

An Economic Analysis of Harvest Behavior: Integrating Forest and Ownership Characteristics

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ABSTRACT. This study provides insight into the determinants of timber supply from private forests through development of both theoretical and empirical models of harvest behavior. A microeconomic model encompasses the multiple objective nature of private ownership by examining the harvest decision for landowners who derive utility from forest amenities and from income used for the consumption of other goods. Tobit analysis is used to estimate the relationship between harvest behavior and forest, owner, and economic characteristics from cross-sectional data for individual forest plots in New Hampshire. The empirical results highlight the influence of forest characteristics and landowner affluence on the harvest decision. Decomposition of the Tobit coefficients indicates that changes in timber supply are expected to result primarily from changes in the number of acres from which timber is offered for sale and to a much lesser extent from changes in per-acre harvesting intensity. Marginal supply responses varied considerably depending on the values for the other coefficients and variables, underscoring the need to consider the shape of the distribution as well as the mean values for the explanatory variables when projecting harvest behavior. *FOR. SCI.* 35(4):1088-1104.

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TIMBER GROWTH IN THE NORTHEASTERN FOREST has outpaced removals over the past several decades (see, for example, Frieswyk and Malley 1985). The latest nationwide timber assessment showed that growing stock volume in the Northeast has increased by 73% since 1952 (USDA For. Serv. 1988). Increased use of this vast forest resource could stimulate the regional economy and breathe economic life into many rural communities.

Nonindustrial private forestland owners hold almost three-quarters of the region's timberland and therefore hold the key to increased utilization. Ownership surveys conducted by the Northeastern Forest Experiment Station reveal that most of these owners hold land primarily for reasons other than timber production (Birch 1988, Birch and Dennis 1980, Kingsley and Birch 1977). Determining how much timber is available from this sector is difficult because multiple objectives cause these owners to respond to economic forces in a more complex and less predictable way than forest industry. Planning and development of a cohesive policy to address the nonindustrial sector is further hampered by a lack of knowledge of how trends in demographic patterns of landownership and forest characteristics will influence harvest behavior. There is concern that an increasingly affluent landholding population will be less prone to harvest timber and that parcelization of large forest tracts will further limit timber availability.

The overall objective of this study is to provide insight into the determinants of timber supply from private forests. Specific objectives include obtaining a better understanding of the relationships between the harvest behavior of nonindustrial landowners and selected forest, owner, and economic variables.

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The objectives are accomplished through development of both theoretical and empirical models of harvest behavior. A microeconomic model is presented that encompasses the multiple objective nature of private ownership by examining the harvest decision for landowners who derive utility from forest amenities and from income used for the consumption of other goods. Tobit analysis is used to estimate the relationship between harvest behavior and forest, owner, and economic characteristics from cross-sectional data for individual forest plots in New Hampshire. The full integration of forest, owner, and economic variables and the in-depth interpretation of the Tobit coefficients distinguish this study from previous work.

A MICROECONOMIC MODEL OF HARVEST BEHAVIOR

This model follows an approach originally developed by Becker (1965) to analyze an individual's choice in allocating time between work and leisure. Other studies that use variations of the household production model to study landowner behavior include Binkley (1981), Boyd (1984), Johansson and Lofgren (1985), and Max and Lehman (1988).

The landowner's problem is to maximize utility from the consumption of nontimber or forest-related amenity values and from the generalized purchasing power of income, subject to two constraints:

$$\max U(A, I) \quad (1)$$

subject to

$$I = PH + E \text{ and } A = V - H$$

where

$U(A, I)$ = a utility function defined over A and I ,

A = volume of timber reserved for amenities,

I = total income,

P = stumpage price,

H = volume of timber harvested,

E = exogenous income,

and

V = total timber volume available.

The first constraint defines the total amount of available income as the sum of timber income and exogenous income and the second limits the amount of timber, either sold or retained, to the total available. In addition we assume that benefits increase in both variables but at a decreasing rate and that amenities are a luxury good ($\partial^2 U / \partial I^2$, $\partial^2 U / \partial A^2 < 0$, $\partial^2 U / \partial A \partial I \geq 0$).

The first-order conditions of the Lagrangian solution for utility maximization indicate that at the optimum:

$$P \frac{\partial U}{\partial I} = - \frac{\partial U}{\partial A} \frac{\partial A}{\partial H} \quad (2)$$

The utility derived from additional timber income will equal the utility of the amenities foregone to obtain that income. The landowner will choose the combination of timber reserved for amenities and income for which the psychic rate of tradeoff between the two is equal to the rate at which they can be traded in the market.

Comparative statics analysis examines the effect of changes in the values of exogenous variables and parameters on the solution values. To examine a variable's influence on timber supply we differentiate Equation (2) with respect to the variable of interest. We are particularly interested in the influence of changes in stumpage price on timber harvesting and this result ($\partial H/\partial P$) is provided in Appendix A. The direction of the response is ambiguous due to the opposing influence of substitution and income effects. Since the individual is a supplier of timber, an increase in stumpage price effectively raises the cost of reserving timber for amenities. The substitution effect of a price increase on timber reserved for amenities, A , is therefore negative, leading to an increased harvest. However, the higher income, I , resulting from an increased price will increase the demand for amenities and tend to reduce the timber harvest.

