# Production Economics of Private Forestry: A Comparison of Industrial and Nonindustrial Forest Owners

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This paper compares the production behavior of industrial and nonindustrial private forestland owners in the southeastern U.S. using a restricted profit function. Profits are modeled as a function of two outputs, sawtimber and pulpwood. one variable input, regeneration effort. and two quasi-fixed inputs, land and growing stock. Although an identical profit function is rejected, the results indicate behavior consistent with profit-maximizing motives under both ownerships. The two ownerships have similar responses to input and output price changes, both in the shon-run and in the long-run. However, nonindustrial owners appear to place a higher value on their standing timber and forestland than do industrial owners. The difference in estimated shadow values indicates that significant nonmarket benefits are being captured by nonindustrial owners and the benefits are reflected in their production behavior.

*Key* words: duality, forest production. restricted profit functions. timber supply and demand elasticities.

A concern in the forestry literature is the perceived difference in production behavior between industrially owned forest land and land managed by nonindustrial private forest (NIPF) owners (Clawson; Binkley; USDA Forest Service). For instance, in the southern United States, a large share of the region's softwood timber production (35%) comes from the relatively small share of forested acreage (23%) owned by forest industries. A much larger share of the region's forest lands (67%) is held by NIPF owners, but they produce a smaller share of the region's softwood timber products (58%) from their lands (USDA Forest Service). Numerous public intervention attempts have been made to improve NIPF output (Boyd and Hyde).

The differences in relative output reflect differences in management approach between the two ownerships. Industrial forest lands, held by firms which also own wood processing facilities, are managed almost exclusively for timber production. On NIPF land, however, the production of nontimber benefits may be of equal or greater importance than the production of timber (Hartman; Binkley; Boyd). In addition to this choice of output mix, other 'market failure" reasons are attributed to NIPF landowners in order to reconcile their production decisions. These reasons include varying capital access constraints, technical ignorance, and even lack of profit motive (Kuuluvainen; Johansson and Lofgren), which influence NIPF owners' response to market signals and therefore influence regional timber production. Timber supply issues are increasingly important as timber inventories and production on large areas of public lands in other regions are being reduced.

The purpose of the present study' is to test assertions concerning the production capabilities of NIPF and industrial ownerships. Our hypothesis is that NIPF owners manage their land in a manner consistent with the profit motives maintained by industrial owners. However, their production decisions involve additional consider-

ations beyond timber, such as nontimber goods and services, and other factors which affect the level of timber outputs from their land. Thus, profit functions may differ between ownerships as different management objectives are pursued.

We test this hypothesis using several procedures: (1) examine the first and second order conditions for profit maximization using an estimated restricted profit function for each ownership; (2) statistically test for equivalent profit functions and, by duality, identical production technologies between the two ownerships; (3) compare the implicit marginal valuation of standing timber and forest land under the two ownerships; and (4) compare restricted (short-run) and unrestricted (long-run) output supply and input demand responses given shifts in relative prices. Together, these tests provide insight into the modeling of timber markets and into the appropriate design of policies aimed at increasing timber production from private sources.

## A Dual Model of Forestry Production

Following the approach used by Wear and Newman to model the production behavior of in-- dustrial timber producers, we posit a multi-input, multi-output production (transformation) function for the forestry sector:

$$(1) \qquad T(Y_t, G_t, R_t, L_t) = 0.$$

Y is a vector of outputs, G is the level of timber growing stocks, R'is regeneration effort, $L$ is forestland, and $t$ indexes time. Growing stocks are viewed as an aggregate measure of accumulated forestry capital adjusted through time by forest regeneration inputs, forest growth, and forest removals (outputs).

Long-run profit maximizing behavior by a landowner can be modeled using the profit function dual $(\Pi)$ to the transformation function:

$$(2)$$
$$\Pi(p) = \max_{Y,G,L,R} [p_Y Y - p_R R - E(p_G; p_Y, p_R, \rho)$$
$$G(Y, L, R, G_{-1})$$
$$- \frac{p_L}{\rho} L; T(Y, G, L, R) = 0] = 0.$$

Profit maximization implies efficient intertemporal allocation and (2) reduces the infinite series of intertemporal decisions to a two-period model similar to those presented by Max and Lehman and Hultkrantz and Aronsson. The long-run profit function is made up of three compo-

nents: the first two terms define net pre-tax revenues in the present period (product revenue minus regeneration cost); the third term defines the expected value of timber growing stocks given current output and variable input prices and discount rate $(\rho)$; and the final term is the infinite stream of discounted land rents.

It may seem unusual to find no reference to harvest age in a model of forest production. This result arises from the partial static equilibrium formulation and the underlying transformation function. Because we explicitly account for growing stock levels, the ratio of growing stocks to land exactly identifies the harvesting age in a partial equilibrium context. The aggregation of stand-level forest management problems to a forest firm with a fully regulated forest (uniform distribution of age classes between zero and the harvest age) has been demonstrated by Comolli, based on insights developed by Smith. Comolli's model allows the Faustmann rotation length problem to be specified in terns of input and output quantities alone, facilitating standard comparative statics analysis of timber supply. Furthermore, Comolli derives a firm-level profit function analogous to (2) from the stand-level problem (pages 302-05, equation 11). For our purposes, partial equilibrium is a reasonable assumption for a region with a largely agricultural forest sector (i.e. the U.S. South) but may become dubious when applied to an old-growth mining probiem (i.e. the Pacific Northwest).

