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Fuelwood Use in U.S. Counties

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by
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This study explains and determines fuelwood consumption at the county level based on county economic and demographic conditions, and identifies U.S. counties where potential fuelwood use problems and benefits are greatest. The percentage of wood- burning households in a county is estimated and multiplied by estimated average wood consumed per wood-burning household in that county to produce an estimate of total county fuelwood use. Use estimates are then compared to forest inventory data to identify potential problem/benefit areas. Parameters in estimating equations are determined from fuelwood use data for individual households from a 1980-81 nationwide survey of 5,506 households.

This report is divided into two parts: findings and methods. The findings section is a description of the study problem and results. The second part, methods, provides a detailed account of the methods used, caveats and recommendations for further research.

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Part I: Findings

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[29]. 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. "Local areas" refers to individual counties in a state.

Fuelwood Use Per County

High fuelwood use poses potential problems and opportunities for certain local areas:

Problems

– Competition between fuelwood and other wood users.

– Air pollution from wood burning.

– Damage to ecosystems from wood harvesting.

Opportunities

– Thinning for fuelwood increases the rate and quality of tree growth.

– Increased local employment and income.

– Decreased export of local dollars to buy non-wood heating fuels.

Business and government can better deal with these problems and opportunities if, for local areas, they know current fuelwood consumption and the likely change in consumption as economic conditions change.

The intensity of fuelwood use in each county in the continental United States was estimated, and five measures of use intensity were used to rank counties. Tables 1-4 show the 10 counties in each of nine regions that have the highest intensity use according to the following measures:

– Percentage of wood burners.

– Amount burned per wood-burning 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. If a county has over 6,000 persons per square mile (as noted in the methods section), its wood use is likely to be 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 numbers of heating degree-days

Table 1. Ten Counties in Each Region with the Highest Estimated Percentage of Woodburners, 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	Non-wood Fuel Price	Wood Fuel Price	Rela-tive Price	Persons Per Sq. Mi.	Land Area
			(1000S)		——— Cords ———				($1000)			($ Per MMBTU)	($/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.
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.
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.
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	38.8	319.
CS	KY	McCreary	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.

Table 1 continued on next page

Table 1. (Continued)

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	Non-wood Fuel Price	Wood Fuel Price	Rela-tive Price	Persons Per Sq. Mi.	Land Area
			(1000S)		——— Cords ———				($1000)			($ Per MMBTU)	($/Cord)			(Sq. Mi.)
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.
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.

for their region, substantial forestland and high relative prices for non-wood fuel. In most regions, non-income 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 percent in Mineral, Colo., to a low of 46 percent in Shannon, Mo., and Hampshire Count): W. Va. (Table 1). High estimates for counties in other regions range from 50 to 73 percent.

Counties with high amounts burned per wood-burning household are similar to those with a high percentage of wood burners. Forty-two of the 90 high percentage user counties are also high amount-burned counties. The high amount-burned counties have low household income, a high percentage of forestland and low population density. Amount burned per wood burner for the top 10 counties in each region ranges from a high of 6.01 cords in Hinsdale, Colo., to a low of 3.56 cords in Okanogan, Wash. (Table 2). The highest estimated

Table 2. 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	Non-wood Fuel Price	Wood Fuel Price	Rela-tive Price	Persons Per Sq. Mi.	Land Area
			(1000S)		——— Cords ———				($1000)			($ Per MMBTU)	($/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	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.
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	4929.
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.
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.	9.9	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	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	Conejos	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.
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	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	Lk 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	McCreary	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	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.

Table 2 continued on next page

Table 2. (Continued)

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	Non-wood Fuel Price	Wood Fuel Price	Rela-tive Price	Persons Per Sq. Mi.	Land Area
			(1000S)		——— Cords ———				($1000)			($ Per MMBTU)	($/Cord)			(Sq. Mi.)
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	NY	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.
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.

amount burned per wood burner is for Keweenaw County, Mich.: 6.6 cords per wood burner.

Counties with high use per household over all households are similar to those with high use under the previous two measures. Fifty-nine of the 90 counties with high use per household 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 forestland and high relative price for non-wood fuel. Amounts of fuelwood used per household for counties on this list range from 5.14 cords for Mineral, Colo., to 1.69 for Traher, W. Va. (Table 3).

Counties with high fuelwood use per square mile are the most densely populated counties in their regions. To the extent that these counties have population densities greater than 6,000 persons per square mile, estimates of use per square mile are probably too high. But only nine such counties occur among the top 90 counties. We are more confident of the estimates for the remaining 81 counties (Table 4).

The major cities in counties with highest use per square mile are shown in Table 5. Identifying counties with high use per square mile does not identify cities with highest use per square mile. Some high use cities are in large counties with lower average use per square mile.

Table 3. 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	Non-wood Fuel Price	Wood Fuel Price	Rela- tive Price	Persons Per Sq. Mi.	Land Area
			(1000S)		——— Cords ———				($1000)			($ Per MMBTU)	($/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	6864.	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.	0.206	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.
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	McCreary	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.

Table 3 continued on next page

Table 3. (Continued)

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	Non-wood Fuel Price	Wood Fuel Price	Rela-tive Price	Persons Per Sq. Mi.	Land Area
			(1000S)		Cords				($1000)			($ Per MMBTU)	($/Cord)			(Sq. Mi.)
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.
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	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	AR	Searcy	3.2	68.	4.56	3.11	15.	21.	7.6	3858.	73.	8.84	40.	0.221	13.3	664.
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	Bledsoe	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.

Counties with higher intensity of harvest on forestland (forest use) have the following characteristics:

– Lower than median population density.

– Lower than median percentage forestland.

– Higher than median income.

– Certain larger cities.

The two counties in each region with the highest forest use are shown in Table 6.

The fifth measure of intensity of forest use was derived by dividing state fuelwood use into five categories:

(1) 0 to 40 cords per square mile of forest.

(2) 41 to 99 cords per square mile of forest.

(3) 100 to 306 cords per square mile of forest.

(4) more than 306 cords per square mile of forest.

(5) independent cities or counties with 1 percent or less forestland.

