Harvesting Choices and Timber Supply among Landowners in the Southern United States

Daowei Zhang,[1] Xing Sun,[2] Brett J. Butler[3] and Jeffrey P. Prestemon[4]

[1]*Alumni and George Peak Jr. Professor of Forest Economics and Policy, School of Forestry and Wildlife Science, Auburn University, Auburn, AL 36849-5418 (phone: 334-844-1067; fax: 334-844-1084; e-mail: zhangd1@auburn.edu).*
[2]*Assistant Professor, Institute of Finance and Economics Research, Shanghai University of Finance and Economics, No. 777 Guoding Road, Shanghai, PR China, 200433 (corresponding author: phone: +86 21-6590-3266; e-mail: sun.xing@mail.shufe.edu.cn).*
[3]*Research Forester, U.S. Forest Service, 160 Holdsworth Way, Amherst, MA 01003 (phone: 413-545-1387; e-mail: bbutler01@fs.fed.us).*
[4]*Project Leader, Forest Economics and Policy Research, Southern Research Station, USDA Forest Service, PO Box 12254, 3041 Cornwallis Road, Research Triangle Park, NC 27709 (phone: 919-549-4033; fax: 919-549-4047; e-mail: jprestemon@fs.fed.us).*

The recent rise of institutional timberland ownership has led to a significant change in the structure and conduct of the timber industry in the United States. In this study, we apply a two-period harvest model to assess the timber harvesting behavior of various landowners at the stand level by utilizing USDA Forest Service Forest Inventory and Analysis data for nine southern states. Forest industry and institutional timberland owners were found to be more likely to conduct partial and final harvests than nonindustrial private forest landowners. Aggregately, Timberland Investment Management Organizations were found to be most, and timberland Real Estate Investment Trusts to be least, price-responsive among ownership groups.

La hausse récente du nombre de propriétaires institutionnels de terrains forestiers exploitables a modifié considérablement la structure et la gestion de l'industrie du bois aux États-Unis. Dans le présent article, nous avons appliqué, en utilisant des données tirées de la Forest Inventory Analysis (FIA) (Analyse de l'inventaire forestier) du Service des forêts des États-Unis dans neuf États du sud, un modèle fondé sur deux périodes de récolte pour évaluer le comportement de divers propriétaires selon la période de récolte du bois. Selon les résultats de notre étude, l'industrie forestière et les propriétaires institutionnels de terrains forestiers exploitables sont plus susceptibles d'effectuer des coupes partielles et totales que les propriétaires non industriels de forêts privées. Globalement, parmi les divers groupes de propriétaires, les organismes de gestion des placements dans les terrains forestiers exploitables (TIMO) sont les plus sensibles aux prix, tandis que les sociétés de placement immobilier dans le secteur forestier sont les moins sensibles aux prix.

INTRODUCTION

Timberland ownership has changed dramatically in the United States in the two last decades (Zhang et al 2012). In particular, institutions now own most of the timberlands previously held by vertically integrated forest industry companies. These institutional investors include two broad groups. The first is diverse and generally includes pension funds, endowments, foundations, insurance companies, and family trusts (Binkley

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et al 1996). This group alone is sometimes referred to institutional timberland owners in the forestry literature. Often these institutions hire Timberland Investment Management Organizations (TIMOs) to purchase timberlands on behalf of the institutions, manage the timberlands, and sell their timberlands within a specified investment period, usually 5 to 15 years. While TIMOs do not legally own the timberlands, this acronym is sometimes used to represent this group of institutional owners.

The other institutional timberland owners are mutual funds which hold the majority of stocks of publicly traded timberland Real Estate Investment Trusts (REITs). REITs are corporate entities that make investment in real estate and are required to distribute 90% of their taxable income back to the investors. Unlike traditional industrial timberland owners, REITs do not pay income taxes at the corporate level; their shareholders pay taxes on dividends they receive as do investors in any other type of publicly traded corporation. Also, in contrast with traditional industrial timberland owners whose main assets are forests products manufacturing facilities, the assets of timberland REITs are mostly timberlands.

The rise of institutional timberland ownerships has altered the structure of timber markets and may have triggered a significant change in the conduct of the forest industry in the United States. However, there has been no analysis of timber supply for institutional timberland owners, partly because the rapid rise of this ownership class is a recent phenomenon and publicly available databases had not previously recorded these ownerships distinctly from other corporate ownerships prior to 2003. Since forests owned by institutional owners are not directly tied to particular forest products mills, some (e.g., Binkley et al 1996) hypothesize that institutional owners might be inclined to be more patient (i.e., posting a higher reservation price) in timber harvesting than industrial timberland owners. Yet, it is unclear if institutional owners differ in their timber supply from other landowners.

The purpose of this paper is to estimate the timber harvesting responses of various timberland ownership categories—traditional vertically integrated industrial companies, TIMOs, timberland REITs, and other private (that roughly corresponds to the traditional concept of nonindustrial private forest [NIPF]) landowners in the U.S. South where institutional timberland ownerships are concentrated. We apply a two-period model to stand-level observations on USDA Forest Service Forest Inventory and Analysis (FIA) plots that have been measured in two consecutive survey cycles in nine southern states. The next section provides a review of literature, followed by methodology and data. The remaining sections present empirical results and conclusions.

LITERATURE REVIEW

Several scholars (e.g., Rinehart 1985; Zinkhan 1988; Binkley et al 1996; Clutter et al 2005; Binkley 2007; Butler and Wear 2013) have discussed the causes of rising institutional timberland ownership and of declining industrial timberland ownership. They conclude that policy, institutional, and market factors have raised the opportunity costs for forest products companies to continue to own large amounts of timberlands, despite the fact that timberland ownership may enhance the profitability of these companies and lower their levels of risk (Li and Zhang 2014). Other scholars focus either on the demand or supply side of institutional timberland ownership. On the demand side, Rinehart (1985) and Binkley et al (1996) look into the impacts of timberland investment as part of the portfolio of institutional investors; Sun and Zhang (2001) and Mei and Sun (2008) examine the financial characteristics of timberland investments. On the supply side, Mendell et al (2008) use an event study approach and conclude that REITs are a financially advantageous method to hold industrial timberlands rather than traditional C-corporations, which most forest products companies are and which pay corporate taxes and dividend taxes by their shareholders. Similarly, Sun and Zhang (2011) find that industrial timberland sales have benefited the shareholders of forest products firms. Zhang et al (2012) identify all timberlands owned by institutions in the U.S. South and document the magnitude, forest characteristics, and some management activities of institutional—the same underlying data set is basis for the current study.

