Linking Harvest Choices to Timber Supply

Jeffrey P. Prestemon and David N. Wear

ABSTRACT. Aggregate timber supply by ownership was investigated for a small region by applying stand-level harvest choice models to a representative sample of stands and then aggregating to regional totals using the area-frame of the forest survey. Timber harvest choices were estimated as probit models for three ownership categories in coastal plain southern pine stands of North Carolina using individual permanent and remeasured stand-level data from last two available USDA Forest Service Forest Inventory and Analysis (FIA) surveys. The timber harvest decision was modeled as a function of timber values, a cost factor, and stand volume as a proxy for nontimber values. Probit models were statistically significant at 1% for all ownerships. Area expansion factors (the portion of forest area in the region represented by the sampled stand) were then combined with harvest probabilities to model the aggregate effects of price changes on timber supply, given a fixed forest area. Implied price elasticities were estimated using this modeling of aggregate effects, and a bootstrapping procedure was applied to estimate confidence limits for supply elasticities with respect to price. Our results showed that NIPF and industry were elastically responsive in the aggregate when price increases are perceived as temporary but much less elastically and usually negatively responsive when increases are perceived as permanent. Results are consistent with theory of optimal rotations and highlight the critical influence of both existing inventory structure and expectations on aggregate timber supply. FOR. Sci. 46(3):377-389.

Additional Key Words: Elasticities, aggregate, expectations, probit, pine.

TIMBER SUPPLY IS ULTIMATELY DETERMINED by the accumulation of individual timber harvesting decisions within a region. While there are substantial separate literatures on aggregate timber supply and on individual harvest choices (see Wear and Parks 1994), there has been little explicit analysis of the aggregate supply implications of observed individual behavior. Our objective is to model harvest choices in a way that allows direct inferences regarding aggregate timber supply.

Aggregate supply models are typically estimated as single equations for broad regions (e.g., U.S. South, Pacific Northwest) and broad owner groups (e.g., forest industry, nonindustrial private forests) and provide a useful structure for examining the short-term implications of changes in timber demand.[1] We argue that these models, as usually specified, do not provide especially useful insights into the consequences of changes in the supply structure of timber. This shortcoming is the result of the aggregation process implied by aggregate supply models. Aggregate supply at the regional level is defined as a response to changes in aggregate inventory quantity. Any change in the structure of forests (e.g., urban development) must therefore be channeled through its effect on aggregate inventory to define an impact on total timber produced. An alternative approach is to explicitly aggregate the outcomes of harvest choices made at the micro (forest stand) level.

Our contention is that this "bottom-up" type of approach could provide a useful means of defining the market implications of changes in supply factors. These factors include changes in land uses, shifts in forest productivity, and changing management intensity, all of which tend to be concentrated in certain places or forest types within a region. That is, they are not amenable to "averag-

---

[1] In an econometric sense, aggregate supply can be viewed as simply a means to formally identify the demand relationship for estimation.

Jeffrey P. Prestemon is Research Forester and David N. Wear is Project Leader, respectively, Economics of Forest Protection and Management, Forestry Sciences Laboratory, USDA Forest Service, Research Triangle Park, NC 27709. J.P. Prestemon can be reached at (919) 549-4033; Fax: (919) 549-4047; E-mail: jprestemon@fs.fed.us.

Manuscript received April 17, 1998. Accepted December 17, 1999.

Reprinted from *Forest Science,* Vol. 46, No. 3, August 2000. Not for further reproduction.

ing" across the region through aggregate variables. Our objective then is to model aggregate timber supply as an aggregation of harvest decisions at the micro unit rather than as an aggregate response function.

Timber harvest timing is a fundamental question for forest economics and has been investigated in various ways. Numerous studies have investigated harvest choices using normative models ranging from simple capital accounting frameworks (e.g., the standard Faustmann model and its many variants) to various dynamic optimization approaches. This body of work dates at least to the 1840s. A more recent track of literature examines observed harvest choices using discrete choice econometric models (e.g., Binkley 1981, Boyd 1984, Dennis 1989,1990, and Kuuluavainen and Salo 1991). Provencher (1995, 1997) points out that while normative analyses of forest management have generally been rooted in very precise formulations of the decision making process, the specifications of these positive discrete choice models have been less precise, appealing to variables that have only indirect links to latent decision criteria. As a result, the economic interpretation of these models may be tenuous. Understanding the implications of observed behavior for timber supply requires a more tractable linkage between the decision model and the econometric model.

The previously cited discrete harvest choice models have been formulated as reduced-form models in that they model harvest choice as a function of price and variables that describe the stand and owner using standard binary choice formulations (probit, Tobit, and logit). As an alternative to this approach, Provencher (1995) applied a structural model that links a stochastic dynamic programming formulation of the harvest decision directly to econometric estimation. This provides a direct tie between an intertemporal decision making process and the estimated model but, because it requires custom programming, is a computationally expensive approach. Another, more feasible, approach also examined by Provencher (1997) calls for altering the standard discrete choice model so that its independent variables are taken directly from a specification of the underlying decision making process. His Monte Carlo analysis indicates that a simple form of this model could substantially outperform standard reduced-form models in explaining harvest choices.

Our approach is to estimate a discrete model of harvest choice that accounts for variable site quality, stand conditions, and multiple products, and to apply it to observations of actual harvest choices on plots recorded by a standard forest inventory. The model is more closely linked to actual decision criteria because it appeals explicitly to revenue terms rather than price terms in the specification. Then, by coupling predicted harvest probabilities from these harvest choice models with representative data on stands, we develop inferences regarding the supply response of different forest owner groups. Because the forest inventory uses an area-frame sample, we can use the area expansion factor (i.e., area of forest represented by each plot) to "expand" each harvest probability to an implied timber output response. By comparing output responses across price scenarios, we use the models to estimate medium-run timber supply elasticities with respect to price changes that are perceived either as completely transient or permanent. This provides empirical estimates of phenomena that have, until now, been explored only through normative harvest models.

Methods

The timber supply model examined here builds from a representative sample of coastal pine forests in North Carolina and uses an area frame sample of the region-forest inventories conducted by the USDA Forest Service-to infer landowner and regional aggregate responses to changes in supply determinants. The individual stand harvest decision was modeled as a binary choice: to harvest or not to harvest, given a set of stand and site characteristics. Then, area expansion factors defined by the area frame sample were combined with stand-level volumes and the predicted stand harvest probability for each stand to produce an estimate of aggregate supply, similar to an approach used by Hardie and Parks (1991) in their analysis of reforestation in the South. Estimates of aggregate supply responses to price changes could then be generated by perturbing prices and observing the simulated aggregate changes in supply. In the following subsections, we outline the binary choice model, explain the simulation of aggregate supply responses, and specify our data generation process.

Harvest Choice

We start with a two-period model of the optimal harvest choice, deriving from Faustmann and Hartman (1976) and originally developed by Max and Lehman (1988). We posit that in every period, landowners compare the net benefits of harvesting their timber at the beginning of the period (π_t^1) with the net benefits of delaying harvest (π_t^0):

$$\begin{aligned}\pi_t^1 &= u(0) + p_t' q(a) - C(Z) + \Psi(Z,a) + \varepsilon^1\\ \pi_t^0 &= u(a) + \rho E[u(0) + p_{t+1}' q(a+1) - C(Z)\\ &\quad + \Psi(Z,a+1)] + \varepsilon^0\end{aligned} \tag{1}$$

where

p_t = a vector of timber product prices at time t

$q(a)$ = a vector of harvestable timber products available at current stand age a,

u(u) = money metric of non-timber utility derived from a stand of age a ***(in the case of harvest, age is set to zero),***

$C(Z)$ = a harvest cost function that depends on site variables (Z),

$\psi(Z, a)$ = the postharvest or bareland value of the stand,

ρ = $(1 + r)^{-1}$ where r is the appropriate discount rate,

ε^1 = an error associated with inaccurately calculating the net benefits associated with a current harvest, and

ε^0 = an error associated with inaccurately estimating the expected net benefits of a future harvest.