Table 4. 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 Per Burner	Wood Per HHold	Wood Per Sq. Mi.	Wood Per Sq. Mi. Forest	Median HHold Income	Heating Degree Days	Pct. Forest Land	Non-wood Fuel Price	Wood Fuel Price	Rela-tive Price	Persons Per Sq. Mi.	Land Area
			(1000S)		——— Cords ———				($1000)			($ Per MMBTU)	($/Cord)			(Sq. Mi.)
NW	OR	Multnomah	223.3	48.	1.74	0.83	457.	1114.	16.1	4666.	41.	10.20	68.	0.154	1330.1	423.
NW	WA	King	498.2	61.	1.95	1.19	279.	465.	20.7	4574.	60.	12.01	67.	0.178	596.7	2128.
NW	OR	Washington	91.1	64.	1.94	1.24	158.	292.	21.6	4666.	54.	9.93	69.	0.144	343.3	716.
NW	WA	Pierce	174.5	57.	2.32	1.33	139.	252.	17.2	4908.	55.	12.89	69.	0.187	289.8	1676.
NW	WA	Kitsap	52.8	53.	1.91	1.01	135.	208.	18.9	4574.	65.	8.15	74.	0.110	374.4	393.
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	WA	Clark	68.9	52.	1.94	1.02	111.	199.	19.0	4908.	56.	7.17	71.	0.102	306.6	627.
NW	WA	Spokane	128.6	51.	2.13	1.09	80.	306.	15.9	6454.	26.	7.59	69.	0.110	194.4	1758.
NW	OR	Marion	74.5	54.	2.13	1.15	74.	164.	16.1	4666.	45.	10.24	71.	0.144	175.6	1166.
NW	WA	Thurston	46.5	52.	2.12	1.11	72.	106.	17.9	4574.	68.	7.55	74.	0.102	174.0	714.
NRM	ID	Canyon	28.6	39.	2.87	1.13	56.	90.	13.8	5476.	62.	9.49	52.	0.184	144.9	578.
NRM	ID	Ada	63.3	34.	1.95	0.67	41.	291.	17.5	5476.	14.	9.30	53.	0.177	165.9	1043.
NRM	ID	Kootenai	21.3	42.	3.12	1.32	23.	36.	15.2	6694.	62.	6.79	51.	0.132	47.8	1249.
NRM	ID	Bannock	22.4	41.	2.66	1.09	22.	155.	17.5	7908.	14.	8.69	52.	0.166	58.3	1122.
NRM	ID	Payette	5.6	42.	3.41	1.43	20.	32.	11.7	5476.	62.	9.37	51.	0.184	39.1	402.
NRM	MT	Silver Bow	14.7	30.	3.21	0.95	19.	37.	14.6	7960.	52.	5.80	53.	0.110	53.3	715.
NRM	ID	Nez Perce	12.5	39.	2.76	1.07	16.	26.	15.9	5104.	62.	7.51	53.	0.143	39.4	844.
NRM	ID	Bonneville	21.3	45.	2.85	1.28	15.	106.	18.2	7908.	14.	8.80	52.	0.169	35.9	1836.
NRM	ID	Latah	10.3	42.	3.39	1.42	13.	22.	14.0	6690.	62.	6.99	52.	0.135	26.4	1090.
NRM	MT	Missoula	28.2	38.	3.21	1.22	13.	25.	16.3	7218.	52.	6.20	52.	0.119	29.1	2612.
SRM	CA	San Francisco	299.9	12.	0.33	0.04	255.	25489.	15.9	2322.	1.	9.05	120.	0.075	15088.3	45.
SRM	CA	San Mateo	225.3	34.	0.65	0.22	111.	740.	23.2	2322.	15.	9.18	119.	0.077	1313.9	447.
SRM	CA	Orange	687.1	27.	0.46	0.12	109.	776.	22.6	1794.	14.	8.43	120.	0.070	2471.5	782.
SRM	CO	Jefferson	129.8	44.	1.21	0.53	88.	8821.	24.0	6342.	1.	6.08	115.	0.053	474.8	783.
SRM	CA	Sacramento	300.2	29.	0.99	0.29	88.	628.	17.4	3258.	14.	8.03	118.	0.068	803.5	975.
SRM	UT	Salt Lake	202.2	29.	1.13	0.33	87.	1454.	18.4	5767.	6.	4.88	120.	0.041	810.3	764.
SRM	CA	Alameda	427.4	22.	0.63	0.14	82.	8188.	18.7	2322.	1.	9.06	119.	0.076	1508.0	733.
SRM	CO	Boulder	69.2	44.	1.94	0.86	79.	226.	19.8	6342.	35.	6.46	110.	0.059	253.5	748.
SRM	CO	Arapahoe	105.9	46.	1.28	0.59	79.	7855.	23.9	6342.	1.	6.27	119.	0.053	368.4	797.
SRM	CA	Los Angeles	2735.1	18.	0.62	0.11	76.	542.	17.6	1794.	14.	8.08	119.	0.068	1837.7	4069.
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	MI	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.

Table 4 continued on next page

Table 4. (Continued)

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	Non-wood Fuel Price	Wood Fuel Price	Rela-tive Price	Persons Per Sq. Mi.	Land Area
			(1000S)		——— Cords ———				($1000)			($ Per MMBTU)	($/Cord)			(Sq. Mi.)
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	Bronx	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	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.
NE	MA	Suffolk	252.4	13.	1.05	0.13	600.	60020.	12.8	6220.	1.	11.62	92.	0.126	11609.7	56.
NE	MA	Middlesex	475.6	32.	1.58	0.51	293.	681.	20.4	6755.	43.	11.43	92.	0.125	1657.0	825.
NE	MA	Norfolk	207.8	35.	1.50	0.52	276.	627.	21.9	6220.	44.	11.85	92.	0.129	1539.6	394.
NE	RI	Providence	209.2	25.	2.14	0.54	269.	456.	14.8	6169.	59.	11.27	92.	0.123	1373.4	416.
NE	CT	Fairfield	280.8	37.	1.48	0.55	245.	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.	512.	18.4	5884.	47.	11.43	92.	0.125	1260.5	604.
NE	MA	Essex	228.5	28.	1.71	0.47	219.	561.	18.1	6220.	39.	11.51	92.	0.126	1282.7	494.
NE	CT	Hartford	289.7	32.	1.70	0.54	213.	484.	20.1	6328.	44.	11.14	92.	0.122	1093.1	739.
NE	RI	Kent	54.1	33.	2.03	0.67	210.	328.	18.5	6169.	64.	11.49	92.	0.125	891.1	173.
NE	MA	Hampden	157.8	34.	2.38	0.81	206.	350.	16.2	6755.	59.	12.59	92.	0.137	715.7	619.
SC	TN	Knox	117.6	33.	1.77	0.58	133.	444.	14.8	4198.	30.	9.89	62.	0.161	629.3	508.
SC	TN	Hamilton	103.2	36.	1.97	0.70	131.	243.	15.7	4198.	54.	10.09	65.	0.155	523.2	550.
SC	TN	Davidson	177.9	25.	1.45	0.36	128.	440.	16.4	3961.	29.	8.97	67.	0.133	940.6	508.
SC	AL	Jefferson	244.4	27.	1.72	0.46	101.	157.	15.7	3572.	64.	7.47	65.	0.115	602.1	1115.
SC	TN	Hamblen	17.3	41.	2.05	0.84	94.	347.	13.3	4198.	27.	9.99	51.	0.195	318.1	155.
SC	TN	Sullivan	52.0	36.	1.91	0.68	86.	239.	15.5	4198.	36.	10.22	61.	0.168	348.6	413.
SC	TN	Anderson	24.7	48.	2.26	1.08	80.	128.	16.1	4198.	62.	9.30	54.	0.173	201.0	335.
SC	TX	Dallas	577.9	15.	0.74	0.11	76.	7594.	18.6	2453.	1.	8.84	68.	0.130	1811.9	859.
SC	TN	Shelby	268.9	17.	1.24	0.21	74.	390.	15.3	3817.	19.	6.33	67.	0.095	1029.3	755.
SC	TN	Carter	17.8	50.	2.82	1.40	72.	107.	11.4	4198.	67.	10.38	54.	0.191	144.3	348.
SE	VA	Winchester	7.9	23.	2.22	0.52	1375.	2696.	14.0	5104.	51.	12.61	59.	0.214	6739.0	3.
SE	VA	Bristol	7.2	28.	2.58	0.72	1298.	2546.	13.3	5238.	51.	13.55	59.	0.230	4760.5	4.
SE	VA	Petersburg	14.9	25.	2.23	0.56	1044.	1607.	13.4	4303.	65.	11.78	59.	0.200	5131.9	8.
SE	VA	Alexandria	49.2	31.	1.00	0.31	1023.	2624.	21.0	5104.	39.	10.42	59.	0.177	6881.1	15.
SE	VA	Roanoke	40.0	26.	2.23	0.59	870.	1475.	13.3	5055.	59.	10.15	59.	0.172	3711.9	27.
SE	VA	Falls Church	4.3	41.	0.90	0.37	782.	2006.	24.5	5104.	39.	10.01	59.	0.170	4757.5	2.
SE	VA	Charlottesvill	15.4	24.	2.07	0.51	777.	1274.	13.9	4341.	61.	10.99	59.	0.186	3991.6	10.
SE	VA	Norfolk	88.4	20.	2.20	0.45	746.	1223.	12.5	3921.	61.	11.02	59.	0.187	5037.3	53.
SE	VA	Richmond	86.0	22.	2.16	0.47	681.	1048.	13.6	4303.	65.	10.97	59.	0.186	3653.6	60.
SE	VA	Covington	3.5	30.	2.27	0.68	593.	682.	13.7	5055.	87.	8.23	59.	0.139	2265.8	4.

