Heating Costs and Household Wood Stove Acquisition: A Discrete Choice Demand Model

Paul Francis Scodari and Ian W. Hardie

This paper examines the acquisition of wood stoves by New Hampshire households through use of a utility-maximizing discrete choice model. The analysis is based on the hypothesis that wood stoves are acquired to decrease the monetary costs of home-heating. Operating costs associated with heating with conventional fuel burning capital and with a combination of conventional and wood stove heating capital are estimated. These operating costs are used to estimate probabilities of 1979 wood stove acquisition for particular types of New Hampshire households.

One of the most important components of the increase in residential fuelwood demand over the last decade has been the entry of new fuelwood consumers. This entry has resulted in large part from the decision of households to add wood-heating equipment to their existing heating systems. While this has been a national phenomenon (U.S. DOE 1983), it has been especially evident in Northern New England where household heating requirements are well above the national average (Bailey and Wheeling 1982a,b,c). In New Hampshire, for example, homeowners using wood as a heating fuel increased from 5 percent in 1970 to 50 percent in 1979. In 1979 wood was burned for heat by 55 percent of Vermont's owner-occupied households and by 51 percent of Maine homeowners.

The large percentage of homeowners in Northern New England burning wood for heat can be traced to relative cost differences between heating with purchased wood and heating with conventional heating fuels. In New Hampshire, the cost of home-heating with fuel oil in 1979 was 1-2 times as great as heating with purchased wood on a heat-equivalent BTU basis (Bailey and Wheeling). Similar estimates hold for Vermont and Maine where fuel oil accounts for the majority of conventional fuel use. This is a conservative indication of the cost difference because many Northern New England homeowners have been able to procure fuelwood from non-market sources. In the three states discussed above, 50-60 percent of all wood burned in 1979 was home-cut instead of purchased. These figures suggest that expected heating cost savings are the primary motive behind the household decision to begin burning wood.

This paper presents an analysis of the household wood stove acquisition decision. The analysis is micro in nature, being based on a set of observations from households in the State of New Hampshire. It rests on a utility-maximizing discrete choice model of the type pioneered by McFadden (1973, Domen-cich and McFadden, 1975). In recent years this framework has been used to integrate entry-exit consumer behavior into traditional demand analysis. This approach has been used to model consumer demand for transportation (Domencich and McFadden, Lerman 1976), consumer durables (Hausman 1979, Lee and Trost 1978), and energy consumption (Hartman 1979, Hardie and Scodari, 1982).

The household wood stove acquisition decision presumably involves a tradeoff between initial capital costs and expected heating cost savings throughout the life of the stove. A lack of capital cost data prevented an analysis of this capital-operating cost tradeoff. Instead, the formulated model expresses the household wood stove acquisition decision in terms of

The authors are, respectively, Staff Economist, Environmental Law Institute, Washington, D.C. and Associate Professor, University of Maryland, College Park.

Scientific Article No. A-3945, Contribution No. 6929 Maryland Agricultural Experiment Station. Support for this research was provided under a cooperative agreement with the Northeastern Forest Experiment Station, Broomal, Pennsylvania. Computer facilities were provided by the University of Maryland Computer Science Center.

the tradeoff between annual operating costs associated with heating with only conventional heating capital and with a combination of conventional and wood stove heating technology. Operating costs for the two capital stock heating alternatives are estimated using household socioeconomic and heating characteristics. The discrete choice model relies on these operating costs to estimate probabilities of 1979 wood stove acquisition for various types of New Hampshire owner-occupied households.

The data used in this analysis are taken from the 1979 and 1980 New England Fuelwood Surveys. These surveys were conducted by the Governor's Council on Energy and analyzed by the Economic Reporting Service, U.S. Department of Agriculture. Telephone interviews were utilized to gather information from a random sample of 5600 households in six New England states. The 1979 survey covered 813 households in New Hampshire. The 1980 survey followed up on over 200 of these New Hampshire households. After elimination of incomplete responses and observations on households that acquired stoves prior to 1979, 117 observations were available for use in estimation of the wood stove choice model.

The Model

Each household is assumed to make one of two choices: to heat only with the existing heating system built into the house or to acquire a wood stove and to heat with a combination of wood and non-wood fuels. It is further assumed that each household has a well-defined conditional utility function which measures the desirability of these two options. Utility rankings from this function can be expressed as a function of the expected monetary operating costs of the two heating alternatives. The utility rankings are random because of unobserved or unmeasured attributes of the heating alternatives and because of variations in the tastes and preferences of the sampled households (Hausmann and Wise 1978). The household is presumed to purchase the woodstove whenever the utility resulting from heating with wood exceeds the utility from heating without wood.