E = the expectations operator

As described by Max and Lehman (1988), this two-period model can be extended by induction argument to an infinite time horizon (i.e., in the spirit of a forward dynamic programming problem). The errors in (1) may be associated with inaccurate calculations by the landowner or with factors unobserved by the analyst but observed by the landowner, but they are assumed to be uncorrelated with the decision variables. For example, Max and Lehman address taxes as well as income in their normative analysis. These and other factors describing landowners are not available in U.S. forest surveys.

Within this framework (and applying the usual curvature assumptions) timber harvest should occur when the difference between the period t net benefits of harvesting and the discounted net benefits of delaying harvest are nonnegative. Define the binary variable y_t as:

$$y_t = \begin{cases} 1 \text{ if } y_t^* = \pi_t^1 - \pi_t^0 > 0 \\ 0 \quad \text{otherwise} \end{cases} \tag{2}$$

In other words, we assume that the landowner's objective is to maximize discounted utility as follows:

$$\max_{y_t} \left\{ y_t \pi_t^1 - (y_t - 1)\pi_t^0 \right\} \tag{3}$$

This binary formulation could be extended to allow for partial harvesting (y_t would then be defined as continuous and bounded by zero and one; see Max and Lehman 1988). Our binary formulation appears appropriate for the coastal plain of North Carolina, where nearly all softwood harvests derive from clearcuts.

The latent variable y_t^* is equivalent to the intertemporal value comparison, and the harvest criterion [Equation (3)] suggests a set of measurable independent variables that directly influence y_t^* :

$$\begin{aligned} y_t^* &= p_t' q(a) + u(a) - C(Z) + \Psi(Z,a) - \{u(a) \\ &\quad + \rho[E(p_{t+1}' q(a+1) - C(Z) + \Psi(Z,a+1))]\} + \varepsilon^1 - \varepsilon^0 \\ &= g(p_t' q(a) - \rho E[p_{t+1}' q(a+1)], Z, a) + \varepsilon \\ &= f(\beta' \mathrm{x}_t) + \varepsilon_t \end{aligned} \tag{4}$$

where ε_t is a random disturbance with mean zero and variance σ^2, and other variables are as previously defined. As shown, x_t is the vector of some combination of the variables shown in $g[\cdot]$ and β is the vector of parameters describing the effects on the latent variable $y*$ of each expression of the variables in $g[\cdot]$. Consistent with Faustmann and Hartman (1976), the problem described in Equations (l)-(4) asserts that owners examine discounted expected change in revenues along with realized and foregone nontimber values (proxied by stand age, a, here). As shown in (4), stand features that influence costs (Z) should enter the equation to proxy for the unmeasured harvest costs. It should be noted that the bareland value terms are excluded from Equation (4). We rationalize this on the grounds that the difference $\Psi(Z,a) - \rho\psi(Z, a + 1)$ is likely very small and, more important, that it is likely to be imperceptible to the landowner. Therefore, we can characterize the conditional probability of harvest $[PR(y_t = 1|x_t)]$ as follows:

$$\begin{aligned} PR(y_t = 1 \mid x_t) &= PR(y_t^* > 0) \\ &= \Phi(\beta' x_t) \end{aligned} \tag{5}$$

where Φ is the $\mathcal{N}(0,1)$ cumulative distribution function of the value comparison, y_t^*, evaluated at x_t. By assuming a normal distribution for y_t^* Equation (5) can be fit using a probit binary choice model.

Given the criteria outlined in equations (1) through (5), expectations on direction of variables in (4) and (5) are found by evaluating the comparative statics of (4). The effect of the change in timber value is clear from the partial derivative of the latent variable in (4) with respect to this change in value:

$$dy * / d[V_t - \rho E(V_{t+1})],$$

where

$$V_t = p_t' q(a)$$

and

$$E(V_{t+1}) = E[p_{t+1}' q(a+1)].$$

Because V_t, ρ, and $E(V_{t+1})$ are all positive, y_t^* increases in the quantity. Further, Equation (4) implies that the partial derivative with respect to a current price change will be positive because the change in value is increasing in p_t Partial derivatives of the latent variable in (4) with respect to an index of site variables, dy_t^* / dZ, will depend on whether C(Z) $- \rho E[C(Z)]$ is positive or negative. The size of C(Z) may vary nonlinearly with Z and will also depend on the discount rate (p) used by the timber owner.

Empirical Estimation of Harvest Choice

Empirical estimation of a model such as (5) can be conducted using stand level data on timber volume and values and other site-specific variables. Such an application should account for any systematic differences in the distribution of y_t^* across stands, minimize the chances of heteroscedasticity of the variance of ε_t and the possibility of nonzero correlations between ε_t and the right-hand-side variables included in the index function in (4), and account for possible nonlinear effects of site variables on cost and on utility. One plausible systematic difference across stands may be associated with ownership. Newman and Wear (1993) find evidence that private industrial forest owners have different alternative rates of return from those of nonindustrial owners. Another systematic difference across stands, also perhaps associated with ownership, might be in the mix of nontimber values provided by the stand to its owner. This suggests estimating separate models for different ownership groups (i.e., industrial and nonindustrial, private and public). Equal decision models across ownerships, however, could be evaluated with likelihood ratio tests.

Our data set also allows for more detail in the definition of revenue terms in the harvest choice. In particular we can define both sawtimber and pulpwood revenues and volumes. Incorporating separate revenue variables could allow for insights into the substitutability/complementarity of these timber products. Constraints in empirical estimation on the influences of pulpwood and sawtimber values would ensure that all wood values, regardless of the timber product from which they emanate, have similar influence on the probability of harvest. Comparison of constrained and unconstrained models defines a test for qualitatively different responses to signals from the two product markets.

The specific form of Equation (5) is (introducing the ownership category index, i):

$$y^*_{i,t} = \beta_{0i} + \beta_{1i}V_{p,t} + \beta_{2i}V_{s,t} + \beta_{3i}V_{p,t+1} + \beta_{4i}V_{s,t+1} + \beta_{5i}D + \beta_{6i}q_t + \beta_{7i}D^2 + \beta_{8i}q_t^2 + \varepsilon_{i,t} \quad (6)$$

where $V_{p,t}$ and $V_{s,t}$ are current values ($\$\text{ha}^{-1}$) of pulpwood and sawtimber inventory $V_{p,t+1}$ and $V_{s,t+1}$, are discounted expected pulpwood and sawtimber values ($\$\text{ha}^{-1}$), q_t is period t stand volume (m^3ha^{-1}). Stand volume, rather than stand age, is introduced as a measure of nontimber values, because (1) stand age estimates are sometimes difficult to obtain accurately (an examination of the age-distributions in our FIA data set reveals a clumping of stand age estimates around multiples of 5 yr), and (2) we believe that stand volumes are more closely related to these values, because it is probably the structure of the forest that matters, rather than its age. We include both linear and squared stand volume terms, since we want to allow utility to vary nonlinearly with stand volumes. We incorporate one cost factor, an element of Z, the distance (m) from the nearest road to the stand (D). Because, as described above, costs possibly vary nonlinearly with site factors, we include linear and quadratic expressions of this distance variable in (6). In empirical estimation, constraints were imposed to force the effects of pulpwood and sawtimber values to be equal: $\beta_{1i} = \beta_{2i}$, and $\beta_{3i} = \beta_{4i}$. These restrictions were evaluated with a likelihood ratio test. Further, since ρ_i is unknown, and because theory suggests that $\rho_i\beta_{1i} = -\beta_{3i}$ and $\rho_i\beta_{2i} = -\beta_{4i}$ [see Equation (4)], the value of ρ_i is revealed as $\rho_i = -\beta_{3i} / \beta_{1i} = -\beta_{4i} / \beta_{2i}$. Therefore, empirical estimates of (6) can reveal the discount rate, r_i, applicable to each owner. If $m = (t + 1) - t$ is the number of years elapsed between surveys, then $r_i = \rho_i^{-1/m} - 1$.