Each of the first four categories accounts for 23 percent of U.S. fuelwood use. The fifth category contains 8 percent. Table 7 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 percent 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 forestland, possibly improving the prospects for more organized treatments of forestland with fuelwood removals. Six states have 50 percent or more of their fuelwood coming from counties where fuelwood use is .48 cord or more per acre of forest: 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.

Table 5. Major Cities in Counties with the Highest Fuelwood Use Per Square Mile, 1981[1].

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

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

Table 6. 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	[1]14
NRM	Bannock	ID	Pocatello	155	[1]14
SRM	Santa Clara	CA	San Jose	3531	[1]2
SRM	Marin	CA	Richmond	2953	[1]2
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

[1] Estimate is for a group of counties.

Determinants of Use

In addition to estimating fuelwood use for individual counties, the mathematical estimates developed in this study show the general influence of county economic and demographic factors on fuelwood use behavior.

The influence of household income varies widely with population density and income. Participation in wood burning is higher in low population density areas than in high density areas, and it increases with income. Data from the National Residential Fuelwood Use Survey confirm that participation increases with income in both rural (lower density) and urban (higher density) areas. Our estimated amounts burned by wood burners are greater in low density areas. That is, elasticity with respect to population density is negative. At high population densities, amounts burned decrease rapidly with higher income. At low population densities, increasing income decreases wood burning slightly at low incomes, but as income continues to increase, amount burned begins to increase. These changes may indicate a difference in attitude between low income and high income households in rural areas. 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 wood- burning equipment used, and wood-burning purpose among income groups and density groups. In both high and low density counties, participation in wood burning increases with income. In higher density areas, some low income wood burners use wood in stoves for space heat, but as income increases, many more wood burners burn only small amounts in fireplaces for pleasure. In low density counties, many more wood burners use stoves, and as income increases, there is less of a trend to burn only 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 wood burners. As a result, wood burning increases with income in lower density counties.

As a consequence of this behavior pattern, increasing income alone will increase wood burning in higher income, lower density areas but will decrease wood burning in higher density areas. Increasing the relative price of non-wood fuels increases wood burning the most in counties where relative non-wood fuel price is low. As relative price increases, the upward influence on wood burning decreases. 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 wood- burning needs are limited by the need to heat a house of fixed size in a given climate.

If income and relative price of non-wood fuel both increase at the same percentage rate, counties with low densities and high income will show the greatest rate of increase in wood burning. For high density counties, the effect of higher relative non-wood fuel price is moderately offset by the tendency to decrease burning as income increases.

If it is assumed that the variable percentage forestland is a proxy for degree of access to forestland for harvesting fuelwood, then a given percentage increase in forestland access will cause the greatest absolute increase in wood burning per household for low density, highly forested counties. But the greatest percentage increase in wood burning per household will occur in highly forested, middle density counties.

Table 7. State Level Estimates of Residential Fuelwood Consumption by intensity of Forest Use in individual Counties, 1980–81.

State	Estimated consumption	Intensity of fuelwood use in a county (cords per square mile of forest)				
		0 to 40	40 to 99	99 to 306	More than 306	Cities and low forest counties[1]
	(million cords)	(percent of total state consumption)				
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		48
Connecticut	.71		5	31	64	
Delaware	.07		49		51	
D.C.	.01					100
Florida	.65	42	41	5	4	9
Georgia	.97	51	24	21	5	
Idaho	.44	55	24	21		
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		
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	5
North Carolina	2.05	14	42	37	7	
North Dakota	.17	12	4			84
Ohio	1.98	3	13	31	48	5
Oklahoma	.36	22	15			63
Oregon	1.44	35	28	23	13	1
Pennsylvania	1.89	12	34	36	16	2
Rhode Island	.20			16	84	
South Carolina	.84	37	40	23		
South Dakota	.18	25	4			72
Tennessee	1.42	12	42	31	14	
Texas	.99	24	11	2	9	55
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	5
West Virginia	.61	45	46	9		
Wisconsin	1.18	28	26	19	23	4
Wyoming	.19	65	35			

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

PART II: Methods

Household Consumption Modeling

Neoclassical economic theory explains that individual household consumption is the result of a household's choosing products to maximize utility, subject to an income constraint. But this theory is not sufficient for a model of consumption for a group of households. 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 price[2]. Unfortunately, it has been shown that even if every consumer in a group 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[2].

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 below to show what economic factors influence energy use. Following that, two theoretically justifiable models are discussed. These models require data on individual households. The second of these models was used to predict county fuelwood consumption for this study.

Models of Aggregate Household Consumption.

Hartman reviews 19 residential energy demand models, excluding models that include wood, that explain three long-run consumer decisions [10].

– Should a home heating device be purchased?

– What characteristics and fuel should the device have?

– How much fuel should be used in the device?

In the short run, equipment is fixed and the consumer decides only how much fuel to use. Hartman's models explain, to varying degrees, demand for energy-using appliances and demands 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 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 fuel price, substitute fuel prices, income, and cost to buy and maintain equipment.

Long- and short-run behavior is 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 that have separate equations for stock level and stock utilization, and allow partial adjustment of stock demand toward theoretical market equilibrium each period.

Hartman also examines five models that 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 vs. short-run and sophistication in behavioral assumptions. One detailed and flexible model reviewed by Hartman gives 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.

The cross elasticities developed by this study are:

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

They suggest that similar price changes in various fuels have different effects on consumption of alternative fuels.

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

One simple aggregate demand model for fuelwood, proposed by Lipfert, estimates the density ofwood smoke pollution by relating average wood burning per household in New England counties to county heating degree-days as a proxy for climate and population density[18]. His model is:

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

where W = standard cords ofwood used per household per 10,000 heating degree-days in a county, and
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 three 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 and retail price of wood.

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. Individual characteristics for many households in an area are needed to make projections. As with aggregate models, models of individual household energy demand should account for decisions about which kind of fuel to use and 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 of individual fuelwood use used in this study is based on these models[9,8].

