Science, Vol. 40, No. 1, pp. 192-208

Measuring Net Investment and Productivity in Timber Production

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ABSTRACT. An index number approach is developed for measuring changes in inputs, outputs, and total factor productivity in a timber-producing sector. These methods are applied to timber production in the U.S. South for the period 1952 to 1985. Results suggest that development of the sector may be described by an adjustment phase between 1952 and 1962 and a growth phase between 1962 and 1985. Aggregate output grew during the latter period at an annual rate of 2.0% for the forest industry and 1.2% for all other private lands. Input growth was also strong for the industry reflecting expansion in both the area of timberland and the intensity of management. On other private lands, however, timberland and inputs showed steady declines. Output growth net of input growth shows that productivity grew at about 0.5% per year on the industry lands and 2.5% per year on other private lands. However, the strong productivity measure for the other private ownership likely reflects measurement error related to the classification of timberland. These results demonstrate the potential hazards of using either trends in timberland area or gross investment (planting) alone to assess the development of a timber-producing sector. FOR. SCI. 40(1):192–208.

ADDITIONAL KEY WORDS. Index numbers, total factor productivity, production function.

NUMEROUS FACTORS MAY SIMULTANEOUSLY INFLUENCE timber production within a region. These factors include changes in land uses, which contract or expand the area of forests, and investment and other activities that alter the quality of forest assets. These anthropogenic factors, along with the biological processes of growth, mortality, and predation, make forest assets dynamic and variable quantities. This study attempts to sort out the various factors that influence forests and forestry and to measure resulting aggregate changes in timber production over time within a region. In addition to describing general methods for forest sector measurement, this paper presents a case study of softwood timber production in the U.S. South. It has two primary objectives: (1) to measure net investment in timber production, and (2) to define an economic measure of changes in timber productivity.

Net investment is defined as gross investment minus depreciation of assets and defines total change in the physical inputs to a production process. While gross investment in the form of tree planting has been the exclusive focus of investment analysis in forest production (e.g., Brooks 1985, Boyd 1984), several other factors also cause appreciation or depreciation of forest assets. Accordingly, gross investment alone may tell us little about the overall development of a timber-producing region. For example, if strong growth in forest planting was offset by factors such as urbanization and agricultural development, then gross investment could be strongly positive while net investment (total change in forest assets)

Reprinted from *Forest Science,* Vol. 40, No. 1, February 1994.

might actually be negative. Therefore, a net measure of investment, which accounts for all relevant changes in forest stocks, is needed to assess whether productive capacity is expanding or contracting within a region.

However, a measure of net investment may not capture all changes relevant to the productive capacity of a sector. This is because the investment measure defines changes in the physical scale of inputs but not changes in their quality. Quality, measured as the productivity of inputs, may be influenced by technological change and other forces, and these need to be addressed when evaluating the historical development of production. Forest productivity in general and growth declines in particular are contemporary topics of debate in the U.S. South (e.g., Bechtold et al. 1991 and associated responses, Newman 1991). These studies indicate that softwood growth rates have declined or leveled off in the South over the last 20 yr. However, these studies are based on physical measures of inventory and therefore cannot account for input substitution in the production of timber nor for product measures of output (Wear 1991). These important factors are incorporated in the productivity measures developed in this study, providing some economic insight into a debate that has, to this point, been argued in physical terms alone.

The paper presents the research as follows. The next section describes methods used to develop input, output, and productivity measures and the underlying assumptions of the approach. The application to timber production is then developed, and the approach to measuring and aggregating timber inputs and outputs is described. These methods are then used to analyze timber production in the U.S. South for the years 1952 to 1985. The paper concludes with a summary of findings and implications as well as suggestions for future research in this area.

METHODS

The conceptual foundation of production economics is a production function that translates combinations of inputs into combinations of outputs. A sufficiently specified production function can be used to define expansion and substitution effects of changes in both inputs and outputs (Sakai 1974) and to identify shifts in the production function that imply productivity change. While direct measurement of the production function is generally impractical, index number theory provides practical methods for measuring changes in total inputs and outputs consistent with an implicit production function. Accordingly, comparisons of input and output accounts can provide insights into productivity changes.

Index number theory has its roots in neoclassical growth theory, which dates to Solow's (1957) aggregate production function study of the U.S. economy. Neoclassical growth theory focused on using aggregate production functions to separate growth in inputs (via investment) from progress in technology (e.g., Denison 1967). Explicit connections between aggregate production functions and index number theory, which dates back at least to Fisher (1922), were first developed by Diewert (1976) and then extended, most notably by Caves et al. (1982a and 1982b). This work has focused on developing index numbers that are rigorously connected to economic production models. The most useful index numbers are those that apply to a broad set of economic circumstances, and the most general index numbers-labeled "superlative" index numbers by Diewert (1976)—are defined by production functions with flexible functional forms. The Tornqvist superlative index, which is commonly employed in applied production studies, is here applied to timber production.