Most studies of timber supply focus on forest industry or NIPF landowners (Amacher et al 2003). The frameworks used in these studies are either profit maximization, including the Faustmann Model (e.g., Hyde 1980; Newman and Wear 1993), or utility maximization which include the two-period model which will be used in this study (e.g., Prestemon and Wear 2000; Polyakov et al 2010). The choice of analytical framework is largely dependent on whether the landowners under study are considered mainly as producers or consumers. But the empirical results are similar under either framework. For example, industrial forest owners are found to be more responsive to prices than NIPF landowners (e.g., Newman and Wear 1993; Prestemon and Wear 2000; Liao and Zhang 2008), and among NIPF owners, multi-objective landowners have harvested more than other owners groups such as farmers, recreationists, and investors (Kuuluvainen et al 1996). Further, both forest industry and NIPF landowners exhibit behavior that is consistent with profit-maximizing motives (Newman and Wear 1993). The empirical models used in these studies have included probit (Boyd 1984; Dennis 1990; Prestemon and Wear 2000), conditional logit (Polyakov et al 2010), tobit (Dennis 1989), and system of equations approaches (Newman 1987; Liao and Zhang 2008).

Explanatory variables influencing the harvest probability usually include market factors, timber stand characteristics, landowner characteristics, and government programs (e.g., cost sharing or technical assistance). The effect of market factors is an important empirical question and has evolved over time (Binkley 1981; Hultkrantz and Aronsson 1989; Hyberg and Holthausen 1989; Dennis 1990; Kuuluvainen et al 1996). Some studies (Binkley 1981; Boyd 1984) find that stumpage prices are significantly and positively related to harvest behavior. However, Dennis (1989) notes that stumpage price has an ambiguous effect on timber harvesting due to the opposing effect of substitution and income effects in the U.S. North. In their two-period model, Prestemon and Wear (2000) use the *Timber Value* variable to replace the stumpage price variable; they motivate their empirical specification on the fact that, according to a Hartman (1976) or Faustmann (1849) decision rule, landowners respond to change in stand value, not to prices per se; stand growth changes are therefore as relevant as timber price changes in the decision rule. They find that timber harvest probability was positively influenced by present timber value and negatively influenced by future timber value for both industrial and NIPF landowners. Landowners harvest when the rate of change in stand plus bare-land value falls below the alternative rate of return. The current study builds on existing literature, especially Prestemon and Wear (2000), and extend it to two new types of ownerships using plot level data.

METHODOLOGY

Theoretical Model

A utility maximization might be more approximate than a profit maximization function because NIPF contributed more softwood supply than all of the other three ownership groups. Under the utility maximization framework, a two-period approach of optimal harvest choice is developed by Max and Lehman (1988), which is based on Faustmann (1849) and Hartman (1976) and has since been used by Koskela (1989), Kuuluvainen (1990), Ovaskainen (1992), Prestemon and Wear (2000), and Polyakov et al (2010). Assume that a representative landowner maximizes the present utility of consumption over two periods (the present vs. the future, labeled as $i = 1, 2$, respectively). His/her utility function U can be expressed as

$$\max U = u(C_1) + \beta u(C_2) \tag{1}$$

where

$u(.)$ = a utility function of consumption with a positive but diminishing rate
C_i = consumption in period i
β = $(1+\rho)^{-1}$ where ρ is the landowner's discount rate.

In what follows, P_i is stumpage price in period i, Q_i represents the volume of timber removal or timber supply in period i, K_i is postharvest (remaining) timber stock in period i, S is net savings for the first period (saving as $S > 0$ and borrowing as $S < 0$), and Z is a group of site variables that affect growth rate and harvesting costs (and thus stumpage). In the first period, the landowner's consumption is constrained by the revenue from timber sales minus net saving. The second-period consumption is defined by the sum of timber revenue and past savings with the interest minus the second-period saving.

$$\begin{aligned} C_1 &= P_1 Q_1 - S \\ C_2 &= P_2 Q_2 + (1+r) S = P_2 Q_2 + (1+r)[P_1 Q_1 - C_1] \end{aligned} \tag{2}$$

where r is a market interest rate. To define desirable removal volume of timber Q and postharvest timber stock K, denote A as the exogenously given initial stock of timber and $g(K_1, Z)$ as the concave growth function of the standing stock of timber in the first period. Hence, the harvests for periods 1 and 2 (excluding corner solutions) are, respectively,

$$\begin{aligned} Q_1 &\leq A \\ Q_2 &\leq K_1 + g(K_1, Z) \end{aligned} \tag{3}$$

and the respective expression of the postharvest stock is expressed as

$$\begin{aligned} K_1 &= A - Q_1 \\ K_2 &= (A - Q_1) + g(A - Q_1, Z) \end{aligned} \tag{4}$$

Substituting Equations (2), (3), and (4) into (1), the maximized discounted utility over the two periods becomes:

$$\max_{C_1, Q_1} U = u(C_1) + \beta u\{P_2[(A - Q_1) + g(A - Q_1, Z)] + (1 + r)[P_1 Q_1 - C_1]\} \quad (5)$$

The choice variables of this optimization problem are present consumption and harvest. The first-order conditions for present harvest can be written as

$$U_{Q1} = \beta u'(C_2)\{(1 + r) P_1 - [1 + g'(A - Q_1, Z)]P_2\} = 0 \quad (6)$$

Because we assume $u(')>0$, the condition for optimal first-period harvest can be simplified as

$$P_1 = [1 + g'(A - Q_1, Z)]P_2/(1 + r) \quad (7)$$

At the optimal point, the left-hand side of Equation (7) represents the marginal revenue with respect to the present harvest and the right-hand side represents its marginal opportunity cost (the discounted value of the future harvest). Note that, if non timber value metrics were incorporated, which are typically associated with timber age or timber volume, into Equation (2), the optimal condition in Equation (7) will be a little more complicated. Nonetheless, the basic identity of marginal revenue and marginal cost holds (Polyakov et al 2010).

