WORKING PAPER

LONG RUN TIMBER SUPPLY: PRICE ELASTICITY, INVENTORY ELATICITY, AND THE CAPITAL–OUTPUT RATIO

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IIASA
International Institute
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FOREWORD

The objective of the Forest Sector Project at IIASA is to study long-term development alternatives for the forest sector on a global basis. The emphasis in the Project is on issues of major relevance to industrial and governmental policy makers in different regions of the world who are responsible for forest policy, forest industrial strategy, and related trade policies.

The key elements of structural change in the forest industry are related to a variety of issues concerning demand, supply, and international trade in wood products. Such issues include the growth of the global economy and population, development of new wood products and of substitute for wood products, future supply of roundwood and alternative fiber sources, development of new technologies for forestry and industry, pollution regulations, cost competitiveness, tariffs and non-tariff trade barriers, etc. The aim of the Project is to analyze the consequence of future expectations and assumptions concerning such substantive issues.

This article represents an equilibrium analysis of timber supply. Based on a single model of timber production, the characteristics of supply function have been studied in detail. Such an analysis provides foundations for the Project's efforts to study long-term development of forest resources in market economies.

Markku Kallio
Leader
Forest Sector Project

ABSTRACT

Timber production requires substantially more capital per unit output than do most economic enterprises. The quantity of capital deployed depends primarily on the rotation length and the output price of stumpage. In a long run timber supply model this gives rise to a "backward bending" supply curve. This paper summarizes a long run model of timber supply, and computes the associated price and inventory elasticities. The role of capital in timber production is explored through a continuous time formulation of the usual Faustmann point input/point output model. The theoretical results are illustrated through an example based on loblolly pine yields.

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INTRODUCTION

This paper analyses the long run supply of timber, with particular attention paid to the role of capital. The model is long run in the sense that the time period of the analysis is adequate for the capital stock to adjust to the economically optimal steady state level. The period of time necessary for this condition to be met depends on the initial age structure of the forest, the level of demand and the underlying biological productivity of the forest; it might range from less than a decade to more than a century.

This model of timber supply dates at least to Vaux's (1954) analysis of timber production in California, and has been used many times since: for the Douglas fir region of the United States by the USDA Forest Service (1963) and Hyde (1980), for pine in the southern US by Robinson (1980) and for the spruce-fir resource in Maine by Binkley (1983). Jackson (1980) and Hyde (1980) discuss some of the theoretical aspects of the model.

The present analysis is both narrower and deeper than these other efforts. The rotation age is the only decision variable considered. To a great extent, the rotation age determines the quantity of capital used in timber production, so an analysis of capital logically focuses on this variable. In addition, the rotation length is perhaps the single most important variable determining the level of output from a forest (Davis, 1976). This analysis omits any formal discussion of management intensity or the amount of land devoted to timber production, although the concluding section comments on how variables would influence the present results . Similarly the nontimber products of the forest (recreation, water, environmental services) which may affect the optimal harvest period are excluded from consideration (see Hartman, 1976 and Bowes, Krutilla, and Sherman, 1984 for discussions of how the presence of valuable nontimber forest products affects the analysis). This narrow perspective is adopted to focus on the role of capital in timber production, and is consistent with, for example, Samuelson's (1976) treatment of the problem.

The remainder of the paper is in four parts and a concluding comment. The first section details the long run supply model. This section shows that the price elasticity of supply may be negative, indicating a backward bending supply curve for timber. Instability may arise in the long run market equilibrium because of this unusual supply behavior.

Many short run models of timber supply use the level of timber inventory to explain harvest levels. Section 2 below compares the inventory elasticity implied by the long run model with the results from these studies.

The fourth section examines the capital/output ratio for the steady state forest, and clarifies the importance of capital in timber production

The fifth section uses yield information for loblolly pine grown in the southeastern United States to demonstrate the practical significance of the theoretical results.