Caves et al. (1982a) have shown that Tornqvist quantity indices can be derived from transcendental logarithmic (translog) production models under a wide variety of economic conditions. Their application requires only competition in input and output markets and static equilibrium. The corresponding Tomqvist total factor productivity index can measure shifts in the production function net of shifts along translog production surfaces (i.e., it accounts for substitution) if these conditions are satisfied and constant returns to scale hold. If these conditions do not hold, then econometric methods are required to sort out production specifications and to separate scale and other effects from productivity shifts. These econometric models allow testing of various hypotheses regarding the production specification but they must be implemented with highly aggregated data. This study applies the Tomqvist indices based on the homogeneous translog production model and therefore adopts these production assumptions.

The translog transformation (production) function is defined as

$$F(\ln \boldsymbol{X}_t; \ln \boldsymbol{Y}_t; t) = 1 \tag{1}$$

where X is a vector of inputs, Y is a vector of outputs, and t dates the technology and equation (1) defines technically efficient combinations of inputs and outputs. The equality defines the translog as a Taylor series expansion around the unit vector. Output and input quantity indices are developed from the production model by comparing quantities in (1) at two observations, in this case t and $t-1$ (see Caves et al. 1982a for a complete development). Consider

$$F\left(\ln \frac{\boldsymbol{Y}_t}{\boldsymbol{\delta}_t}; \ln \boldsymbol{X}_{t-1}; t\right) = 1$$

$$F(\ln \delta_{t-1} \boldsymbol{Y}_{t-1}; \ln \boldsymbol{X}_t; t) = 1 \tag{2}$$

where δ_t is the proportional difference between output in periods t and t 1 given input in period t, and δ_{t-1} is the inverse relationship [e.g., the first equality in Equation (2) defines the proportion of output producible in period t with input levels observed for period $t-1$]. The proportional change in output is defined by equating these two functions, requiring proportional changes to be base-year invariant, and solving for the rate of change. Caves et al. (1982a) derive the equation for proportional change in total output $\delta_{t,t-1}$ as

$$Q^* = \ln \delta_{t,t-1} = \frac{1}{2} \sum_{k=1}^{d} (u_{k,t} + u_{k,t-1}) \ln \left(\frac{Y_{k,t}}{Y_{k,t-1}}\right) \tag{3}$$

where $u_{k,t}$ is the revenue share of output k in period t and Q^* is the proportional change in the Tomqvist output index. The same logic applied to inputs defines the Tomqvist input index:

$$F^* = \ln \lambda_{t,t-1} = \frac{1}{2} \sum_{l=1}^{m} (v_{l,t} + v_{l,t-1}) \ln \left(\frac{X_{l,t}}{X_{l,t-1}}\right) \tag{4}$$

where $v_{l,t}$ is the cost share of input 1 at time t and F^* is the proportional change in aggregate input. Because these indices define output and input changes consistent with movement along the transformation surface, then shifts in aggregate input will just exhaust changes in aggregate output if the transformation function is unchanged between periods (and markets are competitive). However, if the transformation function shifts between periods, then the difference between rates of change in input and output describes the resulting shift in the total productivity of factors of production. Proportional change in total factor productivity is defined as the simple difference between the output and input changes:

$$TFP" = Q^* - F^* \tag{5}$$

Therefore, (5) measures change in the aggregate output:input ratio, the standard measure of productivity.

Equation (5) reflects the static nature of the production model and the Tornqvist index applied here by comparing input growth with output growth in each period. This may provide a misspecification in the case where investment is accelerated in anticipation of future production opportunities-i.e., when the rate of expansionary investment changes dramatically over time. However, because primary inputs (planting) represent a relatively small share of input costs in forestry (3–5%) the static model was adopted for this analysis. The alternative dynamic models (e.g., Bemdt et al. 1981) address these problems, but because they demand econometric analysis, require highly aggregated data. The static model was therefore selected because it allows maximum detail to be applied to the study of forest capital. This may be an important tradeoff, which is discussed further in the concluding comments of the paper.

FOREST MANAGEMENT

The timber producer manages a complement of forest assets that are described by the species of trees, the intensity of management, and the age (or condition) of the trees. These physical assets can be viewed as financial instruments: each forest stand is essentially a complement of capital, labor, and land inputs with a financial maturity date defined by the difference between the stand age and the eventual harvest age. Forest owners derive revenue from forest management in period t as follows:

$$Rt = \sum_{k=1}^{d} q_{k,t} Y_{k,t} \tag{6}$$

where q_k is the price of forest product k and Y_k is the volume of the product produced. The associated costs of forest management in period t are defined as

$$C_t = \sum_{i=1}^{b} \sum_{j=1}^{c} p^r_{ij,t} A_{ij,t} + w_t I_t \tag{7}$$

where $p^r_{ij,t}$ is the per acre rental price of forest type i and age j at time t, and $A_{,,}$ is the corresponding acreage of this class of forest capital. The quantity defined by the summation is therefore the capital bill for the forest sector. w_t is the cost of planting and Z is the number of acres planted, so the second term defines gross investment in forestry.