Aggregate Supply Effects

To estimate the effects of a change in price on total regional quantities of sawtimber and pulpwood over the 6 yr intersurvey period for the subset of pine stands in the region, area expansion factors were used. Following Hardie and Parks (1991), the expected harvest volume of pulpwood and sawtimber for each ownership class was a function of probability of harvest, period t stand (timber) volume, and the area expansion factor for the sampled stand (i.e., the area of similar forest represented by the stand):

$$E(H_{ik}) = \sum [\Phi(\beta_i' x_{ij})] q_{ijk} F_{ij}$$

where H denotes the total harvest volume in the subscripted category, the i subscript denotes ownership, j denotes the stand, k denotes the product, F is the area expansion factor associated with the stand, q is the stand volume per acre, and other variables are as defined. Equation (7) is the structural specification of the timber supply function, comparable to a reduced-form aggregate supply function, where aggregate quantity supplied [$E(H_{ik})$] is on the left and aggregate prices and current inventory volumes (contained in the vector x) are on the right. The difference between (7) and the traditional aggregate supply function estimate is that inventory volumes are summed across all stands for aggregate supply models. In econometric estimation of an aggregate supply model (e.g., Newman 1987), prices combine with inventories to drive the supply quantity (see Provencher 1997). In that sense, we obtain a closer approximation of the structural supply model than one might obtain from estimation of purely aggregate models. The effects of changes in either period t prices, period $t + 1$ prices, or both prices were then modeled by estimating the effects on revenue terms, simulating harvest probabilities and the resulting harvest of timber volumes, expanded across all stands using area expansion factors.

Given our probit specification, elasticities of supply with respect to price changes for each product category and ownership were estimated by

$$\frac{[E(H'_{ik}) - E(H_{ik})] / E(H_{ik})}{[dp_k / p_k]} \quad (8)$$

where $E(H'_{ik})$ was the expected total harvests (i.e., summed across all stands) after a product k price (p_k) change and dp_k/p_k was the percentage change in product k price.

Manipulating prices in periods t and (or) $t + 1$ provides insights into different types of expectations regarding the persistence of price changes. Elasticities with respect to period t (or $t + 1$) prices provide an estimate of the supply response to a perceived temporary price change, including their effects on timber opportunity costs and expected value growth. The response engendered from such a price change would come from those forest owners perceiving timber prices to be stationary--consistent with the kind of model advanced by Brazee and Mendelsohn (1988), wherein prices contain a long-run average plus a zero-mean innovation. The elasticities with respect to a simultaneous shift in period t and period $t + 1$ prices define the supply response to a price shift that is perceived to be permanent, and these are consistent with perceptions that prices are stochastically nonstationary-any price change is a permanent innovation.

The substantial variation in explanatory variables (Table 1), combined with few harvests in the industry group, led us to suspect that probit model estimates might be substantially sample-dependent, and this guided our strategy for calculating supply elasticities. Aggregate supply elasticities could have been calculated by simply summing responses of each stand by product within ownership groups, given a marginal

Table 1. Summary statistics for survey 5 (period t) and survey 6 (period $t + 1$).

	Variable	Units	Population mean	Sample mean	Sample minimum	Sample maximum	Sample SD
NIPF	Survev5 net pulpwood volume	m3ha-1	39.31	16.23	0.00	64.29	12.80
	Survey 6 net pulpwood volume	m3ha-1	46.17	47.06	0.00	218.70	36.70
	Survey 5 net sawtimber volume	m^3ha^{-1}	68.55	69.46	0.00	404.73	76.45
	Survey 6 net sawtimber volume	m3ha-1	76.84	77.81	0.00	550.14	89.93
	Survey 5 stand age	y	34.73	34.86	2.00	105.00	18.61
	Survey 5 basal area	m^2ha^{-1}	23.43	23.65	0.08	58.35	12.33
	Site Index	m (50-yr basis)	21.57	21.42	12.20	30.49	3.49
	Survey 5 distance to road	m	238.50	333.30	30.49	1,609.76	394.99
	Elapsed time	y	6.29	6.22	6.00	6.50	0.11
	Area expansion factor	ha		1,246.69	841.76	1,699.31	194.13
	Harvest probability	y^{-1}	0.03	0.03			
Industry-managed	Survey 5 net pulpwood volume	m^3ha^{-1}	36.75	37.33	0.00	191.61	35.08
	Survey 6 net pulpwood volume	m^3ha^{-1}	70.77	71.55	0.00	207.01	42.55
	Survey 5 net sawtimber volume	m^3ha^{-1}	19.80	19.78	0.00	299.93	40.03
	Survey 6 net sawtimber volume	m^3ha^{-1}	39.46	39.45	0.00	378.86	52.25
	Survey 5 stand age	y	21.19	23.07	5.00	96.00	16.05
	Survey 5 basal area	m^2ha^{-1}	18.06	18.25	0.09	44.41	10.99
	Site Index	m (50-yr basis)	21.40	21.42	12.20	30.49	3.49
	Survey 5 distance to road	m	215.55	220.02	30.48	1,609.76	30.49
	Elapsed time	y	6.29	6.28	6.00	6.60	0.10
	Area expansion factor	ha		1,222.84	424.52	3,155.00	321.74
	Harvest probability	y^{-1}	0.01	0.01			
Government	Survey 5 net pulpwood volume	m^3ha^{-1}	23.86	27.54	0.00	118.36	26.46
	Survey 6 net pulpwood volume	m^3ha^{-1}	34.97	38.18	0.00	132.70	31.58
	Survey 5 net sawtimber volume	m^3ha^{-1}	37.22	41.38	0.00	219.91	47.76
	Survey 6 net sawtimber volume	m^3ha^{-1}	50.45	56.72	0.00	306.71	59.15
	Survey 5 stand age	y	40.16	34.86	2.00	105.00	18.61
	Survey 5 basal area	m^2ha^{-1}	14.39	15.79	0.24	45.30	9.97
	Site Index	m (50-yr basis)	17.64	21.58	9.15	33.54	4.35
	Survey 5 distance to road	m	317.48	246.89	30.49	1,609.76	273.31
	Elapsed time	y	6.25	6.29	6.00	6.60	0.11
	Area expansion factor	ha		1,262.11	17.81	3,084.99	571.28
	Harvest probability	$^{-1}$	0.01	0.01			

price change, and standard errors could have been calculated by applying a gradient method to the model estimates. But elasticities of supply when aggregated across many stands, especially when considering the errors associated with FIA harvest volumes, could not be estimated in this simple fashion. Thus, we exploited the data on hand to calculate the implied elasticities using a bootstrap procedure to estimate standard errors of elasticity estimates. The bootstraps were done by implementing a method described by Efron and Tibshirani (1993, p. 47): (1) randomly selecting, with replacement, n_i observations, where n_i is equal to the actual number of observations in the original samples on NIPF and industry stands; (2) estimating probit harvest models for each ownership category with these bootstrap samples; (3) applying the estimated models to the data corresponding to the n_i randomly selected stands for each ownership, calculating product supply responses with respect to 1% price changes in the period t prices, period $t + 1$ prices, and, to simulate permanent price changes, periods t and $t + 1$ together, adding to each supply response estimate an additional normally distributed random error associated with aggregate harvest volume estimates with FIA data (where standard deviations of estimates varied with estimated aggregate harvest volumes, as derived from Sheffield and Knight (1986, p. 37)); (4) repeating steps (1)-(4) 499 more times. Standard errors of each of these elasticities were reported as the standard deviations of the 500 bootstraps for each elasticity. The analysis of elasticities was done for separate NIPF and industry models and was programmed in the spreadsheet package, Excel.

Data

Data for all variables except timber prices and future product volumes were taken from FIA surveys 5 and 6, the most recent two surveys available for the Coastal Plain of North Carolina (Table 1). Sampled stands were measured during the summers of 1983 and 1989, so that the time elapsed between period t and period $t + 1$ was 6 yr.

While standing volumes of sawtimber and pulpwood were observed for all sampled stands, in period t, and for all unharvested stands in period $t + 1$, expected volumes in period $t + 1$ were not observed. The expected period $t + 1$ volumes were estimated by fitting quadratic models of pulpwood and sawtimber volume to unharvested stands. These quadratic equations predicted survey 6 volumes of pulpwood and sawtimber as a function of survey 5 volumes, survey 5 stand age (yr), survey 5 stand basal area, and site index (base age 50).[2] By using predicted values for survey 6 volumes, our data set is consistent with the

---

[2] These equation estimates are available from the authors.

model's structure (i.e., decisions are based only on values observed at the beginning of the period).