Empirical Model for Harvest Choice

To link Equation (5), a general utility equation, to a money metric utility equation, which can be used in an empirical application of the two-period harvest choice model (Prestemon and Wear 2000) for sampled forest stands along with estimation of timber benefits, the objective of the discounted utility-maximizing landowner can be expressed as

$$Y^* = P_1 Q_1 + \Psi(Q_1, Z) + \beta E[P_2 Q_2] + \varepsilon = f(\omega' x) + \varepsilon \quad (8)$$

where Y^* is the maximized discounted monetary utility, $\Psi(Q_1, Z)$ is the discounted residual value of the harvested stand, E is an expectation operator, and ε is the associated error term. The variable Y^* suggests a set of explanatory variables that directly influence the harvest choice and is denoted as x. The dependent variable (Y_{ij}) is a set of neutrally exclusive binary choices (denoting the harvest choice as i and the ownership category as j), and is defined as:

$$Y_{1j} = \{1 \text{ if a partial harvest was conducted, 0 otherwise}\}$$

$$Y_{2j} = \{1 \text{ if a final harvest was conducted, 0 otherwise}\}$$

and

$$Y_{0j} = \{1 \text{ if no harvest was conducted, 0 otherwise}\}$$

A probability of harvest choice is estimated from the multinomial logit model:

$$PR(Y_{1j}) = \frac{e^{\omega_1{}'x}}{1 + e^{\omega_1{}'x} + e^{\omega_2{}'x}}$$

$$PR(Y_{2j}) = \frac{e^{\omega_2{}'x}}{1 + e^{\omega_1{}'x} + e^{\omega_2{}'x}}$$

and

$$PR(Y_{0j}) = \frac{1}{1 + e^{\omega_1{}'x} + e^{\omega_2{}'x}} \tag{9}$$

where ω_1 and ω_2 are the estimated parameters in each of harvest choice. Then, $\sum_{i=1}^{3} PR(Y_{ij}) = 1$. The log-likelihood for the multinomial logit model is generated by Newton's method:

$$\log L = \sum_{i=1}^{3} \sum_{j=1}^{n} d_{ij} \log PR(Y_{ij}) \tag{10}$$

where $d_{ij} = 1$ if $Y_{ij} = i$, and $d_{ij} = 0$ otherwise.

The estimated coefficients in a multinomial logit specification are difficult to explain since the odds ratio, PR_{ij}/PR_{0j}, is not directly tied to the other choices (Greene 2003), expressed as the following equation:

$$\ln \frac{PR_{ij}}{PR_{0j}} = \omega_i' x \tag{11}$$

The marginal effects represent a percent change in the dependent variable due to an incremental change in the respective independent variable. By differentiating Equation (9), the marginal effect of a variable, denoting as b, on the probabilities is mathematically expressed as if there are totally d independent variables:

$$Marginal\ Effect = PR_b \left(\beta_b - \sum_{c=1}^{d-1} PR_c \beta_c \right) \tag{12}$$

where c indicates all other independent variables except b.

In this study, we estimated Equation (8) using stand-level data on harvest choices and correlated explanatory variables. Previous studies find that different forest ownerships have different rates of return (Newman and Wear 1993; Prestemon and Wear 2000) as they manage their forests for various objectives and have different constraints and responses to market forces (Young and Reichenbach 1987; Pattanayak et al 2002). Hence, in this study we analyze four ownership categories (i.e., forest industry, TIMOs, REITs, and NIPF landowners) through separate estimation models.

In particular, Equation (8) is mathematically expressed as (denoting the ownership category as j, pulpwood as p, and sawtimber as s):

$$\begin{aligned} Y_j^* = {} & \omega_{0j} + \omega_{1j} Timber\,Value_{p,1} + \omega_{2j} Timber\,Value_{s,1} + \omega_{3j} Timber\,Value_{p,2} \\ & + \omega_{4j} Timber\,Value_{s,2} + \omega_{5j} Volume_1 + \omega_{6j} Volume_1^2 + \omega_{7j} Growth_1 \\ & + \omega_{8j} Growth_1^2 + \omega_{9j} Stand\,Origin + \omega_{10j} Coastal\,Plain \\ & + \omega_{11j} Distance + \omega_{12j} Slope + \in_j \end{aligned} \tag{13}$$

In this equation, *Stand Origin* is equal to 1 if the stand is artificially regenerated and 0 otherwise. *Distance* is equal to 1 if horizontal distance to improved road was less than or equal to 0.5 miles and 0 otherwise. Similarly, *Coastal Plain* indicates whether the stand was sampled from coastal plain physiographic region or not. *Slope* is the percent slope of the stand (where 100% = 45 degrees and thus the maximum value would be 200%). *Volume* is defined as total stand merchantable volume of all live trees per hectare during the re-measurement period. *Growth* is total net growth of all live trees per hectare during the re-measurement period. *Timber Value* is calculated by multiplying stumpage price by stand merchantable volume. Additionally, for all sampled stands estimated in the model, three additional independent variables are defined as *Forest Industry*, *TIMOs*, and *REITs* that are equal to 1, separately representing the timberland ownership, and 0 otherwise.

Note that we imposed a condition in our empirical estimation so that the effects of pulpwood and sawtimber revenues are equal: $\omega_{1j} = \omega_{2j}$, and $\omega_{3j} = \omega_{4j}$. Furthermore, Equation (8) suggests that $\beta_j \omega_{1j} = -\omega_{3j}$, and $\beta_j \omega_{2j} = -\omega_{4j}$, where β_j is equal to $(1 + \rho_j)^{-1}$, in which ρ_j is the discount rate of the ownership group j. Therefore, the discount rate of return for each ownership group, ρ_j, equal to $\beta_j^{-1/t} - 1$, where t is the number of years elapsed between two periods.

Separating revenues of timber stumpages enable us to examine the substitution or complementary relationship between two timber products. Furthermore, conditions of empirical estimation on the influences of sawtimber and pulpwood values ensure the inclusion of all wood values, regardless of the timber product from which they originate (Prestemon and Wear 2000). Introducing stand merchantable volume and net growth volume, rather than stand age and site index, could provide more accurate and closer information on stand condition and structure, due to a five- to seven-year cycle design on re-measurement of the FIA plot.