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

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

where D_i is 1 with probability P_i, the probability of their burning any fuelwood, zero otherwise, and q_i is the amount of wood used if the household burns wood. Thus total wood used by a group of m households would be

$$\sum_{i=1}^{m} Q_i = \sum D_i q_i$$

To explain the probability of a household's burning wood, p, it must be assumed that utility gained from home heating is weakly separable from utility gained by using other products, and 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 it may be asserted that demand for home heating is not influenced by quantities and prices of non-heating products used[4]. If it is assumed that utility from home heating for a household has a fixed "representative household component and a random component, then the probability of fuelwood use, p, is explained as follows:

Let

$$U_{1n} = \overline{U}_1 + e_{1n} \qquad (5)$$

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

$$U_{2n} = \overline{U}_2 + e_{2n} \qquad (6)$$

be the utility that consumer n obtains from burning a non-wood fuel only. Terms $\overline{U}_1$ and $\overline{U}_2$ are representative consumer utilities where

$$\overline{U}_{in} = \overline{U}_i(Y_n, P_n, a_n),\ i = 1 \text{ or } 2 \qquad (7)$$

and

y = consumer income,

p = heating fuel prices (vector), and

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

$$\overline{U}_{1n} + e_{1n} > \overline{U}_{2n} + e_{2n} \qquad (8)$$

or

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

Let

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

and

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

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

$$P_n = \text{Prob}\,[e_{12n} < \overline{U}_{12n}]. \qquad (10)$$

An empirical model can be formed using theoretical equation (10) and data on individual households, provided values of $\overline{U}_{12n}$ can be computed, and an assumption is made about the distribution of e_{12n}. If e_{12n} has a normal distribution and $\overline{U}_{12n}$ 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[11,12]. Hardie and Scodari suggest $\overline{U}_{1n}$ and $\overline{U}_{2n}$ and thus $\overline{U}_{12n}$ and P_n should be determined by factors that influence non-wood heating costs:

- Type and price of non-wood heating fuel(s) used.
- Type ofheating appliances in the house.
- Maintained indoor temperature.
- Climate.
- Amount of insulation.

– House size.

– Type and location of house.

Other factors are those that influence wood fuel heating costs:
– Cost to own and maintain a wood heater.

– Purpose of wood burning: heating or enjoyment.

– Access to a wood supply.

– Occupations of household members (influences time cost for wood cutting).

Other determining factors are related to a households characteristics:

– 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[8].

Hardie and Scodari develop a theory of how much wood a household will burn (q_i in equation 2), how much they will purchase or cut themselves, and how much non-wood fuel they will use[9]. Fuelwood consumption may be modeled without reference to prices for non-home-heating products consumed, assuming weak separability of home heating utility. Their theoretical fuelwood use equation is:

$$Q_w = q_w(P_f, P_e, P_w, P_c, P_h, C; k) \qquad (11)$$

where

P_f = price of non-wood fuel used (natural gas, fuel oil, propane),

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, and

k = non-wood heating fuel used.

Hardie and Hassan have prepared 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[8]. Probit models for each of five census regions predict probability of burning wood based on:

– House area heated (square feet).

– Heating degree-days (under 50 degrees F).

– Family size.

– Firewood price ($/cord).

– Non-wood fuel price ($/MMBtu).

– Household income ($1,000).

– 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 bias correction procedure developed by Heckman[13,14] and variables for:

– The ratio of firewood price to non-wood fuel price.

– House area heated.

– Heating degree-days.

– Family size.

– Household income.

– Kind of non-wood fuel used (i.e., electricity, oil, gas, LP gas).

– Whether 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 wood-burning households. Binary variables were also included in the OLS regression for each of five census regions (regional shift variables).

Hardie's model predicts probability of wood burning and average use given the characteristics of a single household. Characteristics of a large random sample of households in an area can be predicted using equation 3 for each household. But in making regional estimates, Hardie and Hassan instead use average characteristics of households by region to predict probability of wood burning, and average characteristics over the whole United States to predict average wood use. To use Hardie's model correctly to predict county-level fuelwood use, characteristics of a representative group ofhouseholds in each county are needed. 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.

County-Level Fuelwood Consumption

As an alternative to Hardie's empirical model, consider the following two-equation model that explicitly links average house-hold characteristics in a county to the probability ofwood burning, p_i, and the average amount burned per wood-burning household, q_i. Using these two equations, wood burned per county is computed as follows:

$$Q_i = P_i \cdot q_i \cdot N_i \qquad (12)$$

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 wood-burning household in county, and

N_i = the number of households in county i.

To form the equation for P_i, it is necessary to assume: a household with average characteristics in a county has an average likelihood for burning wood among all households in the county; these average households have utility for home heating that is weakly separable from utility for other products consumed; and the utility from heating for these average households may be modeled by an equation with two components - one giving the value ofutility of a representative average household and another giving the differences 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 wood-burning household, we assume that the average amount burned by wood-burning households in a county can be expressed as a function of average wood burner characteristics in the county, and that the average characteristics ofwood burners in a county are highly correlated with the average characteristics for all households in the county.

Predicting Percent Wood Burners

The assumptions above for predicting percentage of wood burners, p_i, allows use of the household utility theory expressed in equations 4- 10. The differences in formulation here are that utility is for a representative average household in a county, not a representative individual household; and that utility of the representative average household is dependent on average county characteristics, not individual household Characteristics. To explain the equation to estimate percentage of wood-burning households in a county, the household utility hypothesis is restated for an average household in a county:

$$\text{Let } U_{1i} = \overline{U}_1(X_{1i}) + e_{1i} \text{ and} \qquad (13)$$
$$U_{2i} = \overline{U}_2(X_{2i}) + e_{2i} \qquad (14)$$

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

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

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

$U_2(X_{2i})$ = the utility for not burning wood for a representative average household wood in a county, based on average characteristics, X_{2i}, of households in county i, and

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:

$$\text{Prob (burning)} = \text{Prob } (U_{1i} > U_{2i})$$

$$= \text{Prob } (U_{1i}(X_{1i})+e_{1i} > U_{2i}(X_{2i})+e_{2i})$$

$$= \text{Prob } (U_{1i}(X_{1i})-U_{2i}(X_{2i}) > e_{1i}-e_{2i}) \qquad (15)$$

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

$$\overline{U}_{1i}(X_{1i}) \cdot \overline{U}_{2i}(X_{2i}).$$

$$\text{Let } f_i = \overline{U}_{1i}(X_{1i}) \cdot \overline{U}_{2i}(X_{2i})$$

$$= \sum_{j=1}^{n} a_j Z_{ji} \qquad (16)$$

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 county i, is given by the cumulative normal distribution function:

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

where f_i is given by equation 16. The parameters a_j in equation 16 are estimated by a maximum likelihood procedure that uses data on individual households, and their county characteristics, Z_{ji}, which come from the National Residential Fuelwood Use Survey[27]. The survey gave data on 5,569 households, indicating whether 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 and Housing. County fuelwood price estimates came from the National Residential Fuelwood Use Survey, and non-wood fuel prices came from the Los Alamos National Laboratory[19]. (See the Appendix for an explanation of data characteristics and sources.)

Amount Burned By Wood Burners

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

Model Specification and Parameter Estimation

Model specification is the procedure by which the independent variables are identified and 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.

Percent of Wood Burners

To specify a probit equation for P_i (equation 17), county-level variables, Z_j, for equation 16 are used to determine the utility of burning wood and not burning wood. Following the theoretical model of Hardie and Scodari, factors were sought that influence:

- Non-wood heating costs.
- Fuelwood heating costs.
- Household tastes and preferences.