1. LONG RUN SUPPLY, PRICE ELASTICITY AND MARKET INSTABILITY

The long run timber supply model has two parts. The first describes the rotation decisions of forest owners as a function of timber price and other relevant parameters. This decision determines the level of timber production. The second explains precisely how the amount of timber produced depends on the rotation age, and therefore on price.

Landowner Behavior

The forest owner selects the rotation age which maximizes the net present value π of timber receipt summed over an infinite planning horizon. Capital markets are perfect so the forest owner can lend and borrow at a constant, known interest rate i. (Equivalently, land markets perfectly reflect the present value of partially grown stands). Timber yield v per unit area is a known function of stand age t; the yield function does not change over time. Regenerating a stand costs c per unit area, an amount which is constant through time. Lastly, the even-aged forest is regenerated promptly after clearcutting if it is profitable to do so.

These assumptions imply the rotation problem is stationary, so the forest owner solves

$$\max_t \pi(t) = -c + pv(t)e^{-it} + \pi(t)e^{-it} \qquad 1.1$$

The stumpage price p is endogenous. The optimal rotation age $t^*(p)$, and therefore the level of output, varies with price level.

The first order optimality conditions for $t^*(p)$ can easily be found (see Jackson, 1980; Hyde, 1980; or Chang, 1983) by solving $\frac{d\pi}{dt} = 0$.

$$\frac{\dot{v}}{v - \frac{c}{p}} = \frac{i}{1 - e^{-it}} \qquad 1.2$$

where $\dot{v} \equiv \frac{dv}{dt}$

Timber Output

Given the optimal rotation age, how much timber is produced? In the long run, capital can adjust to the economically desirable level. For timber production this implies that the forest has no timber older than $t^*(p)$, and each year all timber reaching this age is harvested. Averaged over a rotation, the annual output of a forest of area A is $Av[t^*(p)]/t^*(p)$. Without loss of generality this paper takes $A=1$, so the supply function is

$$s(p) = \frac{v[t^*(p)]}{t^*(p)} \qquad 1.3$$

A "fully regulated" forest produces identically the long run average annual output each year. This is achieved by an arrangement of age classes so that each occupies an area equal to A/t^*.

Before continuing, it will be helpful later in the analysis to note that supply is maximized at the rotation age which satisfies

$$\frac{\dot{v}}{v} = \frac{1}{t} \qquad 1.4$$

Equation 1.4 is simply a restatement of the forester's familiar maxim that average annual output is maximized when current annual increment ($\dot{v}$) equals mean annual increment (v/t). It is natural to call the rotation which satisfies 1.4 the maximum sustained yield (MSY) rotation. For typical timber yield functions, rotations are less than MSY if an only if $\dot{v}/v > 1/t$.

Long Run Supply

The supply model is illustrated in Figure 1. The top panel depicts the optimal rotation condition 1.2. The lower panel shows forest growth/steady state supply, equation 1.3. Given all the parameters of the model except price, the supply curve is defined by the following algorithm. For a given p, 1.2 is solved (upper panel of Figure 1) to find the optimal rotation age. Long run supply then can be found by 1.3 (the lower panel of Figure 1). The process is iterated for various price levels until the supply curve is identified with suitable precision.

The supply function can also be developed in another way . First solve 1.2 for p to link price directly with the optimal rotation age

