A Household Production Analysis of Fuelwood Demand in Rhode Island

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A model analyzing household substitution of fuelwood for other heating fuels is needed to clarify the relationship between energy prices and patterns of forest resource utilization. This paper employs the household production methodology to model fuelwood demand in Rhode Island. Data from a cross-sectional survey of 515 households are employed to test a discrete-choice model of household participation in wood-burning and a four-equation system modeling household production of heat and aesthetic benefits from fuelwood and stove capital. Control of selection bias via inclusion of an appropriate instrument allows analysis of aggregate demands. Some broad policy prescriptions applicable to the Northeast generally are presented.

Introduction

During the past ten years residential consumption of fuelwood in the Northeast has more than doubled as a result of household substitution away from relatively high-priced oil, gas and electric heat (Stoddard, 1979; Bailey, Wheeling and Lenz, 1983b). The average efficiency of wood-burning units has approximately doubled as well, as households have adopted airtight wood stoves in place of open fireplaces (Molzan, 1983; Mackenzie, 1985).

It is important to analyze the effects of high level of fuelwood demand on other forest values, viz. the sawtimber industry, watershed quality, wildlife habitat, recreation, etc. Strong demand for fuelwood may provide sufficient economic justification for timber stand improvement on many of the overstocked stands that typify much of the region's forests. On the other hand, a strong fuelwood market may lead to localized overcutting, the diversion of sawtimber-quality trees to fuelwood use, and a decline in habitat and watershed quality.

The objective of this paper is to develop a demand model for fuelwood, based on individual household behavior, which can generate predictions on both individual and aggregate demand levels. Evaluation of the determinants of fuelwood demand is a necessary first step in evaluating the likely impacts on the forest resource base from fuelwood harvesting and the potential severity of resulting resource use conflicts. Before appropriate public policy can be defined to harmonize conflicts between forest values, the nature of the market and non-market demands for those various values must be clarified.

This study focuses on fuelwood demand in Rhode Island. Despite its very high population density, some 59 percent of Rhode Island's land area was forested in 1972 (Peters and Bowers, 1977), and almost all the fuelwood consumed by Rhode Islanders is harvested within the state (Mackenzie, 1985). Net volume of growing stock in 1972 was 347.2 million cubic feet (mmcf), of which 272.2 mmcf or 78 percent was in hardwoods (Peters and Bowers, 1977).

The typical stand is overstocked with fairly slow-growing trees of generally insufficient diameter for sawtimber use. Mean annual increment per acre is typically less than 40 cf. Mean annual increment statewide was estimated at 17.4 mmcf in 1979, of which 9.5 mmcf was hardwood growth (Millar, 1984).

In 1982–83 fuelwood consumption alone was estimated to have been 17.0 mmcf (Mac-

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kenzie, 1985). The sawtimber harvest was approximately 3.2 mmcf or 20 million board feet (mmbf) (DFE, 1983). Growth to removals ratios can be roughly estimated at 0.7 for hardwoods and 3.0 or more for softwoods. Otico (1985) verifies a long-run trend of softwoods, particularly white pine, replacing hardwoods as a result of the fuelwood market's strong preference for hardwoods.

During the winter of 1982–83 an estimated 84,000 Rhode Island households burned approximately 213,000 cords of fuelwood. Burned at an average efficiency of 41 percent, this wood generated some 2.0 trillion effective BTU's of heat. Wood thus supplied approximately eleven percent of all residential heating requirements in the state (Mackenzie, 1985).

Methodology

A number of studies have analyzed local, regional or national demands for fuelwood. Those attempting to model demand adopt one of two approaches. The majority of demand models employ cross-sectional data on individual households or areas, using price variations between contemporaneous observations to explain variations in quantities of fuelwood demanded. In generating conclusions about aggregate demand, most of these studies fail to differentiate between the extensive and intensive margins of demand, i.e. between the determinants of whether a household will burn fuelwood at all and the determinants of how much wood a wood-burning household will consume. Stoddard (1979) and Slott (1982) have studied the consumption patterns of households already burning wood, but did not deal with changes in the incidence of wood-burning; Taylor-Brown (1980) has analyzed incidences of wood-burning by county for New England, but did not deal with any quantities consumed. Hardie and Hassan's (1984) study of fuelwood demand in the six regions of the United States models both consumption by individual households and the incidence of participation in two equations for each region. Scodari and Hardie (1984) develop a discrete-choice model of wood stove acquisition by New Hampshire households, but do not directly address the fuelwood consumption decisions of these households.