We also considered for inclusion factors identified as important in previous empirical work. Hardie and Hassan included, as determinants of heating costs, square feet of area heated, heating degree-days, number of household members, price of wood fuel and type of non-wood heating equipment[8]. To account for variation in tastes and preferences, they constructed separate probit equations for each of five census regions. A second empirical model, used by Lipfert, predicted average household fuelwood use in a county based on heating degree-days (which has a major influence on heating cost) and logarithm of population density (which is related to the cost of heating with wood)[20]. Population density is linked to cost of wood burning insofar as households in high density areas have greater difficulty in finding, cutting and hauling wood, or have greater costs in buying wood. Thus, households in high density areas are less likely to burn wood. This is confirmed by Skog and Watterson. They show that households are less likely to burn wood than rural households: 23 percent vs. 45 percent, respectively[28]. Another factor that influences cost of wood burning, in addition to population density, is access to forestland to cut wood. We use percent forestland in a county as a measure of the 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 wood burners in a county (Table 8). These include eight dummy (0, 1) variables to denote when a county is in one of nine regions. Dummy variables account for regional differences in costs and tastes not accounted for by the other 11 variables. Five variables are taken from the Hardie and Hassan model and used in the form of county averages: heating degree-days, average non-wood fuel price, fuelwood price and fraction of households using each of six types of non-wood heating equipment. Median household income is included as a chief determinant of tastes. Median number of household members was initially included but later discarded because its coefficient was not significantly different from zero.

A second probit equation was formed to allow for the possibility that the influence of four variables - heating degree-days, household income, non- wood fuel price and wood price - is not strictly proportional to the value of the variables. These four variables were squared and included in the second probit equation (Table 9). Parameters were estimated using a

Tables. 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*	
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.
[2] Deleted category is fraction of households with electric heat pumps, fireplaces, wood stoves, portable room heaters or no heating equipment.
[3] Regions 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.

maximum likelihood technique for probit models[15]. Parameter estimates, statistics to test if parameters are significantly different from zero, and elasticities of wood-burning probability with respect to model variables are also shown in Tables 8 and 9.

Amount Burned by Wood Burners

To specify an equation for amount burned by wood burners in a county, q_i in equation 12, we sought county-level variables, $X_j (j = 1...m)$ that influence amount burned. Using county-level variables to predict individual household fuelwood use means the greater predictive power of individual household characteristics, such as kind of non-wood fuel used, is lost. But a direct link between county-level characteristics and county fuelwood use is gained.

Previous studies suggest what variables account for variation in fuel use. Lin, Hirst and Chon, in their state-level aggregate model, use prices of the three fossil fuels to predict demand for residential heating fuels [10]. 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[18]. The only other variable in Lipfert's model is heating degree-days. Hardie and Scodari suggest a theoretical model of individual household fuelwood use that uses prices of wood and of each non-wood fuel, the value of household labor to harvest and haul fuelwood, last season's heating bill and type of non-wood fuel used[9]. Hardie and Hassan, in their empirical model of individual household fuelwood use, use relative price of non-wood fuel to wood fuel, area of the house heated, heating degree-days, family size, income, kind of non-wood fuel and whether fuelwood was purchased[8].

Based on these previous studies, the following five county variables were selected for use in the equation for fuelwood consumed by wood burners:

- Median household income.
- Heating degree-days.
- Percent forestland.
- Price of non-wood fuel divided by price of wood fuel.
- Population density.

The price of non-wood 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 non-wood fuels were not used, to simple the model. It is assumed that consumers will exhibit rational economic behavior and that non-wood 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 wood burning, it is included here. Certain influences associated with population density - income, percent forest and fuel prices - are included separately. Including these variables helped to determine the influence of density alone.

Household income (not included in Hardie's models) is included as a proxy for house area heated and family size.

Table 9. 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	−.11488E-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 heater	−.00826	−1.52**		−.11
Regional dummy variables				
Pacific Northwest	.60437	4.08*		
Northern Rocky Mountains	−.22485	−1.07***		
Southern Rocky Mountains	.81261	4.93*		
Lake States	.0			
Central States	−.18582	−2.52*		
Mid Atlantic	.18082	2.80*		
North East	.50410	3.83*		
South Central	.12636	1.61**		
South East	.0			

[1] *Indicates coefficient is significant at 95% level of confidence.
**Indicates coefficient is significant at the 90% level of confidence.
***Indicates coefficient is significant at 85% level of confidence.
[2] *Indicates quadratic expression is significant at 95% level of confidence.
[3] Deleted category is fraction of households with electric heat pumps, fireplaces, wood stoves, portable room heaters or no heating equipment.

Ease of access to forestland for harvesting was included by using percent forestland in the county. No distinction is made between public and private forest, a potentially important influence on access.

One concern in using countywide variables covering all households is that they may not represent the average wood burner well. However, that will not cause difficulties if the variation in county averages from one county to another is the same as variation in wood burner averages from one county to another. We assume countywide averages are highly correlated to county averages for wood burners.

Three equations were formed to determine amount burned by wood burners using the selected variables:

X_1 = 1n INC = 1n(median household income)

X_2 = 1nHDD = 1n(heating degree-days)

X_3 = 1n FOR = 1n(percent forestland)

X_4 = 1n REL = 1n(price of non-wood fuel divided by price of wood fuel)

X_5 = 1n PD = 1n(population density)

Q_w = 1n(amount burned by household)

e = error term

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

$$Q_w = \sum_{j=1}^{4} \left(\sum_{k=1}^{4} a_{jk} X_5^k\right) X_j + e \qquad (19)$$

$$Q_w = \left(\sum_{k=1}^{4} a_{1k} X_5^k\right) X_1 + \left(\sum_{k=1}^{4} a_{2k} X_5^k\right) (X_1)^2 + \left(\sum_{k=1}^{4} a_{3k} X_5^k\right) (X_1)^3 + \left(\sum_{k=1}^{4} a_{4k} X_5^k\right) X_2 + \left(\sum_{k=1}^{4} a_{5k} X_5^k\right) (X_2)^2 + \left(\sum_{k=1}^{4} a_{6k} X_5^k\right) X_3 + \left(\sum_{k=1}^{4} a_{7k} X_5^k\right) (X_3)^2 + \left(\sum_{k=1}^{4} a_{8k} X_5^k\right) X_4 + \left(\sum_{k=1}^{4} a_{9k} X_5^k\right) (X_4)^2 + e \qquad (20)$$

Equations 18-20 are formed using natural logarithms of variables because error term estimates were more nearly normally distributed than for linear equations, and because coefficients represent the elasticity of wood use with respect to independent variables. Equation 18 uses only four variables, leaving out 1n (population density). Equations 19 and 20 allow elasticities of wood use with respect to X_1-X_4 to vary with 1n(population density). Equation 20, in addition to allowing variation in elasticity depending on 1n(population density), allows variation in elasticity depending on the value of each predictor variable.

Equations 19 and 20 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 1n(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 United States. Independent variables are county characteristics for those individual households.

Equations 18-20 were tested to see if their parameter estimates are biased as a result of their being fit on data for wood burners only. Equation 12 estimates total wood burning in a county by multiplying probit equation estimates ofpercent burners times amount burned from equations 18, 19 or 20. The probit models are fit on data from both wood burning and non-wood-burning households. Equations 18-20 are fit on data from wood burners only. Therefore, counties with a high proportion of wood burners are overrepresented in the determination of parameters for equations 18-20. The effect of the overrepresentation, or sample selection bias, on parameters in equations 18-20 was tested by including an instrumental variable LAMBDA in equations 18-20 and determining if it had a coefficient significantly different from zero.

LAMBDA for a household in county j is given by

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

where f is the standard normal distribution function and F is the cumulative standard normal distribution function[8]. Z_{ij} and a_i are variables and parameters, respectively, from the probit model and predict probability 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 percent 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 percent confidence level. LAMBDA is excluded from these two equations so differences between their predictions and those of equation 20 are not due to use of LAMBDA.

Parameter estimates for equation 18-20 are shown in Table 10. 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 percent of the variance not yet accounted for.

Table 10. Terms and Parameter Estimates for Equations (18), (19) and (20) Which Predict Amount of Fuelwood Used by a Household.