The harvest index (y_t), needed for empirical estimates of Equation (6) was specified as a dummy variable indicating whether or not the stand was harvested between surveys 5 and 6. The indication of harvest was as defined by FIA: the removal of the vast majority of merchantable timber on the site. Stands that had no significant timber harvesting activities and stands with FIA harvests accounted for about 90% of sampled stands qualifying as remeasured and majority southern pine in the coastal plain of North Carolina. The remaining 10% of stands included those that experienced some harvesting but not what FIA would describe as a harvest. These remaining stands underwent selection and high-grading harvests, commercial thinning, precommercial thinning, timber stand improvement cuts, or other cutting. It is likely that modeling these kinds of harvesting activities is more complex, and because of the paucity of observations on these kinds of stands, reasonable empirical estimates of any models probably would not have been possible. These stands, and hence this proportion of timber growing in the region, were ignored in the empirical results that we report. Strictly speaking, then, our results apply only to 90% of the population of coastal southern pine stands.[3]

Stumpage price data were obtained from Timber Mart-South (Norris Foundation 1983-1990) for the coastal region (old region number 3) of North Carolina. Real stumpage prices in period t (1983) and period $t + 1$ (1989) were taken as the average annual consumer price index-deflated (setting the January 1986 consumer price index equal to 100) stumpage prices over the years 1983 through 1989, or \$3.0m^{-3} (\$11.0 cd^{-1}) for pulpwood and \$35.0m^{-3} (\$158.6 mbf^{-1}) for sawtimber. These prices did not vary by plot. Constant real prices for the survey period reflect our assumption that timberland owners in North Carolina in the mid- 1980s did not expect real increases in prices for southern yellow pine pulpwood and sawtimber. This, we believe, is justified: during a number of years. when price expectations were developed for the late 1980s (say, between 1977 and 1986), real prices for these products were flat by most measures (Norris Foundation, 1977-1986). While regional stumpage prices are held constant, we allowed for cost variation among plots by using the distance variable, which is indexing for the cost of timber removal. Even with price constant across stands, Equation (6) is estimable because of variation in the revenue variables; this revenue variation across stands is generated by variation in stage of stand growth and product mixes. How each producer reacts to the change in the rate of value growth of timber on her land reveals the underlying discount rate and the potential effects of prices on the harvest decision, as shown in Equation (6).

Results

Table 1 provides summary statistics for variables used in the analysis. Overall there was a higher tendency for harvest in the population of NIPF owners than industry and government. Industry-managed stands in the 1980s were younger than NIPF stands-about 15 yr, on average-and hence had higher average timber volume growth and timber value growth rates. The timber value of the sample average industry stand grew at a rate twice that of the sample average NIPF stand, while the probability of harvest of industry-managed stands was less than half that of NIPF-owned stands.

Equation Estimates

Table 2 reports maximum likelihood estimates of probit models of timber harvest, Equation (6). Results are reported for models with constraints imposed on the value coefficients, since likelihood ratio tests of these constraints for each ownership showed that they could not be rejected for NIPF and industry. Goodness of fit and model significance measures, including likelihood ratio test statistics (distributed χ^2 with six degrees of freedom) for model statistical significance and percent correct predictions, all indicated that the model was statistically significant for all ownerships-although no individual coefficient was statistically different from zero at 5% significance for government-owned stands.

The signs of coefficients were consistent with expectations for NIPF and industry ownerships but only for industry were coefficients on period t and period $t + 1$ values statistically different from zero at 5% significance. Stand volume was significantly related to timber harvest probability. Distance was significantly related to harvest probability on NIPF forests only, but t-values were larger than one for both linear and squared terms for all ownerships. Tests of equal effects of product values (pulpwood and sawtimber) showed that a null hypothesis of equal effects could not be rejected for any ownership category. Equality of models across ownerships was tested with an asymptotically valid F-test [see Greene (1990, p. 355)], and the test rejected equality of all ownership models and equality of NIPF and industry models at 1% significance.

The implied real discount rates for NIPF and industry owners were 18% for NIPF owners and 2% for industry. Of course, given the coefficient estimate on period $t + 1$ value in the NIPF model, there is low confidence on the NIPF discount rate estimate. Since the government responses were counter to theoretical expectations, the discount rate was ignored, and we provide no further analysis of government responses to prices. Using the NIPF and industry discount rates, we calculated for each stand the implied expected change in discounted timber value, $V_{i\ t} - \rho_i V_{i\ t+1}$, and reestimated (6) with these constraints imposed. The results are shown in Table 3. The main findings are that the discounted change in value for NIPF ownerships is statistically different from zero at 6% significance.

The implied effects, using the NIPF and industry models shown in Table 3, of changing period t and $t + 1$ prices, distance from the nearest road, and plot volume are displayed graphically in Figures I-4 for NIPF and industry. These

---

[3] Nonetheless, there are no statistically significant differences (at 10% significance) between included and excluded plots in the average site index, initial stand age, initial plot basal area, initial pulpwood volume, or initial sawtimber volume.

Table 2. Estimated probit equations for NIPF, industry, and government southern pine stands in coastal North Carolina.

Variable	NIPF	Industry	Government
Constant	-1.92** (0.24)	-1.56** (0.44)	-43.18 (31.61)
Timber value, period t ($)	0.00076 (0.00050)	0.0037** (0.0010)	-0.0022 (0.0054)
Timber value, period t + 1 ($)	-0.00023 (0.00049)	-0.0033** (0.0012)	0.016 (0.011)
Distance from road (m)	0.0016 (0.0012)	-0.0002 (0.0015)	0.047 (0.035)
(Distance from road)^2/10,000	-0.027 (0.017)	-0.008 (0.014)	-0.88 (0.73)
Plot volume (m^{3}ha^{-1})	0.0062* (0.0036)	0.030** (0.010)	0.49 (0.42)
(Plot volume)^2	-0.000019** (0.000005)	-0.00011** (0.00004)	-0.0027 (0.0022)
Number of observations	541	268	112
Test of zero coefficients, $\sim\chi^2(6)$	54.91**	29.00**	17.52**
Percent correct predictions	83.9	92.5	98.2
Test of equal product effects, $\sim\chi^2(2)$	0.24	0.21	0.97
Test of equality of all models, $-F_{21,900}$	3.49**		
Test of equality of NIPF and industry models, $\sim F_{7,795}$	3.41**		

Note: Standard errors in parentheses; asterisks indicating coefficients were statistically different from zero at 5 (*) or 1 (**) percent significance; timber value is the sum of pulpwood stumpage plus sawtimber stumpege values. The test of equal product effect was done by separately estimating a model with current and discounted values of pulpwood and sawtimber (i.e. with eight independent variables and a constant rather than seven and a constant) and comparing likelihood ratio test statistics with those of the models estimated in Table 2.

Table 3. Estimated probit equations for NIPF and industry southern pine stands in coastal North Carolina, with discount rates calculated for NIPF and industry from results in Table 2.

Variable	NIPF	Industry
Constant	-1.92** (0.23)	-1.56** (0.42)
Discounted change in timber value, period t to t + 1 ($)	0.00076” (0.00040)	0.0037** (0.001)
Distance from road (m)	0.0016 (0.0012)	-0.0002 (0.0015)
(Distance from road)^2/10,000	-0.027 (0.017)	-0.008 (0.014)
Plot volume (m^{3}ha^{-1})	0.0062* (0.0027)	0.030** (0.008)
(Plot volume)^2	-0.000019** (0.000005)	-0.00011** (0.00004)
Number of observations	541	268
Likelihood ratio, zero coefficients	54.91**	28.88**
Percent correct predictions	83.9	92.5

NOTE: Standard errors in parentheses; asterisks indicating coefficients were statistically different from zero at 5 (*) or 1 (**) percent significance; timber value is the sum of pulpwood stumpage plus sawtimber stumpage values.

a Statistically different from zero at 6% significance.

figures show the effects for the hypothetical stands within each ownership that contain average pulpwood and sawtimber volumes and the average distance to the nearest road. Figure 1A shows that, consistent with expectations, sawtimber price in period t was positively related to harvest probabilities for both NIPF and industry-managed stands. Over the entire range of prices, the probability of harvest on industry land was about 0.10 less than on NIPF land. Figure 1B shows the effect of the period t sawtimber price on aggregate supplies, calculated using Equation (8), for the region as a whole. This figure shows that the effect of price is positive on total harvest quantities for both ownerships and emphasizes the dominant role of nonindustrial forests (government harvests are included, even though they were held constant, to put the three ownership groups into perspective). The effects of period t + 1, though not shown, would be essentially opposite in effect to those shown in Figures 1A and 1B.