The alternate approach is a time-series analysis such as Criner and Unterstein (1983) employed in modeling aggregate demand for fuelwood in Maine; however this methodology does not allow for disaggregation of results to explain the behavior of individual households in determining the choices that are made at either margin of demand.

Specification of the demand model presented below was based on the household production methodology developed by Becker (1965), Lancaster (1966) and Pollack and Wachter (1975, 1977). Hardie and Scodari (1982) show how the methodology might be applied to the problem of measuring fuelwood demand. Their theoretical specification is implicitly short-run, treating heating capital (furnaces, wood stoves) as fixed or exogenous to the decision-making process, and thus is not really appropriate for analyzing long-run patterns of forest resource utilization. The paper provides no empirical test of their model.

Households are treated as cost-minimizing producers of commodities Z (such as heat), which are arguments in a household utility function U(Z), and which are produced from marketed goods X (such as fuelwood, oil, etc.) which are generally not direct arguments in the utility function. Thus the demand for fuelwood is derived through a production function for wood heat.

The household's expenditure function $E = E(P,w,Z)$ minimizes the direct costs of producing a predetermined level of heat from various sources (oil, gas, wood, etc.). P and w are goods prices and the household's opportunity cost of labor directed to heat production. The first partials of this expenditure function with respect to goods prices are cost-minimizing (i.e. heat-held-constant) input demand functions $X = X(P,Z)$. The partial derivatives with respect to Z yields the shadow prices R(P,Z) which are marginal implicit cost functions for the respective commodities.

The optimal levels of Z are now determined by maximizing the household's utility function U(Z) subject to the expenditure (budget) constraint

$$M = R(P,Z)'Z$$

Solving the first order conditions yields commodity demands $Z = Z(P,M)$ which can be estimated simultaneously with the goods demands as the structural form

$$X = X(P,Z)$$
$$Z = Z(P,M)$$

since M (income) identically equals total expenditures (Pollack and Wachter, 1977). Additional variables can be introduced for identification purposes if more than one commodity demand function is being estimated.

Data

Data for the estimation procedure was obtained from a telephone survey of 515 randomly-selected Rhode Island households conducted during the summer of 1983. The incidence of wood-burning in the sample was 27 percent (139 households). Data on fuels used, percent contributions to total heat from each fuel, total heating expenditures and a variety of socio-economic factors were obtained for all households. Data on fuelwood acquisition and consumption, burning unit characteristics, expenditures of money and household labor on processing and burning wood, and perceived costs and benefits of burning wood were obtained for all wood-burning households (Table 1).

Estimates were derived of each household's total effective heat yield from wood. A hedonic-pricing approach was employed to evaluate each household's marginal labor costs per cord wherever wood was purchased in incompletely processed form (uncut or unsplit) or harvested by the household itself. Thus an imputed price (PW) for stove-ready wood was calculated from household labor inputs and any reported purchase price. Households were asked whether they burned wood for cost-savings (the dummy variable COSTSAV), for aesthetic enjoyment (the dummy AESTH) or both. They were also asked whether they enjoy handling wood and whether they were bothered by dirt or ashes getting into the house (the dummies ENJOY and DIRT).

Some significant differences between households using fireplaces and households using wood stoves or furnaces were immediately apparent. Households using fireplaces spent an average of $879.85 on heat during the 1982–83 winter; households that did not burn wood spent an average of $708.75 on heat; households using wood stoves or furnaces spent an average of $528.82 on heat. Fireplace users had an average annual household income of approximately $34,300, predominantly harvested their own wood, and burned an average of 0.97 cords; wood stove users had an average annual household income of approximately $28,200, predominantly bought their wood, and burned an average of 2.94 cords. Households that did not burn wood had an average annual household income of approximately $22,800.