The utility gained by the nth household from the acquisition and use of a wood stove can be written as:

(1) $$U_{n1} = \hat{U}(\hat{C}_{n1}) + \epsilon_{n1}$$

and the utility from heating without a wood stove as:

(2) $$U_{n2} - \hat{U}(\hat{C}_{n2}) + \epsilon_{n2}$$

In this specification, U (•) represents the expected utilities common to the population of households evaluating the two heating alternatives. The e are random terms measuring the deviation in utility between the nth household and the average or representative household. $\hat{C}_{n}i$ and $\hat{C}_{n2}$ are the expected operating costs of the heating systems for the nth household.

A utility-maximizing household would acquire a stove if:

(3) $$\hat{U}_{nl}(\hat{C}_{n1}) + \epsilon_{n1} > \hat{U}_{n2}(\hat{C}_{n2}) + \epsilon_{n2}.$$

Since $\epsilon_{n}i$ and e_{n2} are stochastic, this choice can be assigned a probability:

(4) $$P_{nl} - \text{prob}[\hat{U}_{nl} + \epsilon_{nl} > \hat{U}_{n2} + \epsilon_{n2}].$$

Thus

(5) $$P_{n1} = \text{prob}[\epsilon_{n2} - \epsilon_{n}i \_< \hat{U}_{n1} - \hat{U}_{n2}]$$
$$= \text{prob}[\eta n.21 < U_{n\cdot 12}]$$

where $\eta_{n\cdot 21} = \epsilon_{n2} - \epsilon_{nl}$ and $\hat{U}_{n\cdot 12} - \hat{U}_{n1} - \hat{U}_{n2}$. Given this specification, a sample of observed household choices can be used to estimate the probability that an average household will purchase a wood stove.

To implement this estimation, a first order Taylor series expansion around a point in cost space is used to represent the expected household utility of each heating alternative. The utility of each alternative can then be written as:

(6) $$U(\hat{C}_{nj}) = \alpha_{OJ} + \alpha_{iJ}(\hat{C}_{nJ}) \qquad j = 1, 2$$

where a_{oj} is the portion of the Taylor series expansion involving only the element around which the expansion is made. The ay parameter represents the first derivative of expected utility with respect to the expected operating costs of heating alternative j.

Given this specification of preferences, $\hat{U}_{n\cdot 12}$ in (5) may be rewritten as:

(7) $$\beta'' Z_n - \beta_o + \beta_1(\hat{C}_{n1}) + \beta_2(\hat{C}_{n2})$$

where $\beta_o = (\acute{\alpha}_{01} - \acute{\alpha}_{o2})$, $\beta_1 = a\hat{U}_{n\cdot 12}/a\hat{C}_{n1}$ and $\beta_2 = dUn.i2/3C_{n2}$. These £ parameters can be estimated using a probit model if the ϵ_{n1} and ϵ_{n2} are assumed to be independently and identically normally distributed over the population of decision-making households, and if these error_terms do not depend on the values of $C_{n}j$ and $\bar{C}_{n2}$. Since normality is preserved under subtraction, the error term $n_{n\cdot 21}$ will also be independently and identically normally distributed.

In the probit model, the probability of stove acquisition by a household with given expected operating costs is $[\beta\phi Z_n]$, where Øis the cumulative standard normal distribution function. The probability of using only non-wood heating systems is $1 - \varnothing[\beta' Z_n]$. Parameter estimates are obtained by maximizing the log-likelihood function

$$(8) \quad L(\beta^*) - \Sigma_{N1} 1n\varnothing[\beta' Z_n] + \Sigma_{N2} 1n[1 - \varnothing)\ \beta' Z_n].$$

where N_l is the group of sample households which have acquired a wood stove and N_2 is the set of sample households which have not. Only relative estimates can be obtained for /3, as this procedure requires the standard error of estimate to be set equal to one.

Equations (7) and (8) imply that the likelihood function is a function of expected operating costs. Thus the model specification will be complete if values can be obtained for these costs. Although expected heating costs are latent variables, estimates can be obtained for representative households corresponding to each of the N sample households. Following Hausman (1981), the estimated cost values are obtained by regressing actual monetary heating costs against observed household characteristics. Two regressions are obtained, one for each of the subsamples of NI and N_2 households. That obtained from the first subsample is used to estimate expected heating costs for the heating system with a wood stove. That obtained from the second is used to estimate expected heating costs in the absence of a wood stove. In both cases, estimates are obtained for the full sample of N households. These expected values are then utilized in the maximum likelihood estimation of the probit model.