The long-run forestry solution in the presence of competitive markets for products and factors along with free entry defines a zero profit condition (Samuelson 1976; Comolli). However, the long-run is best viewed as a target which would likely never be attained (Kulatilaka). This is because resource stocks, like most capital stocks. may not adjust instantaneously to short-run price changes. For example, adjustment in forest stocks is bounded from above by a biological growth process and, although land may be purchased or sold, the complement of growing stock on purchased land cannot be perfectly controlled.

Given some exogenous price variability, this slow adjustment process suggests that the conditions defined by (2) are only approached. Accordingly, we define a restricted profit function in which land and growing stocks are treated as quasi-fixed inputs to the forestry production process and where outputs and regeneration input are treated as fully variable quantities.

$$(3) \qquad R\Pi(p; G, L) = \max_{Y,R} [p_Y Y - p_R R; G$$
$$= G^*, L = L^*, T(Y. G, L. R) = 0]$$

where *'s indicate existing leveis of the quasi-fixed factors.

The focus of the profit maximization formulation in (3) is the economics of timber production. However, forestland jointly produces other nontimber (and often nonmarket) forest goods and services such as hunting, wind breaks, bird-watching, and *other* amenity values. It has been asserted-that the production of many important nontimber outputs are proportional to the quantity of existing growing stocks (Hartman) and that NIPF owners are more concerned with the production and consumption of these nontimber goods and services than are industrial owners.' Under these assertions, NIPF owners should differ from industrial owners with respect to the net annual price they expect from both their growing stocks $[E(p_G)]$ (equivalent to the timber value plus the nontimber goods and service value) and their bare land value $(p_L)$.

Because the profit function is restricted with respect to growing stocks and land variables, we can proceed without direct knowledge of these amenity values or of the Iandowner's personal discount rate. The marginal value (shadow price) of these inputs can be derived from the estimated restricted profit functions by taking the partial derivative of the restricted profit function with respect to the levels of quasi-fixed inputs. If land and growing stock quantities are at their optimal levels, then these shadow prices define respective market rental prices (Samuelson 1953; Squires). Therefore, with quantities at the long-run solution defined in (2), the shadow price of the land input derived in (3) defines $p_L$; the shadow price of G derived in (3) defines $p_G = E(p_G; p, \rho)$.

The restricted profit function can also provide considerable information regarding the supply of timber products and demand for forestry inputs. The envelope condition allows the direct derivation of short-run input demand and output supply responses for variable factors. In addition, because restricted and unrestricted profit functions are dual to a common production technology, an estimated restricted profit function can define long-run adjustments for both variable and quasi-fixed inputs (Lau; Wear and Newman). Thus, given quantities at their optimal levels defined by (2), we can use the results'

from the analysis of the restricted profit function (3) to define long-run elasticities. This follows from the Le Chatelier principle that the long-run profit function is an envelope of short-run profit functions. If $L*$ and G* denote solutions to the long-run problem and are elements of the vector $Z$ of quasi-fixed inputs, then the following equations will hold:

$$(4.1) \quad \nabla_{pp_z} \Pi(p, p_z) = \nabla_{pz} R\Pi(p; z) \cdot [-\nabla_{zz} R\Pi(p; z)]^{-1}$$

$$(4.2) \quad \nabla_{p_z p_z} \Pi(p, p_z) = -[\nabla_{zz} R\Pi(p; z)]^{-1}$$

$$(4.3)$$
$$\nabla_{pp} \Pi(p, p_z) = \nabla_{pp} R\Pi(p; z) + [\nabla_{pz} R\Pi(p; z) \cdot [-\nabla_{zz} R\Pi(p; z)]^{-1}]^T \cdot \nabla_{zp} R\Pi(p; z)$$

where $\Pi(p, p_z)$ is the long-run profit function and $\nabla_{ij}$ is the gradient of this long run function with respect to input or output prices $i$ and $j$.

These equations define long-run elasticities of output supply and input demand for all quantities. While the length of time between the short-run and long-run is unspecified in a cross-sectional model (and could be as long as 20-30 years for southern forestry), the long-run results provide insight into the eventual price-responsiveness of the two ownerships.

## Data and Estimation Methods

The estimated model is a three-input, two-output restricted profit function for both industrial and NIPF ownerships in the Coastal Plain region of the southeastern U.S. Data are cross-sectional, county level observations of industrial forest and NIPF acreage from five southeastern states: Virginia, North Carolina, South Carolina, Georgia, and Florida. The data were compiled primarily through surveys performed in each state by the U.S. Forest Service, Southeastern Forest Experiment Station, during the period from 1984 to 1988. We limit the analysis to Coastal Plain southern pine production to address production units with similar production technologies.