Table 1. 1982 Rhode Island Fuelwood Survey Summary Statistics

Variable	Description	N	Mean	Std. Dev.
BURN	= 1 if household burns wood, = 0 otherwise.	515	0.27	0.444
AGE	Age of householder (years).	495	48.36	16.62
HOUSE	= 1 if single-family structure, = 0 otherwise.	513	0.694	0.461
PR.ALT.F	Price of household's alternative fuel ($/mill. BTUs).	515	12.46	1.78
PCT.FOR	Percent of town land area in forest.	515	28.79	23.72
HPTHHEAT	Household's estimated seasonal heat requirement (mill. BTUs).	446	71.274	21.623
YRS.EDUC	Householder's years of schooling.	502	13.29	3.25
LOTSIZE	Size of house lot in acres.	458	1.74	9.56
EST.INC	Estimated 1982 household income ($ thousands).	446	23.749	14.790
WOODHEAT	Estimated total heat from wood (mill. BTUs).	139	29.776	16.262
AESTH	= 1 if household reports aesthetic benefits from burning wood, = 0 otherwise.	139	0.612	0.487
ST.EFFIC	Estimated burning unit efficiency.	139	0.41	0.22
TOTCORDS	Total 1982–83 fuelwood consumption in cords.	139	2.52	1.91
PW	Reported price of purchased, stove-ready fuelwood; imputed price of fuelwood requiring household labor input.	139	96.82	18.76
OWNRENT	= 1 if owner-occupied household, = 0 otherwise.	513	.224	.417
HRSWORK	Hours per week spent at work by householder.	474	33.1	18.3
YRSWOOD	Years household has burned fuelwood.	135	7.02	9.48
COSTSAV	= 1 if household is burning for cost savings on heating, = 0 otherwise.	139	0.777	0.416
ENJOY	= 1 if householder enjoys processing or handling wood, = 0 otherwise.	139	0.568	0.495
DIRT	= 1 if household reports problems with dirt or ashes from burning wood, = 0 otherwise.	139	0.460	0.498

Model Specification and Estimation Procedures

Based on procedures developed by Heckman (1976, 1979) and discussed by Amemiya (1973, 1974, 1978), the specification begins with a discrete-choice model of participation in woodburning estimated for all households in the sample:

(1) $\text{Prob(BURN)} = B_{10} + B_{11}*\text{AGE} + B_{12}*\text{HOUSE} + B_{13}*\text{PR.ALT.F} + B_{14}*\text{PCT.FOR} + B_{15}*\text{HPTHHEAT} + B_{16}*\text{YRS.EDUC} + B_{17}*\text{LOTSIZE} + B_{18}*\text{EST.INC} + e_1.$

This model transforms the discrete participation decisions of individual households into probabilities that given households will burn wood. This approach has been used by McFadden (1973) to model choice of travel mode and Baughman and Joskow (1975) to model appliance purchases. Results from a logit version of this model are included in Table 2 below.

It appeared that the estimated likelihood that a household would burn wood was correlated with the quantity of wood heat that household generated. Thus an instrument to account for this (and eliminate the bias that would otherwise be imparted to other parameters in the demand system) was developed and included in the subsequent system of equations. This instrument is the inverse of Mill's ratio:

$$f(XB/\sigma)/[1 - F(XB/\sigma)]$$

where XB/σ is the normalized linear combination obtained from the discrete choice model, and f( ) and F( ) are the standard normal density and distribution functions respectively. While σ itself cannot be estimated (Maddala, 1978), the scaled logit or probit estimates B/σ are used in calculating the instrument. The orthodox procedure (Heckman, 1976, 1979) utilizes Probit parameters in the construction of the bias-correction instrument. In this case, an approximate instrument was generated from the logit parameters (McFadden, 1974) and compared with one generated from a Probit version; the two instruments had a correlation of 0.97, justifying the use of the more easily-derived logit-based instrument, identified as LAMBDA below and included in the WOODHEAT equation.

Table 2. Logistic Estimation of BURN/No-BURN Model (Equation 1)

Variable	Parameter	Chi-Square
AGE	−0.02348	6.87
HOUSE	1.75040	17.30
PR.ALT.F	0.06721	4.61
PCT.FOR	0.01662	10.22
HPTHHEAT	0.009664	7.33
YRS.EDUC	0.08753	3.73
LOTSIZE	0.03937	4.51
EST.INC	0.009689	1.08
Intercept	−4.87362	24.78

Concordance of Predicted vs. Actual: 0.808
N = .515; Incidence of Wood-Burning = 0.27.

A preliminary specification of the demand system with WOODHEAT as the sole production commodity and fuelwood (TOTCORDS) and burning unit efficiency (ST.EFFIC) as the input goods yielded counter-intuitive signs on the price parameters PW and PR.ALT.F. These results stemmed from the contrary characteristics of fireplace and wood stove users and indicated that the aesthetic benefits primarily realized by fireplace users should be incorporated into the model as another reason for burning wood.