$$p = \frac{c}{v - \frac{\dot{v}(1 - e^{-it})}{i}} \qquad 1.5$$

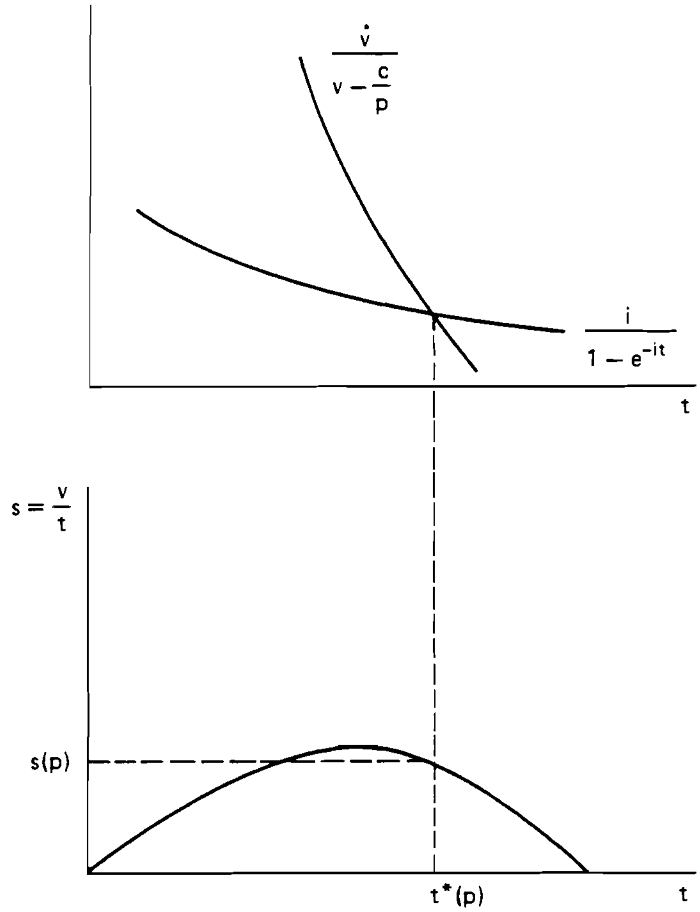

FIGURE 1. Optimal rotation and timber supply.

Given a yield model $v(t)$, cost and interest rate, the supply curve can be constructed by examining a series of rotation ages. For each rotation age, 1.5 gives the price which makes that rotation optimal, and 1.3 gives the supply at that price.

The procedure is illustrated in Figure 2. The NW quadrant labelled $t^*(p)$ plots 1.5. The SW quadrant plots 1.3. The SE quadrant contains a 45° transfer line to map the average output from the SW quadrant onto the quantity axis of the supply curve, $s(p)$, which is shown in the NE quadrant.

Figure 2 shows the construction of the supply curve for three important cases. In case (a), the price is so low that $\pi = 0$, and no long-run production takes place. Case (b) occurs at MSY. Binkley (1985) has shown that the MSY rotation occurs at a price of