The Slutsky equation decomposes $\partial H/\partial P$ into the two separate effects:

$$\frac{\partial H}{\partial P} = \left. \frac{\partial H}{\partial P} \right|_{U=\text{constant}} + H \frac{\partial H}{\partial I} \quad (3)$$

The first term on the right-hand side gives the substitution effect, which measures the change in timber harvest resulting from a price change if utility is held constant. This is depicted graphically in Figures 1 and 2 as the movement from an initial utility maximizing choice (A_1, I_1) to point S on the same utility curve. The second term in Equation (3) gives the income effect caused by a price change and explains the movement from point S to the new utility maximizing choice (A_2, I_2). As illustrated, the combined effect can be quite different. In Figure 1 the substitution effect of a price increase outweighs the income effect and the landowner reserves less timber for amenities, resulting in a larger harvest. In this case the individual landowner's supply curve for timber has a positive slope as depicted in Figure 3a. Figure 2 shows the opposite situation. The income effect outweighs the substitution

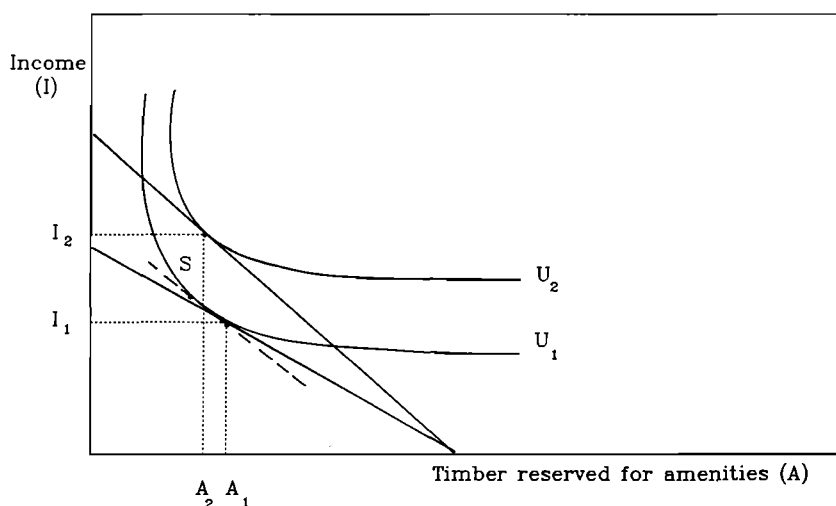


FIGURE 1. Substitution and income effects of a change in stumpage price when the substitution effect is greater.

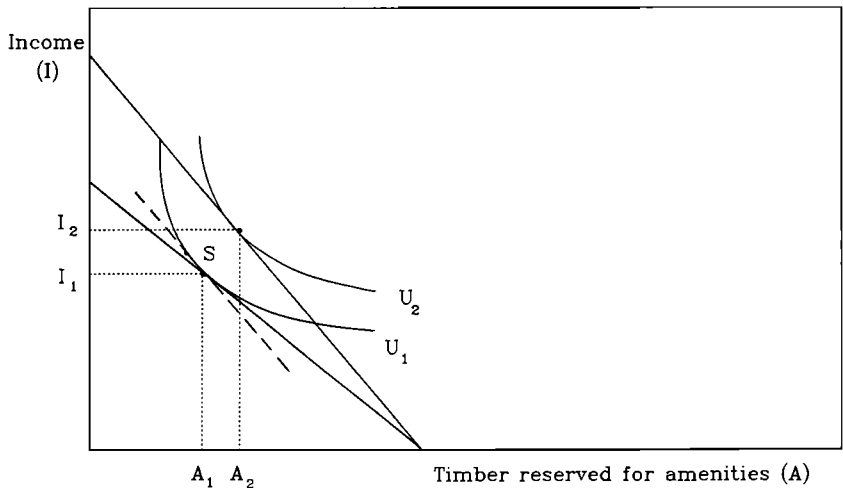


FIGURE 2. Substitution and income effects of a change in stumpage price when the income effect is greater.

effect and the landowner's demand for reserved timber increases, leading to a reduced harvest. In this situation the individual's supply curve for timber is backward bending as illustrated in Figure 3b. Which of these situations is appropriate is an important empirical question.

Binkley (1981) did not specify a form for the utility function and also found the relationship between price and timber harvest to be ambiguous. His empirical work, which indicated a positive harvest response to increased price, suggests that the substitution effect was stronger than the income effect.

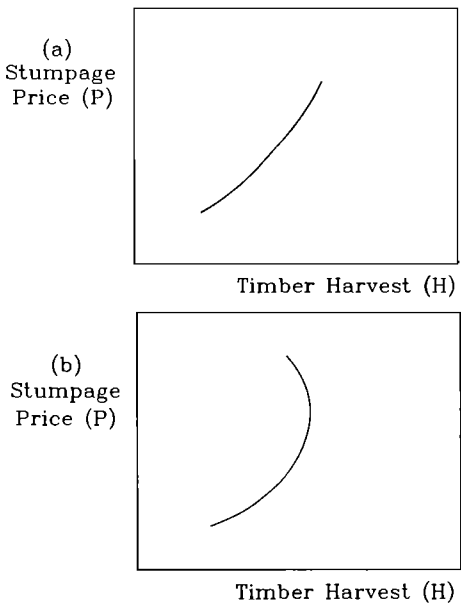


FIGURE 3. Two possible shapes for an individual landowner's supply curve for timber.