The rental price ($p^r_{ij,t}$) measures the value of the service provided by the durable asset. Rental markets rarely operate for durable goods in any sector, so rental prices must be deduced from purchase prices, which are observable. The analyst derives the rental price by relating the purchase or asset price of a durable good to the discounted value of its anticipated stream of services (Christensen and Jorgenson 1969) as follows:

$$p^r_{ij,t} = p^a_{ij,t-1}\, r_t + \delta\, p^a_{ij,t-1} - (p^{a*}_{ij,t} - p^a_{ij,t-1}) \tag{8}$$

where $p^a_{ij,t}$ is the purchase price of the asset type ij in period t, r is the rate of return (discount rate), δ is the depreciation rate, and the term in brackets defines anticipated capital gains (p^{a*} is the anticipated equilibrium asset price in the referenced period). The crux of measuring the capital service flows implied by forest inventories is deriving these rental prices, and this is developed in the next section of the paper.

Measuring total input to timber production requires aggregating the input quantities described in Equation (7) using Equation (4). The Tomqvist quantity index for inputs represented by existing forests is

$$A^*_t = \frac{1}{2}\sum_{i=1}^{b}\sum_{j=1}^{c} (v_{ij,t} + v_{ij,t-1})\ln\left(\frac{A_{ij,t}}{A_{ij,t-1}}\right) \tag{9}$$

$$v_{ij,t} = \frac{p^r_{ij,t}A_{ij,t}}{\sum_{g=1}^{b}\sum_{h=1}^{c} p^r_{gh,t}A_{gh,t}} \tag{10}$$

where A^* is the rate of change in the aggregate forest input and v's are cost shares of the respective forest types and ages.

Forest stock (9) and regeneration inputs (gross investment) are combined to form the total input index

$$F^* = \frac{1}{2}\left[(v_{A,t} + v_{A,t-1})\ln\left(\frac{A^*_t}{A^*_{t-1}}\right) + (v_{I,t} + v_{I,t-1})\ln\left(\frac{I_t}{I_{t-1}}\right)\right] \tag{11}$$

where $v_{A,t}$ and $v_{I,t}$ are cost shares of standing forest capital and regeneration effort respectively [defined, respectively, by the two terms on the right hand side of Equation (7) divided by C_t] and Z is the area regenerated. F^* therefore represents net change in all inputs and thus net investment in timber production.

The Tomqvist output index for forest products is defined by aggregating the output quantities described in Equation (6) using Equation (3)

$$Q^* = \frac{1}{2}\sum_{k=1}^{d} (u_{k,t} + u_{k,t-1})\ln\left(\frac{Y_{k,t}}{Y_{k,t-1}}\right) \tag{12}$$

where Q* is the rate of change in output and u's are revenue shares. The difference between Q* and F^* is the rate of change in total productivity. When quantities are set equal to one in an arbitrary base year, these proportional changes can be used to define input, output, and productivity indices.

FOREST VALUATION

The input index (11) depends critically on forest rental prices and therefore on asset values for forest stocks. Because rental prices for forests are unobserved, they must be derived from these asset prices, rates of return, and physical depreciation as described by Equation (8).

A forest produces fiber (a physical product) throughout its life. However, unlike other forms of capital, the fiber can be captured only periodically, when the stand is harvested. The result is a "lumpy" output stream dissimilar to the service streams of most physical capital assets. The lumpiness of the revenue stream is not, however, necessarily inconsistent with the concept of a rental price for forests. This is because the capital service of interest here is essentially a financial concept tied to the biological accumulation of fiber (biological growth) and a maturity date. If the market for forestland is efficient, forest owners may adjust their forest asset portfolio in response to changing prices and land prices should reflect the anticipated services of forested lands.

Forest rent is not unfamiliar to the student of forest management. Following Samuelson (1976), the familiar stand replacement or rotation problem can be completely described by an initial harvest sequence and a stream of discounted land rents:

$$0 = \max_T \left[B(T)e^{-rT} - c(k,l) - \int_0^t Re^{-rt}dt \right]. \tag{13}$$

If land remains indefinitely in a forest use, then solving for the optimal harvest period (T) defines the relationship between land rent (R), asset value (p^a), periodic harvest revenue ($B[T]$), and stand establishment costs ($c[k,l]$):

$$p_0^a = \frac{R}{r} - \frac{B(T)}{e^{rT} - 1} - \frac{c(k,l)}{1 - e^{-rT}}. \tag{14}$$

This model addresses the special case where cleared land is evaluated. We are concerned here, however, with deriving rental values for established forests of various ages and types. Problem (13) can be modified to account for these existing stocks:

$$0 = \max_T \left[B(T)\, e^{-r(T-t)} - \int_0^{T-t} Re^{-rs}ds + p_0^a e^{-r(T-t)} \right] \tag{15}$$

where t is the age of the existing stand. The first two terms are benefits and rents accruing between the present and the initial harvest, while the third term is the bare land value discounted from the time of the initial harvest ($T - t$). Note that because $t > 0$, the regeneration costs of the existing stand are sunk. Within this formulation, the optimal rotation age may not change with stand age as long as prices are constant. As prices change from period to period the optimal rotation age for classes of forest also change. Asset value at age t is given by:

$$p_t^a = \frac{R}{r} = [B(T) - c(k,l)] \frac{e^{-r(T-t)}}{1 - e^{-rT}}. \quad (16)$$