	Equation parameters (a_{ij})		
Term in equation	**(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)	4.507 E-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)	1.969 E-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
$(1n FOR)^2$			−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

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 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 percent confidence level.

The adjusted coefficient of determination, (R^2), indicating the fraction of variance in natural logarithm of fuelwood use accounted for by an equation, is a 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[8].

Equations 18-20 estimate Q_{wi}, which is 1n(amount burned) for anaverage wood burner in county i. Call this estimate $\overline{Q}_{wi}$.

$$Q_{wi} = \overline{Q}_{wi} + e.$$

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

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

where SE is the standard error in estimating $\overline{Q}_{wi}$. Values for SE for equations 18-20 are given in Table 10. Since SE is only an estimate, an adjustment was made to the initial estimates of q_i and Q_i. Recall that

$Q_i = p_i q_i N_i$ (see equation 12).

An adjustment factor k was computed for equations 18-20 such that total U.S. wood burning estimated equals the survey estimate for 1980-81 - 40.5 million cords:

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

where m is the number of counties in the United States and

$$q_i' = kq_i$$

$$Q_i' = kQ_i$$

where q_i' and Q_i' are adjusted estimates for amount burned by the average wood burner and total amount burned in county i, respectively (for equation 20, k = .98508).

County Fuelwood Production Models

County fuelwood production estimates were produced by multiplying estimated county wood burners (probit equation 2) by estimated amount burned per wood burner in that county (equations 18, 19 or 20), summing these for each county in the United States and adjusting the totals of the summations so as to be consistent with the 1980-81 survey estimate. Thus, three models of county fuelwood production were used. They differed according to the equation used to estimate amount burned per wood burner (equations 18- 20) and were designated as Model I, II and III, with Model I containing equation 18, Model II equation 19, and Model III equation 20. Because of the results of statistical tests, county estimates of fuelwood production shown in the "Results" section of this report were produced using Model III, consisting of probit equation 2 and equation 20.

Validation

Validation is the process of establishing confidence in the soundness and usefulness of a model. 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 evaluating criteria. For scientists, a model is useful if it gives insight into the workings of a real system, makes correct predictions or stimulates questions for future research. For public leaders and their analysts, a model is useful if it explains the causes of problems and provides a basis for designing policies to alleviate problems[6].

The validation steps taken here are an effort to satisfy the validation interests primarily of scientists. Forrester and Senge suggest specific validation tests for models constructed from a system dynamics perspective. Rather than adapt their tests of model structure, behavior and policy consequences to the two-equation model used in this study, certain general validation tests suggested by Kaplan were used[16]. Kaplan suggests that theories are validated by evaluating how they meet norms of correspondence (to the real world), coherence (in a larger body of knowledge) and 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 that 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. . . ."[16]

The notion of concatenation of evidence suggests the coherence criterion - the model should fit into established theory Coherence also favors a theory or model that is simple to explain and that has a simple mechanism for determining behavior. When developing models, Kaplan asserts, "We are to introduce a complicating factor only if we have reason to expect error from its omission. . .. "[16]

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 manage me tit in counties using the most fuelwood.

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 day groups and other 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 11 shows households subdivided into approximately equal sized groups based on county characteristics. Table 12 compares predictions of probit equations 1 and 2 to survey results. Table 13 compares equation estimates of amount burned by wood burners to survey results. Table 14 compares predicted average amounts burned over all households, as computed by combining probit equation 2 and each of the amount equations, to survey results. (Probit equation 2 was chosen to pair with each amount equation because results in Table 12 suggest it predicts better than probit equation 1.)

Percent wood burners is predicted best by probit equation 2, which includes squared terms (Table 9). For probit equation 2, predictions for various subgroups differ from survey results by 7 percent or less except for one fuelwood price category, one relative non-wood fuel price category, one "percent forestland" category and one "percent homeowners" category. The probit equation underpredicts the most for counties with low percent forestland (-10.9 percent). It overpredicts the most for counties with low median income (5.8 percent).

Table 11. 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
Percent forestland		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 12. Survey and Probit Equation Estimates of Average Percent Wood-burners for Subgroups of Counties, 1980–81.

County characteristic and quartile of households	Percent of households burning wood: Survey	Probit equation 1	Probit equation 2	Percentage difference between survey and equation estimates: 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
Nonwood fuel price					
1	23.1	24.9	22.9	7.8	- .9
2	26.7	27.3	27.0	2.2	1.1
3	32.5	30.3	30.9	-6.8	-4.9
4	28.6	29.0	28.1	1.4	-1.7
Price of fuelwood					
1	32.4	32.7	33.5	.9	3.4
2	23.5	23.1	21.8	1.7	-7.2
3	33.7	35.0	33.4	3.9	- .9
4	21.1	21.0	20.5	- .5	-2.8
Nonwood fuel price divided by price of wood					
1	24.6	25.6	24.3	4.1	-1.2
2	23.3	22.6	21.6	3.0	-7.3
3	28.8	29.1	28.4	1.0	-1.4
4	34.1	34.2	34.8	.3	2.1
Percent forestland					
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

Table 12 continued on next page

Table 12. (continued)

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
Population density					
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
Percent rural population					
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
Percent home owners					
1	19.0	17.6	17.3	−7.4	−8.9
2	26.0	27.4	26.6	5.4	2.3
3	30.8	31.5	30.2	2.3	−1.9
4	34.6	35.1	36.0	1.4	2.6
Region					
Northwest	55.1	58.3	58.1	5.8	5.4
N. Rocky Mnts.	41.6	38.0	38.6	−8.7	−7.2
S. Rocky Mnts.	29.0	30.6	28.6	5.5	−1.4
Lake States	28.3	29.5	28.5	4.2	.7
Central States	25.2	25.4	25.2	.7	.0
Mid Atlantic	20.5	20.0	19.5	.6	−4.9
North East	34.1	35.9	35.5	5.3	4.1
South Central	26.8	26.4	25.7	−1.5	−4.1
South East	31.2	29.6	29.6	−5.1	−5.1

Predictions of amounts burned by equations 18-20 show greater percent differences from survey estimates than predictions made by the probit models (Tables 12 and 13). Discussion is focused on equation 20 because 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 percent. Six categories have differences of 17 percent or more:

- Highest income counties are predicted 18 percent too high.

- Highest fuelwood price counties are predicted 27 percent too high.

- Highest population density counties are predicted 30-36 percent too high.

- Next to lowest percent rural households group is predicted 37 percent too high.

- Next to lowest percent homeowners group is predicted 17 percent too high.

- The two Rocky Mountain regions are predicted 44 percent and 26 percent too 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 percentage forestland counties and overpredicts for high percentage forestland counties (Table 13). Predictions for households in counties with low population density are good, but for high density counties they are high. 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 that the combined influence of two or more factors, at high densities, decreases wood burning.

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 13, 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 wood burner 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 9) with amount equations 18 through 20, respectively (Table 10). 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 14). 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 percent. Six categories differ by 17 percent 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 15). For Model III, overpredictions of average amount burned become larger as density increases beyond 6,000 persons per square mile. For counties with 1,508-6,000 persons per square mile, predictions average 7.8 percent too high. For counties with 6,000-13,087 persons per square mile, predictions average 44 percent too high, and for counties over 13,087 persons per square mile, predictions average 160 percent too high. Six and one-half percent of households are in counties with 6,000 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 6,000 persons per square mile. It overpredicts by only 1.4 percent, on average.

The foregoing 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 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 to 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.

