.6	394.		
NE	RI	PROVIDENCE	209.2	25.	2.14	0.54	269.	0.54	456.	14.8	6169.	59.	11.27	92.	0.123	1373.4	416.		
NE	CT	FAIRFIELD	280.8	37.	1.48	0.55	245.	0.55	532.	23.0	5884.	46.	11.22	92.	0.123	1289.4	626.		
NE	CT	NEW HAVEN	271.8	31.	1.72	0.54	241.	0.54	512.	18.4	5884.	47.	11.43	92.	0.125	1260.5	604.		
NE	MA	ESSEX	228.5	28.	1.71	0.47	219.	0.47	561.	18.1	6220.	39.	11.51	92.	0.126	1282.7	494.		
NE	CT	HARTFORD	289.7	32.	1.70	0.54	213.	0.54	484.	20.1	6328.	44.	11.14	92.	0.122	1093.1	739.		
NE	RI	KENT	54.1	33.	2.03	0.67	210.	0.67	328.	18.5	6169.	64.	11.49	92.	0.125	891.1	173.		
NE	MA	HAMPDEN	157.8	34.	2.38	0.81	206.	0.81	350.	16.2	6755.	59.	12.59	92.	0.137	715.7	619.		
SC	TN	KNOX	117.6	33.	1.77	0.58	133.	0.58	444.	14.8	4198.	30.	9.89	62.	0.161	629.3	508.		
SC	TN	HAMILTON	103.2	36.	1.97	0.70	131.	0.70	243.	15.7	4198.	54.	10.09	65.	0.155	523.2	550.		
SC	TN	DAVIDSON	177.9	25.	1.45	0.36	128.	0.36	440.	16.4	3961.	29.	8.97	67.	0.133	940.6	508.		
SC	AL	JEFFERSON	244.4	27.	1.72	0.46	101.	0.46	157.	15.7	3572.	64.	7.47	65.	0.115	602.1	1115.		
SC	TN	HAMBLÉN	17.3	41.	2.05	0.84	94.	0.84	347.	13.3	4198.	27.	9.99	51.	0.195	318.1	155.		
SC	TN	SULLIVAN	52.0	36.	1.91	0.68	86.	0.68	239.	15.5	4198.	36.	10.22	61.	0.168	348.6	413.		
SC	TN	ANDERSON	24.7	48.	2.26	1.08	80.	1.08	128.	16.1	4198.	62.	9.30	54.	0.173	201.0	335.		
SC	TX	DALLAS	577.9	15.	0.74	0.11	76.	0.11	7594.	18.6	2453.	1.	8.84	68.	0.130	1811.9	859.		
SC	TN	SHELBY	268.9	17.	1.24	0.21	74.	0.21	390.	15.3	3817.	19.	6.33	67.	0.095	1029.3	755.		
SC	TN	CARTER	17.8	50.	2.82	1.40	72.	1.40	107.	11.4	4198.	67.	10.38	54.	0.191	144.3	348.		
SE	VA	WINCHESTER CIT	7.9	23.	2.22	0.52	1375.	0.52	2696.	14.0	5104.	51.	12.61	59.	0.214	6739.0	3.		
SE	VA	BRISTOL CITY	7.2	28.	2.58	0.72	1298.	0.72	2546.	13.3	5238.	51.	13.55	59.	0.230	4760.5	4.		
SE	VA	PETERSBURG CIT	14.9	25.	2.23	0.56	1044.	0.56	1607.	13.4	4303.	65.	11.78	59.	0.200	5131.9	8.		
SE	VA	ALEXANDRIA CIT	49.2	31.	1.00	0.31	1023.	0.31	2624.	21.0	5104.	39.	10.42	59.	0.177	6881.1	15.		
SE	VA	ROANOKE CITY	40.0	26.	2.23	0.59	870.	0.59	1475.	13.3	5055.	59.	10.15	59.	0.172	3711.9	27.		
SE	VA	FALLS CHURCH C	4.3	41.	0.90	0.37	782.	0.37	2006.	24.5	5104.	39.	10.01	59.	0.170	4757.5	2.		
SE	VA	CHARLOTTESVILL	15.4	24.	2.07	0.51	777.	0.51	1274.	13.9	4341.	61.	10.99	59.	0.186	3991.6	10.		
SE	VA	NORFOLK CITY	88.4	20.	2.20	0.45	746.	0.45	1223.	12.5	3921.	61.	11.02	59.	0.187	5037.3	53.		
SE	VA	RICHMOND CITY	86.0	22.	2.16	0.47	681.	0.47	1048.	13.6	4303.	65.	10.97	59.	0.186	3653.6	60.		
SE	VA	COVINGTON CITY	3.5	30.	2.27	0.68	593.	0.68	682.	13.7	5055.	87.	8.23	59.	0.139	2265.8	4.		