Elasticity of Timber Supply Hypothesis

The choice variables have different effects on the optimal harvest decision. Total differentiation of Equation (7) with respect to Q_1 and P_1 and then simplifying obtains:

$$\frac{dQ_1}{dP_1} = -\frac{1 + r}{g'' P_2} > 0 \tag{14}$$

Equation (14) implies that present timber supply is positively related to present timber price. Similarly, totally differentiating Equation (7) with respect to Q_1 and P_2, we see that present timber supply is negatively related to future timber price:

$$\frac{dQ_1}{dP_2} = \frac{1 + g'}{g'' P_2} < 0 \tag{15}$$

Therefore, we hypothesize that the elasticity of timber supply is positive with respect to present stumpage prices and opposite to future stumpage prices.

Aggregate Elasticity of Timber Supply for Model Validation

The ability to estimate a binary choice model depends on the size of the sample and lack of harvest activity for many landowners in the sample (Prestemon and Wear 2000). Thus, we calculate regional elasticity of timber supply to evaluate the performance of stand elasticity estimates using a multinomial logit model. The expected harvest volume of pulpwood and sawtimber for each ownership group was a function of probability of harvest, present stand volume, and the area expansion factor for the stand (as determined by FIA):

$$E(H_{jk}) = \sum_{n=1}^{N} [PR(Y_{jn})] Q_{1jnk} S_n \tag{16}$$

where j denotes ownership, k denotes the forest product, and n denotes the stand. H_{jk} is defined as the total harvest volume in the jth ownership group for kth product. Q_{1jnk} is defined as the present stand volume on the nth stand in the jth ownership group for kth product. S_n is the area expansion factor associated with the nth stand, which is provided by FIA.

Prestemon and Wear (2000) showed how to use Equation (16) to obtain aggregate elasticities of timber supply with respect to price changes in each ownership group for each product:

$$\frac{[E(H'_{jk}) - E(H_{jk})/E(H_{jk})]}{[(P'_k - P_k)/P_k]} \tag{17}$$

where $E(H'_{jk})$ is the expected total harvest quantity when the price of kth product changes from P_k to P'_k.

Using a bootstrap procedure, we calculate the aggregate supply elasticities with respect to present price change for each ownership group and estimate the standard deviations of the bootstraps for each elasticity. A bootstrap procedure is conducted using the following steps (Greene 2003): (1) randomly drawing a bootstrap sample of size M by sampling with replacement from the original samples on industry, TIMOs, REITs, and NIPT stands, where M is equal to the actual number of observations in each ownership group; (2) estimating multinomial logit models for each ownership group with the M bootstrap samples; (3) applying the estimated models to the M samples, and calculating product supply responses with respect to 1% price increase in the present stumpage prices; (4) repeating (1)–(3) 800 more times.

Table 1. Summary of the most recent pair of inventories with the fixed radius plots[a] sampled from USDA FIA database covering nine[b] southern states

State	Present period	Future period
Alabama	2001–05	2006–10
Arkansas	2000–05	2006–10
Florida	2002–07	2008–10
Georgia	1998–2004	2005–10
North Carolina	2003–07	2008–10
South Carolina	2002–06	2007–10
Tennessee	2000–04	2005–09
Texas (Eastern Region)	2001–03	2004–08
Virginia	1998–2001	2002–07

Notes: [a]Only stands with the obtainable re-measurement data during the present and future period were selected in the study in response to the nature of constructing a two-period production function.
[b]Due to FIA annual data availability, Mississippi, Louisiana, and Oklahoma were excluded from the study.

DATA

The USDA Forest Service FIA program has established a grid of permanent monitoring plots across the United States at a sampling intensity of one plot per 2,400 ha (Bechtold and Patterson 2005). Since the late 1990s, FIA has moved from a periodic full sampling of plots to an annual partial sampling of plots. At present, approximately 15–20% of plots across the South are re-measured annually, yielding a five- to seven-year cycle in the southern United States. We selected the most recent two full inventory cycles (covering 10 to 14 years) in nine southern states (Table 1). FIA has data for all variables mentioned in Equation (13) in the sampled states (Woudenberg et al 2010), except stumpage prices and future product volumes for pulpwood and sawtimber. FIA data on volumes by forest product type, ownership, harvest choices, and site characteristics can be compiled for matched stands for these two inventories. Volumes of all live trees and sawtimber were estimated from the plot (stand) records of FIA, and volume of pulpwood was calculated as the difference between the volume of all live trees and the sawtimber volume for every stand. FIA defines a final harvest and a partial harvest as well. A final harvest is defined as the removal of the majority (70% or more) of merchantable on the site and a partial harvest defined as undertaking selection and high-grading harvests, commercial thinning, or shelterwood harvests on the site.

Stumpage prices were obtained from Timber Mart-South (various years). Since FIA provides estimates on total timber harvest on stands in each period, we can tie prices to the timber harvest by using the average price between the two specific measurement years during the present and the future periods. Hence, real stumpage prices for every sampled stand were taken as the mean stumpage prices with deflated consumer price index (setting the average consumer price index of the first quarter 1992 equal to 100).

For unharvested stands in the present period, expected volumes for pulpwood and sawtimber were not observed in the future period. Quadratic regression models, separately for pulpwood and sawtimber, were applied to estimate the expected merchandise volumes

Table 2. Summary statistics for all ownerships

Variable	Units	Sample mean	Sample SE	Sample min	Sample max
Present sawtimber net volume	m^3ha^{-1}	37.94	55.26	0.00	494.85
Present sawtimber removal volume	m^3ha^{-1}	6.63	24.76	0.00	310.12
Present sawtimber net growth volume	m^3ha^{-1}	13.04	24.02	−252.58	220.16
Present pulpwood net volume	m^3ha^{-1}	69.01	51.98	0.00	355.21
Present pulpwood removal volume	m^3ha^{-1}	12.21	34.50	0.00	364.61
Present pulpwood net growth volume	m^3ha^{-1}	24.21	37.30	−125.84	489.05
Stand age	year	25.00	17.44	0.00	130.00
Basal area	m^2ha^{-1}	21.65	11.62	0.00	115.23
Stand origin		0.57	–	0.00	1.00
Coastal plain		0.51	–	0.00	1.00
Distance to road (miles)		0.53	–	0.00	1.00
Slope (%)		5.35	8.72	0.00	90.00
Industry		0.16	–	0.00	1.00
TIMOs		0.09	–	0.00	1.00
REITs		0.08	–	0.00	1.00
Partial harvest		0.17	–	–	–
Final harvest		0.08	–	–	–

in future period (Prestemon and Wear 2000). The quadratic function was expressed as a set of variables during the present period, including merchandise volumes and net growth volumes of products, stand basal area, and stand age.