Figures 2A and 2B show the effect of permanent sawtimber price changes-changing the price of sawtimber in periods t and t + 1 together. Because the proportion of volume in sawtimber generally increases with stand age, the effect of a permanent price increase for sawtimber is to increase the expected discounted real value growth rate of the stand and to simultaneously increase the opportunity cost of timber

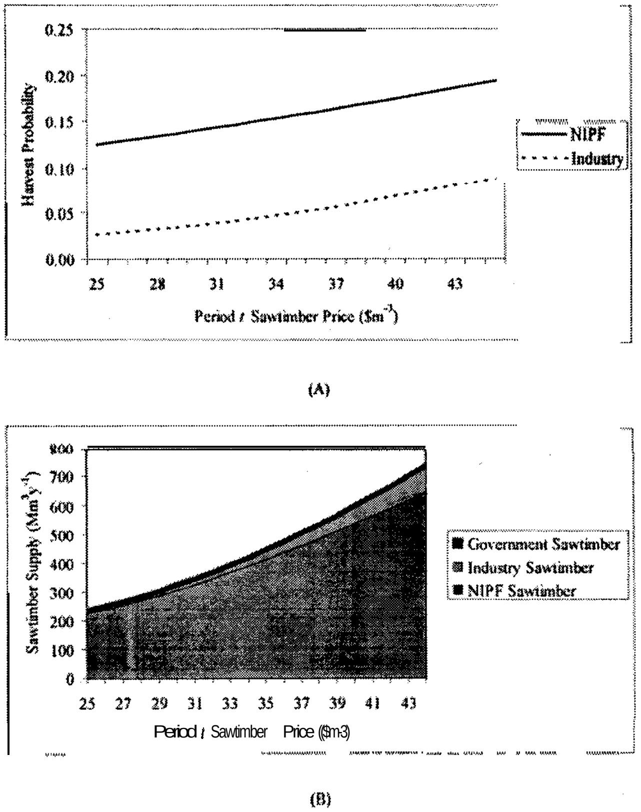


Figure 1. North Carolina coastal southern pine harvests by ownership versus period *t* price of sawtimber on (A) the probability of harvest between surveys, evaluated at population averages of stand variables for each ownership; and (B) annual regional sawtimber harvest quantity (government harvests invariant to timber values).

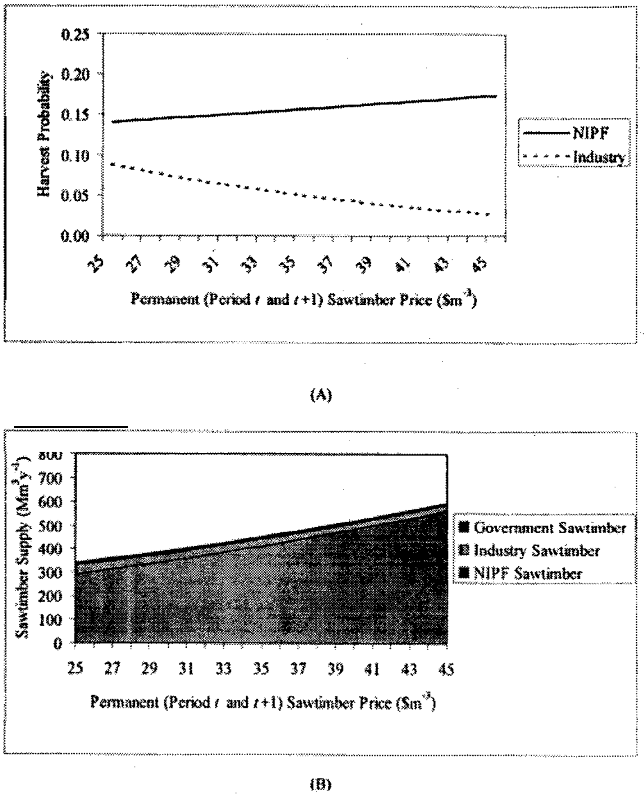


Figure 2. North Carolina coastal southern pine harvests by ownership versus permanent (period *t* and *t*+1) price of sawtimber on (A) the probability of harvest between surveys, evaluated at population averages of stand variables for each ownership; and (B) annual regional sawtimber harvest quantity (government harvests invariant to timber values).

capital. It is the net effect of these two variables that determines whether a particular stand is more likely or less likely to be harvested after a permanent price change. Thus, because the mix of pulpwood and sawtimber volumes vary by stand, the net effect depends on the current state of the inventory.

Figure 2A shows that, for the average stand, the probability of harvest increases with permanent sawtimber price increases on NIPF lands, implying that the effect of sawtimber price through timber opportunity cost is greater than the effect through timber value growth. For average industry-managed stands, the effect of a permanent sawtimber price change on total harvest is broadly negative, implying that its effect through timber opportunity cost is smaller than its effect through timber value growth. Figure 2B shows that, consistent with 2A, total NIPF harvests would increase with permanent price increases, but industry harvests would decrease.

We note that Figures 1A and 2A could have been developed for industry and NIPF stands with median, rather than average, levels of timber volumes and distances to nearest road. If the median, rather than the average, were used for industry stands, we would have observed no response at all from industry owners to changes in timber prices in those figures, since the median sawtimber volume on industry stands in period *t* was zero. Hence, we can state that at least half of all industry stands would be unresponsive to these period *t* sawtimber prices.

Figure 3 shows that, for an average NIPF stand, increasing distance from road was positively related to harvest probability for shorter distances, then negatively for longer distance, with the highest probability of harvest found around the intermediate distance of around 300 m from the nearest road. This effect might be revealing that, despite presumably lower extraction costs, stands located closer to roads face different cost structures from those farther from roads. Stands close to roads may not be harvested because of legal or aesthetic constraints, but, once distance is sufficiently great (e.g.,

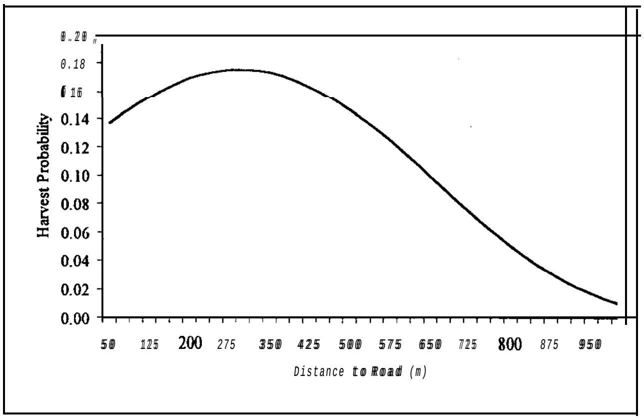


Figure 3. The effect of stand distance from the nearest road on the probability of harvest between surveys, nonindustrial private and industry-managed southern pine forests in the North Carolina coastal plain.