Table 18.--Major cities in counties with the highest fuelwood
use per square mile, 1981¹

Region	County	State	Major city	Cords per sq. mile	Population per square mile
PNW	Multnomah	OR	Portland	457	1330
NRM	Canyon	ID	Caldwell	56	145
SRM	San Francisco	CA	San Francisco	225	15088
	San Mateo	CA	San Mateo	111	1314
LS	Milwaukee	WI	Milwaukee	219	4072
CS	St. Louis	MO	St. Louis	313	7428
	Cuyahoga	OH	Cleveland	226	3286
MA	Hudson	NJ	Jersey City	428	11610
	New York	NY	Manhattan	351	62099
	Bronx	NY	Bronx	317	28511
	Essex	NJ	Newark	272	6547
	Kings	NY	Kings	266	31870
	Union	NJ	Elizabeth	259	4894
NE	Suffolk	MA	Boston	600	11610
	Middlesex	MA	Waltham	293	1657
SC	Knox	TN	Knoxville	133	629
SE	Winchester City	VA	Winchester	1375	6740
	Bristol City	VA	Bristol	1298	4761

¹More than one county may be listed for a region until a county with less than
6000 persons per square mile is included.

Model III can potentially identify intensity of harvest on forest land in a county better than intensity of local wood stove pollution in a city within a county.

This is because most fuelwood is cut by households themselves in their own counties. Three-quarters of all fuelwood is cut by households and half of these households travel less than 5.5 miles to cut wood.⁶⁰ Wood use in a county divided by forest area will give an indication of the harvest pressure on forest land. Estimates of percent forest land are not available for all counties or county equivalents listed by the Bureau of Census. For certain western states percent forest land is only available for groups of counties. For those cases averages were assigned to individual counties. In the east, a number of small cities are independent. In these cases percent forest land is set at 1%.

In forming a table of counties with high use per square mile of forest, cities with one percent forest or with area less than 80 square miles have been excluded. Counties with higher forest use that meet these criteria have the following characteristics:

- lower than median population density
- lower than median percent forest land
- higher than median income

⁶⁰Skog and Watterson. 1983. Residential fuelwood use in the United States. p. A-40.

- contain larger cities.

The two counties in each region with the highest forest use are shown in Table 19.

A second more general way to identify where forest use is greatest is to estimate, for each state, the percent of fuelwood that comes from counties with high intensity forest use. To do this we first divided fuelwood use (40.5 million cords in 80-81) into intensity of forest use categories. Roughly equal amounts of fuelwood were consumed in counties with the following cords use per square mile of forest:

- (1) 0 to 40 cords per square mile of forest
- (2) 40 to 99 cords per square mile of forest
- (3) 99 to 306 cords per square mile of forest
- (4) more than 306 cords per square mile of forest

Independent cities, or counties with only 1% forest land were placed in a 5th category. The first four categories contain 23% of U.S. fuelwood use each. The fifth category contains 8%. Table 20 shows which states have a relatively large fraction of fuelwood consumed in counties with high use per square mile of forest. The following states have 70% of their fuelwood coming from counties in categories 3 or 4: Connecticut, Indiana, Iowa, Maryland, Massachusetts, Nebraska, New Jersey, Ohio, Rhode Island, and Washington. These states are likely to have drain focused on fewer acres of forest land, possibly improving the prospects for

Table 19.--Selected counties in each region with high fuelwood use per square mile of forest, 1981

Region	County	State	Major city	Cords per sq. mile forest	Percent forest
NW	Multnomah	OR	Portland	1114	41
NW	King	WA	Seattle	465	60
NRM	Ada	ID	Boise	291	114
NRM	Bannock	ID	Pocatello	155	114
SRM	Santa Clara	CA	San Jose	3531	12
SRM	Marin	CA	Richmond	2953	12
LS	Hennepin	MN	Minneapolis	6696	2
LS	Wayne	MI	Detroit	2282	9
CS	DuPage	IL	Wheaton	4019	5
CS	Douglas	NB	Omaha	3603	2
MA	Montgomery	MD	Bethesda	833	22
MA	Allegheny	PA	Pittsburg	703	18
NE	Middlesex	MA	Waltham	681	43
NE	Norfolk	MA	Quincy	627	44
SC	Knox	TN	Knoxville	444	30
SC	Davidson	TN	Nashville	440	29
SE	Fairfax	VA	Fairfax	1101	39
SE	Pinellas	FL	St. Petersburg	702	14

1Estimate is for a group of counties.