This can be used to define the asset value of a forest stand at age $t < T$, given the corresponding biological growth function, a discount rate, and all relevant costs and prices. For the empirical work that follows, two additional formulas for forest asset valuation are employed. The first defines an average asset price for a complement of forest stands. We consider a forest with stands distributed uniformly across age classes up to the optimal rotation age (the so-called normal or fully regulated forest). The distribution of forest area (E) across age classes $a(t)$ is thus given as

$$a(t) = \begin{cases} \frac{E}{T} \text{ for } 0 < t < T \\ 0 \text{ otherwise} \end{cases} \quad (17)$$

and total forest value is obtained by integrating Equation (16) across age classes

$$E\, p_n^a = \int_o^T a(s) \left[\frac{B(T) - c(k,l)}{e^{rT} - 1}\right] e^{rs}\, ds \quad (18)$$

Dividing by the total area gives the average asset price for the "normal" forest:

$$p_n^a = \frac{B(T) - c(k,l)}{Tr} \quad (19)$$

We also consider the case where the stand age exceeds the optimal replacement date $(t > T)$. Here the forest is assumed to indefinitely maintain a biological age of T-that is, the stand maintains constant nominal value after financial maturity consistent with an asymptotic revenue function. With t set to T, Equation (16) becomes

$$p_M^a = \frac{B(T) - c(k,l)}{1 - e^{-rT}} \quad (20)$$

which is equivalent to the returns from immediate harvest plus the bareland value. In the empirical work that follows, all three variants of the forest asset valuation equation (16, 19, and 20) are applied.

DATA

These methods are applied to private timber production in the U.S. South for the years 1952-1985. In this region, most forests are managed by private owners with varied characteristics. Previous studies have distinguished between the group of private owners who hold timber-using facilities, the forest industry, and all other private, or nonindustrial, owners. These two ownership groups display structural dissimilarities in their production behavior (Newman and Wear 1993), and they are examined separately here as well.

Measuring the inputs to timber production described by Equation (9) requires two types of data. One is a physical description of the forest-the acreage in each forest type and age distributions across forest types. These data are represented by the A matrix in Equation (9). The second is a measure of forest rent for each of these forest type or age classes; these data are used to define the cost share terms (v_{ij}) in Equation (9).

For softwood timber production in the U.S. South, there are three relevant forest types: pine plantations, natural pine, and mixed pine hardwood. The USDA Forest Service periodically reports the total timberland acreage for these forest types, on the basis of its ongoing forest inventory surveys. The benchmarks reported in the South's Fourth Forest Report (USDA Forest Service 1988) were used to develop historical acreage figures for the South. Two methods were employed to interpolate acreage between the benchmark years (1952, 1962, 1970, 1977, and 1985). For plantations, annual changes in area were assumed to be directly proportional to the forest planting [acres, the measure of I in Equation (10)] reported for that year in the same document. For natural pine and mixed pine hardwood types, annual changes were assumed to be directly proportional to softwood harvest quantities in each year.

A simple growth accounting method was applied to the plantation acres to determine their age distribution. The few plantation acres in place by 1952 were assumed to be uniformly distributed between ages 0 and 5. For each subsequent year, the net increase in plantation acres was assigned to the zero age class and existing acres were aged 1 yr. For valuation, acres were described by 10-yr age classes and assigned an average asset value for the class. For the other forest types, half of the area was assumed to be uniformly distributed between the age of zero and the optimal harvest age, and the other half was assumed to be financially mature. Few data were available on actual age class distributions for these forest types, but a review of existing evidence (e.g., forest survey reports) suggested this approximation of the age structure.

Asset prices were established by Equations (16), (19), and (20) using empirical timber yield tables constructed by Vaseivich (USDA 1988, based on the work of McClure and Knight 1984) for each forest type, a time series of softwood pulpwood and sawtimber prices constructed by Newman (1987) for the South, and a Southwide regeneration cost series developed by Brooks (1985) and extended by Lee et al. (1992). The optimal replacement age or rotation was determined in each period for each forest type by solving Equation (13), and the asset values were computed according to Equations (16), (19), and (20).

The rental price of forest assets could then be derived from these asset values using Equation (8) and appropriate rates of return and depreciation and anticipated capital gains. Alternative formulations of the rate of return and anticipated capital gains have been examined by Harper et al. (1989), who find little guidance in capital theory for deciding among them. Their alternatives for the rate of return include sector-specific internal rates, a variable external rate defined by bond indices, and a constant real rate of return. They reject the variable external rate but do not express an unambiguous preference for any of the remaining alternatives. Harper et al. also estimate capital input measures using two alternative measures of the capital gains term. One assumes that all capital gains are transitory and fully anticipated, thereby setting the capital gains term to zero in Equation (8). The other assumes that investment behavior is myopic and that capital gains are defined as the full difference between present and lagged asset valuations. They find, as do several others (e.g., Ball 1985), that the myopic model of capital gains may generate negative rents, which are untenable within the index number approach. Negative rents were derived here when the myopic model was applied to forest inputs.