$$p = \frac{c}{v}\left[\frac{1}{1 - \frac{1 - e^{-it}}{it}}\right] \qquad 1.6$$

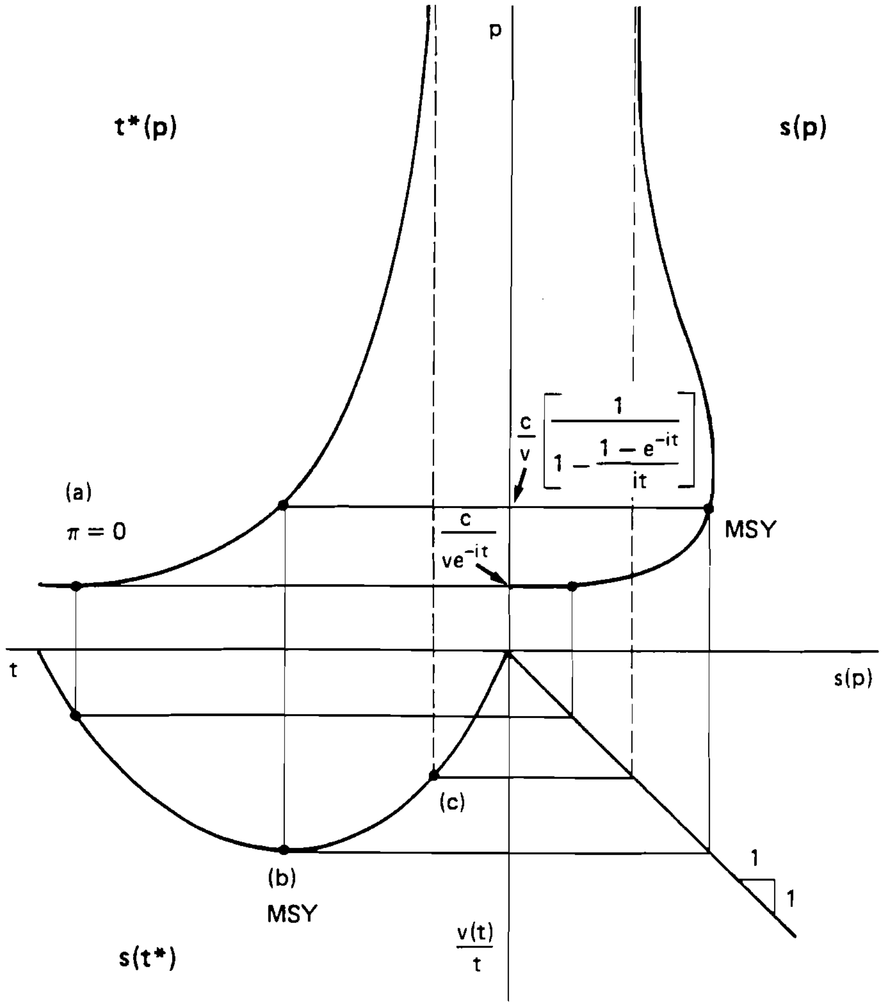

FIGURE 2. Long run timber supply.

Case (c) occurs at the quantity asymptote of the supply curve. To see this asymptote, refer to 1.2. Note that as $p \rightarrow \infty$, the ratio of c/p approaches 0. The left hand side of 1.2 approaches $\dot{v}/v$, and the supply curve grows increasingly inelastic at a price determined by the interest rate and the biological productivity of the forest.

From Figure 2, it is clear that the supply curve can have a negative slope. In general, what is the price elasticity of supply implied by this model? By definition, the price elasticity is

$$\varepsilon_p = \frac{ds}{dp} \cdot \frac{p}{s} = \frac{ds}{dt} \cdot \frac{dt}{dp} \cdot \frac{p}{s} \qquad 1.7$$

Since

$$\frac{ds}{dt} = \frac{\dot{v}t - v}{t^2} \text{ , and} \qquad 1.8$$

$$\varepsilon_p = \frac{dt}{dp}\left[\frac{\dot{v}}{v} - \frac{1}{t}\right]p \text{ .} \qquad 1.9$$

It is well known that $\frac{dt}{dp}$ is negative, so the sign of the long run supply elasticity depends on the sign of $\dot{v}/v - 1/t$. If the price level is such that $\dot{v}/v < 1/t$, then the price elasticity of supply is positive. Recall that this condition obtains only if the optimal rotation age is greater than the MSY rotation. Consequently, only if the optimal rotation is longer than MSY will the long run supply curve have the usual positive slope. Otherwise, the supply curve will have a negative slope. The "backward bending" supply phenomenon has been noted by Clark (1976) for the case of fisheries, and in passing by Hyde (1980) for the case of timber (although his empirical examples do not reveal this situation).

Before turning to questions of market equilibrium, note that if prices are so low that $\pi < 0$, no production at all will occur in the long run. High enough costs on interest rates can clearly lead to a situations where all production occurs on the negatively sloped part of the supply curve. Thus, unlike Clark's (1976) fisheries example, the entire long run timber supply curve might have a negative slope. This occurs because inputs are required to produce timber, where Clark (1976) takes the fishery to be wholly self reproducing.

Market Instability

For an *open access* fishery, Clark (1976) points out that the backward bending supply curve can lead to unstable market equilibria. Figure 3 shows the situation for *competitive* timber supply with three levels of demand. The lowest level of demand, D_1, corresponds to the usual sort of market equilibrium, and the stability of E_1 depends on well-known elasticity and adjustment conditions. At a slightly higher level of demand, D_2, three market equilibria exist, and it is easy to see that E''_2 is unstable. Short run timber demand is thought to be very inelastic. Long run demand is likely to be more elastic but if it remains fairly inelastic, then the price level associated with the equilibrium point E'''_2 could be much higher than that associated with E'_2. The market instability implied by this analysis would then translate into dramatic price instability. Finally, if the market equilibrium settles at E'''_2, the increase in demand from D_1 to D_2 is accompanied by a decrease in consumer's surplus.