The variable input, regeneration effort (R), is the average annual acres planted to pine during the survey' period. We assume that capital and labor are' separable in fore& regeneration, allowing the use of an aggregate regeneration input variable. For each ownership in each county, acres of land in pine'production $(L)$ and volume of pine growing stock $(G)$ were also determined and specified as quasi-fixed variables (all vol-

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[1] Industrial (as well as some NIPF) landowners have begun to market some of the non-timber values of their forest lands through the sale of hunting I-. However. industrial landowners primary consideration remains the production of timber products and we assume that these other activities do not impact their management plans.

umes are in thousand cubic feet [mcf]). Average annual outputs were separated into pine sawtimber, $Y_S$ (volume harvested from trees greater than 9 inches in diameter), and pulpwood, $Y_P$ (volume harvested from trees less than 9 inches). Corresponding output prices ($p_S$ and $p_P$) were taken from the quarterly Timber Mart South stumpage price reports and averaged for each state's survey period (Norris). These prices are reported by subregions in each state and were assigned to counties within each subregion.

A unit cost index was constructed for regeneration effort ($p_R$) by taking the average price of site preparation and planting for each county. Observations were costs reported by private land owners applying for federal cost share funds under the Forestry Investment Program (FIP) in 1984. Some counties contained insufficient observations to estimate a cost so that for these counties, costs were averaged with adjacent counties. These costs are assumed to be similar for both NIPF and industrial forest landowners because PIP required planting techniques similar to those used on industrial lauds. However, NIPF owners receive federal subsidies for forest planting which were estimated, on a per acre basis, as the sum of all relevant federal subsidies for planting received by each state divided by planted acres. The resulting average subsidy of $27 per acre was subtracted from the planting cost for NIPF owners.[2]

In compiling these data, only counties in which both industrial and NIPF production occurred were considered for inclusion in the analysis. Counties in which either zero acres were regenerated or no sawtimber or pulpwood harvests occurred were excluded. The resulting dataset contained observations for 132 counties.[3] To correct for heteroskedasticity between widely differing county sizes, each county's quantity variables were divided by the square root of the total southern pine acreage in that county. We also normalized the independent variables by their sample means so that the point of expansion for Our second order approximation to the restricted

profit function is the unit vector. Summary statistics for the data used in the analysis are presented in table 1.

Restricted profit, defined as the net of product revenue and total variable cost (regeneration cost), is estimated using a Generalized Leontief functional specification as a second-order ap proximation to the actual restricted profit function. The specific function estimated is

$$( \quad 5 \quad ) \qquad R\Pi(p; Z) = \sum_{i=S,P,R} \sum_{j=S,P,R} \alpha_{ij} p_i^{1/2} p_j^{1/2}$$

$$+ \sum_{i=L,G} \sum_{j=L,G} \beta_{ij} Z_i Z_j + \sum_{i=S,P,R} \sum_{j=L,G} \gamma_{ij} p_i Z_j + \epsilon_{R\Pi}$$

Following Hotelling's lemma, we obtain short-run output supply functions for sawtimber and pulpwood and a derived demand function for regeneration effort by taking the first derivative of (5) with respect to output prices and regeneration costs, respectively. This gives the following equations:

(6.1)
$$Y_S = \sum_{i=S,P,R} \alpha_{Si} \left(\frac{p_i}{p_S}\right)^{1/2} + \sum_{j=L,G} \gamma_{Sj} Z_j + \epsilon_S$$

(6.2)
$$Y_P = \sum_{i=S,P,R} \alpha_{Pi} \left(\frac{p_i}{p_P}\right)^{1/2} + \sum_{j=L,G} \gamma_{Pj} Z_j + \epsilon_P$$

(6.3)
$$-X_R = \sum_{i=S,P,R} \alpha_{Ri} \left(\frac{p_i}{p_R}\right)^{1/2} + \sum_{j=L,G} \gamma_{Rj} Z_j + \epsilon_R.$$

Symmetry is imposed on the system by requiring the following: $\alpha_{ij} = \alpha_{ji}$, $\beta_{ij} = \beta_{ji}$, and $\gamma_{ij} = \gamma_{ji}$ for all $i$ and $j$. The $\epsilon_i$ in equations (5), (6.1), (6.2), and (6.3) represent the respective error terms for each equation. The errors are assumed to occur contemporaneously as additive, joint normal disturbances with zero means. Such cross-equation restrictions necessitate the simultaneous estimation of this entire system of· equations. All right-hand-side variables are considered exogenous. While prices would be endogenous at the sector level, we did not consider this a problem given that observations are cross-sectional and that production units are small relative to the forest products sector as a whole.

Zellner's seemingly unrelated regression . method is used to estimate the eight equation system (the profit and derived equations for NIPF owners and the corresponding four equations for industrial owners); the individual symmetry restrictions are applied during the estimation pro-

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[2] WC would have preferred to distinguish between subsidized and unsubsidized regeneration by NIPF owners but the requisite data are unavailable. About 30% of the total acres planted by NIPF owners in the South in 1985 received federal subsidies (USDA Forest Service, tables 2-12 and 2-14).