Increased insight into the comparative statics may be obtained by specifying a Cobb-Douglas utility function:

$$U = A^a I^b, \quad (4)$$

where a and $b < 1$. Solving for the optimal timber harvest (H) yields:

$$H = \frac{b}{a + b} \left[V - \frac{aE}{bP} \right]. \quad (5)$$

The comparative statics influencing timber harvesting are examined by differentiation of the above equation with respect to each of the endogenous variables. The importance of the *ceteris paribus* assumption must be recognized. All variables except the one under consideration are held constant. Differentiation yields:

$$\frac{\partial H}{\partial P} = \frac{aE}{(a + b)(P^{**2})} > 0 \quad (6)$$

$$\frac{\partial H}{\partial E} = - \frac{a}{(a + b)P} < 0 \quad (7)$$

$$\frac{\partial H}{\partial V} = \frac{b}{(a + b)} > 0 \quad (8)$$

The non-ambiguity of the price-harvest relationship [Equation (6)] arises from the nature of the Cobb-Douglas utility function, which is characterized by unit elasticity of substitution. In this case the substitution effect is stronger than the income effect, causing price increases to lead to larger timber harvests. This is shown by using the Slutsky equation to decompose (6) into the substitution (9) and income (10) effects:

$$\left. \frac{\partial H}{\partial P} \right|_{U=\text{constant}} = \frac{a(a + b)E + abP \left[V - \frac{aE}{bP} \right]}{[(a + b)^{**2}](P^{**2})} \quad (9)$$

$$H \frac{\partial H}{\partial I} = - \frac{ab \left[V - \frac{aE}{bP} \right]}{P(a + b)^{**2}} \quad (10)$$

The comparative statics analyses also show that decreases in exogenous income [Equation (7)] or increases in timber volume [Equation (8)] will lead to larger timber harvests. These results follow from the assumptions of decreasing marginal utility for both income and timber reserved for amenities.

DATA SOURCES AND CHARACTERISTICS

This study used data for New Hampshire collected by the USDA Forest Service in 1973 and 1983. The data include information on 68, 1/5-ac fixed-radius plots measured in both surveys. The sampling design provides area estimates of timber growth and removals over the 11-year period between surveys as well as estimates of forest characteristics like species composi-

tion, elevation and soil drainage class. A detailed explanation of survey procedures is provided by Frieswyk and Malley (1985). Descriptive statistics are provided in Table 1.

Landownership data for each sample plot were obtained from a 12-page questionnaire sent to landowners in conjunction with the forest survey. Information on size of holding, tenure of ownership, owner attitudes, harvesting behavior, demographics, and various other items was obtained. The owners' education and age were measured categorically and transformed into continuous variables. Education levels were quite high with over half of the owners being college graduates, while only four did not complete high school. Fifty-one of the plots were held by owners that were over 55 years old, and 23 considered themselves retired.

A series of dummy variables were used to represent other ownership characteristics. Occupation was examined in the form of professional/non-professional and retired/not retired dummy variables. Professionals are assumed to include managers, administrators, and other white collar occupations. A city/rural variable was used to estimate the relationship between a landowner's early life environment and harvest behavior. The variable was coded 1 if an owner spent most of his or her first 12 years in a city with a population of 10,000 or more. Other dummy variables were used to estimate the relationship between harvest behavior and whether the owner was a New Hampshire resident or not, had an income of \$30,000/yr or more, or was involved in a land sales activity within the past 10 years or not.

Stumpage prices are from the *New Hampshire Forest Market Reports*, published annually by the New Hampshire Cooperative Extension Service. Data were derived from an annual survey, conducted by the individual county foresters in the state. Because of variation in stumpage prices due to quality, location, accessibility, and other factors, a range of prices rather than single figures were reported. Sawtimber prices were reported by county and species and are measured in dollars per thousand board feet (mbf) (International 1/4-inch rule).

TABLE 1. Descriptive statistics (N = 68).

Variables ^a	Units	Mean	Standard deviation of variable	Harvested mean	Nonharvested mean
Timber harvest	bd ft/ac	111	332	628	0
Timber volume	bd ft/ac	961	949	1,597	824
Volume (white pine)	bd ft/ac	477	934	1,275	306
Ratio (white pine)	Proportion	0.41	0.42	0.73	0.34
Volume (red oak)	bd ft/ac	79	197	136	67
Ratio (red oak)	Proportion	0.10	0.24	0.15	0.08
Sawlog price index	1983 dollars	55.9	4.1	57.5	55.6
Education	Years	15.9	3.8	13.7	16.4
Landowner age	Years	59	12	60	58
Tenure	Years	23	13	23	23
Dummy variables:					
Professional	Proportion	0.44	0.50	0.33	0.46
Income greater than \$30,000 ^b	Proportion	0.57	0.50	0.33	0.61
New Hampshire resident	Proportion	0.72	0.45	0.75	0.71

^a See Table 2 for definitions of selected variables.

^b N = 58.

The exact price that each landowner received in the event of a sale or may have been offered if no sale was made is unknown, so price indices were constructed to proxy for offer prices. The midpoints in the annual range of prices for six sawlog species—spruce/fir, hemlock, white pine, hard maple, paper birch, and red oak—were used to construct weighted average county-level stumpage price indices in both nominal (current dollars) and real (1983 dollars). The weights are the relative proportion of total timber removals for each species during 1983, as reported in Frieswyk and Malley (1985) and Nevel, Engalichev, and Gove (1986). Together these species comprised 92.5% of total sawlog removals in New Hampshire during 1983.

ANALYSIS OF CENSORED SAMPLES

We assume that landowners harvest timber when their desire to do so reaches a certain level and a measure of that desire is provided by the quantity of timber harvested. However, no measure is obtained if there is no harvest, so the sample is censored at zero. A censored sample is one in which some observations on the dependent variable corresponding to known sets of independent variables are not observable (Judge et al. 1985). A well-known model dealing with censored samples is Tobin's (1958) analysis of consumer durables, and models of this type are often called "Tobit models." A detailed discussion of Tobit analysis is provided in Appendix B.