One possible approach was to estimate separate models for fireplace users and wood stove users (Molzan, 1983). The chosen alternative was to try to account for such differences within a unified model incorporating aesthetic benefits as another endogenously determined commodity: a second version of the household production system was specified with the 0-1 variable AESTH (modeled via a second logit equation) included as a proxy for this unquantifiable second commodity.

The testing of this model thus begins with the logit estimation of equation (1), from which the instrument LAMBDA is constructed for inclusion in the subsequent 2SLS estimation of four equations (see Table 1 for variable definitions):

(2) $\text{WOODHEAT} = B_{20} + B_{21}*\text{AESTH} + B_{22}*\text{ST.EFFIC} + B_{23}*\text{LAMBDA} + B_{24}*\text{PR.ALT.F} + B_{25}*\text{PW} + B_{26}*\text{EST.INC} + B_{27}*\text{HOUSE} + e_2$

(3) $\text{Prob(AESTH)} = B_{30} + B_{31}*\text{WOODHEAT} + B_{32}*\text{PR.ALT.F} + B_{33}*\text{PW} + B_{34}*\text{OWNRENT} + B_{35}*\text{AGE} + B_{36}*\text{HRSWORK} + B_{37}*\text{YRSWOOD} + B_{38}*\text{COSTSAV} + e_3$

(4) $ST.EFFIC = B_{40} + B_{41}*WOODHEAT + B_{42}*AESTH + B_{43}*OWNRENT + B_{44}*AGE + B_{45}*YRSWOOD + B_{46}*COSTSAV + B_{47}*YRS.EDUC + e_4$

(5) $TOTCORDS = B_{50} + B_{51}*WOODHEAT + B_{52}*AESTH + B_{53}*ST.EFFIC + B_{54}*COSTSAV + B_{55}*ENJOY + B_{56}*DIRT + e_5$

As expected, the probability of a household's reporting aesthetic enjoyment of burning wood diminishes as the quantity of wood consumed increases. This implies a violation of an assumption underlying the traditional household production methodology however: the requirement of constant-returns production means that one joint product must be produced in constant proportion to the other (Barnett, 1977), i.e. they are perfectly complementary. Here they are substitutes, which may allow for discontinuities in production where the production-possibilities hypersurface may not be quasi-concave.

Estimation Results

The 2SLS estimation results presented in Table 3 reveal that AESTH and WOODHEAT are in fact commodity alternatives rather than joint products as traditionally defined. Households burning wood for aesthetic benefits are likely to burn less wood and use less efficient

Table 3. Two-Stage Estimation Results From Household Production System

Equation	(2)	(3)	(4)	(5)
	Dependent Variables			
RHS Variable	WOODHEAT (2SLS)	AESTH (2-stage logit)	ST.EFFIC (2SLS)	TOTCORDS (2SLS)
WOODHEAT	−1	−0.06218	0.0034235	0.09333
		[5.39]	(2.59)	(10.39)
AESTH	−13.105	−1	−0.11434	−0.77245
	(1.33)		(1.84)	(2.40)
ST.EFFIC	59.1320		−1	−6.41043
	(3.06)			(6.21)
LAMBDA	−6.6159			
	(1.66)			
PR.ALT.F	0.20720	0.103562		
	(0.43)	[3.71]		
PW	−0.08454	−0.01356		
	(1.63)	[3.36]		
ESTINC	−0.18401			
	(1.36)			
HOUSE	−14.96165			
	(1.35)			
OWNRENT		1.74381	−0.09051	
		[1.49]	(1.66)	
AGE		−0.06962	−0.002104	
		[9.04]	(1.83)	
HRSWORK		−0.04875		
		[6.65]		
YRSWOOD		0.063989	−0.002192	
		[1.90]	(1.42)	
COSTSAV		−1.81246	0.16739	0.95910
		[1.93]	(3.33)	(2.89)
YRS.EDUC			0.0097043	
			(2.37)	
ENJOY				0.25332
				(1.72)
DIRT				−0.20508
				(1.26)
Intercept	44.3155	8.43405	0.23376	2.28217
	(2.11)	[13.76]	(1.84)	(5.39)
R-Square	.39		.58	.72

Concordance of Predicted vs. Actual AESTH: 0.83
Chi-Square statistics in [brackets]; t-statistics in (parentheses).

burning units (generally open fireplaces), thus generating less heat from wood, than households burning primarily for cost savings. For the latter, the aesthetic appeal of woodburning seems to disappear as wood consumption and stove efficiency are increased.