[3] A total of 196 coastal plain counties are located in the 5 state region. Only 147 of these counties contain both industrial and NIPF forestland. Fifteen counties were excluded due to an absence of forestry activities. The deleted counties are either urban or suburban (primarily in Northern Virginia and Florida). While these counties may present interesting economic questions. they were dropped to reduce econometric complexity.

**Table 1. Summary Statistics of County Data for Industrial and NIPF Ownerships used for Restricted Profit Function Analysis**

| | Industry | | NIPF | |
|---|---|---|---|---|
| | Mean | S.D. | Mean | S.D. |
| # Obs. | 132 | | 132 | |
| R | 2,052 | 1,896 | 2,932 | 1,842 |
| L | 55,928 | 5 1,220 | 58,128 | 32,257 |
| G | 49,293 | 41,182 | 81,080 | 49,100 |
| $Y_s$ | 2.408 | 1,904 | 3.644 | 2,482 |
| $Y_P$ | 1,644 | 1,911 | 1,264 | 966 |
| $p_R$ \$/ac. | 116 | 44 | 89 | 27 |
| $p_P$ \$/mcf | 360 | 126 | 360 | 126 |
| $p_S$ \$/mcf | 1,160 | 171 | 1,160 | 171 |

cess. While the derived supply and demand equations could have been estimated alone, the profit function estimates were needed to evaluate shadow prices and long-run elasticities.

We also tested the hypothesis of identical NIPF and industrial profit functions and, implicitly, identical production technologies. To do this, we compared models with and without cross-ownership constraints on the system of equations using an F-test.

## Estimation Results

Table 2 presents coefficients of the estimated restricted profit function for each ownership. These results are obtained using the combined data set. Ten of the fifteen coefficients are significant at the 10% level or better for NIPF ownerships while twelve are significant for the industrial equations. To gauge overall model fit, we calculate the system $R^2$ proposed by McElroy (as presented by Judge et al., page 477) for systems of equations:

$$(7) \qquad R^2 = 1\left[\frac{e'(\Sigma^{-1} \otimes I)\, e}{y'(\Sigma^{-1} \otimes D_T)\, y}\right]$$

where $e$ are the GLS residuals, the numerator $(\Sigma^{-1} \otimes I)$ is the covariance matrix of the joint disturbance vector, and $D_T$ is a matrix for transforming y observations into deviations from their respective means. The $R^2$ value defines an F statistic for the hypothesis of overall system significance:

$$(8) \qquad F = \frac{R^2}{1 - R^2} \frac{MT - \Sigma_i K_i}{\Sigma_i K_i - M}.$$

The estimated $R^2$ for the overall system of equa-

tions is 0.63 and the F value is 32.56. The 1% level critical value with 52 numerator and 996 denominator degrees of freedom is 1.52, indicating rejection of the zero-coefficient null hypothesis.

Profit maximization implies that the following properties are maintained by the estimated restricted profit function for each ownership type: (1) it is nondecreasing in output prices and nonincreasing in input prices; (2) it maintains symmetry of second-order price terms: (3) it possesses a positive definite price Hessian matrix; and (4) it maintains positive linear homogeneity in prices (Chambers, pp. 123-30 and 277-81). We tested the first condition at sample means and rejected the null hypotheses of zero slopes in favor of the alternative hypothesis of increasing (decreasing) output (input) price gradients for the restricted profit function for both ownerships based on a one-tailed t-test at the 5% level.[4] We tested the second condition, symmetry, using a standard F test with 12 restrictions and 996 degrees of freedom.[5] The calculated F value was 1.771 (with a critical F value at the 1% level of 2.18) so that the imposition of symmetry could not be rejected. Symmetry was maintained in subsequent tests.

For the third condition, positive definiteness of the Hessian, numerical analysis showed that the second order conditions (non-negative ei-

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[4] We calculated the output supply and input demand gradients (6.1–6:3) at the mean of the data and the own price variances are calculated using the appropriate linear combination of the terms from the variance-covariance matrix of the coefficients. The respective t-values for industry and NIPF owners for sawtimber are 2.61 and 4.63; for pulpwood are 2.04 and 1.81; and for regeneration 2.28 and 2.46.

[5] The degrees of freedom is equal to MT − K, where M equals the number of equations (8), T equals the number of observations per equation (132), and K equals the number of explanatory variables (60).