Both regression models are linear in form and have standard error assumptions. Since the NI sample size would be small if it included only households that purchased wood stoves during 1979, this subsample is augmented by observations on households that have acquired stoves prior to the 1979 season. These observations came from the larger sample of 200 New Hampshire households covered by the 1979 and 1980 surveys. A "year of stove ownership" explanatory variable (denoted by YRS) is included in the regression to eliminate any systematic differences due to the year of purchase.

The dependent variable Q is defined as the household's monetary expenditure for wood and non-wood heating fuels. This variable is regressed against the following explanatory variables:

AGE = age of household head
FAM = number of persons in household
HSG = 1 if a high school degree is the highest degree attained by the household head, 0 otherwise
CG = 1 if a college degree has been at tained by the household head, 0 otherwise
INC1 = 1 if annual household income is less than 10,000 dollars, 0 otherwise
INC2 = 1 if annual household income is between 10,000 and 25,000 dol lars, 0 otherwise YRS — years of stove ownership PC — price per cord of wood, either paid by the household or the average price for the township or county in which the household is located
ELEC = 1 if household has an electric resistance heating system, 0 otherwise
FP = 1 if household has an open unmodified fireplace, 0 otherwise
LC = household's previous winter heating cost assuming space heat was produced without burning wood.

The first six explanatory variables listed above characterize the household in terms of size, life cycle, income and education. ELEC is included to distinguish households with this type of heating system from those with the more common fuel oil and liquid propane systems. A dummy variable is included for households with open unmodified fireplaces to account for the possibility that these households burned wood for aesthetics instead of for heat.

Electricity is the second most commonly used non-wood heating fuel in New England and is substantially more expensive than fuel oil. Fuel oil is the most common. Some households burned liquid propane but none of the sample households used natural gas.

The lagged heating cost LC embodies the hypothesis that household expectations about heating costs are adaptive in nature. Since the data used in the analysis is obtained from a cross-sectional survey, only the most simple adaptive expectations structure is used. No attempt is made to separate short and long run adjustments to cost changes because the lagged heating cost variable is also expected to act as a proxy for a myriad of factors not included in the model. Among these are size, age and heating efficiency of the house, number of heating degree days per year, and heat conservation efforts employed by the household.

Expected heating costs for the second heating alternative are estimated using the subsample of households who did not acquire a wood stove. The dependent variable C_2 is defined as the household monetary expenditure for fossil fuels or for electricity used for heating. This variable is regressed against AGE, FAM, HSG, CO, INC1, INC2, ELEC and LC.

Analytical Results

Estimation results for the two heating cost regression equations are presented in Tables 1 and 2. Those for the probit model of household wood stove acquisition are given in Table 3. As might be expected, the lagged heating cost variable dominates the heating cost regressions. Coefficients for this variable reflect the expected decrease in heating costs for the subsample of households with wood stoves. Other variables constant, households without wood stoves would expect heating costs to vary less from the previous year's costs than households with wood stoves. There is also some indication in Table 1 that fuelwood is an income inferior good, a result that has also been obtained in some recently estimated models of national residential fuelwood demand (Hardie and Hassan 1984). In general, however, conclusions should not be drawn from parameters of these regression equations. They are developed for predictive purposes and not for structural implications.

Table 1. Estimated heating expenditure equation for households with wood stoves

Variable	Estimated Coefficient	Standard Error
intercept	-101.72	279.88
AGE	2.44	2.44
FAM	-2.60	2.57
HSG	74.69	77.95
CG	64.67	88.68
INC1	-242.97	120.20
1NC2	-220.85	97.16
YRS	.58	6.92
PC	.45	3.33
ELEC	-32.58	79.58
FP	-91.34	75.79
LC	.51*	.069

* Significant at . 10 level
Number of observations = 61 R^2 = .6237
Standard error of estimate = 205.2 F = 7.385

Table 2. Estimated heating expenditure equation for households without wood stoves

Variable	Estimated Coefficient	Standard Error
intercept	-32.17	65.82
AGE	.93	.74
FAM	23.20*	6.35
HSG	-11.32	27.33
CG	-3.30	35.62
INCI	7.82	37.24
INC2	64.76	33.10
ELEC	-96.21*	37.60
LC	.91*	.04

* Significant at .10 level
Number of observations =104 R^2 = .881
Standard error of estimate = 96.47 F = 87.91

The discrete choice model's parameter estimates are both significantly different from zero at the .10 significance level. The negative coefficient on the Cj variable indicates that as the cost level of heating with wood rises, the probability of the household acquiring a wood stove decreases. The positive coefficient on C_2 indicates that the higher the level of heating costs for fossil fuel or electric systems, the greater the probability a New Hampshire household will acquire a wood stove. These results suggest that the New Hampshire households respond to changes in heating costs in an economically rational manner.