For every stand, ownership was determined based on the method described in Zhang et al (2012). Note that FIA has collected and maintained the name and address information from the tax records only since 2004 (prior to which private timberlands are classified as either industrial or nonindustrial owners), while the present period covered the length from 1998 to 2007 across different southern states (Table 1). Thus, the ownership classification was done only for a fraction of the FIA plots. Taking Alabama as an example, there were about 20–25% of FIA stands which ownership categories could be classified during the present period (as this information is only available for plots inventoried in 2004 and 2005). Further, among the stands with the obtainable ownership details, there were about 13% of the stands for which ownership categories changed between the present period and the future period (e.g., from industrial to TIMOs or REITs). Since we do not know exactly in which year the legal ownership transfer took place, we have identified timberland ownership of the present period the same as the ownership of the future period. This may slightly overestimate the size of industrial ownership and possibly affect the elasticities estimated.

RESULTS

Table 2 provides the descriptive statistics for variables used in the regression analysis. NIPF landowners owned 67% of sampled plots, forest industry 16%, TIMOs 9%, and REITs 8%.

Table 3. Sample statistics by each type of ownership

	Forest industry		TIMO		REIT		NIPF	
Variable	Mean	SE	Mean	SD	Mean	SD	Mean	SD
Sawtimber net volume	30.84	46.21	27.71	44.06	27.25	43.84	41.67	56.89
Sawtimber removal	8.24	25.77	8.56	25.94	12.77	27.76	5.11	22.22
Sawtimber net growth	12.75	20.49	12.69	21.84	14.72	23.32	12.62	22.31
Pulpwood net volume	63.40	50.53	61.41	49.58	53.22	45.27	72.97	51.90
Pulpwood removal	15.56	36.42	19.60	45.67	22.36	45.23	9.08	28.27
Pulpwood net growth	24.33	33.21	27.61	39.86	27.79	39.59	23.14	36.77
Stand age	22.43	16.02	19.59	13.80	20.25	16.00	26.84	18.00
Basal area	20.14	11.29	20.09	11.16	17.75	11.49	22.62	11.44
Stand origin	0.77	–	0.80	–	0.74	–	0.48	–
Coastal plain	0.46	–	0.52	–	0.51	–	0.51	–
Distance to road	0.51	–	0.55	–	0.61	–	0.53	–
Slope	6.14	8.36	5.51	9.77	2.18	5.01	5.53	8.94
Obs. #	749		407		385		3191	
Partial harvest	0.20		0.23		0.19		0.16	
Final harvest	0.09		0.12		0.20		0.06	

Table 3 presents the statistics of the variables by ownership. The mean probabilities of partial and final harvest for forest industry, TIMOs, and REITs were higher than for NIPF owners. Across all four ownership categories, net volume, merchantable volume removals, and net growth volume for pulpwood was higher than for sawtimber. The average stand ages were 22, 20, 20, and 27 years, respectively, for forest industry, TIMOs, REITs, and NIPF landowners. Since the mean stand age for NIPF stands was higher than those owned by forest industry and institutional entities, net growth volume of NIPF all live trees was smaller.

Harvest Choices

The results of the multinomial logit regressions for all FIA plots are reported in Table 4, and separate multinomial logit regressions for each ownership group are reported in Tables 5–8. In general, the goodness of fits shows that these models fit well, and most of the variables have the expected signs and are significant.

The results in Table 4 provide a direct comparison of harvesting probability among various landowner groups. Specifically, the coefficients of the variables Industry, TIMOs, and REITs are positive at the 10% significance level. This implies that industrial owners, TIMOs, and REITs are more likely to conduct timber harvesting than NIPF landowners. The probability of a partial harvest on industrial, TIMO, and REIT stands was 4%, 6%, and 3% higher, and the probability of a final harvest was 1%, 3%, and 5% higher, respectively, than for NIPF stands.

The results on other variables are also largely consistent with expectations. The present timber value, stand volume, and net growth volume were positively related to the probability of partial and final harvest at the 1% level; their marginal effects were also significant at the 1% level, except the impact of net growth volume on final harvest.

Table 4. Estimation results of multinomial logit regression equations for ALL landowners' harvest choices of a specific type of timber harvesting ($N = 4{,}732$)

	Partial harvest ($N = 806$)		Final harvest ($N = 356$)	
Variable	Coefficient (z-test)	Marginal effect	Coefficient (z-test)	Marginal effect
Constant	−2.31* (−13.20)	–	−4.51* (−15.84)	–
Timber value (\$/acre), t	1.23E-3* (10.26)	1.50E-4*	1.08E-3* (5.90)	3.35E-5*
Timber value (\$/acre), $t+1$	−1.19E-3* (−10.14)	−1.45E-4*	−9.37E-4* (−5.32)	−2.84E-5*
Stand volume ($m^3 acre^{-1}$)	0.02* (11.45)	2.25E-3*	0.02* (6.68)	4.59E-4*
(Stand volume)^2	−2.80E-5* (−9.25)	−3.41E-6*	−2.54E-5* (−5.63)	−7.95E-7*
Growth volume ($m^3 acre^{-1}$)	3.70E-3* (2.89)	5.28E-4*	−0.01* (−3.35)	−3.88E-4*
(Growth volume)^2	9.54E-6** (2.19)	1.57E-6*	−6.02E-5* (–2.15)	−2.33E-6*
Stand origin	1.25* (10.41)	0.14*	2.85* (12.70)	0.10*
Coastal plain	−0.61* (−6.78)	−0.08*	−0.18 (−1.35)	–
Distance to road	−0.03 (−0.28)	–	−0.03 (−0.20)	–
Slope	−0.04* (−6.13)	−4.75E-3*	−0.02** (−2.01)	−4.49E-4
Industry	0.31** (2.76)	0.04*	0.41* (2.59)	0.01*
TIMOs	0.53** (3.78)	0.06*	0.77* (4.18)	0.03*
REITs	0.27*** (1.75)	0.03	1.39* (8.24)	0.05*
Log likelihood	−2,922.57			
Chi-square	862.12**			

Note: *, **, and *** indicate significance at 1%, 5%, and 10%, respectively.