To define forest rental prices, full anticipation of capital gains is assumed, and the long-run implicit (aggregate) rate of return is applied to the asset prices described above:

$$p^r_{ij,t} = (r + \delta)\ p^a_{ij,t} = \beta\ p^a_{ij,t} \tag{21}$$

where β is the aggregate rate of return. β was calculated for each ownership by imposing long-run competitive conditions on the sector. Accordingly, total revenues [Equation (6)] over the period are set equal to total costs [Equation (7)]:

$$\sum_{t=1952}^{1985} \sum_{k=1}^{d} q_{k,t} Y_{k,t} = \sum_{t=1952}^{1985} \sum_{i=1}^{b} \sum_{j=1}^{c} p^r_{ij,t} A_{ij,t} + w_t I_t \tag{22}$$

Substituting (21) into (22) defines β as the average ratio of revenue flow to forest asset value over the historical period. β equals 2.28% for the industry ownership and 1.84% for the nonindustry. In effect, this is consistent with capital gains being averaged out over the historical period and is reflected as an adjustment to the discount rate.

Revenue indices [Equation (11)] were computed using price and quantity data for two outputs, softwood pulpwood and sawtimber. Total quantities and prices of softwood pulpwood and sawtimber produced in the South were developed by Newman (1987, pers. comm.). The shares of each product produced from industrial and nonindustrial lands were derived from Adams et al. (1988).

TABLE 1.

Average rates of change in input, output and TFP measures between inventory benchmark years. Rates measure proportional change in the referenced quantity.

	Industry			Other private		
Period	Input	output	TFP	Input	Output	TFP
1952-1985	0.0140	0.0070	-0.0070	- 0.0108	0.0039	0.0149
1962-1985	0.0159	0.0204	0.0045	-0.0127	0.0116	0.0247
1952-1962	0.0075	0.0229	-0.0302	-0.0047	-0.0133	-0.0086
1962-1970	0.0205	0.0257	0.0051	-0.0134	0.0085	0.0222
1970–1977	0.0135	0.0209	0.0073	-0.0116	0.0085	0.0204
1977-1985	0.0098	0.0101	0.0004	-0.0103	0.0148	0.0254