Table 20.--State level estimates of residential fuelwood consumption by intensity of forest use in individual counties, 1980-81.

State	Intensity of fuelwood use in a county (cords per square mile of forest)					More Cities than 306 forest counties ¹
	Estimated consumption	0 to 40	40 to 99	99 to 306		
U.S. TOTAL	40.5	23	23	23	23	7
Alabama	1.05	46	33	22		
Arizona	.29	40	6	54		
Arkansas	.53	71	20	9		
California	1.90	9	18	23	34	17
Colorado	.76	32	13	8	64	48
Connecticut	.71		5	31	51	
Delaware	.07		49			
D.C.	.01					100
Florida	.65	42	41	5	4	9
Georgia	.97	51	24	21	5	
Idaho	.44	55	24	21		

(million cords) -----(percent of total state consumption)-----

Table 20 (cont'd.)

State	Intensity of fuelwood use in a county (cords per square mile of forest)					Estimated consumption	-----((percent of total state consumption)-----				
	0 to 40	40 to 99	99 to 306	More than 306	Cities and low forest counties ₁		(million cords)				
Illinois	1.09	8	14	11	50	21					
Indiana	.96	5	16	30	49						
Iowa	.55	1	8	32	39	20					
Kansas	.26	7	18	16	22	37					
Kentucky	.87	36	42	11	10						
Louisiana	.42	68	18	5	9						
Maine	.75	54	16	30							
Maryland	.52	6	19	25	48	3					
Massachusetts	1.21		8	29	60	3					
Michigan	1.68	25	9	26	40						
Minnesota	.92	40	8	16	25	11					
Mississippi	.64	72	25	3							
Missouri	.82	37	19	21	21	2					
Montana	.32	79	9	12							

Table 20 (cont'd.)

State	Intensity of fuelwood use in a county (cords per square mile of forest)				More Cities than and low 306 forest counties ¹
	Estimated consumption	0 to 40	40 to 99	99 to 306	
(million cords) -----(percent of total state consumption)-----					
Nebraska	.21	5	17	43	36
Nevada	.26	26	34	36	3
New Hampshire	.50	21	29	50	
New Jersey	.75			43	57
New Mexico	.31	34	41	7	18
New York	1.92	11	34	24	27
North Carolina	2.05	14	42	37	7
North Dakota	.17	12	4		
Ohio	1.98	3	13	31	48
Oklahoma	.36	22	15		84
Oregon	1.44	35	28	23	5
Pennsylvania	1.89	12	34	36	63
Rhode Island	.20			16	1
South Carolina	.84	37	40	23	2

Table 20 (cont'd.)

State	Intensity of fuelwood use in a county (cords per square mile of forest)				More than 306 forest counties ¹
	Estimated consumption	0 to 40	40 to 99	99 to 306	
	(million cords)	----- (percent of total state consumption) -----			
South Dakota	.18	25	4		72
Tennessee	1.42	12	42	31	14
Texas	.99	24	11	2	9
Utah	.30	25	18	19	38
Vermont	.33	21	62	16	
Virginia	1.96	14	38	16	30
Washington	1.99	16	9	34	37
West Virginia	.61	45	46	9	5
Wisconsin	1.18	28	26	19	4
Wyoming	.19	65	35		

¹Includes cities that are independent and have no estimate of percent forest.
Includes counties with little forest where no estimate of percent forest is available.

more organized treatments of forest land with fuelwood removals. The difficulty in organizing treatments also depends on the degree to which forest land is divided among many owners.

VI. CONCLUSIONS

This section discusses three topics: (1) findings about county level household fuelwood use and fuelwood use behavior as determined by county demographic and economic conditions, (2) caveats for using Model III to make short term predictions of county fuelwood use and (3) recommendations for future research to project fuelwood use and to identify local areas with the greatest fuelwood use.

Findings

Probit equation 2, when applied to U.S. county data for 1980, estimates that participation in household fuelwood use is greatest for counties with very low population densities, high heating degree days, substantial forest land and high relative price for nonwood fuel. It is notable that these counties have low incomes since probit equation 2 indicates that percentage of burners increases with county income (Table 2). Nonincome factors are more important in determining counties with high participation. The highest estimated percentage of burners is for Mineral county, Colorado; 86 percent. High estimates for counties in other regions range from 50 to 73 percent (Table 14).