Least-squares estimation procedures produce biased and inconsistent estimates for censored samples because the conditional expectation of the error term is not zero (see Appendix B). Amemiya (1973) provides a maximum likelihood procedure that provides consistent and asymptotically normal parameter estimates for censored samples. This procedure was used for the Tobit analyses presented in the next section.

Coefficients obtained from Tobit analysis must be interpreted with care. McDonald and Moffitt (1980) state: "It is common error in the literature to assume that Tobit beta coefficients measure the correct regression coefficients for observations above the limit." They show that Tobit analysis can be used to determine both changes in the probability of being above the limit, zero in the case at hand, and changes in the dependent variable if it is already above the limit. Thus the change in timber harvest resulting from a change in an explanatory variable may be decomposed into the marginal change in harvest volume on lands being harvested and the change in the probability that land will have harvest activity. This decomposition, which is exemplified by Equation (11), is quite useful information for policy decisions and planning. (See Appendix B for notation definitions and a more detailed discussion.)

$$\frac{\partial E(Y_i)}{\partial X_{ik}} = F(Z) \frac{\partial E(Y_i^*)}{\partial X_{ik}} + E(Y_i^*) \frac{\partial F(Z_i)}{\partial X_{ik}} \quad (11)$$

RESULTS

Table 2 provides a brief description of each variable and Table 3 gives the Tobit results. The results are discussed first with respect to the estimated signs and statistical significance of each coefficient and then with respect to the magnitude and interpretation of the coefficients.

Since white pine and red oak are both commercially valuable, their presence was expected to enhance the probability of harvest. This hypothesis was supported by the statistical analyses which yielded positive coefficients

TABLE 2. Variable summary.

Variable	Definition (unit)
<i>MBF</i>	Timber volume (mbf/ac).
<i>RP</i>	Proportion of white pine; ratio = [volume of white pine (mbf/ac)/ <i>MBF</i>].
<i>RO</i>	Proportion of oak; ^a ratio = [volume of oak (mbf/ac)/ <i>MBF</i>].
<i>SPI</i>	Sawlog price index [real (1983) dollars, weighted by state level production].
<i>ED</i>	Years of formal education.
<i>INC</i>	Dummy variable, coded 1 if landowner's income was greater than \$30,000/yr, and 0 otherwise.
<i>PRO</i>	Dummy variable, coded 1 if landowner was employed in a white collar occupation.

^a Includes red, white, and black oak.

for each species variable that were significant at least at the 10% level. Stands that were subsequently harvested contained an average of 50% of their total volume in white pine and 18% in red, white, or black oak. This was more than double the percentages of these species present in stands that were not harvested.

The results also showed a positive correlation between timber harvesting and per-acre volume. Mean per-acre volumes prior to harvest were 1.6 mbf for harvested plots, compared to 0.9 mbf for plots that were not subsequently harvested. This correlation conforms to the comparative statics results previously discussed. It was shown that, under the assumptions of the model, higher timber volumes effectively lower the marginal opportunity cost of harvesting. Another reason may be that higher per-acre volumes provide economies of scale in harvesting.

Positive coefficients were obtained for the price variable, but these cor-

TABLE 3. Tobit results [dependent variable: volume (mbf) of timber harvest during the period 1973-1983].

Explanatory variables	Coefficient	S.E.
<i>N</i> = 68		
Constant	-2.765	2.319
<i>RP</i>	1.810*	0.693
<i>RO</i>	1.432**	0.764
<i>MBF</i>	0.320*	0.119
<i>SPI</i>	0.040	0.036
<i>ED</i>	-0.127*	0.053
<i>PRO</i>	0.585	0.381
Log-likelihood = -22.952		
<i>N</i> = 58 ^a		
Constant	-4.533	2.804
<i>RP</i>	1.955*	0.796
<i>MBF</i>	0.472*	0.134
<i>SPI</i>	0.039	0.041
<i>INC</i>	-1.007*	0.418
<i>PRO</i>	0.707**	0.421
Log-likelihood = -14.631		

* Significant at 5% level.

** Significant at 10% level.

^a Excludes observations without income information.

relations were not statistically significant at even the 20% level. There are several possible reasons for the apparent lack of price responsiveness. The income and substitution effects, which normally have opposing influences on timber harvesting, may have canceled one another out. However, before accepting this conclusion, note a likely "error in variables" problem. The price variable measures cross-sectional price variation among counties but probably does not measure the price offered to a particular landowner, in a given year, accurately. If the price index measures the true offer price with a random error, then the statistical significance of the price coefficient will be biased toward zero and the probability of incorrectly rejecting the hypothesis that the coefficient is not zero is greater than the indicated level of significance.

The theoretical groundwork showed that the harvest decision is influenced by the level of exogenous income and by the relative values landowners place on amenities and consumption. There is concern that changing demographic patterns of landownership may adversely affect timber supply. Several explanatory variables that measure a landowner's education, age, occupation, early life environment and state residency were examined to provide insight into the merit of these concerns. Analyzing the effect of income required deletion of 10 observations because the owners did not respond to that question.

Results for the analyses that did not include income as an explanatory variable are discussed first. The coefficient for years of formal education was negative and significant at the 5% level. There are several plausible explanations for this correlation. Education may directly influence the way individuals value amenities and income or it may proxy for social background or other factors that influence harvest behavior. Also, more educated landowners may have larger income levels, which our theoretical analyses suggest reduce the marginal utility of timber income. Results of a least squares regression indicated a positive correlation between education and income that was significant at the 1% level.