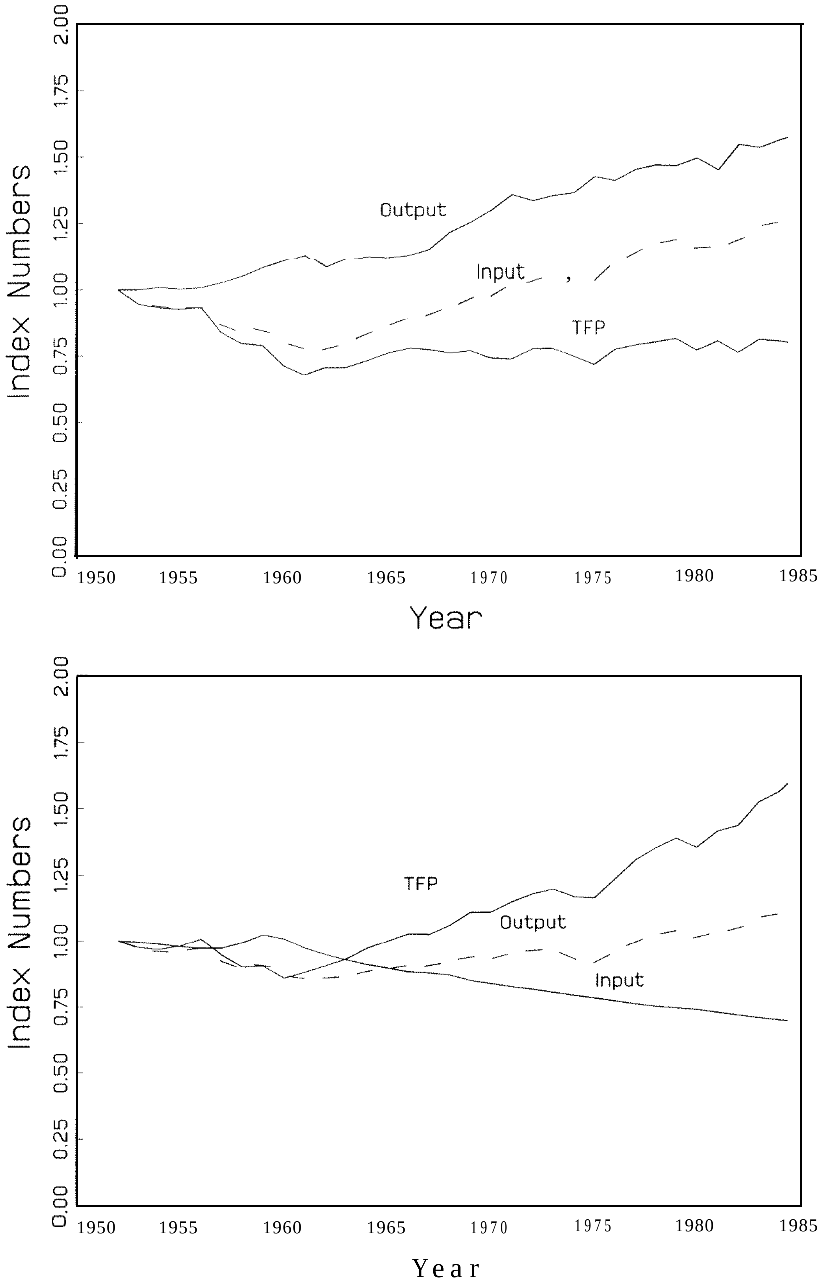

FIGURE 1. (a) Input, output, and total factor productivity indices for the industry ownership (base year is 1952); (b) Input, output, and total factor productivity indices for the other private ownership (base year is 1952).

RESULTS AND DISCUSSION

Index numbers for inputs, outputs, and Total Factor Productivity (TFP) for timber production in the U.S. South are summarized by ownership group in Table 1 and graphed in Figure 1. These results suggest that the historical period has two distinct subperiods. The period 1952-1962 can be characterized as an adjustment period with large increases in planting effort (especially on nonindustrial lands) and substantial change in the output mix. In contrast, the period 1962-1985 displays relatively steady progressions in all quantity indices. For this reason, the following discussion of results generally focuses on developments over this second period.

INDUSTRY

For the industry ownership, input, output, and total factor productivity grew between 1962 and 1985. Input grew at an average annual rate of 1.6% (Table 1) as the industry increased both its total timberland area and intensity of management. Because the total area of industry timberland grew at about 1 .O% per year, the 0.6% residual rate of change can be attributed to changes in the distribution of forest area among cover and age categories. This difference between the change in forest area and the capital measure of forest input defines a "capital composition effect" (Harper et al. 1989, p. 343). Roughly 30% of input expansion on industry lands can be attributed to changes in forest asset structure (i.e., to changes in the composition of forests).

Output grew approximately 50% faster than input (2.0%/yr) over this period. As a result, total factor productivity expanded at about 0.5%/yr. However, productivity growth falls to essentially zero during the period 1977-1985. While the productivity of timberlands therefore grew beyond what can be explained by forest type conversions (e.g., natural to planted pine) over the historical period as a whole, productivity appears to have leveled off over the most recent period. This rate and pattern of change in productivity is strikingly similar to Newman's (1991) findings for southern forestry. His study, based on a biological production function estimated with data for large substate regions, also indicates a residual productivity change of 0.5%/yr over a similar time period, with productivity leveling off over the last 10 yr.

OTHER PRIVATE

Results for the other private ownership suggest a substantially different history of development. While output has grown (1.2%/yr), though at a rate substantially lower than the rate for industry, input quantities have declined over the period 1962-1985 (− 1.3%/yr). The rate of change in input is almost exactly equivalent to the rate of change in the area of pine-producing land, indicating no discernible capital composition effect on other private timberlands. The combination of output growth and input decline indicates a large rate of growth in total factor productivity. The TFP growth rate (2.5%) is more than three times the rate for the industry. This is a considerably counter-intuitive result, especially given the higher intensity of management on industry lands, and suggests that the TFP results should be interpreted with caution.

INTERPRETING TFP RESULTS

Because Total Factor Productivity is output growth unexplained by measured input growth, its accuracy depends on an accurate accounting of inputs. In this case, the primary measures of inputs are surveys of timberland defined by a physical production criterion. A critical assumption of this approach is that timberland area provides an accurate index of change in the assets actually dedicated to timber production.[1] The assumption appears reasonable for the industry, where, by definition, timberland is acquired for timber production. However, the assumption is tenuous for the other private ownership, where objectives may vary. The large TFP findings for other private lands may indicate a nonconstant relationship between timberland and timber-producing assets, casting doubt on input measures for this ownership. For example, these results may indicate substantial growth at the extensive margin on other private lands.

While there is considerable reason to doubt that the large TFP findings for other private lands relate to underlying forest productivity, the findings for the industry are consistent with other aggregate studies of physical timber productivity. Still it bears repeating that TFP is merely a residual unexplained by a constant production technology. Therefore, any unmeasured change in the forest sector-e.g., changing shares of other inputs such as intermediate treatments—would be captured as part of the TFP residual. Attributing productivity change to causal factors is difficult, especially in the case of forestry where "nature's technology" is central to production.

In studies of manufacturing sectors, TFP growth is generally equated to improvements in the human technologies used to produce goods. This interpretation of TFP rests on the assumption that technology is progressive, moving forward without moving backward. When technological change is progressive, production in a previous period can serve as a valid benchmark for evaluating production in the present. These effects can therefore be used to assign benefits to technology-enhancing research. However, for timber production, the case for ubiquitous progressive change is not nearly as strong, and it may be unreasonable to equate technological change and TFP growth.