Table 13. Survey and Equation Estimates of Average Amount Burned per Wood-burning 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)
	—(cords)—						
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
Nonwood fuel price							
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
Price of fuelwood							
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
Nonwood fuel price divided by price of wood							
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
Percent forestland							
1	1.12	1.25	1.07	1.06	11.6	−4.5	−5.4
2	1.38	1.43	1.53	1.48	3.6	10.1	7.2
3	1.86	2.01	1.99	1.98	8.1	7.0	6.4
4	1.49	2.66	2.76	2.84	6.8	10.8	14.1
Population density							
1	2.58	2.41	2.69	2.68	−6.6	4.3	3.9
2	2.05	1.93	2.10	2.12	−5.9	2.4	3.4
3	1.12	1.53	1.53	1.52	36.6	36.6	35.7
4	.81	1.45	.99	.99	79.0	22.2	22.2
Percent rural population							
1	.79	1.35	.93	.92	70.9	17.7	16.5
2	1.04	1.46	1.46	1.42	40.4	40.4	36.5
3	1.86	1.90	2.09	2.11	2.2	12.4	13.4
4	2.69	2.62	2.84	2.87	−1.6	5.6	6.7
Percent home owners							
1	1.05	1.51	1.19	1.15	43.8	13.3	9.5
2	1.40	1.66	1.64	1.64	18.6	17.1	17.1
3	2.00	1.87	2.03	2.03	−6.5	1.5	1.5
4	2.39	2.27	2.45	2.49	−5.0	2.5	4.2

Table 13 continued on next page

Table 13. (continued)

County characteristic and quartile of households	Amount burned				Percentage difference between survey and equation estimates		
		Equation					
	Survey	(18)	(19)	(20)	(18)	(19)	(20)
	—(cords)—						
Region							
Northwest	2.30	2.18	2.41	2.66	−5.2	5.2	15.7
N. Rocky Mtns.	2.47	2.46	3.09	3.55	−.4	25.1	43.7
S. Rocky Mtns.	.90	1.03	1.13	1.13	14.4	27.8	25.6
Lake States	1.19	1.98	2.02	2.21	−13.5	−11.8	−3.5
Central States	1.96	1.86	1.88	1.85	−5.1	−4.1	−5.6
Mid Atlantic	1.85	1.93	1.61	1.73	4.3	−13.0	−6.5
North East	2.29	2.44	2.32	2.56	6.6	1.3	11.8
South Central	1.86	1.75	1.90	1.68	−5.9	2.2	−9.7
South East	1.85	2.12	2.17	2.01	14.6	17.3	8.6

Comparing model estimates of amount burned to nine state survey estimates for 1980-81 shows Model III underestimates by 20 percent or more in four states and overestimates by 20 percent or more in one state (Table 16). Comparing Model III estimates to state survey estimates for other years shows Model III usually underestimates total consumption. Many state estimates are probably too high - the resurvey conducted for the National Residential Fuelwood Use Survey found households overestimated by an average 18 percent on the initial survey[27]. The state 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 wood burners for counties with high incomes and high population density and underpredicts for counties with low income.

- Model III overpredicts average fuelwood use by 68 percent for counties with a population density above 6,000 per square mile. Model III predicts fairly well for counties with densities under 6,000 persons per square mile. The specification of equation 20 needs to be improved to predict wood use at high densities.

Comparisons with state-level estimates indicate that Model III underestimates total fuelwood use in states and counties (if independent state survey results are correct).

Validation by Coherence

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[18,17,8]. The elasticities of variables from these previous studies have signs that match the signs of elasticities for equations developed here (Table 17).

The elasticities of the probability of wood burning 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 elasticity for income in probit equation 2.

The elasticities for amount burned by wood burners from equation 20 are compared to elasticities from Hardie's amount equation for individual households. Elasticity signs match, with the partial exception of income elasticity discussed below Elasticities for equation 20 vary with population density and are shown in Table 18. Elasticities of amounts burned by wood burners are short-term demand elasticities indicating how much fuelwood demand would change in the absence of entry into and exit of households from wood burning. Short-term demand elasticities are positive for heating degree-days and for relative price of non-wood fuel for both 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 18).

Income elasticities of fuelwood use for the average wood burner vary from small positive values to negative values over income groups and population groups, largely because of differences in the type of wood-burning equipment the average wood burner is most likely to use and differences in wood-

burning purpose. In low density counties, the average wood burner uses a stove and burns wood to provide much of his space hear. In higher density counties, the average wood burner is more likely to have a fireplace 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: higher income households may have larger houses to heat, they may be more likely to heat entirely with wood, or they may view greater wood burning as part of a lifestyle to be desired.

In higher density counties with low income, the average wood burner is fairly likely to own a stove and burn wood for space heating. But, as average income increases, the average wood burner 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 the inconvenience of wood use in high density areas. On the other hand, 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 (percentage forestland) is greater for highly forested, middle density counties. Response is lowest for counties with little forest. These findings suggest increased access to forestland may increase average

Table 14. 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
	—(cords)—						
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
Nonwood fuel price							
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
Price of fuelwood							
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
Nonwood fuel price divided by price of wood							
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
Percent forest land							
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
Population density							
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
Percent rural population							
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
Percent home owners							
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

Table 14 continued on next page

Table 14. (continued)

County characteristic and quartile of households	Amount burned				Percentage difference between model and survey		
	Survey	Model[1] I	Model[1] II	Model[1] III	I	II	III
	—(cords)—						
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

[1] Model 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).

Table 15. Survey and Equation Estimates of Percent Burners, Average Fuelwood Use by Wood Burners, 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 wood burners		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

wood burning by the greatest percentage in highly forested, moderately populated rural counties.

The short-term response of wood-burning households to increasing relative price of non-wood fuel increases sharply as county population density increases above 1,800 persons per square mile. Even though wood burners in high density areas are responsive to relative non-wood fuel price changes, they are even more responsive to changes in income. In high density areas, if income increases as fast as relative non-wood fuel price, fuelwood use by wood burners will decrease. But, in middle and upper income, low density areas, equal percentage increases in income and relative non-wood fuel price will cause an increase in wood burning.

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 9).

The differences between short- term and long-term elasticities are smallest for percentage forestland. This is due to the low entry/exit elasticity of .15 from probit equation 2 (Table 9). 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 8). The net long-term elasticity is positive for most combinations of income and population density. Only at high densities or low incomes does overall wood burning 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 wood burners. 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 19). Long-term elasticity with respect to relative price of non-woodfuel moves from less than 1 to greater than 1 as density increases. The elasticity is also much higher at

Table 16. 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[2]					
			1979–80	1980–81	1981–82	1982–83	1983–84	1984–85
			— (million cords) —					
Alabama	.76	1.05						
Arizona		.29						
Arkansas	.85	.53						.63
California	1.84	1.90						
Colorado	.39	.76				.50 ('82)		
Connecticut	.44	.71	.91			.66		
Delaware		.07						
D.C.		.01						
Florida	.62	.65						
Georgia	.73	.97		1.70				
Idaho	.39	.44	.37					.66
Illinois	1.58	1.09				1.70		
Indiana	.86	.96						
Iowa		.55						
Kansas		.26						
Kentucky		.87						
Louisiana		.42						
Maine	.84	.75						
Maryland	.49	.52		.94				
Massachusetts	1.07	1.21			1.20			
Michigan	1.79	1.68			2.86	3.14		
Minnesota	.96	.92	1.31					
Mississippi		.64						1.42
Missouri	1.23	.82			1.79			1.50
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		3.16		
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				
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		.40	
Virginia	1.76	1.96						

Table 16 continued on next page

Table 16. (continued)

STATE	Residential fuelwood use survey 1980–81[1]	Estimate by Model III 1980–81	Other survey results[2] 1979–80	1980–81	1981–82	1982–83	1983–84	1984–85
Washington	1.67	1.99	1.21					
West Virginia	.64	.61						
Wisconsin	1.28	1.18	1.97	1.35				
Wyoming	.14	.19						

[1] Relative standard error of estimate varies from 15 to 50%.