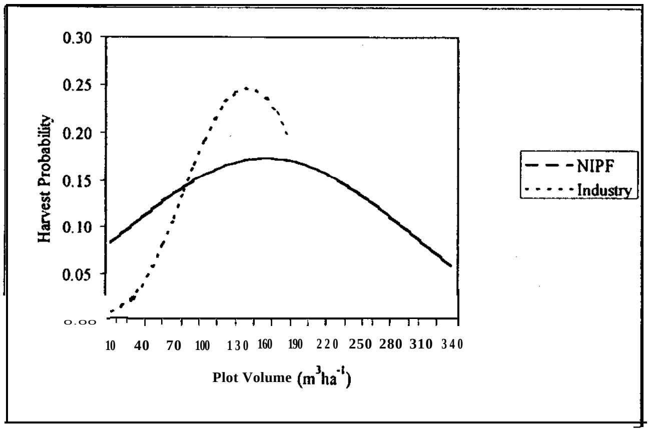
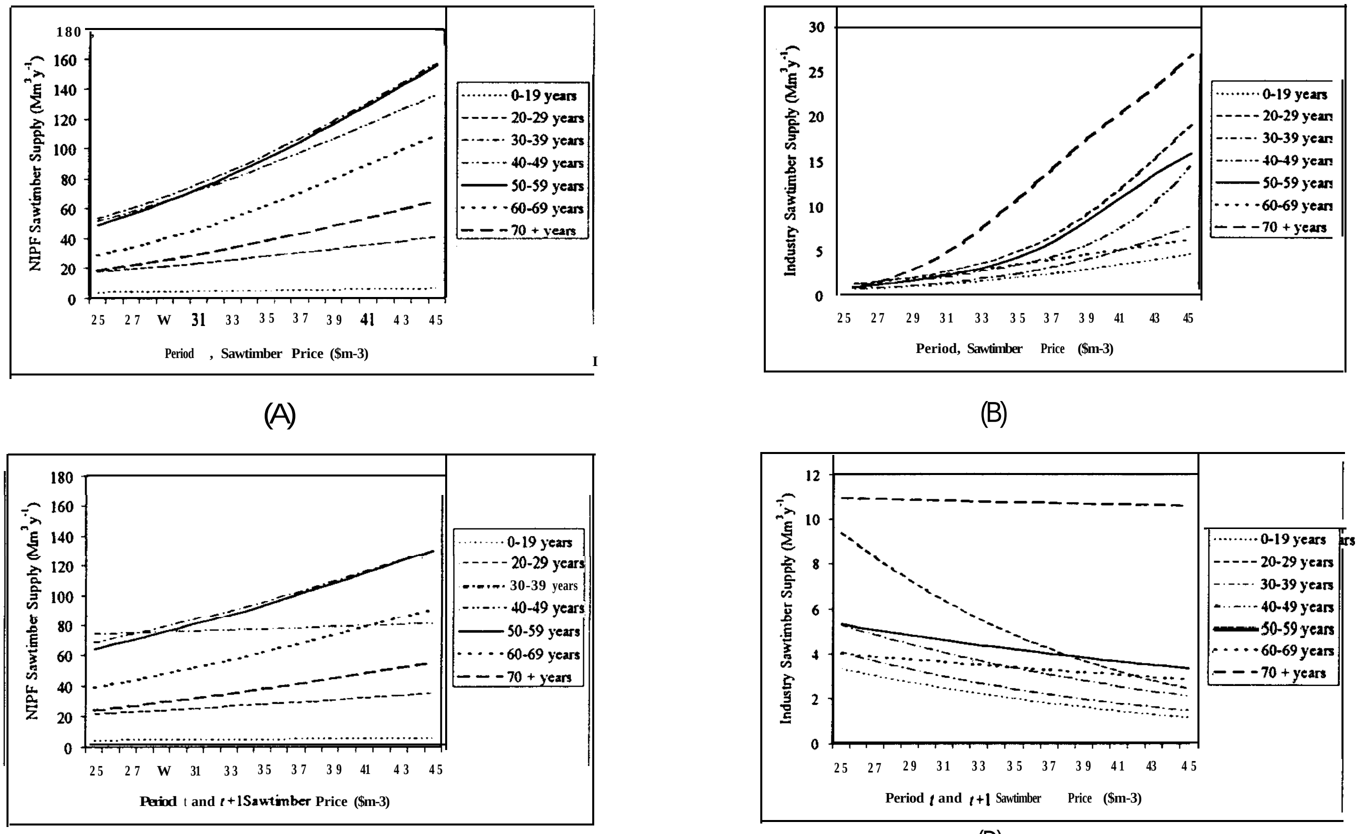


Figure 4. The effect of plot volume on the probability of harvest between surveys, nonindustrial private and industry-managed southern pine forests in the North Carolina coastal plain.

beyond view of the public), the economic effects of greater road distances begin to be important. Alternatively, stands growing closer to roads might also be more likely to be part of a wooded acreage of a homeowner that values a southern pine stand more for its nontimber benefits than the revenue that would accrue from a timber harvest.

Figure 4 demonstrates the effects of initial stand volumes on harvest probability, given average changes in discounted expected values and distances to road. It is difficult to separate out the combined effects of stand volumes and changes in stand values, but industry and NIPF stands show that the effect of initial stand volume is positive on harvest probability for low stand volumes and then turns negative. The negative effect at higher stand volumes might be implying the increasing amenities provided by a heavily forested landscape for some owners-particularly nonindustrial owners. Heavily wooded stands-beyond stand volumes of 150 m^3 /ha-are less likely to be harvested. For industry, harvest probability increases throughout most of the range defined by the sample's limits (two standard deviations from the ownership's sample average).

Clearly, the characteristics of the inventory, not just ownership, affect the amount of harvests and their response to prices. Across any region, there are several factors that interact to define price responsiveness, including: (1) the stand state, characterized by stage of growth, size, and species distributions; (2) site quality, which determines growth rates of value and volume; (3) ownership characteristics besides broad ownership classification. In our empirical model, we assumed that owners were homogeneous in all characteristics within a broad ownership group (NIPF, industry, government). Species mixes, as well, were implicitly assumed not to vary among stands. Site quality, stand volumes, and stand age are implicitly or explicitly part of our empirical model and therefore can be related to harvest tendencies. To illustrate the effects of some of these factors on harvest responsiveness, Figures 5A-5D report NIPF and industry responses of sawtimber harvests to period t and combined period t and $t + 1$ sawtimber prices, disaggregated by stand age class. These figures can be viewed as displaying the harvest responses to price changes that are perceived to be temporary and permanent, respectively. What is most infor-



(A)

(B)

(C)

(D)

Figure 5. Age-class responses to period t sawtimber prices on sawtimber harvests by (A) NIPF and (B) industry and period t and $t + 1$ (permanent) saw-timber prices on sawtimber harvests by (C) NIPF and (D) industry.

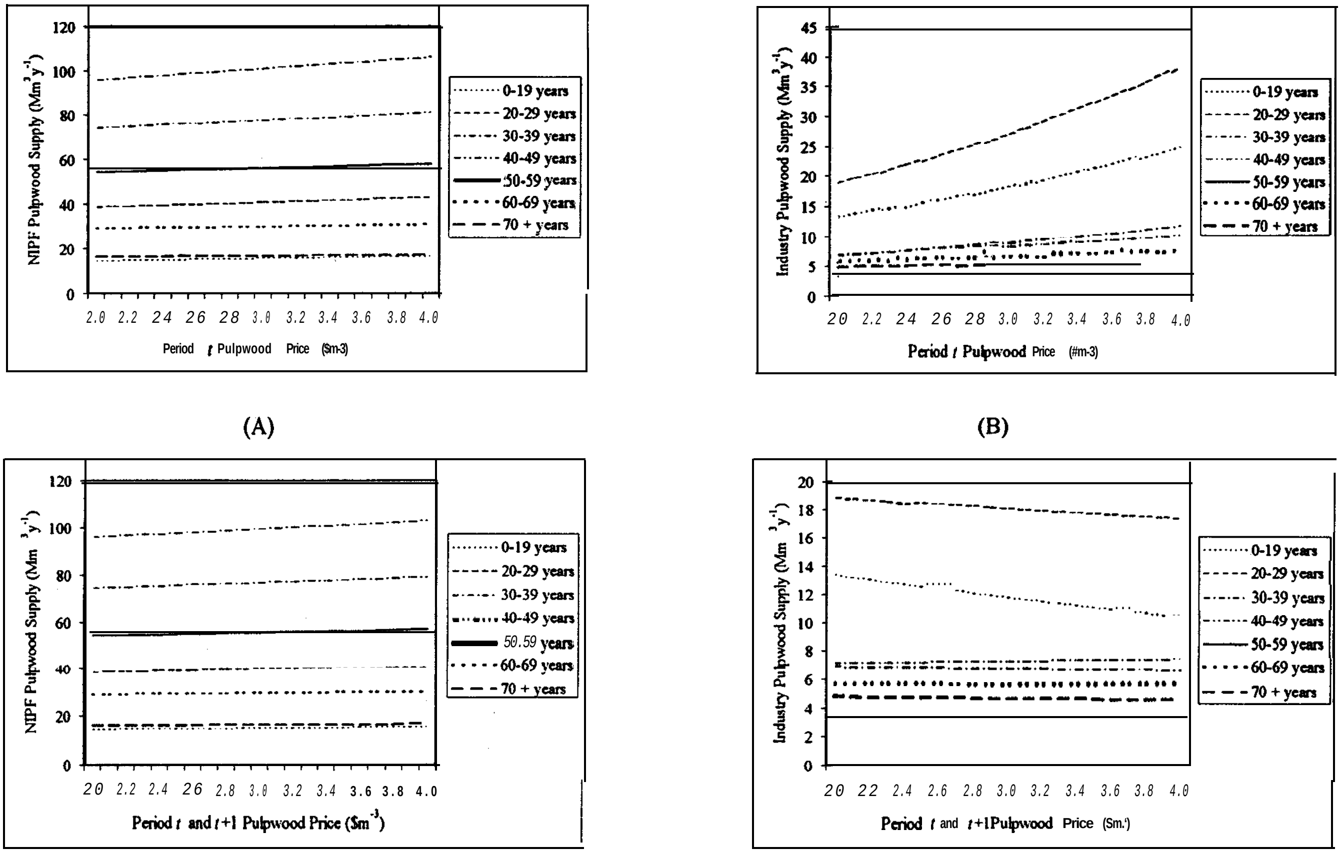
mative from these figures is the varying slope of harvest response. For period *t* sawtimber prices, slopes increase progressively by age through the 50-59 year age class-the older the stand, the more responsive it is to sawtimber price, presumably because older stands have disproportionately larger sawtimber volumes, so that a higher sawtimber price means that the combined effect of higher opportunity cost and lower value growth is larger than for younger stands. This finding is consistent with what Provencher (1997) demonstrated should be the response to age when price is properly included as part of the revenue term. But this increasing responsiveness with age is violated for the oldest forests held by NIPF owners, where harvesting of the oldest stands is relatively unresponsive to sawtimber price. The oldest stands on NIPF lands might remain unharvested because of the substantial amenities associated with them, or because these same stands have been subject to other (unmodeled) constraints to harvest. Indeed, the difference in responses between the second oldest age group and the oldest might imply the value of these amenities in dollar terms.