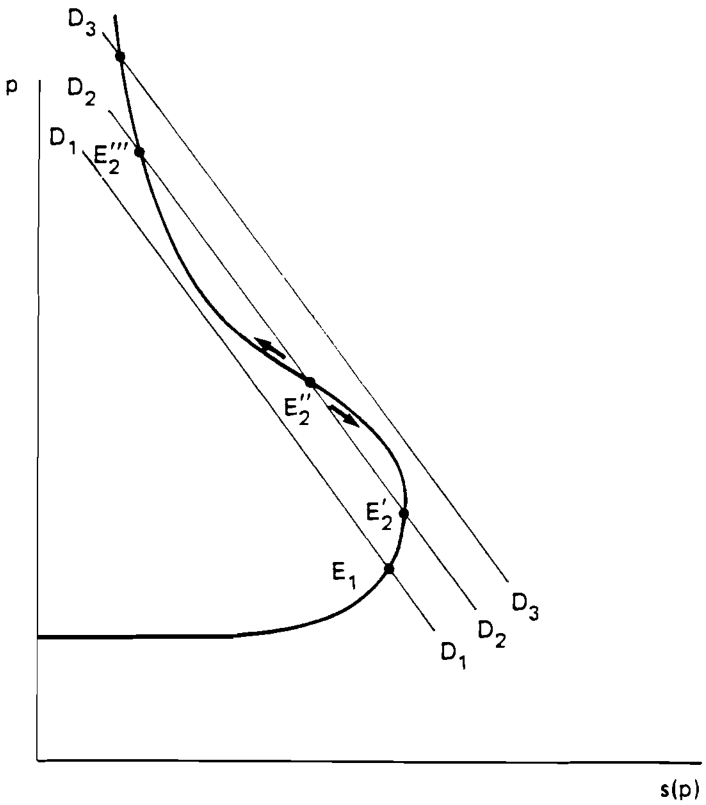

FIGURE 3. Instability in long-run timber markets.

2. INVENTORY ELASTICITY

In this supply model, timber supply is implicitly a function of timber inventory level. Many forest sector models use the level of timber inventory as a determinant of timber supply behavior (e.g. Adams and Haynes, 1980; Binkley and Cardellichio, 1985). Consequently it is of some interest to examine how supply responds to inventory level in this long run model.

The inventory of a unit area, steady state forest is

$$I = \frac{1}{t} \int_0^t v(z)dz \qquad 2.1$$

This inventory can be increased in three general ways. The first two cases reflect exogenous changes in the inventory, where the third incorporates endogenous inventory changes.

The first way to alter the inventory adds to the forest another unit of land which is identical to that already in production. Alternatively, the yield function can be increased by a constant fraction at all ages. In both cases it is obvious that the inventory elasticity is 1 because both supply (1.3) and inventory (2.1) are augmented by precisely the same amount.

The third, more interesting, case alters the inventory endogenously by changing some parameter – i, c or p – so that the optimal rotation age changes. An "apparent" inventory elasticity of supply can be calculated. This elasticity is termed an "apparent elasticity" because both the change in supply and the change in inventory are due to the exogenous change in some other model parameter.