The influence of occupation on the harvest decision was examined using two dummy variables that indicated whether the landowner was a professional or was retired. The results indicated a positive coefficient for the professional dummy variable that was significant at the 10% level only when income was included as an explanatory variable ($N = 58$). There is no clear intuitive interpretation of these results. Professionals may view their forest more as an income-producing asset and thus have a higher tendency to harvest than others. No relationship between harvesting and the "retired" dummy variable was established.

Several other variables were examined, but correlations were not significant at the 20% level. These include age of the landowner, whether the landowner spent the first 12 years of his or her life in a city or not, or was a New Hampshire resident or not, tenure of ownership, and whether or not the landowner was involved in the purchase or sale of woodland within the last 10 years.

The effect of income on the harvest decision was analyzed by including a dummy variable that indicated if a landowner's annual income was over \$30,000 or not. Tobit analysis yielded a negative coefficient that was significant at the 5% level. Therefore, the null hypothesis that income does not influence the harvest decision was rejected. Binkley (1981) also found a negative relationship between the probability of harvest and a landowner's income in several formulations of his empirical model. Adding education as

an explanatory variable yielded negative coefficients for both income and education, but neither were significant at the 5% level. This lack of significance is probably due to the collinear nature of the two variables.

MAGNITUDE AND INTERPRETATION OF THE COEFFICIENTS

Thus far we have discussed the implications of the results only with respect to the estimated signs of the coefficients. The sign of the coefficient indicates the direction of change, but the magnitude is determined by the value for all the independent variables and coefficients. Figure 4 shows the X_iB distribution. The results were interpreted at three values for the explanatory variables: (1) $X_iB = -1.75$, the 31st percentile, arbitrarily chosen to represent the lower portion of the X_iB distribution; (2) $X_iB = -1.0983$, computed using the mean values of the explanatory variables for the entire sample ($N = 68$); and (3) $X_iB = 0.0384$, computed using the mean values for the harvested plots ($N = 12$). The interpretations vary considerably.

Decomposition of the Tobit results are provided in Table 4. The expected timber harvest, $E(Y)$, may be obtained by multiplying the probability of harvest, $F(Z)$, by the expected harvest given that the plot is harvested, $E(Y^*)$ [Equation (B.6)]. Each of these values varied significantly, depending on the values for the explanatory variables. It is not surprising that each estimate was greater when evaluated at the means for the plots that were subsequently harvested, however, note the magnitude of the differences. $E(Y)$ was 18.5 times greater; $F(Z)$, 9.6 times greater; and $E(Y^*)$, 1.9 times greater when evaluated at the means of the harvested plots versus the entire sample. The probability of harvest, $F(Z)$, was miniscule when computed at the -1.75 value for X_iB and this led to an extremely low expected harvest, $E(Y)$.

A deeper understanding of the marginal change in harvest behavior caused by changes in the explanatory variables will aid in decision making and policy development. The next three rows of Table 4 show the estimated changes in harvest volumes and probability of harvest resulting from marginal changes in an explanatory variable. As expected, the marginal changes

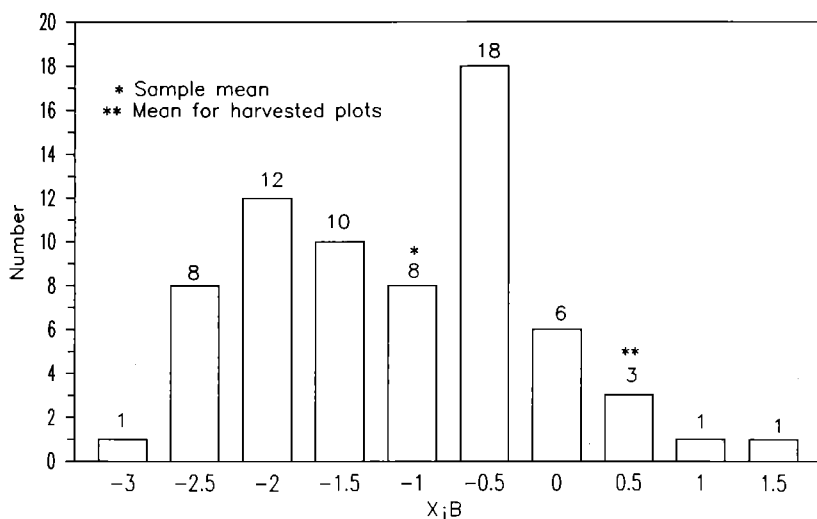


FIGURE 4. The X_iB distribution for the cross-sectional sample of individually owned forest plots.

TABLE 4. *Decomposition of the Tobit results for the cross-sectional sample of individually-owned forest plots (N = 68), evaluated at three sets of values for the explanatory variables.*

	Evaluated at		
	31st Percentile	Mean for sample	Mean for harvested plots
	$X_iB = -1.7500$	$X_iB = -1.0983$	$X_iB = 0.0384$
Expected harvest (mbf): $E(Y)$	0.0012	0.0158	0.2930
Probability of harvest (proportion): $F(Z)$	0.0053	0.0545	0.5223
Expected harvest conditional on being above limit (mbf): $E(Y^*)$	0.2186	0.2899	0.5610
Changes due to a change in variable X_k :			
$\partial E(Y)/\partial X_k$	0.0053 B_k	0.0545 B_k	0.5223 B_k
$\partial F(Z)/\partial X_k$	0.0223 B_k	0.1611 B_k	0.5812 B_k
$\partial E(Y^*)/\partial X_k$	0.0839 B_k	0.1432 B_k	0.3758 B_k
Change due to increased per-acre harvest (mbf): $F(Z)\partial E(Y^*)/\partial X_k$	0.0004 B_k (8%)	0.0078 B_k (14%)	0.1963 B_k (38%)
Change due to increased probability of harvest (mbf): $E(Y^*)\partial F(Z)/\partial X_k$	0.0049 B_k (92%)	0.0467 B_k (86%)	0.3260 B_k (62%)

in harvesting behavior were greater when the probability of harvest was near 0.5, as it was for the mean values of the harvested plots.