**Table 2.  Estimates of Coefficients for the Restricted Profit Function** (equation 5) for **both Industrial and NIPF Ownerships"**

| | Industry | | NIPF | |
|---|---|---|---|---|
| Cross-Coefficient | Estimate | S.E.[b] | Estimate | S.E.[b] |
| **price-s-price** | | | | |
| $\alpha_{SS}$ | 7.12 | 1.43* | 6.48 | 1.69* |
| $\alpha_{PP}$ | 7.21 | 1.23* | 4.24 | 1.08* |
| $\alpha_{RR}$ | 1.35 | 1.00 | 5.34 | 1.08* |
| $\alpha_{SP}$ | -3.53 | 0.95' | -1.26 | 0.89 |
| $\alpha_{PR}$ | −1.72 | 0.80* | -1.26 | 0.71** |
| $\alpha_{RS}$ | -0.39 | 0.90 | -3.82 | 0.77* |
| **price-x-2** | | | | |
| $\gamma_{SG}$ | 1.69 | 0.91" | 5.38. | 1.18* |
| $\gamma_{SL}$ | 1.83 | 0.92* | 3.49 | 1.48* |
| $\gamma_{PG}$ | -0.61 | 0.57 | -0.31 | 0.57 |
| $\gamma_{PL}$ | 3.44 | 0.58* | 2.00 | 0.65* |
| $\gamma_{RG}$ | 1.04 | 0.49* | -0.89 | 0.78 |
| $\gamma_{RL}$ | -4.98 | 0.49* | -4.77 | 0.91* |
| **z-x-z** | | | | |
| $\beta_{GG}$ | 1.99 | 0.76' | -1.10 | 1.02 |
| $\beta_{LL}$ | 1.88 | 0.59' | -1.24 | 1.23 |
| $\beta_{LG}$ | -1.48 | 0.68* | 2.94 | 1.16' |

[a] Variables of the profit function are estimated simultaneously with the variable input demand and supply functions. Coefficients for these latter functions are contained in the profit function and are thus not repeated.
[b] Starred variables indicate significance level of the estimated coefficient.
  * indicates significance at the 5% level.
** indicates significance at the 10% level.

genvalues) held for all observations under both ownerships. The latter is not a statistical test of the second-order conditions. However, these mathematical results, and the statistical **results** for the first-order conditions of positive valued output supplies and negative valued input demand, indicate that each ownership maintains an estimated profit function consistent with a profit maximization hypothesis. That is, profits are positively related to output prices and negatively related to input prices.

The model (5) does not impose linear price homogeneity. Therefore, we tested for homogeneity at sample means using model estimates. For homogeneity to hold,

$$R\Pi(\lambda p; Z) = \lambda R\Pi(p; Z).$$

In the present model,

$$R\Pi(\lambda p; Z) = \lambda R\Pi(p; Z)$$
$$+ (1 - \lambda) \sum_{i=G.L} \sum_{j=G.L} \beta_{ij} Z_i Z_j.$$

so

$$\sum_{i=G.L} \sum_{j=G.L} \beta_{ij} Z_i Z_j = 0$$

is sufficient for linear homogeneity. We cannot reject price homogeneity using a two-tailed t-test at sample means at the 5% level under either ownership (the **t-values are 0.34** for industry and 0.80 for NIPF).

We tested the hypothesis of identical profit functions between ownerships by comparing the constrained and unconstrained equation systems. The resulting F-statistic (constraints equal 15 and the degrees of freedom equal 966) was *4.03* (the critical value at the 1% level is 2.04), which indicates rejection of the null hypothesis of equivalent profit functions. Therefore, the estimated equations are not consistent with an identical profit function (or production technology) between industrial and NIPF ownerships.

Our working hypothesis suggested that differences in production behavior may be' explained by differences in the relative valuation of standing trees for the production of nonmarket benefits or other constraints on production. We examined this hypothesis by computing and comparing the implicit valuation of growing stocks and land for each ownership. We computed these shadow values for the quasi-fixed factors using average values for the exogenous variables (normalized to unity) and the esti-

mated ownership coefficients. We took the partial derivative of (6) with respect to the quasi-fixed factor and corrected this value for units by multiplying by the ratio of the average heteroskedasticity correction factor ($\bar{H}$ = 326.12) to the average **value** for the fixed input (see table 1). For example, the growing stock shadow value equation for producer k is, when evaluated at the mean of the data

$$(9) \quad p_{G,k} = \left[ 2 \sum_{i=G,L} \beta_{G,i} \right.$$

$$+ \sum_{j=R,S,P} \gamma_{Gj} p_J \; (\bar{H}/\bar{G}_k/1000)$$

$$= [2(\beta_{GG} + \beta_{GL}) + \gamma_{SG} + \gamma_{PG}$$

$$+ \gamma_{RG}](\bar{H}/\bar{G}_k/1000)$$

$$= [a'b](\bar{H}/\bar{G}_k/1000)$$

where a is a (5 x 1) vector of 1's and 2's and b is a (5 x 1) vector of coefficients. The quasi-fixed factor is divided by 1000 because profit is measured in thousands of dollars. The resulting shadow values are therefore dollars per thousand cubic feet for growing stock and dollars per acre for land. The estimated variance is calculated directly from the variance-covariance matrix of the estimated coefficients ($\Omega$). Thus, for growing stock