Stove efficiency (ST.EFFIC) plays a dual role in the demand system. Its 2SLS instrument enters the WOODHEAT equation as a determinant of heat production. However the 2SLS instrument for WOODHEAT enters the ST.EFFIC equation as an *ex ante* determinant of how much heat a household expects to get in deciding how efficient a stove to purchase. ST.EFFIC enters the TOTCORDS equation as a substitute input, as suggested by its negative parameter.

The signs on all parameters in all five equations appear to support the household production hypothesis as formulated here. Only the parameter on PR.ALTF in the WOODHEAT equation is wholly insignificant, indicating that PR.ALTF mainly determines whether or not a household will burn wood rather than how much wood it will burn or how much heat it will generate from wood. Wealthier households are more likely to get involved in woodburning, *ceteris paribus*, but among woodburners the poorer households tend to burn more wood to satisfy more of their total heating needs. Thus among wood-burning households wood burned for heat appears to be an inferior good; wood burned for aesthetics is a normal good.

The negative parameter on LAMBDA indicates that households that are predicted more likely to burn wood tend to generate more wood heat than households that are predicted less likely to burn wood, *ceteris paribus*. The 90-percent significance level of the parameter on LAMBDA indicates that the inclusion of this bias-correction instrument was necessary for correct specification of the model. The significance of LAMBDA implies heteroskedasticity in the WOODHEAT equation caused by the variables PR.ALT.F, EST.INC and HOUSE. The WOODHEAT equation was also expected to be heteroskedastic with respect to ST.EFFIC. A Glejser test (Maddala, 1978) verified both problems, but treating them (Heckman, 1979; Amemiya, 1978; Lee, Maddala and Trost, 1980) was not deemed worthwhile.

The linear specifications of WOODHEAT, ST.EFFIC and TOTCORDS only approximate the true relationship in which WOODHEAT equals stove efficiency times cords consumed. Because of the trade-off relationship between WOODHEAT and AESTH production, however, both WOODHEAT and ST.EFFIC must be included in the model, and linear specifications appear to be the only practical alternative. Thus the assumption of constant-returns production which guarantees the uniqueness of the shadow prices R(P,Z) (Pollack and Wachter, 1975) is only locally valid. A range of non-uniqueness of the shadow prices would imply discontinuities in the derived demands for Z, and hence for X. These results are locally but not necessarily globally optimal. Since the linear forms only approximate the true system which would derive from the engineering function, and since no demands for fuel substitutes were included to make this a complete demand system, no tests of parameter restrictions were justified.

Interpretation of Results

The system's elasticities were calculated by a straightforward decomposition of the model to show the effects of a small change in an exogenous variable on (1) the probability of participation, determined by the discrete-choice part of the model, and (2) the degree of participation, determined by the 2SLS equations. This approach is entirely analogous to that developed by McDonald and Moffitt (1980) for Tobit models. For any Heckman-type model of the form $Y = Prob * Q$ where Prob and Q are both functions of X, the elasticity of Y with respect to X is simply the sum of the elasticities of Prob and Q with respect to X.

Elasticities were calculated for the short-run with all the right-hand side endogenous variables in the system held constant; for the medium-run with all the RHS endogenous variables allowed to vary once in a single iteration through the system; and for the long-run with the RHS endogenous variables allowed to vary through repeated iterations until stable elasticity values are obtained.

Elasticities were calculated at the sample mean values for all variables in the system. Regardless of the time horizon, the system elasticities are generally low. Elasticities of the probability of participation in the fuelwood market (BURN) were calculated as $B*X*0.73$ where 0.73 is the mean probability that a sample household does not burn wood. These elasticities range from 0.8 (HOUSE, YRS. EDUC and AGE) to 0.04 (LOTSIZE); even in the long-run aggregate demand system, where the elasticities from the BURN equation are added to the elasticities of the corresponding variables in the household production system, AESTH is only elastic with respect to AGE (2.5), COSTSAV (1.2), HOUSE (1.4), HRSWORK (1.1) and PR.ALT.F (1.2). As expected from the engineering relationships between fuel consumption, burning efficiency and heat output, WOODHEAT, ST.EFFIC and TOTCORDS are generally very close to unitary elastic with respect to each other in the short run. In the long run WOODHEAT and ST.EFFIC are only elastic with respect to YRS.EDUC (1.2 in both equations) and the elasticity of TOTCORDS is less than 0.5 with respect to all variables in the system except YRS.EDUC (0.86), COSTSAV (0.83) and AESTH (0.59).