By definition the inventory elasticity ε_I is

$$\varepsilon_I = \frac{\mathrm{d}s}{\mathrm{d}I}\cdot\frac{I}{s} \tag{2.2}$$

which can be rewritten

$$\varepsilon_I = \left[\frac{\mathrm{d}s}{\mathrm{d}t}\cdot\frac{1}{\frac{\mathrm{d}I}{\mathrm{d}t}}\right]\frac{I}{s} \tag{2.3}$$

From 2.1.

$$\frac{\mathrm{d}I}{\mathrm{d}t} = \frac{v - I}{t} \tag{2.4}$$

Substituting the value of $\frac{\mathrm{d}s}{\mathrm{d}t}$ from 1.8 and rearranging gives

$$\varepsilon_I = \left[\frac{\dot{v}}{v} - \frac{1}{t}\right]\frac{\int_0^t v(z)\mathrm{d}z}{(vt - \int_0^t v(z)\mathrm{d}z)} \tag{2.5}$$

Because $\dot{v} > 0$, $v(t)t > \int_0^t v(z)\mathrm{d}z$ for all values of t, and the numerator of the second term in 2.5 is positive. Thus the sign of the apparent inventory elasticity depends on the sign of the term in brackets. This term is positive if $t^* < MSY$, zero if $t^* = MSY$, and negative if $t^* > MSY$. The apparent inventory elasticity is positive for short rotation, falls to zero at *MSY* and then becomes negative.

At any point along the long run supply curve, the price and inventory elasticities will have opposite signs (except at *MSY* where they are both identically zero). Most supply studies take both elasticities to be positive.

Timber supply studies which employ inventory as an independent variable generally use one of two approaches to estimate the requisite elasticity. First, because time series data on timber inventory levels are frequently poor (and inventory would probably change only gradually over time in any case), it sometimes is not possible to obtain usuable statistical estimates for an inventory term. In such cases the supply variable can be recaste as the ratio of harvest to inventory, and the inventory variable omitted from the independent variables. This specification implicitly constrains the inventory elasticity to be unity. To see this, consider a supply function specified as

$$\frac{s}{I} = f(p, X) \tag{2.6}$$

or

$$s = f(p, X)I \tag{2.7}$$

where X is vector of nonprice independent variables thought to affect supply. The inventory elasticity of supply in this model is

$$\frac{ds}{dI} \cdot \frac{I}{s} = f(p, X)\frac{I}{s} = 1 \tag{2.8}$$

In some US regions, Adams and Haynes (1980) use this specification for softwood timber supply. The Data Resources, Inc. FORSIM softwood sector model uses this specification in all regions as does the model of the US hardwood lumber sector developed by Binkley and Cardellichio (1985). Using a unitary inventory elasticity is consistent with the first two kinds of inventory elasticities discussed above.

For some regions, Adams and Haynes (1980) were able to estimate softwood stumpage supply equations with inventory as an independent variable. For the regions where this was possible, they obtained estimates ranging from 0.2 to 1.46, with perponderance of values near 0.5. As shown in section 4, these results are not empirically inconsistent with the third case examined if timber rotations are less than *MSY*.

3. CAPITAL : OUTPUT RATIO

Because of the long time period involved in forest production, capital is a critical input. The capital stock required for a steady state forest can be measured in several ways, and the present analysis uses perhaps the most conservative definition.

This definition can be developed most easily using a continuous time model of the timber production process. In each period the net income for a unit of forest can be decomposed into three parts:

$p\dot{v}$ = gross income 3.1a

ipv = opportunity cost of the growing stock 3.1b

r = land rent 3.1c

In this context, the net present value function can be written as

$$\pi(t) = -c + \int_0^t p\dot{v}(z)e^{-iz}dz - \int_0^t ipv(z)e^{-iz}dz - \int_0^t re^{-iz}dz \tag{3.2}$$

Before using these definitions to derive the capital:output ratio, let us show that 3.2 is equivalent to 1.1. First, integrate the first integral in 3.2 by parts

$$\int_0^t p\dot{v}(t)e^{-iz}dz = pv(t)e^{-it} + \int ipv(z)e^{-iz}dz \qquad 3.3$$

Now substitute 3.3 into 3.2 to get

$$\pi(t) = -c + pv(t)e^{-it} + \int_0^t re^{-iz}dz \qquad 3.4$$

Efficient land markets imply that r adjusts so $\pi = 0$ (see Samuelson, 1976 on this point). Integrating the last term of 3.4 and imposing this condition implies

$$\frac{r}{i} = \frac{-c + pv(t)e^{-it}}{1 - e^{-it}} \qquad 3.5$$

The term on the left hand side of 3.5, r/i, is simply the capitalized value of land rents, and corresponds to the economic rent we seek to maximize in 1.1. Thus 4.2 is precisely equivalent to the original problem. Casting the problem as a continuous input/continuous output problem gives precisely the same results as the more conventional point input/point output formulation.