$$(10) \quad S(p_{G,k}^*)^2 = (a'\Omega a) \, (\bar{H}/\bar{G}_k/1000)^2.$$

Because they are derived from the estimated coefficients of the restricted profit function, the shadow values should be interpreted as annual rental rates corresponding to $E(p_G)$ and $p_L$ in (2). For growing stock, NIPF owners maintain a shadow price of $31.97/mcf compared with a value of $20.84/mcf for industrial owners. For bare forest land, NIPF maintain a **value** of $23.17/ac compared to $6.38/ac for industry. It is difficult to validate these shadow prices without observations on the markets for cleared forest land and for forest stocks. Rough comparison, however, suggests that these estimates are reasonably close to available proxies. Using a 5 percent interest rate, the capitalized growing stock values are $417 for industry and $639 for NIPF. These values fall between the average pulpwood and sawtimber prices as shown in table 1. Capitalized land prices are $127/ac for industrial land and $463/ac for NIPF. Washbum estimates values for cutover land in the Georgia coastal plain range from $302/ac to

$497/ac between 1979 and 1988. These Georgia values would be relatively high corn pared to the region as a whole since the state has the strongest forest sector.

We tested the hypothesis of identical shadow prices for each of the fixed factors (Z) between ownerships using a standard t-test:

$$(11) \quad t = \frac{p_{Z,N} - p_{Z,I}}{\sqrt{s(p_{Z,N})^2 + s(p_{Z,I})^2}}$$

The t value for the difference between growing stock values is 1.34; for land values it is 1.56. In both cases we can reject the hypothesis of identical values at only the 20% level with a two-tailed test.

The disparity between these values weakly suggests there are differences between NIPF and industrial owners in perceived returns from their timber. An obvious candidate to explain this difference is that NIPF owners obtain substantial benefits from the timber remaining in place and thus **value** their resources accordingly.: However, the differences shown in both these values may also be related to the relative size of the forest tracts between these ownerships. Based on limited transaction data of farm forestland, de Steiguer found the per acre sale value inversely related to tract size. A smaller tract size could be expected to increase the rotation length by raising harvesting costs and thus increase the opportunity cost on the standing timber (Comolli). Since industrial owners favor much larger tracts, the difference in the estimated shadow values may be related to this difference. These types of scale effects could not be effectively modeled with our data.

As a further comparison of ownership behavior, we used the estimated coefficients to compute the restricted (short-run) supply and demand elasticities at the mean values of the variables (table 3). For instance, the formula for the sawtimber elasticity for **county** k is

$$\eta_{S,k} = -0.5 \left[ \frac{\alpha_{SP} + \alpha_{SR}}{\gamma_{S,k}} \right] \bar{H}.$$

Variances were calculated using the method described in Dorfman, Kling, and Sexton. and Miller, Capps, and Wells. The estimated own-price elasticities, while significantly different from 0 (except for industrial regeneration) are highly inelastic for both ownerships. The respective elasticities are not significantly different between the two ownerships. The ranking of out-

mated ownership coefficients. We took the partial derivative of (6) with respect to the quasi-fixed factor and corrected this value for units by multiplying by the ratio of the average heteroskedasticity correction factor ($\bar{H} = 326.12$) to the average value for the fixed input (see table 1). For example, the growing stock shadow value equation for producer $k$ is, when evaluated at the mean of the data

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$$= [a'b](\bar{H}/\bar{G}_k / 1000)$$

where a is a (5 X 1) vector of 1's and 2's and b is a (5 X 1) vector of coefficients. The quasi-fixed factor is divided by 1000 because profit is measured in thousands of dollars. The resulting shadow values are therefore dollars per thousand cubic feet for growing stock and dollars per acre for land. The estimated variance is calculated directly from the variance-covariance matrix of the estimated coefficients $(\Omega)$. Thus, for growing stock

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$497/ac between 1979 and 1988. These Georgia values would be relatively high Compared to the region as a whole since the state has the strongest forest sector.

We tested the hypothesis of identical shadow prices for each of the fixed factors (Z) between ownerships using a standard t-test:

$$(11) \quad t = \frac{p_{Z,N} - p_{Z,I}}{\sqrt{s(p_{Z,N})^2 + s(p_{Z,I})^2}}$$

The t value for the difference between growing-stock values is 1.34; for land values it is 1.56. In both cases we can reject the hypothesis of identical values at only the 20% level with a two-tailed test.

The disparity between these values weakly suggests there are differences between NIPF and industrial owners in perceived returns from their timber. An obvious candidate to explain this difference is that NIPF owners obtain substantial benefits from the timber remaining in place and thus value their resources accordingly. However, the differences shown in both these values may also be related to the relative size of the forest tracts between these ownerships. Based on limited transaction data of farm forestland, de Steiguer found the per acre sale value inversely related to tract size. A smaller tract size could be expected to increase the rotation length by raising harvesting costs and thus increase the opportunity cost on the standing timber (Comolli). Since industrial owners favor much larger tracts, the difference in the estimated shadow values may be related to this difference. These types of scale effects could not be effectively modeled with our data.