Equation (20), when applied to U.S. county data, estimates that the average amount burned by woodburners is greatest for counties with somewhat lower than median income, much higher than median percent forest land, higher than median relative nonwood fuel price, higher than median heating degree days and much lower than median population density (Tables 5 and 15). The highest estimated amount burned per woodburner is for Keweenaw county, Michigan; 6.6 cords per woodburner. High estimates for counties in other regions range from 4.5 to 6.5 cords (Table 15).

Probit equation 2 and equation (20), when combined as Model III and applied to U.S. county data, estimate average wood use over all households is greatest for counties with the same characteristics as counties with high use per woodburner (Table 16). The highest estimated average use is for Mineral county, Colorado; 5.14 cords. High estimates for counties in other regions range from 2.5 to 4.0 cords per household.

Model III indicates the intensity of forest use from fuelwood harvesting is greater in certain states. Ten states have 70 percent or more of their fuelwood coming from counties where fuelwood use is .15 cords per acre of forest or more. These states are Connecticut, Indiana, Iowa, Maryland, Massachusetts, Nebraska, New Jersey, Ohio, Rhode Island and Washington. Six states have 50 percent or more of their fuelwood coming from counties where fuelwood

use is .48 cords or more per acre of forest. These are Connecticut, Delaware, Illinois, Massachusetts, New Jersey and Rhode Island. To the extent that fuelwood is harvested locally, these states are likely to have fuelwood related forest management opportunities.

Model III, in addition to estimating fuelwood use for individual counties, explains the general influence of county economic and demographic factors on fuelwood use behavior. One finding is that the influence of household income varies widely with population density and income. Probit equation 2 shows participation in woodburning is higher in low density areas than in high density areas and it increases with income (Table 3). Data from the National Residential Fuelwood Use Survey confirms that participation increases with income in both rural (lower density) and urban (higher density) areas. Equation (20) estimates amounts burned by woodburners are greater in low density areas. That is, elasticity with respect to population density is negative (Table 12). At high population densities equation (20) shows that amounts burned decrease rapidly with higher income. At low population densities, increasing income decreases woodburning slightly at low incomes, but as income continues to increase, amount burned begins to increase. These changes at low population density in response to income change may not be significantly different from zero in equation (20), or they

may indicate a difference in attitude between low income and high income households in rural areas (Table 12). When the probit and amount equations are combined in Model III to estimate average amount burned over all households we find that average use is highest in low density counties. In low density counties with high income, average use increases with income. But, in high density counties where average use is lower, average use decreases with increasing income. This pattern is explained by differences in woodburning equipment used, and woodburning purpose among income groups and density groups. In both high and low density counties, participation in woodburning increases with income. In higher density areas, some low income woodburners use wood in stoves for space heat but as income increases many more woodburners only burn small amounts in fireplaces for pleasure. In low density counties many more woodburners use stoves, and as income increases there is less of a trend to only burn small amounts in fireplaces. So, in high density counties, even though participation increases quickly with income, amounts burned drop fast enough with increasing income to leave a net decrease in average amount burned over all households. In lower density counties participation also increases with income, but there is little or no decline in amounts burned by woodburners. As a result, woodburning increases with income in lower density counties.

As a consequence of this behavior pattern, increasing income alone would increase woodburning in higher income lower density areas but would decrease woodburning in higher density areas (Table 13).

Model III shows that increasing relative price of nonwood fuels increases woodburning the most in counties where relative nonwood fuel price is low. As relative price increases the upward influence on woodburning decreases. In fact, Model III shows that the elasticity of woodburning with respect to relative price continues to drop. This means there is an upper limit to the amount of wood a household will burn in response to higher relative prices. High income households in low density areas are closest to their participation and amount burned limits. This behavior makes sense in that only a certain maximum percentage of households will burn wood in response to relative price increases and woodburning needs are limited by the need to heat a house of fixed size in a given climate (Table 13).

If income and relative price of nonwood fuel both increase at the same percentage rate, counties with low densities and high income would show the greatest rate of increase in woodburning. For high density counties, the effect of higher relative nonwood fuel price would be moderately offset by the tendency to decrease burning as income increases (Table 13).

If we assume that the variable for percent forest land in Model III is a proxy for degree of access to forest land for harvesting fuelwood then Model III suggests that a given percentage increase in forest land access would cause the greatest absolute increase in woodburning per household for low density, highly forested counties. But the greatest percentage increase in woodburning per household would occur for highly forested middle density counties (.74 acre per household) (Tables 3 and 13).