The difficulty in evaluating technological change in timber production is related both to the interaction of human and natural technologies and to the time structure of production. Biological growth is a function of a number of factors, including several that are essentially ambient (and typically subsumed within the economist's trend variable). Unmeasured changes in environmental quality or successional changes within forest ecosystems may work against softwood production and define a regressive force unaccounted for by economic and biological production models. This does not suggest that TFP and other productivity findings are irrelevant. Rather, TFP is a net measure that will understate the contribution of technological developments if regressive forces are at work in the sector. Conversely, the impact of technological change may be overstated by residual productivity measures if changes in ambient factors are progressive (for example, if climate warming also increases productivity). In effect, technology assessment in timber production faces substantial specification problems relative to missing variables for primary inputs such as nutrients, solar insolation, and water. Therefore,

[1] Note that the assumption is only that timberland area index for timber-producing assets. Area is an adequate index if the proportion of measured timberland dedicated to production remains constant over the period.

TFP should be interpreted as an aggregate measure which cannot, in this application, be decomposed into environmental and technological components.

GROSS VERSUS NET INVESTMENT

To date, research on investment in forestry has focused exclusively on gross investment measured as the area of land planted with trees. The input indices developed here measure instead net investment-gross investment minus depreciation caused by harvesting and changing land uses. They therefore provide additional insights into the effects of investment by separating input expansion from input replacement.

Figure 2a charts both the input index and the gross investment index (planting) for the industry. While gross investment has expanded at about 5%/yr, net investment has been much more moderate, growing by only 1.6%/yr. The difference between gross and net measures indicates that an increasing share of industry's investment in southern forestry plays a replacement role.

Gross investment is charted with the input index for other private lands in Figure 2b. Here also it appears that planting is increasingly replacement investment. It is also interesting that substantial planting efforts related to Soil Bank programs (1956-1964) did not substantially increase the scale of input on other private lands after land use changes are factored out. These planting efforts just offset the attrition of land from forest uses during this period. Following the Soil Bank program, input levels declined steadily into the 1980s. Results for both ownership groups indicate potential problems with using gross investment (planting) as a summary gauge of forest management within a region.

CONCLUSIONS

This paper addressed two issues: investment and productivity. Previous research has addressed these issues using various approaches but none has addressed both issues in a unified framework. Investment research has focused on gross investment in forestry measured as acres planted within a region (e.g., Brooks 1985, Boyd 1984) with special emphasis placed on the impacts of various forestation policies and programs. Productivity measurement has focused on physical rather than financial measures of productivity and has been limited because of changes in both input and output mixes. Gross investment is offset by harvesting and other activities that alter forest stocks in a region. Because forest rent accounts for more than 90% of costs in forestry, these other activities may have substantial impacts (when compared with forestation activities) on forest production that will not be reflected in gross investment trends. Accordingly, this study examines net investment in the forest sector and attempts to account for all of these activities and their impacts on forest stocks.

Positive net investment on industrial lands in the U.S. South is reflected in both expansion in timberland and management between 1962 and 1985. That is, both the extent and intensity of forest management under industrial ownership have