As a further comparison of ownership behavior, we used the estimated coefficients to compute the restricted (short-run) supply and demand elasticities at the mean values of the variables (table 3). For instance, the formula for the sawtimber elasticity for county $k$ is

$$\eta_{S,k} = -0.5 \left[ \frac{\alpha_{SP} + \alpha}{Y_{S,k}} \right] A.$$

Variances were calculated using the method described in Dorfman, Kling, and Sexton, and Miller, Capps, and Wells. The estimated own-price elasticities, while significantly different from 0 (except for industrial regeneration) are highly inelastic for both ownerships. The respective elasticities are not significantly different between the two ownerships. The ranking of out-

**Table 3. Restricted Output Supply and Variable Input Demand 'Elasticities for Industrial and NIPF Ownerships[a]**

| Elasticity o f | With respect to changes in price of | | |
| --- | --- | --- | --- |
| | Sawtimber | Pulpwood | Regeneration |
| | Industry | | |
| Sawtimber | -0.273' (0.104) | −0.246* (0.080) | -0.027 (0.064) |
| Pulpwood | −0.389* (0.141) | 0.579' (0.192) | −0.190** (0.111) |
| Regeneration | 0.034 (0.081) | 0.150" (0.080) | -0.184 (0.130) |
| | NIPF | | |
| Sawtimber | 0.224* (0.064) | -0.056 (0.042) | −0.169* (0.043) |
| Pulpwood | -0.166 (0.129) | 0.332" (0.179) | -0.166 (0.107) |
| Regeneration | 0.208* (0.053) | 0.068 (0.043) | −0.277* (0.073) |

[a] Starred variables indicate significance level of the estimated elastic iry: standard errors are in parentheses.
* indicates significance at the 5% level.
** indicates significance at the 10% level.

put elasticities appears correct because' pulpwood can be produced from growing stocks of nearly any age, while sawtimber is produced only from larger, older trees.

The negative cross-price effects between outputs indicate that, in the short-run, pulpwood and sawtimber are gross substitutes. 'These values are significantly different from 0 at the 5% level for industrial owners but not so for NIPF. Increasing stumpage prices increase regeneration demands while increasing the cost of regeneration inputs decreases both sawtimber and pulpwood production.

The unrestricted (long-run) supply and demand effects for the profit function for each ownership can be calculated using a two-step process. First, market prices for both variable and quasi-fixed quantities are used to derive the unrestricted, full equilibrium levels for each input. Then these derived levels are used as inputs in equations (4.1), (4.2). and (4.3) to compute the long-run price effects. We estimated the long-run supply and demand elasticities, by assuming that the calculated shadow prices for the quasi-fixed factors approximate the true equilibrium values that these owners would face. This assumption may be questionable given the wide dispersion in these values between the two ownerships because these prices should approach each other in the long-run. Unfortunately, no market

values for the quasi-fixed factors were available for our use in this exercise.

The estimated unrestricted elasticities are shown in table 4. Due to the numerical methods used to estimate these elasticities, variances were not calculated. Therefore, additional caution should be used in interpreting these values and they are presented here to ailow for simple comparisons between the short- and long-run. All own-price elasticities display the anticipated sign for each ownership and NIPF owners show relatively less elastic own-price responses -for all inputs and outputs than do industrial owners. In holding with le Chatelier, the absolute values of long-run elasticities are substantially greater than their respective short-run values.

The magnitude of these long-run effects may seem high when compared with the highly inelastic short-run effects. What must be remembered is that the long-run in forestry is that point in time when the quasi-fixed factors may be completely adjusted in keeping with long-run profit conditions (equation 2). Given the relative inflexibility of the forest growth process, this can be many years. The recovery of the South from a cutover and devastated timber region in the 1930s to the leading forest products region in the country by the 1970s supports the plausibility of these long-run values.

There are some interesting differences be-

**Table 4.  Unrestricted Output Supply and Input Demand Elasticities for Industrial and NIPF Ownerships**

| Elasticity  of | With Respect to Changes In Price of | | | | |
| | Sawtimber | Pulpwood | Regeneration | Growing Stock | Land |
|---|---|---|---|---|---|
| | | | Industry | | |
| **Sawtimber** | 2.452 | 0.925 | -1.663 | −1.263 | −0.451 |
| Pulpwood | 1.466 | 1.846 | −1.985 | -0.870 | −0.457 |
| Regeneration | 2.082 | 1.567 | -2.194 | -0.945 | −0.510 |
| Growing   Stock | 2.882 | 1.252 | − 1.724 | − 1.894 | −0.516 |
| Land | 2.962 | 1.895 | -2.676 | − 1.485 | −0.700 |
| | | | NIPF | | |
| **Sawtimber** | 3.383 | 0.298 | −1.326 | − 1.499 | −0.856 |
| **Pulpwood** | 0.891 | 0.347 | -0.363 | -0.780 | −0.095 |
| Regeneration | 1.637 | 0.150 | -0.656 | -0.888 | −0.242 |
| Growing   Stock | 2.161 | 0.376 | − 1.037 | -0.666 | −0.833 |
| Land | 2.348 | 0.087 | -0.538 | -1.586 | −0.311 |

tween restricted and unrestricted cross price elasticities for outputs. Sawtimber and pulpwood change from substitutes in the short-run to complements in the long-run. This result reflects the fact that large expansion effects exist relative to substitution effects for these joint products, as described by Sakai. Thus, while both ownerships tend to substitute in the short-run between pulpwood and sawtimber in response to price changes, long-run price rises in one good lead to increases for both outputs. Also, both ownerships maintain higher elasticities for sawtimber than for pulpwood in the long-run.