The elasticities of both the discrete-choice BURN model and the four equations in the household production system with respect to the price parameters PW and PR.ALT.F are very low. The elasticity of BURN with respect to PR.ALT.F is 0.6. Even in the long run, with stove efficiency treated as variable, the aggregate demand price elasticities of WOODHEAT and TOTCORDS are less than 0.5 with respect to PR.ALT.F, and less than 0.1 with respect to PW.

Many of the low elasticities reflect the model's integration of cost-saving and aesthetic objectives in wood-burning. For example, the model predicts that as incomes rise, more households will burn wood but each wood-burning household will consume less wood; this implies a shift in objectives from cost-savings to aesthetic enjoyment. The net change in total wood consumption is thus likely to be small.

Several tentative conclusions from the model can be derived and applied toward defining optimal forest policy. It should be noted that the low own- and cross-price elasticities in the model mean that price shifts alone cannot explain much of the historical increase in demand over the past six years. Unpredictable and essentially unquantifiable shifts in household tastes evidently play just as important a role in determining consumption levels. Thus any conclusions derived from the model should be used with caution. In the context of the observed long-run stability of fuelwood prices in Rhode Island, the low price elasticities of demand in the model imply that non-price influences such as tastes have gradually shifted the entire demand schedule to the right, tracing out an elastic supply schedule.

While this model has only been tested on Rhode Island households, its structure and implications may be valid for much of the Northeast. Many of the variables driving the estimated demand system are fairly uniform across the region (e.g. fuel prices, average income and education levels, etc.). Where significant variations do arise (e.g. in total household heating requirements reflecting different levels of heating degree days, or in the percentage of land area in forest) they will only affect the results in proportion to their elasticities in the system.

The estimation results suggest a general approach to managing the external costs (such as reductions in watershed and habitat quality) of current levels of wood-burning. If demand is relatively inelastic as the model indicates, then current consumption levels, with marginal benefits equated to marginal private costs, are likely to be close to socially-optimal consumption levels where marginal benefits match marginal social costs. Thus a rightward shift in demand yields a larger increase in economic surplus than an equivalent rightward shift in supply.

Some very general policy prescriptions emerge: policies should encourage the substitution of fuelwood for alternate fuels, while efforts at limiting externalities from the fuelwood market should be focused if possible on the supply side of the market. The price inelasticities of demand suggest that households will be willing to spend additional money on pollution control technologies (e.g. catalytic converters) rather than cut back significantly on fuelwood consumption if subjected to regulations controlling wood stove emissions. Regulations to insure sound harvesting practices may increase fuelwood prices as the aggregate supply schedule is shifted upward and to the left, however the resulting welfare losses to the fuelwood market itself should be relatively minor compared to those resulting from the equivalent leftward shift in demand which policies to restrict aggregate consumption might cause.

References

Amemiya, Takeshi 1973. Regression Analysis when the Dependent Variable is Truncated Normal. *Econometrica* 41(6):997–1016.

——— 1974. Multivariate Regression and Simultaneous

Equation Models when the Dependent Variables are Truncated Normal. *Econometrica* 42(6):999–1012.

——— 1978. The Estimation of a Simultaneous Equation Generalized Probit Model. *Econometrica* 46(5):1193–1205.

Bailey, M.R. and P.R. Wheeling 1980a,b,c *Wood and Energy in Vermont, Wood and Energy in New Hampshire* and *Wood and Energy in Maine* ERS Staff Reports AGES 820126, 820604 and 820817. Economic Research Service, USDA, Washington DC.

———, ——— and M.I. Lenz 1982, 1983a,b *Wood and Energy in Massachusetts, Wood and Energy in Connecticut* and *Wood and Energy in Rhode Island.* ERS Staff Reports AGES 821028, 830118 and 830512, Economic Research Service, USDA, Washington DC.

Barnett, W.A. 1977. Pollack and Wachter on the Household Production Function Approach. *Journal of Political Economy* 85:1073–1081.