Future timber value and the squared term of stand volume significantly and adversely impacted both of the probabilities of the partial and final harvest, and the squared term of net growth volume was positively related to partial harvest and negatively related to final harvest. The coefficient and marginal effect of *Stand Origin* was positive at the 1% level, suggesting that an artificially regenerated stand increased the probability of a partial harvest by 14% or a final harvest by 10%. Finally, the *Coastal Plain* variable

Table 5. Estimation results of multinomial logit regression equations for Forest Industry landowners' harvest choices of a specific type of timber harvesting ($N = 749$)

	Partial harvest ($N = 152$)		Final harvest ($N = 71$)	
Variable	Coefficient (z-test)	Marginal effect	Coefficient (z-test)	Marginal effect
Constant	−2.19*	–	−4.29*	–
	(−4.44)		(−5.61)	
Timber value ($/acre), t	2.27E-3*	2.81E-4*	2.21E-3*	1.09E-4*
	(6.01)		(4.14)	
Timber value ($/acre), $t+1$	−2.04E-3*	−2.55E-4*	−1.80E-3*	−8.67E-5*
	(−5.72)		(−3.58)	
Stand volume ($m^3 acre^{-1}$)	0.03*	3.85E-3*	0.02*	6.25E-4***
	(5.88)		(2.78)	
(Stand volume)^2	−6.90E-5*	−8.82E-6*	−4.05E-5*	−1.71E-6**
	(–5.17)		(–3.04)	
Growth volume ($m^3 acre^{-1}$)	0.01**	1.96E-3*	−0.01	–
	(2.51)		(–1.40)	
(Growth volume)^2	−4.87E-5	–	−1.27E-5	–
	(−1.63)		(−0.20)	
Stand origin	1.43*	0.15*	3.84*	0.21*
	(4.03)		(5.34)	
Coastal plain	−1.04*	−0.13*	−0.69**	−0.03*
	(−4.44)		(−2.22)	
Distance to road	0.15	–	0.35	–
	(0.58)		(0.98)	
Slope	−0.04*	−0.01*	−0.04***	−1.73E-3
	(−3.15)		(−1.82)	
Log likelihood	−499.56			
Chi-square	192.10*			

Note: *, **, and *** indicate significance at 1%, 5%, and 10%, respectively.

negatively influenced the probability of a partial harvest, largely because partial harvest is less frequently done in coastal plain than in the Piedmont and mountain areas, and the *Slope* variable adversely affected the probability of partial and final harvests.

The results in Tables 5–8 are used to calculate the implied discount rates by ownership group. For partial harvests, the implied real discount rates were 2.8%, 1.2%, 0.2%, and 0.6% for forest industry, TIMOs, REITs, and NIPF landowners, respectively. For final harvests, their respective implied real discount rates were 4.1%, 0.7%, 1.2%, and 4.6%.

Elasticity of Timber Supply

Table 9 reports the estimated means and standard errors of stand-level timber supply elasticities with respect to present and future prices across the four ownership categories. Consistent with our hypothesis, timber supply was positively associated with present

Table 6. Estimation results of multinomial logit regression equations for TIMOs' harvest choices of a specific type of timber harvesting ($N = 407$)

Variable	Partial harvest ($N = 95$)		Final harvest ($N = 50$)	
	Coefficient (z-test)	Marginal effect	Coefficient (z-test)	Marginal effect
Constant	−0.76	–	−5.72*	–
	(−1.30)		(−3.97)	
Timber value (\$/acre), t	1.67E-3*	2.62E-4*	2.80E-3*	8.38E-5**
	(3.55)		(3.88)	
Timber value (\$/acre), $t+1$	−1.57E-4*	−2.46E-4*	−2.74E-3*	−8.33E-5**
	(−3.43)		(−3.93)	
Stand volume ($m^3 acre^{-1}$)	0.01*	2.34E-3*	0.02*	6.07E-4***
	(2.70)		(3.05)	
(Stand volume)^2	−1.33E-5	–	9.92E-6	–
	(−1.24)		(0.67)	
Growth volume ($m^3 acre^{-1}$)	0.01**	1.60E-3**	0.01	–
	(2.06)		(1.10)	
(Growth volume)^2	−6.97E-6	–	−2.01E-4***	−6.96E-6*
	(−0.39)		(−1.73)	
Stand origin	1.04**	0.13***	5.33*	0.18**
	(2.41)		(3.60)	
Coastal plain	−0.47***	−0.08***	0.15	–
	(−1.65)		(0.38)	
Distance to road	−0.47	–	0.57	–
	(−1.38)		(1.01)	
Slope	−0.10*	−0.02*	−0.08**	−1.99E-3
	(−3.66)		(−2.20)	
Log likelihood	−293.63			
Chi-square	129.66*			

Note: *, **, and *** indicate significance at 1%, 5%, and 10%, respectively.

stumpage prices and negatively with future stumpage prices. Sawtimber products were more price elastic than pulpwood products, which is consistent with previous studies (Newman and Wear 1993; Prestemon and Wear 2000; Polyakov et al 2010). Pulpwood supply was more responsive to sawtimber price change than pulpwood price change. Coefficients of cross-price elasticities in timber supply between sawtimber and pulpwood in all four ownerships were significant and positive, indicating that these two types of timber products are complementary.