[2] Sources: (30) (1) (3) (5) (7) (20) (21) (22) (23) (24) (25) (31)

Other sources, alphabetical by state/region:

John I. Green. 1986. Residential fuelwood use in Arkansas [for 1984-85]. Unpublished mimeo. Dept. of Forest Resources, Univ. of Arkansas, Monticello.

William H. Mclain. 1985. Colorado's 1982 fuelwood harvest. USDA Forest Service Resources. Bal. Int-36. Intermountain Research Station, Ogden, UT. p. 2.

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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.

State of Massachusetts, Division of Forests and Parks' Bureau of Forest Development. 1982. Wood burning among Massachusetts residents, 1981-82 data. Springfield, MA. p. 3.

Michigan Dept. of Natural Resources, Forest Management Division. 1984. Fuelwood use in Michigan homes; 1982-83 survey rsults. Lansing, MI. p. 5.

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Nancy J. Bostrom. 1985. Minnesota residential fuelwood study, 1984/85. Minnesota State Pollution Control Agency. St. Paul, MN. p. 5.

Missouri Dept. of Conservation, Forestry Division. 1985. Missouri residential fuelwood survey, 1985: Selected results. Unpublished preliminary mimeo report. Jefferson City.

Vermont Dept. of Forests, Parks and Recreation. 1984. Vermont residential fuelwood assessment supplement, 1983-84. Montpelier, VT.

lower relative prices - when wood does not have as much price advantage. This means that increases in wood burning 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, increase in wood burning 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 wood burning per square mile is not good. Lipfert et al. constructed two single-equation models to predict fuelwood use in individual counties[17,18]. One purpose of these models was to estimate at what population density pollution from wood burning is greatest. His second, more detailed model, based on the same data as Model III, estimated that wood use intensity is greatest at about 6,000 persons per square mile (445 cords per square mile). Model III estimates the highest wood use per square mile would be at 163,000 persons per square mile, which is greater than Manhattan's density of 62,099 persons per square mile. The estimate by Model III is too high, reflecting the finding in Table 14 that Model III overpredicts substantially for densities above 6,000 persons per square mile.

Lipfert's model gives a more realistic level of maximum use but uses 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.

Validation by Pragmatic Uses

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 ofwood-burning may differ, depending on lifestyles 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 forestland increases fuelwood use. But it does not specify what availability characteristics of forestland - such as ownership, size of ownership, species and management activities – would cause more or less fuelwood use.

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?

An aggregate model might be improved in a number of ways:

- Use separate probit models to estimate the likelihood ofwood use by oil, natural gas, electricity and "other" fuel users.

- Use separate equations to predict amount burned by wood burners 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 non-wood 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.

Table 17. 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 wood burner		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		+		–	–	–
Heating equipment used						
Steam radiators	–	–				
Ducted hot air	–	–				
Electric wall heaters	–	–				
Gas or oil room heater	–	–				

[1] Hardie and Hassan. 1984. An analysis of demand for fuelwood. pp. 23-27. For the North Central region the elasticity was negative for heating degree days and positive for electric heating.
[2] Ibid. p. 32, 27.
[3] Elasticity with respect to income is positive for higher income, lower density counties. See Tables 14 & 15.
[4] Lipfert *et al.* 1984. Empirical analysis of residential wood-burning impacts. p. 29.

Caveats

There are a number of caveats for those who would use Model III to predict near future wood burning 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 would be desirable for other years to start with those data for the counties and make adjustments in variables to represent conditions in the years of interest. (Contact the senior 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 designs improve, the average efficiency of wood stoves will improve. This will reduce the amount and cost of wood per unit of heat output. To include this effect in the present model, fuelwood price and relative non-wood fuel price would have to be adjusted. Other trends not reflected in the model include increasing concern for

Table 18. Elasticities of Average Amount Burned by Wood burners 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	−.32	0.18	.01	.15	.59	.59	.59	.17	.15	.13	.14	.20	.25
98	−.30	−.27	−.10	.03	.55	.55	.55	.09	.15	.19	.13	.18	.23
417	−.38	−.50	−.38	−.29	.53	.53	.53	.04	.16	.24	.17	.23	.28
1808	−.82	−.71	−.64	−.59	.51	.51	.51	.03	.16	.24	.25	.30	.36
22026	−2.32	−2.01	−2.32	−2.54	.27	.27	.27	.16	.11	.07	.87	.92	.98

Table 19. Elasticity of Average Amount Burned Over all Households 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
					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

indoor and outdoor air pollution, antipollution regulations, development of wood-burning furnaces with convenient wood chip feed systems, and increasing cost of insurance for homes with wood-burning equipment.

Future Research

Better residential fuelwood use models are needed to project use over many years and to estimate use for small geographic areas (counties or groups of counties). The models that project fuelwood use well over many years and require projection of the fewest exogenous variables may be different than the models that estimate near-term local use most accurately.

One type of longterm 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. Non-wood fuel prices, income and other factors would be projected exogenously to make projections.

The county-level model developed in this study might be improved in a number of ways. 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 this study's model does not measure the predominance of rural households and 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 wood burners 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 are 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 Lipfert's 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 wood burning 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 ofwhether 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 and 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 that 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 was 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. To project fuelwood use, a sample set of households would have to be produced for the year and locality of the projection.

Regardless ofwhether 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 that predict prices and consumption in pulpwood and sawtimber markets.

Appendix – Data Sources

Probit Equations 1 and 2

In the Residential Fuelwood Use Survey conducted by the U.S. Forest Service in 1981, 5,506 households were interviewed; 1,874 had burned wood within the prior 24 months[27]. Those surveyed specified their county of residence, whether they burned wood and how much wood they burned during the preceding 12 months. The survey was conducted from August through October 1981. The probit model dependent variable was 0 to 1, depending on whether 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 (Table 69), 1982.

– Average non-wood fuel price: Prices for natural gas, fuel oil and electricity in S/MMBtu input were converted to SMMBtu output by dividing by average conversion efficiencies of 61, 66 and 100 percent, respectively[26]. Prices were weighted by the percentage 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[19]. Percentage 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 offuelwood 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).

– Percentage forestland: Forestland area and total land area for individual counties (or groups of counties in the West) are from the most recent forest survey reports for individual states published up to 1983 by USDA Forest Service Experiment Stations: Intermountain, Ogden, Utah; North Central, St. Paul, Minn.; Northeastern, Broomall, Pa.; Pacific Northwest, Portland, Ore.; Pacific Southwest, Berkeley, Calif.; Rocky Mountain, Fort Collins, Colo.; Southeastern, Asheville, N.C.; and 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, Mich., based on the county and city data book, 1977, published by the US. 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 wood-burning households were estimated using amount of fuelwood consumed by 1,874 wood-burning households interviewed for the residential fuelwood use survey in 1981. Independent variables were the characteristics of the county in which 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 percentage forestland. Relative non-wood fuel price is the average non-wood 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 - 8 show percentage of households burning wood and amount burned for households grouped by county characteristics. 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:

– Percent rural population: census summary tape file 3C (Table 1).

– Percent homeowners: census summary tape file 3C (Table 97).

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