Responses to permanent sawtimber prices are either flatter or negative across stand ages for both NIPF and industry. For NIPF, curves become more positively sloped for the older stands but are flat for the younger stands. For industry, age appears to be mildly and negatively related to the slope of harvest response to permanent price changes, except for 20-29 yr old stands, where the effect of a permanent price change on harvest was substantially more negative than for other age groups.

Figures 6A-6D show NIPF and industry pulpwood harvest own-price responses by stand age. Figure 6A shows that NIPF stands are largely unresponsive to period *t* pulpwood prices across all age classes, while industry stands (6B) have variable responses and are most responsive in those age classes that contain mostly pulpwood volumes-stands of 0 to 19 and 20 to 29 yr. The figures may also reveal the effects of how we defined pulpwood volume in these stands: pulpwood volume = total volume – sawtimber volume. It is therefore understandable that pulpwood prices have little overall effect on pulpwood harvests: because the most pulpwood volume is obtained from stands of sawtimber age, the majority of pulpwood processed at pulp mills derives from sawtimber harvests. Where pulpwood volume accounts for most of the wood volume in the stand (stands less than 30 yr of age), responses are more elastic. Permanent price effects (Figures 6C and 6D), then, mostly demonstrate the varying volume harvested by stand age class and the negligible effect that pulpwood price has on harvests of these stands. Still, harvests on the youngest industry stands are slightly negatively related to permanent shifts in pulpwood prices.

Bootstrap Elasticity Estimates

Table 4 reports the averages and standard deviations of the bootstrap estimates of supply elasticities with respect to prices for NIPF and industry stands. The bootstrap



(A) (B)

(C) (D)

Figure 6. Age class responses to period tpulpwood prices on (A) nonindustrial private and (B) industry pulpwood harvests, and period *t* and *t* + 1 (permanent) pulpwood prices on (C) NIPF and (D) industry pulpwood harvests.

Table 4. Bootstrap average estimates for elasticities of supply with respect to various price changes.

Supply quantity	Price, period	NIPF	Industry
Temporary price increase			
Pulpwood	Pulpwood, t	0.12	0.66**
		(0.08)	(0.19)
Pulpwood	Sawtimber, t	1.32	2.35*
		(0.93)	(0.97)
Sawtimber	Pulpwood, t	0.09	0.67
		(0.06)	(0.35)
Sawtimber	Sawtimber, t	1.96	7.62*
		(1.35)	(3.25)
Future price increase			
Pulpwood	Pulpwood, $t + 1$	-0.04	–0.75**
		(0.03)	(0.21)
Pulpwood	Sawtimber, $t + 1$	-0.57	–4.10**
		(0.40)	(1.30)
Sawtimber	Pulpwood, $t + 1$	–0.03	-0.77
		(0.02)	(0.42)
Sawtimber	Sawtimber, $t + 1$	–0.76	–9.22*
		(0.52)	(4.22)
Permanent price increase			
Pulpwood	Pulpwood, t and $t + 1$	0.08	–0.09*
		(0.06)	(0.04)
Pulpwood	Sawtimber, t and $t + 1$	0.77	–1.64**
		(0.54)	(0.44)
Sawtimber	Pulpwood, t and $t + 1$	0.06	-0.08
		(0.04)	(0.09)
Sawtimber	Sawtimber, t and $t + 1$	1.13	-1.69
		(0.76)	(1.16)

NOTE: Elasticities are averages estimates of 500 bootstraps. Standard errors, in parentheses, are the standard deviations of 500 bootstrap sample estimates, with asterisks indicating asymptotic statistical difference from zero at 5 (*), and 1 (**) percent significance.

revealed that only weak inferences about NIPF responses can be made, with no elasticity significantly different from zero at 5%. However, nearly all were significantly different from zero at 85% confidence. Given this degree of uncertainty for NIPF responses, our comparisons between industry and NIPF behavior, described below, should be viewed with some caution.

Universally, industry-managed stands were more elastically responsive than NIPF stands to period t own-price changes-and this can be partially explained by what was observed in Figure 5A, where the oldest stands in NIPF ownership seem relatively unresponsive to prices.[4] Own-price elasticities for pulpwood were 0.12 for NIPF owners and 0.66 for industry. For sawtimber, own-price elasticities were 1.96 for NIPF owners and 1.62 for industry. A period t pulpwood price increase induced higher sawtimber harvests (though inelastically), and period t sawtimber price increases induced higher pulpwood harvests, reflecting overall product complementarity. Pulpwood harvests were more responsive to sawtimber price changes than they were to pulpwood price changes, a finding consistent with the differing age class responses to price changes described above. Responses to period $t + 1$ prices (i.e., anticipated future increases) were negative and of similar magnitude to the positive responses to period t price changes.

Permanent price changes-i.e., changing prices in periods t and $t + 1$ together-show that harvests respond inelastically to price, generally. With 1% pulpwood price increases, NIPF owners increase their pulpwood harvest volumes by 0.08% and increase their sawtimber harvests by 0.06%. Industry owners respond to these pulpwood price increases by decreasing pulpwood harvests by 0.09% and sawtimber harvests by 0.08%. In response to 1% sawtimber price increases, NIPF owners increase pulpwood harvests by 0.77% and sawtimber harvests by 1.1%, while industry reduces pulpwood harvests by 1.64% and sawtimber harvests by 1.69%. Such negative price responses by industry are consistent with Figure 5. Price increases perceived as permanent lead to substantial gains in delaying harvest, especially for those stands in the stage of growth where the proportion of the stand in sawtimber is increasing rapidly.

Conclusions

The preceding results suggest that timber supply responses can be obtained from models built directly from forest inventories. Perhaps more important, these models could be used to gauge the change in supply responsiveness between inventories, indicating how inventories are developing in economic terms. The model presented was simple, in that all individuals within an ownership category were assumed to exhibit identical behavior. However, the model introduced a degree of heterogeneity into an aggregate supply model that previously has not been reported. This heterogeneous model relaxed constraints on ownership and some forest conditions. Conceivably, then, with each additional inventory of forest lands across a region, timber supply projections could be

---

[4] A separate bootstrap that dropped from our sample, the NIPF stands older than 59 yr produced average NIPF supply elasticity estimates closer to, but still slightly smaller than, industry supply elasticity estimates.

modeled, given alternative price scenarios, and these projections would more completely take into account variations in timber quality and quantities over time.