In particular, the stand-level multi-year own-price elasticities for sawtimber were 4.24 for forest industry, 5.34 for TIMOs, 0.68 for REITs, and 2.55 for NIPF owners. For pulpwood, own-price elasticities were 0.36 for forest industry, 0.46 for TIMOs, 0.08 for REITs, and 0.18 for NIPF owners. To see if these elasticities differ between owner groups, we did a pairwise comparison. Table 10 reports the comparison of the mean elasticity estimates

Table 7. Estimation results of multinomial logit regression equations for REITs' harvest choices of a specific type of timber harvesting ($N = 385$)

Variable	Partial harvest ($N = 72$) Coefficient (z-test)	Partial harvest Marginal effect	Final harvest ($N = 78$) Coefficient (z-test)	Final harvest Marginal effect
Constant	−2.80*	–	−3.59*	–
	(−3.69)		(−4.34)	
Timber value ($/acre), t	1.44E-3*	1.64E-4**	8.75E-4***	7.40E-5
	(2.65)		(1.62)	
Timber value ($/acre), $t+1$	−1.43E-4*	−1.63E-4**	−8.25E-3	–
	(−2.68)		(−1.58)	
Stand volume ($m^3 acre^{-1}$)	0.03*	3.27E-3*	0.02*	1.93E-3**
	(3.55)		(3.46)	
(Stand volume)^2	−3.90E-5**	−4.36E-6**	−2.76E-5***	−2.46E-6
	(−2.04)		(−1.73)	
Growth volume ($m^3 acre^{-1}$)	0.01	–	−0.02	–
	(1.32)		(–1.40)	
(Growth volume)^2	−1.89E-5	–	−4.52E-5	–
	(−0.67)		(−0.35)	
Stand origin	1.08**	0.08	3.01*	0.33*
	(2.40)		(4.75)	
Coastal plain	−1.49*	−0.17*	−0.99*	−0.09**
	(−3.78)		(−2.78)	
Distance to road	0.33	–	0.45	–
	(0.70)		(0.75)	
Slope	−0.02	–	−0.06	–
	(−0.65)		(−1.51)	
Log likelihood	−285.50			
Chi-square	151.50*			

Note: *, **, and *** indicate significance at 1%, 5%, and 10%, respectively.

of stumpage supply between two ownerships. TIMOs had a more elastic response with respect to stumpage price than industry, REITs, and NIPF landowners. REITs responded the least to stumpage prices among all owners.

Table 11 reports the aggregate elasticity of timber supply with respect to the present stumpage prices. The own-price elasticities for sawtimber were 1.29 for forest industry, 1.33 for TIMOs, 0.57 for REITs, and 0.79 for NIPF owners. For pulpwood, own-price elasticities were 0.43 for forest industry, 0.57 for TIMOs, 0.11 for REITs, and 0.22 for NIPF owners.

Because our results are multi-year elasticities, our sample plots do not include all plots in two consecutive cycles, and only nine southern states were included in this study, our aggregate timber supply elasticities are somewhat higher than these reported in the previous studies on aggregate timber supply (e.g., Adams and Haynes 1980; Newman

Table 8. Estimation results of multinomial logit regression equations for NIPF landowners' harvest choices of a specific type of timber harvesting ($N = 3{,}191$)

	Partial harvest ($N = 487$)		Final harvest ($N = 157$)	
Variable	Coefficient (z-test)	Marginal effect	Coefficient (z-test)	Marginal effect
Constant	−2.61* (−11.80)	–	−4.07* (−11.37)	–
Timber value (\$/acre), t	1.22E-3* (8.47)	1.34E-4*	1.02E-3* (3.85)	2.54E-5*
Timber value (\$/acre), $t + 1$	−1.18E-3* (−8.41)	−1.30E-4*	−8.04E-4* (−3.39)	−1.66E-5*
Stand volume ($m^3 acre^{-1}$)	0.02* (9.59)	2.12E-3*	0.01* (3.79)	2.46E-4*
(Stand volume)^2	−3.11E-5* (−7.88)	−3.41E-6*	−2.40E-5* (−3.93)	−5.24E-7*
Growth volume ($m^3 acre^{-1}$)	0.01* (3.99)	8.05E-4*	−0.01* (−2.72)	−2.78E-4*
(Growth volume)^2	−1.44E-5** (−2.10)	−1.34E-6***	−7.93E-5** (−2.21)	−2.04E-6**
Stand origin	1.45* (10.00)	0.15*	2.65* (9.44)	0.06*
Coastal plain	−0.46* (−4.08)	−0.05*	0.13 (0.69)	–
Distance to road	0.02 (0.13)	–	−0.44** (−2.12)	−0.01**
Slope	−0.03* (−4.12)	−3.55E-3*	4.78E-3 (0.46)	–
Log likelihood	−1,760.19			
Chi-square	404.58*			

Note: *, **, and *** indicate significance at 1%, 5%, and 10%, respectively.

and Wear 1993; Liao and Zhang 2008; Polyakov et al 2010). While there is not a way to convert our multi-year elasticities to annual elasticities, we could consider two extremes. One is that, without information on harvests for each year but only harvests in the multi-year time span, the period elasticity is the same as an annual elasticity. At the other extreme, one could assume that annual harvests are evenly distributed across the years between the two survey cycles. In the latter case, the annual elasticity will be equal to the period elasticity divided by the number of years in the period between the survey cycles. For example, if the FIA survey interval is six years on average, the annual sawtimber supply elasticity for forest industry is simply $1.29/6 = 0.22$. Most likely, though, is that the annual elasticity falls between these two extremes. For example, there could be a partial-adjustments process, in which the elasticity varies

Table 9. Average estimates of stand elasticities of stumpage supply with respect to present and future prices

		Average estimate of stand elasticity (Std. Err.)			
Quantity supply	Price, period	Forest industry	TIMOs	REITs	NIPF
	Present price change				
Sawtimber	Sawtimber, t	4.24*	5.34*	0.68*	2.55*
		(0.21)	(0.31)	(0.06)	(0.06)
Sawtimber	Pulpwood, t	0.43*	0.55*	0.09*	0.21*
		(0.01)	(0.02)	(0.01)	(2.65E-3)
Pulpwood	Sawtimber, t	3.16*	3.93*	0.52*	1.99*
		(0.17)	(0.26)	(0.05)	(0.05)
Pulpwood	Pulpwood, t	0.36*	0.46*	0.08*	0.18*
		(0.01)	(0.02)	(4.32E-3)	(2.36E-3)
	Future price change				
Sawtimber	Sawtimber, $t+1$	−3.88*	−6.12*	−0.92*	−2.28*
		(0.13)	(0.26)	(0.06)	(0.04)
Sawtimber	Pulpwood, $t+1$	−0.41*	−0.66*	−0.12*	−0.20*
		(0.01)	(0.01)	(4.88E-3)	(1.80E-3)
Pulpwood	Sawtimber, $t+1$	−3.88*	−6.10*	−0.92*	−2.28*
		(0.13)	(0.26)	(0.06)	(0.04)
Pulpwood	Pulpwood, $t+1$	−0.41*	−0.66*	−0.12*	−0.20*
		(0.01)	(0.01)	(4.88E-3)	(1.80E-3)

Note: *, **, and *** indicate statistical significance, different from zero at 1%, 5%, and 10%, respectively.

over the years from the beginning to end of the period. This adjustment process would involve an elasticity that starts low and then increases at a decreasing rate, toward convergence, thus producing different short-run (annual) and intermediate run (multi-year) responses to price changes. More importantly, we have found that timber supply elasticities differ among landowners, TIMOs being most responsive to stumpage price changes, followed by forest industry, NIPF, and REITs. Finally and consistent with previous studies (e.g., Newman 1987), sawtimber and pulpwood are found to be complementary goods.