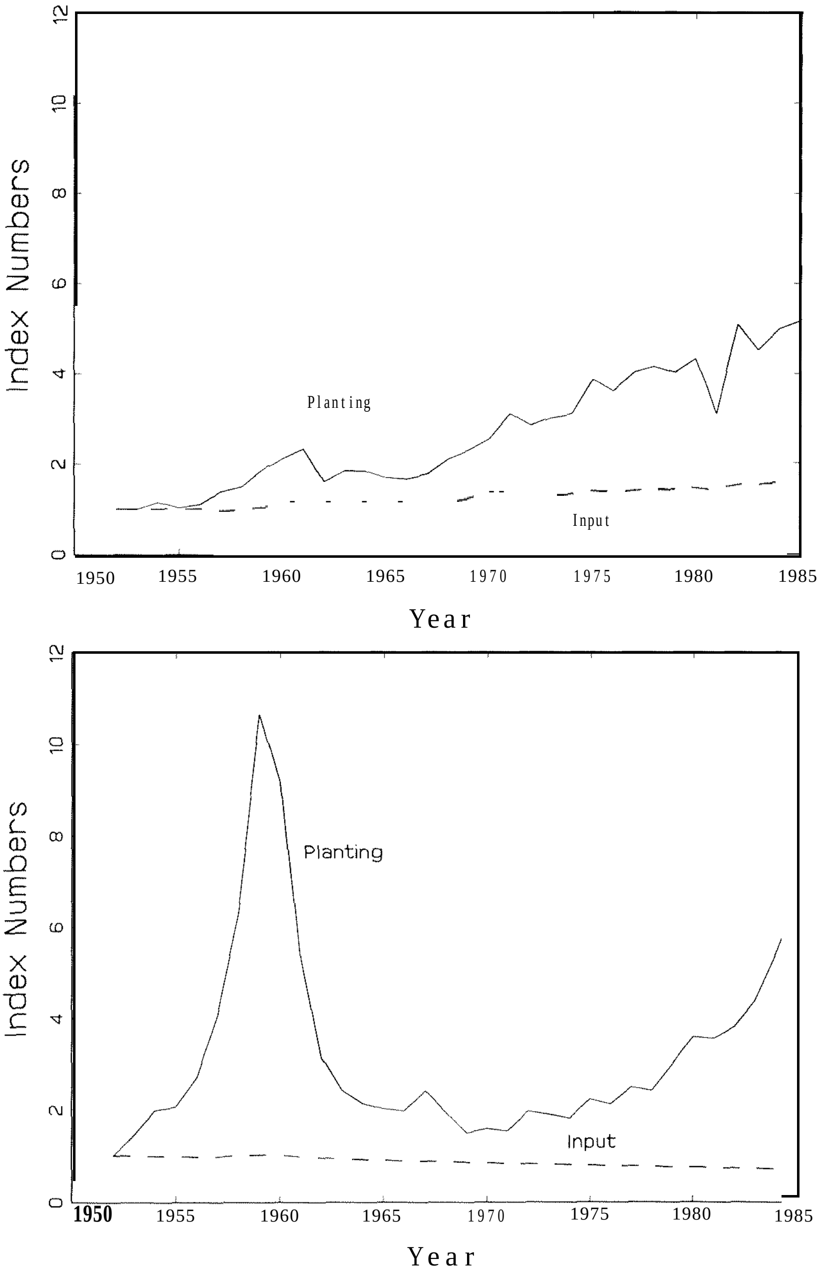

FIGURE 2. (a) Gross investment (planting) and net investment (total input) indices for the industry ownership (base year is 1952); (b) Gross investment (planting) and net investment (total input) indices for the other private ownership (base year is 1952).

increased. However, the rate of net investment is much smaller than the rate of gross investment defined by forest planting efforts. In contrast, there was net disinvestment in nonindustrial timber production, and this explained largely by attrition of land from softwood-producing forest types. However, when growth in other private output is compared with this decline in input, a very large productivity residual results. Rather than measuring the effects of technological change, these results raise questions about the relationship between timberland and timber production in the other private ownership. One explanation might be growth at the extensive margin in timber production, offsetting declines in total timberland. However, this study does not resolve the questions.

These results also raise questions regarding our ability to measure the potential for timber production on other private lands. Timberland is defined as a physical category in forest surveys, not necessarily related to the actual use of forestlands. Many have suggested that regional timber assessments would be greatly improved if forest surveys linked physical inventories with the economic and social characteristics of forest owners. This study provides emphatic support to this suggestion.

The net of output and input growth shows a moderate growth in the productivity of industrial timberland between 1962 and 1985. Even here, where timberland is a well-defined input measure, the interpretation of productivity results may be limited and suggests a substantial need for additional research. In particular, it will be necessary to factor out typically unmeasured environmental changes to define an accurate baseline for gauging the effects of technology. Future research may benefit from examining production at a finer scale of resolution, thereby including site quality variables, but necessarily over smaller regions.

In spite of these limitations, the TFP measure provides a relevant net index of change on industry lands. It improves on previous measures of productivity by addressing both input and product substitution in forestry. These elements are essential for gauging productivity in an environment of changing input and output prices. The results corroborate previous findings which suggest that productivity grew into the 1970s but has leveled off in recent years.

Some basic methodological questions need to be further scrutinized in subsequent research. The index number approach to measuring input, output, and productivity rests on some strong assumptions regarding production technology. The methods used here depend on a static model of production. This may be limiting in cases where stocks may not be optimally adjusted in the short run or where the rate of expansionary investment changes substantially. Alternative dynamic investment models address these adjustment issues, but require strong assumptions of their own (related mainly to input separability and aggregation). Future research might investigate indexing approaches adjusted for subequilibrium and dynamic adjustment costs (e.g., Bemdt and Fuss 1986, Morrison 1986),[2] or third-generation dynamic investment models (e.g., Bemdt et al. 1981).

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[2] These approaches use input shadow prices to calculate cost shares for the Tomqvist indices. The land rents developed here are implicit prices defined by primary product prices and forestation costs. They do not however account for dynamic adjustment costs. The research question is therefore whether cost shares (not rents) defined by shadow prices with adjustment costs differ substantially from the shares developed here.

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Manuscript received August 10, 1992

AUTHORAND ACKNOWLEDGMENTS

David N. Wear is Research Forester, Southeastern Forest Experiment Station, USDA Forest Service, Box 12254, Research Triangle Park, NC 27709. He acknowledges helpful comments from Alan Salmon, David Newman, Brian Murray, and Fred Cubbage. In addition, careful review and comment from one of this journal's associate editors and referees motivated substantial improvements in the paper. Financial support was provided by the Resources Program and Assessment Staff, USDA Forest Service, Washington, DC.