The estimated elasticities presented above can only be imperfectly compared with existing values in the literature because of differences in model structure and regional focus. Adams and Haynes estimated a combined short-run, pulpwood/sawtimber supply elasticity for the southeast U.S. of 0.47 for industrial owners and 0.30 for NIPF owners. Newman estimated an aggregate southern ownership supply elasticity of 0.23 for pulpwood and 0.55 for sawtimber. All these values lie within our restricted elasticity estimates. Few comparable long-run, regional, timber supply elasticity estimates or regeneration demand elasticities exist in the literature. Binkley estimated a Iong-run hardwood sawtimber elasticity of 2.0–3.9 for NIPF owners in New Hampshire and Dennis estimated elasticities between 2.5 and 6.3 for the same region.

## Discussion

The primary focus of this analysis was to compare the behavior of industrial and NIPF owners with respect to the management of their timberlands. Of particular interest is whether NIPF owners act as rational timber producers and therefore provide predictable suppiy behavior. The estimated restricted profit functions provide new insight into this issue. The first- and second-order conditions were met, indicating that NIPF behavior is consistent with profit maximization. The NIPF profit function was found, however, to be statistically different from the industry's profit function, implying also that there are differences in the respective production technologies.

One expianation for the difference in behavior is the joint production of nontimber goods and services on NIPF lands. This explanation is supported by their relatively high shadow values of growing stocks. These values alone do not, however, explain rejection of identical profit functions. If the level of nontimber services was in fact approximated by a linear function of growing stock level, then relative price differences alone would explain differences within the context of a single profit function. We suspect that the relationship between standing forests and nontimber goods and services is more complex and might explain the differences between the two ownerships (Swallow, Parks, and Wear).

Our estimation results suggest that even though a common production technology is rejected, there are many empirical attributes in common between NIPF and industrial ownerships' management behavior. Both show strongly inelastic short-run behavior, changing to highly elastic behavior in the long-run. The former result is surprising since industrial owners have a substantially greater capital base than do NIPF and

should be able to respond more strongly to changing market conditions. Their relatively higher elasticities show that to some extent they do but they still appear constrained by other factors. These factors may be related to the fact that they also carry substantial investments in downstream processing facilities which need continued, assured flows of raw material inputs. In the long-run, both- industrial and NIPF owners will alter their management behavior to take advantage of changed market conditions. A factor that is not addressed here is the length of time between the short- and long-runs. If industrial owners can adjust to the long-run more quickly, either because of larger capital resources or other factors, then their supply response to changing prices should be expected to be higher and more rapid than for NIPF owners, as our results show.

The very inelastic, restricted price and cross-price elasticities of regeneration indicate that forest owners are not greatly influenced in their short-run planting decisions by costs and prices. These results correspond to other studies showing minimal responsiveness (although somewhat larger than the values shown here) in regeneration practices from prices for NIPF owners (Boyd; Royer). However, the long-run results, which have not been previously estimated, show that regeneration demand will respond quite strongly to permanent price changes.

Such changes from the short-run to the long-run present a conundrum for analysts assessing the impact of measures designed to increase timber production by lowering management costs (or perhaps to meet other social objectives by adding environmental or regulatory constraints, thus raising costs). A short-run analysis is unlikely to show substantial diit effects from these efforts as management plans are already in place. The long-term impacts, however, may in fact be quite large. Our results do not comment on efficiency aspects of forestry incentive programs or environmental regulations but they do indicate that these programs can have large long-run impacts.

We reject the hypothesis that NIPF landowners do not respond to price signals. The econometric tests for profit maximizing behavior are all significant and their supply and demand responses are consistent with industrial owners. Our results do suggest that NIPF owners value their timber resource in a different manner than industrial owners. The shadow values that NIPF owners place on their timber and forestland assets are substantially higher than the corresponding values on industrial lands. This suggests that they either receive substantial nonmarket (or non-measured) benefits from liolding timber in place, have differing expectations regarding future prices, or hold a different opportunity cost of capital-

The suggestion that NIPF owners are satisficers who eschew standard profit maximizing behavior for greater overall satisfaction may well miss the point. Our analysis, as have others before, suggests that NIPF owners react to changing market conditions in a manner consistent with a firm with an expanded (i.e. beyond just timber outputs) transformation function. While they may incorporate nonmarket values and other constraints into their decision set they see clearly the trade-offs in their timber land management decisions and act accordingly. Future research must include such external benefits and constraints into market-based supply functions.

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