Baughman, M. and P. Joskow 1975. The Effects of Fuel Prices on Residential Applicance Choice in the United States. *Land Economics* 51(1):41–49.

Becker, Gary 1965. A Theory of the Allocation of Time. *Economic Journal* 75:493–517.

Criner, G.K. and R. Unterstein 1983. An Analysis of Residential Wood Demand in Maine. ARE 362 Staff Paper, December, 1983. Dept. of Agricultural and Resource Economics, Univ. of Maine, Orono.

DFE (R.I. Division of Forest Environment) 1983. Highlights of Data. Mimeo distributed via R.I. Dept. of Environmental Management, Providence, R.I.

Hardie, Ian and P. Scodari 1982. A Model of the Residential Demand for Fuelwood. Contribution #6382, Maryland Agricultural Experiment Station, Univ. of Maryland, College Park, MD.

Hardie, Ian and A.A. Hassan 1984. An Analysis of Residential Demand for Fuelwood in the United States. Staff Paper, Dept. of Agricultural and Resource Economics, Univ. of Maryland, College Park, MD.

Heckman, James J. 1976. The Common Structure of Statistical Models of Truncation, Sample Selection and Limited Dependent Variables, and a Simple Estimator for Such Models. *Annals of Economic and Social Measure* 5:475–492.

——— 1979. Sample Selection Bias as a Specification Error. *Econometrica* 47:153–161.

Lancaster, Kelvin 1966. A New Approach to Consumer Theory. *Journal of Political Economy* 74(2):132–157.

Lee, L., G.S. Maddala and R.P. Trost 1980. Asymptotic Covariance Matrices of 2-Stage Tobit Methods for Simultaneous Equation Models with Selectivity. *Econometrica* 48(2):491–503.

Mackenzie, John 1985. *The Residential Market for Fuelwood in Rhode Island: Demand, Supply and Policy Implications* Ph.D. dissertation, Dept. of Resource Economics, Univ. of Rhode Island, Kingston, RI.

Maddala, G.S. 1978. *Econometrics* McGraw Hill, New York.

McDonald, J.F. and R.A. Moffitt 1980. The Uses of Tobit Analysis. *Review of Economics and Statistics* May, 1980 pp. 318–321.

McFadden, D. 1973. "Conditional Logit Analysis of Qualitative Choice Behavior" in Zarembka, ed., *Frontiers in Econometrics* 1973, Academic Press, New York.

Millar, Scott 1984. *Rhode Island Forest Resources Management Plan* (Report # 45) R.I. Office of State Planning, Providence, RI.

Molzan, David E. 1983. *Estimation of Household Demand for Fuelwood in Rhode Island* M.S. thesis, Dept. of Resource Economics, Univ. of Rhode Island, Kingston, RI.

Otico, Jeffrey 1985. M.S. thesis manuscript, Dept. of Forestry and Wildlife Management, Univ. of R.I., Kingston, RI.

Peters, J.R. and T.M. Bowers 1977. Forest Statistics for Rhode Island. USDA Forest Service Resource Bulletin NE-49. Washington, D.C.

Pollack, R.A. and M.L. Wachter 1975. The Relevance of the Household Production Function and its Implications for the Allocation of Time. *Journal of Political Economy* 83:255–277.

——— 1977. Reply: Pollack and Wachter on the Household Production Function Approach. *Journal of Political Economy* 85:1083–1086.

Scodari, Paul and Ian Hardie 1984. Heating Costs and Wood Stove Acquisition. Selected paper presented at the American Agricultural Economics Association meetings, Cornell University, Ithaca, N.Y.

Slott, Michael 1982. Economic Aspects of Woodfuel Use in New York State. Agricultural Extension Research Paper 82-11, Dept. of Agricultural Economics, Cornell Univ., Ithaca, NY.

Stoddard, Wayne 1979. *Estimation of a Demand Function for Household Firewood Usage in Rhode Island* M.S. Thesis, Dept. of Resource Economics, Univ. of Rhode Island, Kingston, RI.

———, T. Weaver and T. Tyrrell 1979. Household Demand for Firewood in Rhode Island. *Journal of the Northeast Agricultural Economics Council* 8(1):21–23.

Taylor-Brown, Charles 1981. Patterns of Residential Fuelwood Use in New England. Paper presented to the Assoc. of American Geographers, April 20, 1981.