CONCLUSIONS AND DISCUSSION

This paper is a first attempt to study the timber harvesting behavior of the current set of major private landowner groups, including the emerging institutional owners, in the Southern United States. Our results show that TIMOs are the most price-responsive among all ownership categories. This may have something to do with the short investment period of the institutional owners that TIMOs represent and the large acreage of timberland that they hold (Yale Forest Forum Review 2002). Small timberland owners tend to do less frequent forest management practices and timber harvesting due to economies of scales (Cubbage 1983; Siry 2002). Yet, because we use stand-level data, we were

Table 10. Pairwise comparison of average estimates of stand elasticities of stumpage supply with respect to present and future prices between ownership groups

		Difference on averaged estimates of supply elasticities (*t*-test)					
Quantity supply	Price, period	FI vs. TIMOs	FI vs. REITs	FI vs. NIPF	TIMOs vs. REITs	TIMOs vs. NIPF	REITs vs. NIPF
	Present price change						
Sawtimber	Sawtimber, t	−1.10*	3.56*	1.69*	4.66*	2.79*	−1.87*
		(−2.97)	(11.98)	(10.85)	(14.64)	(14.34)	(−11.35)
Sawtimber	Pulpwood, t	−0.12*	0.34*	0.22*	0.46*	0.34*	−0.12*
		(−5.47)	(19.12)	(25.58)	(22.05)	(32.86)	(−15.21)
Pulpwood	Sawtimber, t	−0.77**	2.64*	1.17*	3.41*	1.94*	−1.47*
		(−2.56)	(10.85)	(9.04)	(12.76)	(11.98)	(−10.65)
Pulpwood	Pulpwood, t	−0.10*	0.28*	0.18*	0.38*	0.28*	−0.10*
		(−5.06)	(18.62)	(25.73)	(20.53)	(30.73)	(−14.07)
	Future price change						
Sawtimber	Sawtimber, $t + 1$	2.24*	−2.96*	−1.60*	−5.20*	−3.84*	1.36*
		(8.61)	(−15.68)	(−15.20)	(−19.39)	(−26.31)	(11.44)
Sawtimber	Pulpwood, $t + 1$	0.25*	−0.29*	−0.21*	−0.54*	−0.46*	0.07*
		(16.75)	(−25.36)	(−40.50)	(−34.18)	(−64.00)	(13.37)
Pulpwood	Sawtimber, $t + 1$	2.22*	−2.96*	−1.61*	−5.18*	−3.83*	1.36*
		(8.55)	(−15.68)	(15.24)	(−19.33)	(−26.25)	(11.41)
Pulpwood	Pulpwood, $t + 1$	0.25*	−0.29*	−0.21*	−0.54*	−0.46*	0.07*
		(16.70)	(−25.36)	(−40.54)	(−34.12)	(−63.94)	(13.34)

Notes: FI, Forest industry *, **, and *** indicate statistical significance, different from zero at 1%, 5%, and 10%, respectively.

unable to control for the ownership size effect, or the size effect is partly reflected in the dummy ownership variables. Further, TIMOs are professionals that have the management experience and better access to market information than most NIPF landowners.

Our results also suggest that REITs are the least price-responsive owners to prices among the four ownership groups. Although a timberland REIT is a tax-efficient entity and has professional management that focuses on creating shareholder values, it has several constraints under current tax law. Other than being required to distribute at least 90% of its ordinary income to their shareholders as dividends, a timberland REIT must have more than 50% of its asset value in real property in the trade or business of producing timber and must derive at least 75% of its gross income from real estate sources including timber sales (Wang 2011). As only 25% of the income of a timberland REIT income can be from non timber sources, it has to harvest timber to make required, regular dividend payments, even in the face of weak product markets. With this context, the relatively inelastic timber supply response from this category makes sense. In contrast, cash flow is not required for TIMOs. Thus, TIMOs could cut more timber when market conditions

Table 11. Average estimates of aggregate elasticities of stumpage supply with respect to present price

		Average estimate of aggregate elasticity (Std. Err.)			
Quantity supply	Price, period	Forest industry	TIMOs	REITs	NIPF
Sawtimber	Sawtimber, *t*	1.29*	1.33*	0.57*	0.79*
		(0.03)	(0.05)	(0.08)	(0.02)
Sawtimber	Pulpwood, *t*	0.34*	0.49*	0.05*	0.21*
		(4.37E-3)	(0.01)	(4.36E-3)	(2.50E-3)
Pulpwood	Sawtimber, *t*	0.89*	0.96*	0.47*	0.62*
		(0.02)	(0.03)	(0.04)	(0.02)
Pulpwood	Pulpwood, *t*	0.43*	0.57*	0.11*	0.22*
		(0.01)	(0.01)	(0.01)	(2.62E-3)

Note: *, **, and *** indicate statistical significance, different from zero at 1%, 5%, and 10%, respectively.

are favorable and could afford to not harvest much and let timber appreciate in value when market conditions are unfavorable.

Finally, our results show that the implied real discount rates are less than 5% in the study for all landowners. Comparing the prevailing interest rate in the market such as the primary rate (roughly 5% in real terms between 2000 and 2010), this implies that the required rate of return for timberland investment is generally lower than the market rate. This result is consistent with previous studies, which have indicated that the long-term nature of forestry does not imply that investment in timberland is risky.

The primary limitations of this study are that the data do not cover the entire FIA cycles of all southern states and that detailed ownership information is only available since 2004. When more data become available, one could have a better picture of aggregate timber supply by ownership. Further studies could also explore other forest management activities such as reforestation, land use, and the supply of environmental services by the emerging institutional timberland owners in the United States and elsewhere.

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