Caveats

There are a number of caveats for those who would use Model III to predict near future woodburning in a county or group of counties. First, see the validation section of this report to learn where the model predicts well and where it overestimates or underestimates. In particular, note that Model III overpredicts for counties with high income and very high population density. Second, since county fuelwood use estimates are based on a particular data set for 1980-81 it is best to start with that data for the counties and make adjustments in variables to represent conditions in other years. Contact the author through the U.S. Forest Service to determine if the data set is available. Third, a number of long term trends are not reflected in the model. This is because the model is based on cross-section rather than time-series data. For example, as wood stove design improves the average

efficiency of wood stoves will improve. This will have the effect of reducing the cost of wood per unit of heat output. In order to include this effect in the present model, fuelwood price and relative nonwood fuel price would have to be adjusted. Other trends not reflected in the model include increasing household concern for indoor and outdoor air pollution, antipollution regulations requiring more expensive stoves, development of woodburning furnaces with convenient wood ship feed systems, and increasing cost of insurance for homes with wood burning equipment.

Future Research

There is a need to develop better residential fuelwood use models to (1) project use over many years and (2) to estimate use for small geographic areas (counties or groups of counties). The models which project fuelwood use well over many years and require projection of the fewest exogenous variables may be different than the models which estimate near term local use most accurately.

One type of long term projection model that could estimate use for groups of counties is a two equation supply/demand model based on the increasing amount of fuelwood use data for states or survey units within states. Fuelwood prices for a standard fuelwood commodity might be obtained from newspapers. This type of model could also include such potential fuelwood supply influences as the intensity of pulpwood harvest and

pulpwood prices in an area. An advantage of this type of model would be that fuelwood price would be endogenous. Nonwood fuel prices, income and other factors would be projected exogenously in order to make projections.

There are a number of ways the county level model developed in this study might be improved. These ideas may also help form small area models with different structures. A key notion used in the model developed here is that county characteristics have varying influence depending on population density. But, in less densely populated rural areas the fact that the households are rural may be all that is needed to characterize the influence of other variables. That is, the influence of income, prices and access to forests may not be much different over a wide range of rural population densities. For predominantly rural counties, use of population density as a modifier has the flaws that it (1) does not directly measure the predominance of rural households and (2) it distinguishes between lower and higher density "rural" areas, which may not be necessary. In more predominantly urban areas the influence of varying population density may be more important. If the modifying influence of both prevalence of rural or urban households and density in more urbanized areas cannot be included in one model, then counties with different degrees of urbanization might be modeled separately.

Another problem with the use of population density in the model is that fuelwood use per square mile is projected to increase to unrealistically high levels at high population densities. To prepare a model that would predict amounts burned well at high densities a sufficient sample of woodburners in high density locations is needed. If prediction at higher densities is important for assessing wood stove pollution then extra data collection in high density areas may be needed. If sufficient data is available, overprediction at high densities might be prevented by structuring an amount burned equation so fuelwood use per square mile must decrease beginning at a density to be determined by parameters in the model. This approach was taken in Lipferts' models.

The probit equations used here could be improved by allowing the influence of income to vary with population density (or degree of urbanization). Although participation increases with income at all densities the increase in percent burners per unit increase in income is greater at lower densities.

The probit equations used here estimate the probability of woodburning without determining whether a stove or fireplace is used. It was assumed that households estimate the difference in utility between burning and not burning by weighting economic factors in the same way regardless of whether they intend to burn wood in a stove or a

fireplace. It would be more realistic to assume economic factors are weighted somewhat differently in making the two decisions. This suggests that a multinomial logit or probit model might be used to predict percentage of stove users and percentage of fireplace users separately for a locality. Separate equations would be needed to estimate amounts burned. Such a model would require data for individual households (or possibly groups of households), on equipment used, amounts burned, and on county characteristics. These data might be provided by the triennial Residential Energy Consumption Survey conducted by the Energy Information Administration (EIA) of the U.S. Department of Energy.

It would be relatively easy to develop models which estimate individual household fuelwood use based on characteristics of the individual households using data from EIA surveys or the data used in this study. Although the models would identify the economic influences on individual household fuelwood use, they could not estimate local fuelwood use or project fuelwood use unless a sample set of households with their characteristics were available for each locality. Sets of sample households may become available from the 1980 Census of Population and Housing but they may not be grouped by units as small as counties. In order to project fuelwood use a sample set of households would have to be produced for the year and locality of the

projection.