Equation (11) was used to break the estimated change in harvest volume into two parts: (1) the change in harvested volume for observations that are harvested, weighted by the probability of harvest, and (2) the change in the probability of harvest, weighted by the expected harvest volume, given that the plot is harvested. The last two rows of Table 4 show these results. Fourteen percent of the estimated total response arises from changes in the amount of timber harvested on a per-acre basis, and 86% results from the increased probability of additional acres being harvested, when the explanatory variables were equivalent to the sample mean values. The magnitude of the expected response as well as the proportional breakdown is quite different when evaluated at the means for the harvested plots or for smaller values of X_iB . Eight percent of the estimated harvest response arises from changes on harvested land, and 92% was attributed to changes in the probability of harvest when X_iB equals -1.75 , while the breakdown becomes 38 and 62%, respectively, when evaluated at the mean for the harvested plots.

Table 5 provides the elasticities for the individual variables, computed for values of the explanatory variables at the sample mean and the mean for the harvested plots. In each case, the values for variables other than the one of interest were held constant.

Before drawing conclusions concerning the relative effects of the explanatory variables, it is important to note that the coefficients for the sawlog price index and occupation variable were not different than zero at the 10%

TABLE 5. Elasticities computed at the mean of the independent variables for the sample and for the harvested plots.

Variable		Elasticity	
		At sample mean	At mean for harvested plots
RP ^a	$E(Y)$	2.554	2.340
	$F(Z)$	2.189	1.461
	$E(Y^*)$	0.366	0.879
RO ^b	$E(Y)$	0.475	0.381
	$F(Z)$	0.407	0.238
	$E(Y^*)$	0.068	0.143
MBF ^a	$E(Y)$	1.061	0.912
	$F(Z)$	0.910	0.569
	$E(Y^*)$	0.152	0.343
SPI	$E(Y)$	7.732	4.108
	$F(Z)$	6.626	2.564
	$E(Y^*)$	1.107	1.544
ED ^a	$E(Y)$	-6.964	-3.091
	$F(Z)$	-5.968	-1.930
	$E(Y^*)$	-0.997	-1.162
PRO	$E(Y)$	0.891	0.348
	$F(Z)$	0.763	0.216
	$E(Y^*)$	0.127	0.131

^a Significant at 5% level.

^b Significant at 10% level.

significance level. Further discussion is confined to variables that were significant at the 10% level.

The elasticities for the forest characteristics varied considerably. Roughly, these values followed a 1:2.5:5 ratio for RO, MBF, and RP, respectively. Therefore, a percentage change in the proportion of white pine is expected to result in roughly a 5 times greater change in $E(Y)$, $F(Z)$, and $E(Y^*)$ than would result from a similar percentage change in the ratio of oak. Elasticities are influenced by the original values of the variables, and it can be seen that a given percent change in RP is much greater in actual units than an equal percent change in RO. Therefore, when comparing elasticities, it is important to remember that they measure the expected response to different absolute changes in variables.

Elasticities may not always be the most useful means for assessing the relative impacts to be expected from changes in variables, particularly when equal unit changes in a variable are anticipated. Table 6 shows the estimated change in $E(Y)$, $F(Z)$, and $E(Y^*)$ resulting from an addition of 1% in the proportions of white pine or oak. Thus, in separate analyses, the proportion for pine was changed from 0.409 to 0.419 and for oak from 0.096 to 0.106. The relative values of the percentage changes for the two variables were much closer than the relative values of the elasticities. These results provide additional information which may be quite useful in assessing expected changes in harvest behavior when equivalent absolute changes in a variable are anticipated.

The elasticities were quite large for the education variable. The estimated effect of a 1-year increase in education was to decrease the expected harvest by 36%, the probability of harvest by 32%, and the conditional harvest by 6% when evaluated at the sample mean. Lesser reductions, respectively 21,

TABLE 6. Estimated response to a 1% addition in the proportions of white pine or oak,^a computed at the sample mean.

Variable		Percentage change	Unit change
RP	$E(Y)$ (mbf)	6.33	.0010
	$F(Z)$ (proportion)	5.55	.0030
	$E(Y^*)$ (mbf)	1.00	.0029
RO	$E(Y)$ (mbf)	5.06	.0008
	$F(Z)$ (proportion)	4.40	.0024
	$E(Y^*)$ (mbf)	0.55	.0016

^a Includes red, white, and black oak.

14, and 8%, were estimated when evaluated at the mean for the harvested plots.

The elasticities for the proportion of landowners with an exogenous income greater than \$30,000/yr were computed using the Tobit results for the restricted sample ($N = 58$). The elasticities with respect to $E(Y)$, $F(Z)$, and $E(Y^*)$ were, respectively, -2.81 , -2.58 , and -0.29 . For comparative purposes these were evaluated at the same mean sample values ($N = 68$) for the explanatory variables, other than INC. The mean value for INC was 0.569, computed for the 58 available observations.