While the estimated probit models did not fit the data perfectly, they did significantly explain variation in harvest events, and our bootstraps confirmed that the specification resulted in fairly stable elasticity estimates. We found that NIPF owners respond less elastically to price than do industry owners but that, in many cases, responses to temporary price variations are large for both ownerships. Such large elasticities are perhaps surprising, given accepted short-run supply elasticitiesreported for this timber type (e.g., Newman 1987), but are consistent with long-run responses reported for the Southeastern Coastal Plain by Newman and Wear (1993). These contrasting results serve to remind the readers that harvests were modeled for a 6-year time step, a period that falls between the short- and long-runs in economic terms.[5]

Responses to permanent price changes showed that pulpwood prices affect current harvest quantities inelastically, but that sawtimber prices affect harvests more elastically. Models showed that upward sawtimber price shifts elastically reduce sawtimber harvests on industry lands and fairly elastically increase them on NIPF lands. In contrast, the effects of pulpwood prices are nearly zero, being nearly imperceptable and positive for both sawtimber and pulpwood harvests for NIPF owners and slightly negative on industry lands. The policy implications of such small responses to permanent changes in pulpwood prices are clear: the effects of stumpage taxes or permanent shifts in demand would be borne almost completely by stumpage owners, at least in the medium run. Longer run effects, however, are more difficult to judge, given that our model held forestland area constant, and forestland area is probably price-responsive in the long run (see Parks and Murray 1994, Plantinga 1996).

Additional investigation of how responsiveness to price was related to inventory showed that harvest responsiveness varied by stand age classes. This low and varying responsiveness can be traced to the balance of the higher timber value growth rate plus amenities and the higher opportunity costs of not harvesting. Hence, the price responsiveness of timber producers is inseparable from the state of the inventory and the costs and benefits derived from cutting and not cutting that inventory. Taken together, these results demonstrate critical interactions between the age and quality distributions of forest inventories, forestland ownership, and decision criteria in determining aggregate timber supply. Differences in the supply behavior of industrial and nonindustrial forest landowners have been observed before (e.g., Newman and Wear 1993), but these differences generally have been ascribed to differences in decision criteria, management goals, and wealth. Our results indicate that observed differences in landowner behavior also may be substantially explained by differences in the structures of existing forest inventories.

These findings have implications for aggregate modeling of timber supply and policy analysis. Econometric models of regional timber supply (e.g., Adams and Haynes 1980, Newman 1987) define timber supply as functions of price and total inventory quantity. Our results show that the composition of inventory is as important as the quantity. Further, it was clear from Figures 5 and 6 that because the absolute volumes and responsiveness to price of each product vary by age, absolute quantities supplied and elasticities of responses should depend on the inventory vintage distribution in a region. A potentially fruitful area of research, then, could be to incorporate timber vintage into aggregate supply specifications.

Estimated elasticities indicate important interactions between product markets in defining supply response. We find substantial cross-price elasticities for both sawtimber and pulpwood-pulpwood supply, in fact, is more responsive to sawtimber price than pulpwood price in the short run. These findings highlight the joint production nature of forestry in the South. Harvest timing, in older stands especially, evidently depends on the interplay of these two markets. Accordingly, the aggregate mix of the volumes in each product class will determine whether pulpwood and sawtimber prices have complementary or substitutable effects on supplies of each product and also need to be accounted for in aggregate timber supply models.

Our modeled temporary and permanent price shocks are consistent with two entirely different perceptions of the evolution of stochastic prices. The former is consistent with a perception that prices are stationary, and the latter is consistent with perceptions that prices are nonstationary. It is the mix of these two views across owners that should determine how responsive the aggregate is to prices. But the true mix across owners-whether perceptions align with one ownership group or physical region, or whether perceptions vary over time-and the effects of this mix, is an area worthy of additional investigation.

Literature Cited

BINKLEY, C.S. 1981. Timber supply from private nonindustrial forests. Yale Univ. Sch. of For. and Environ. Studies Bull. No. 9, New Haven, CT.

BINKLEY, C.S. 1993. Long-run timber supply: price elasticity, inventory elasticity, and the use of capital in timber production. Natur. Resour. Mod. 7(2):163-181.

BOYD, R. 1984. Government support of nonindustrial production: The case of private forests. South. Econ. J. 5 1:89-107.

BRAZEE, R., AND R. MENDELSOHN. 1988. Timber harvesting with fluctuating prices. For. Sci. 34(2):359-372.

CLARK, C.W. 1976. Mathematical bioeconomics. Wiley, New York. 352 p.

DENNIS, D.F. 1989. An economic analysis of harvest behavior: Integrating forest and ownership characteristics. For. Sci. 35(4):1088-l 104.

DENNIS, D.F. 1990. A probit analysis of the harvest decision using pooled time-series and cross-sectional data. J. Environ. Econ. Manage. 18(2):176-187.

EFRON, B., AND R.J. TIBSHIRANI. 1993. An introduction to the bootstrap. Chapman and Hall, New York. 436 p.

GREEN, R., W. HAHN, AND D. ROCKE. 1987. Standard errors for elasticities: a comparison of bootstrap and asymptotic standard errors. J. Bus. Econ. stat. 5(1):145-149.

---

[5] Short-run is an output response to a current price change that does not involve a change in productive capacity, whereas a long-run response involves the effects of a current price change on long-run output, a stock shift. We contend that medium-run responses, while not described in texts, are logically found between short- and long-run responses but still reveal relationships among prices and differences among producers

GREENE, W.H. 1990. Econometric analysis. MacMillan, New York. 783 p.

GREENE, W.H. 1995. LIMDEP version 7.0. Econometric software, Plainview, NY.

HARDIE, I.W., AND P.J. PARKS. 1991. Individual choice and regional acreage response to cost-sharing in the South, 1971-1981. For. Sci. 37(1):175-190.

HYDE, W.F. 1980. Timber supply, land allocation, and economic efficiency. Johns Hopkins Press, Baltimore, MD. 225 p.

KUULUVAINEN, J., AND J. SALO. 1991. Timber supply and life cycle harvest of nonindustrial private forest owners: An empirical analysis of the Finnish case. For. Sci. 37(4):101 l-1029.

MAX, W., AND D.E. LEHMAN. 1988. A behavioral model of timber supply. J. Env. Econ. Manage. 15(1):71-86.

NEWMAN, D.H. 1987. An econometric analysis of the southern softwood stumpage market: 1950-1980. For. Sci. 33(4):932-945.

NEWMAN, D.H., AND D.N. WEAR. 1993. Production economics of private forestry: A comparison ofindustrial and nonindustrial forest owners. Am. J. Agric. Econ. 75(3):674-684.

NORRIS FOUNDATION. 1983-1990. Timber Mart-South. The Daniel B. Warnell Sch. of For. Resour., Univ. of Georgia, Athens.

PARKS, P.J., AND B.C. MURRAY. 1994. Land attributes and land allocation: nonindustrial forest use in the Pacific Northwest. For. Sci. 40(3):558-575.

PLANTINGA, A. 1996. The effect of agricultural policies on land use and environmental quality. Am. J. Agric. Econ. 78(4):1082-1091.

PROVENCHER, B. 1995. Structural estimation of the stochastic dynamic decision problems of resource users: An application to the timber harvest decision. J. Env. Econ. Manage. 29(3):321-338.

PROVENCHER, B. 1997. Structural versus reduced-form estimation of optimal stopping problems. Am. J. Agric. Econ. 79(2):357-368.

SHEFFIELD, R.M., AND H.A. KNIGHT. 1986. North Carolina's forests. USDA For. Serv. Res. Bull. SE-88.97 p.

WEAR, D.N., AND P.J. PARKS. 1994. The economics of timber supply: An analytical synthesis of modeling approaches. Natur. Resour. Mod. 8(3): 199-222.