Regardless of whether projection or local use models are the target of research it will be important to link the influence of other wood harvesting and marketing activities (pulpwood and sawtimber markets) to fuelwood use and eventually to include well constructed fuelwood use models in larger models which predict prices and consumption in pulpwood and sawtimber markets.

VII. APPENDIX - DATA SOURCES

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Probit Equations 1 and 2

The Residential Fuelwood Use Survey conducted by the U.S. Forest Service in 1981 interviewed 5506 households; 1874 had burned wood within the prior 24 months.⁶¹ From respondents we learned (1) their county of residence, (2) whether or not they burned wood and (3) how much wood they burned during the preceeding 12 months. The survey was conducted from August through October, 1981. The probit model dependent variable was 0 or 1 depending on whether or not a household burned wood. The probit model independent variables were characteristics of the household's county of residence. These characteristics and their sources are as follows:

Heating degree days: 40 year average heating degree day data by county (65 degree F basis), data tape from the Department of Energy (Mike Lawrence); 1981.

Median household income (1979): Census of Population and Housing, 1980: Summary tape file 3C [machine-readable data file]/prepared by the Bureau of the Census --

⁶¹Skog and Watterson. 1983. Residential Fuelwood use in the United States. p. C-3.

Washington: The Bureau [producer and distributor], 1982. (Table 69).

Average nonwood fuel price: Prices for natural gas, fuel oil and electricity in "\$/MMBtu input" were converted to "\$/MMBtu output" by dividing by average conversion efficiencies of 61%, 66% and 100% respectively.⁶² Prices were weighted by the percent of households using each fuel as their main fuel in the county. Prices are from Los Alamos National Laboratory, 1980 Residential fuel price data base for solar heating market analysis. Percent of households using each fuel is from Census Summary tape file 3C (table 112).

Average fuelwood price: Respondents from the 1981 Residential fuelwood use survey gave the prices paid for their most recent purchase of fuelwood. Prices per cord for respondents purchasing approximately one cord were averaged for urban and rural areas within nine regions. Average fuelwood price for a county was estimated by weighting urban and rural prices for the region by the fractions of urban and rural population in the county. The source of fuelwood prices is the Residential fuelwood use survey conducted by the U.S. Forest Service in 1981. The source of fractions of urban and rural households is the Census Summary tape file 3C (table 1).

⁶²D.L. O'Neal. 1978. Energy and cost analysis of residential heating systems. ORNL/CON-25. (Oak Ridge, TN): Oak Ridge National Laboratory. 64 p.

Percent forest land: Forest land area and total land area for individual counties (or groups of counties in the West) is from the most recent forest survey reports for individual states published up to 1983 by USDA Forest Service Experiment Stations: Intermountain, Ogden, UT; North Central, St. Paul, MN; Northeastern, Broomall, PA; Pacific Northwest, Portland, OR; Pacific Southwest, Berkeley, CA; Rocky Mountain, Fort Collins, CO; Southeastern, Asheville, NC; Southern, New Orleans, LA.

Population density: Calculated by dividing county population by county area. County population is from Census summary tape file 3C (table 1). County area is from: County and City Data tape, 1977; [machine-readable data file] prepared by the Inter-university consortium for Political and Social research, Ann Arbor, MI based on the County and City data book, 1977, published by the U.S. Bureau of the Census. (variables 11 and 12).

Fraction of households using various types of heating equipment: Census Summary tape file 3C (table 111).

Fuelwood Consumption Equations (18), (19) and (20)

Fuelwood consumption equations for woodburning households were estimated using amount of fuelwood consumed by 1874 woodburning households interviewed for the Residential fuelwood use survey in 1981. Independent variables were the characteristics of the county where the household was located. Four of the five county variables

used are the same as for probit equations 1 and 2: median income for 1979, population density, heating degree days and percent forest land. Relative nonwood fuel price is the average nonwood fuel price for the county divided by the average fuelwood price for the county (see sources listed for probit equation variables).

County Variables Used to Subdivide Households

Tables 5 through 8 show percent of households burning wood and amount burned for households groups by county characteristic. Most of the county characteristics used to subdivide households are the same as variables used in the probit and fuelwood consumption equations. Two additional county variables are also used. Their sources are as follows:

Percent rural population: Census Summary tape file 3C (table 1).

Percent home owners: Census Summary tape file 3C (table 97).

VIII. LITERATURE CITED

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