To determine the implications for future timber supplies it is useful to examine trends that have occurred in New Hampshire. Growing-stock volume increased 16% and sawtimber volume increased 26% since 1973 (Frieswyk and Malley 1985). This trend indicates a maturing of the forest that is occurring generally across Northeastern forests. Sawlog quality in New Hampshire is also improving, with grade 1 and 2 sawlogs making up 27% of the pine sawtimber and 36% of the hardwood sawtimber in 1983. Changes in species composition of the forest have also occurred. Together eastern white pine and red, white, and black oak comprised 38% of New Hampshire's total sawlog volume in 1983 compared to 46% in 1973. Red maple, a low-valued species, has increased by more than 137% since 1960 and ranked second to white pine in growing stock volume in 1983. Changes in landownership have also occurred. The general affluence level of landowners has increased. In 1983 almost three quarters (74.2%) of New Hampshire's individually owned commercial forest was held by landowners who completed education beyond high school.

The model was used to simulate the effect of a continuation in the trends on harvest behavior. The assumptions are that the average sawtimber volume over the next decade will increase by 15% and the proportion of white pine and red oak will decrease by 10%. Average education levels are assumed to increase by 0.25 years, and the proportion of "professionally" employed landowners and real sawtimber prices are held constant. The simulations and comparisons are computed for the sample mean and measure harvest behavior for an 11-year interval.

The simulation yields an expected harvest, $E(Y)$, of 12.3 bd ft/ac over an 11-year period, a reduction of 3.5 board feet, or 22%. The expected probability of harvest, $F(Z)$, decreased from 5.5 to 4.4% and the conditional harvest, $E(Y^*)$, decreased from 290 to 283 bd ft/ac. One way to judge the impact of various trend assumptions, without forecasting timber demand, is to calculate the price change necessary to maintain the expected harvest at current levels. An estimated increase of \$1.83 (3%) in the real sawtimber price index is required to maintain current harvest behavior under the trend as-

sumptions outlined in the previous paragraph. Cost-share or other forestry programs may be used to enhance growth or improve species composition and avert the need for increases in real stumpage prices.

SUMMARY AND IMPLICATIONS

The empirical findings highlight the influence of forest characteristics on the harvest decision. High per acre volumes and the presence of commercially valuable species were important determinants of harvest behavior. Strong positive correlations were found between timber harvesting and per-acre timber inventory and the proportions of white pine and red oak found in the stand. A supply elasticity of 1.06 was estimated for the inventory variable which corroborates the inventory elasticity of 1.0 assumed in several aggregate supply studies (e.g., Adams and Haynes 1980, Cardellichio and Veltkamp 1981, and Binkley and Cardellichio 1986).

The theoretical results suggest that timber harvesting is influenced by a landowner's level of exogenous income. Higher exogenous income reduces the marginal utility of income derived from timber harvesting. This reasoning was supported by the empirical analyses which yielded negative correlations between a landowner's exogenous income and timber harvesting. Also, exogenous income and other landowner characteristics may be correlated with the relative values that landowners assign to amenities and income (i.e., the relative magnitude of the exponents in the Cobb-Douglas utility function). This notion has considerable intuitive appeal: different people value amenities and income differently, and these tendencies are expected to be correlated with measurable landowner characteristics.

Timber harvesting was found to be negatively correlated with years of formal education. More educated landowners may value forest amenities higher or they may have larger income levels that reduce the marginal utility of timber income. The empirical analyses also yielded a positive correlation between timber harvesting and whether the landowner was employed in a professional position. Several other owner characteristics were examined but were not significantly correlated with timber harvesting.

Positive coefficients and relatively high elasticities were obtained for stumpage prices; however, the results were not significant at the 10% level. The apparent lack of price responsiveness may be due to the opposing influences of the income and substitution effects or it may be that problems of multicollinearity and measurement are obscuring the empirical results.

Important policy considerations can be ascertained by evaluating the results at different values for the explanatory variables. For instance, the probability of harvest and expected harvest volume were extremely low for observations where X_iB was less than -1.75 . Furthermore, the marginal changes in harvest behavior expected from changes in an explanatory variable were also low for these observations. If increasing the timber harvest is paramount, then effort should be directed at a more responsive portion of the population and these results indicate just how responsive other portions are expected to be. If this sample were representative of the population, then considerable effort could be saved by using the X_iB cutoff of -1.75 , since 21 of the 68 observations were below this level. Of course, this cutoff is arbitrary, and setting an appropriate cutoff would depend on policy objectives, the cost of influencing behavior and the distribution of the values for the explanatory variables for the population of interest.

Although a continuation of the upward trend in timber volume will have a positive effect on timber supply, a net negative effect is anticipated due to

changes in species composition, and the expectation that an increasingly affluent landowning population will be less likely to harvest timber. Decomposition of the Tobit coefficients indicated that changes in timber supply are expected to result primarily from changes in the number of acres from which timber is offered for sale and to a much lesser extent from changes in per-acre harvest intensity. Therefore, the net effect of a continuation in the trends is a decline in the number of acres from which timber is offered for sale within a given distance of a mill. Unless these trends are reversed, or their effects ameliorated, the forestry sector may undergo an adjustment which could result in an extension of mill operating areas or reduction in the number of mills. Cost-share or other forestry programs could lead to enhanced growth or improved species composition which might offset these trends. Efforts might be directed at mitigating the effect of insect and disease attack on certain components of the forest or at policies that would enhance the removal of low value species (i.e., fuelwood harvest). Other programs might be directed at educating landowners to the benefits attainable through multiple-use forest management. The results suggest that increases in timber supply anticipated from forest improvements or increased stumpage prices will occur primarily from an increase in the number of acres available for harvest rather than increased per-acre harvest.