A likelihood ratio test was performed to test the null hypothesis that ft = $/3_2$ = 0. This hypothesis was rejected with 90 percent confidence and the alternate hypothesis was accepted. Thus, the probability of wood stove acquisition is expected to depend on the expected costs of heating. Based on this test, and on the reasonableness of the parameter esti-

Table 3. Estimation results of the probit model of household wood stove acquisition

Variable	Estimated Coefficient	Asymptotic t-statistics
constant	-1.7355	-3.68
E(ci)	**-.0037144**	-2.01
E(c»)	.002867	2.47

Number **of observations =117**
LR statistic with 2 degrees of freedom = 6.72

mates, the probit model was deemed useful for predicting probabilities of wood stove acquisition for New Hampshire households. It should be noted, however, that these predictions will hold for periods other than the **1979** heating season only if there are no structural changes in household wood stove purchase decisions over time.

Probabilities are predicted by inserting cost estimates into the probit model and obtaining a value for the argument of the cumulative standard normal distribution function. Tables for this function can then be used to find the desired probability. When sample average values of Ci and C_2 were inserted in the model, the average probability that a New Hampshire household would acquire a wood stove was found to be 8.5 percent. This value is slightly less than the ten percent of owner-occupant New Hampshire households who reported installing a wood stove in 1979 (Bailey and Wheeling 1982).

The model is also used to derive probabilities of wood stove acquisition for households with different socioeconomic characteristics. These estimates are given in Table 4. The table shows, for example, that when the sample averages for Ci and C_2 for the subsample of households with electric heat are inserted in the model, the probability that a wood stove will be purchased rises to 11.9 percent. Since electric resistance heat cost as much as 1.6£ per 1000 BTU's in New Hampshire in 1978 (U.S. Department of Energy 1982), this result is consistent with the hypothesis that higher alternate heating fuel

Table 4. Predictions of the probability of homeowner wood stove acquisition for different types of households

Category	Household Class	Probability Prediction
	35 or younger	.097
	between 35 & 55 55	.092
Age: Income: Persons:	or older	.075
	less than $10,000	.084
	$10,000-525,000	.121
Education:	more than $25,000	.029
	2 or less 3 or 4 4 or	.069
	more	.097
	less than HS grad.	.131
Conventional heating:	HS grad. college	.127
	grad.	.085
	electricity oil or	.067
	propane	.119
		.087

price increase the household's probability of acquiring a wood stove.

The model predicts that the probability of a household acquiring a wood stove varies inversely with age and education of household head and directly with family size. Age might be expected to have an inverse effect on the probability because heating with wood stoves and cutting firewood involve household labor. Older homeowners may be less willing to spend this labor. Age may also be positively correlated with income. Size of family is generally directly related to size of house and total heating bill. Thus increasing probabilities are reasonable for this variable. The inverse relationship between education and stove acquisition probability is not unreasonable, though there was no a-priori reason to expect that it would be negative.

Perhaps the most interesting probability estimates concern the income variables. The model predicts that households earning more than 25,000 dollars annually are much less likely to invest in wood stoves than households in the lower income brackets. This may be due, in part, to heating costs being a lower percentage of income for these households. It may also reflect a higher value of household time. The probability estimates also indicate that households earning less than 10,000 dollars annually are less likely to purchase wood stoves than those earning 10,000-25,000 dollars. This may be due to differences in size of residence and in heating bills, or it may reflect an inability to afford the capital investment needed to acquire the stove.

This paper has presented a discrete choice model of household wood stove acquisition. The model is based on the hypothesis that wood stoves are purchased to decrease the monetary costs of heating fuels. It provides reasonable predictions of the probability that a New Hampshire household will purchase a wood stove. Thus, the model appears to be successful even though it does not explicitly incorporate the investment trade-off between stove purchase-installation costs and expected operating costs.

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