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APPENDIX A—COMPARATIVE STATICS¹

$$\frac{\partial H}{\partial P} = \frac{\begin{array}{cccccc} + & + & - & + & + & + & - \\ \frac{\partial U}{\partial I} + P \frac{\partial^2 U}{\partial I^2} \frac{\partial I}{\partial P} + \frac{\partial^2 U}{\partial A \partial I} \frac{\partial I}{\partial P} \frac{\partial A}{\partial H} \\ P \frac{\partial^2 U}{\partial I \partial A} \frac{\partial A}{\partial H} + \frac{\partial^2 U}{\partial A^2} \left(\frac{\partial A}{\partial H} \right)^2 + \frac{\partial U}{\partial A} \frac{\partial^2 A}{\partial H^2} \end{array}}{\begin{array}{cccccc} + & + & - & - & + & + & 0 \end{array}}$$

Since the denominator is unambiguously negative, $\partial H/\partial P$ is positive if

$$\frac{\partial U}{\partial I} > P \frac{\partial^2 U}{\partial I^2} \frac{\partial I}{\partial P} + \frac{\partial^2 U}{\partial A \partial I} \frac{\partial I}{\partial P} \frac{\partial A}{\partial H}$$

and negative if

$$\frac{\partial U}{\partial I} < P \frac{\partial^2 U}{\partial I^2} \frac{\partial I}{\partial P} + \frac{\partial^2 U}{\partial A \partial I} \frac{\partial I}{\partial P} \frac{\partial A}{\partial H}.$$

APPENDIX B—TOBIT ANALYSIS

Adapting Judge's et al. (1985) generalized presentation of the Tobit model to the case at hand yields:

$$\begin{aligned} Y_i &= X_i' B + e_i & \text{if } Y_i > 0 \\ &= 0 & \text{otherwise} \end{aligned} \quad (\text{B.1})$$

where

- Y_i = the volume harvested on the i th observation,
- X_i' = a vector of explanatory variables,
- B = coefficient vector,

and

e_i = random disturbance.

If we assume that S of T observations are zero, the regression function can be written:

$$\begin{aligned} E(Y_i | X_i, Y_i > 0) &= X_i' B + E(e_i | Y_i > 0) \\ i &= 1, \dots, T-S. \end{aligned} \quad (\text{B.2})$$

If the disturbances, e_i , are independent and $N(0, \sigma^2)$, Tobin (1958) and Amemiya (1973) show that:

$$E(e_i | Y_i > 0) = E(e_i | e_i > -X_i' B) = \sigma f(Z_i)/F(Z_i) \quad (\text{B.3})$$

where $Z_i = X_i' B/\sigma$, and $f(\)$ is the density function and $F(\)$ the cumulative distribution function of a standard normal random variable evaluated at the

¹ The sign for each term in the equation is shown above or below the respective term.

argument. The regression function for the expected value of Y for observations above the limit (i.e., if $Y_i > 0$) is written:

$$E(Y_i|X_i, Y_i > 0) = X_i'B + \sigma f(Z_i)/F(Z_i) \quad (B.4)$$

$$i = 1, \dots, T-S.$$

Since the conditional expectation of the error term is not zero, the least squares estimator of B is biased and inconsistent. Maximum likelihood procedures are available that provide consistent and asymptotically normal parameter estimates for Tobit models (Amemiya 1973).

McDonald and Moffitt (1980) provide an innovative procedure for interpreting Tobit coefficients. The expected harvest volume, $E(Y_i)$, can be expressed as:

$$E(Y_i) = E(Y_i^*)F(Z_i) + E(Y_i')(1 - F(Z_i)) \quad (B.5)$$

where

$F(Z_i)$ = probability that $Y_i > 0$,

$E(Y_i^*)$ = expected harvest volume conditional upon $Y_i > 0$,

and

$E(Y_i')$ = expected harvest volume conditional upon $Y_i < 0$.

Since $E(Y_i') = 0$,

$$E(Y_i) = E(Y_i^*)F(Z_i). \quad (B.6)$$

Substituting from Equation (B.4) for $E(Y_i^*)$ yields:

$$E(Y) = X_i'B F(Z_i) + \sigma f(Z_i). \quad (B.7)$$

The decomposition proposed by McDonald and Moffitt (1980) is obtained by differentiating equation (B.6) with respect to the k th explanatory variable.

$$\frac{\partial E(Y_i)}{\partial X_{ik}} = F(Z_i) \frac{\partial E(Y_i^*)}{\partial X_{ik}} + E(Y_i^*) \frac{\partial F(Z_i)}{\partial X_{ik}} \quad (B.8)$$

Thus the changes in harvest volume can be broken into two parts: the change in harvested volume for observations above the limit, weighted by the probability of being above the limit and the change in the probability of being above the limit, weighted by the expected harvest volume if above the limit.

Once estimates of B and σ are obtained each term in Equation (B.8) can be determined for values of X_i usually at the mean, $\bar{X}$. $F(Z_i)$ can be obtained directly from statistical tables and $E(Y_i^*)$ can be calculated using Equation (B.4). The partial derivatives are calculated as follows:

$$\frac{\partial F(Z_i)}{\partial X_{ik}} = f(Z_i)B_k/\sigma \quad (B.9)$$

and from Equation (B.4)

$$\begin{aligned} \frac{\partial E(Y_i^*)}{\partial X_{ik}} &= B_k + (\sigma/F(Z_i))\partial f(Z_i)/\partial X_{ik} - (\sigma f(Z_i)/F(Z_i)^2)\partial F(Z_i)/\partial X_{ik} \\ &= B_k[1 - Z_i f(Z_i)/F(Z_i) - f(Z_i)^2/F(Z_i)^2] \end{aligned} \quad (B.10)$$

using

$F'(Z_i) = f(Z_i)$ and $f'(Z_i) = Z_i f(Z_i)$ for a unit normal density.