The continuous formulation is useful because it highlights the role of capital in timber production. In this context, 4.1b comprises the most limited definition of capital possible. That is, treat regeneration costs as "labor", and land rental costs "land" (although land has adequate durability to be viewed as a form of capital).

In the steady state forest the current annual value of the average capital deployed k is

$$k/yr = \frac{ip}{t}\int_0^t v(z)dz \qquad 3.6$$

Capitalized over perpetuity at rate i, the capital deployed in a steady state forest becomes

$$k = \frac{p}{t}\int_0^t v(z)dz \qquad 3.7$$

By 1.3, the annual income from the forest is

$$y = p \cdot s(p) = \frac{pv(t)}{t} \qquad 3.8$$

The capital : output ratio k/y is then

$$\frac{k}{y} = \frac{\int_0^t v(z)dz}{v(t)} \qquad 3.9$$

Suppose that the discount rate i increases. How does the capital/output ratio respond? The rotation will decrease (see, for example, Chang, 1983), and by 2.4 the value of the capital embodied in the inventory of growing stock will decline. Output may increase or decrease with the change in rotation, so the direction of the change in k/y is ambiguous. The loblolly pine example developed below shows that for most rotations of interest, $\frac{d\frac{k}{y}}{dt}$ is positive, so increases in interest rates will lead to reduction in the use of capital per unit output.

4. AN EXAMPLE: SI 80 LOBLOLLY PINE

While the foregoing theoretical analysis provides some definitive results concerning the nature of the long run supply curve for timber, the practical importance of some of the theoretical concerns is not readily apparent. To provide a modest degree of empirical insight into the nature of this timber supply model, this section presents an example using yield information for SI 80 loblolly pine.

To ease the numerical burden of the example, the cubic foot/acre yields given by Schumacher and Coile (1960) were fit to a two-parameter yield equation

$$\ln[v(t)] = \underset{(6.31.4)}{8.8216} - \underset{(46.2)}{23.512/t} \qquad R^2 = 0.998, \quad n = 6 \tag{4.1}$$

The numbers in parentheses are the t-statistics for the null hypothesis that the associated coefficient is zero. For the purposes of this example, ordinary least squares regression produced an acceptable fit to the yield table.

For this example, regeneration costs \$50/acre and the interest rate equals 0.025. Binkley (1985) has shown that for the long run supply curve to have any positively sloping portion, the interest rate must be less than the inverse of the *MSY* rotation. Applying 1.4 to 4.1 shows a *MSY* rotation of 23.5 years, so the interest rate must be less than 1/23.5=0.043 to show the general case of where the supply curve has first a positive slope at low prices then a negative slope at higher prices. A comparatively low rate of $i = 0.025$ was taken in order to illustrate the general principles involved. Indeed it is of some interest that more realistic interest rates would produce supply curves which are either almost perfectly inelastic or slope backwards throughout their entire range.

Figure 4 shows the long run supply curve for this situation. For rotation ages ranging in 1 year increments from 1 to 50, 1.5 was solved for the price which makes that rotation age optimal (for $t < 19$, the $p(t^*) < 0$). Supply at each price was determined from 1.3. Figure 4 plots the results of these calculations. The initial part of the curve slopes upward until the price rises to the point that *MSY* is reached. Under the assumptions of this example, *MSY* occurs at a price of 0.082/cf, or about \$6.40/cd. The curve is asymptotic at a quantity of about 103.5 cf/ac/yr, or at a supply level which is about 98% of the *MSY* supply. For $p < 0.0360$, $\pi < 0$ and no long run production occurs. This price corresponds to an optimal rotation age of 30 years.

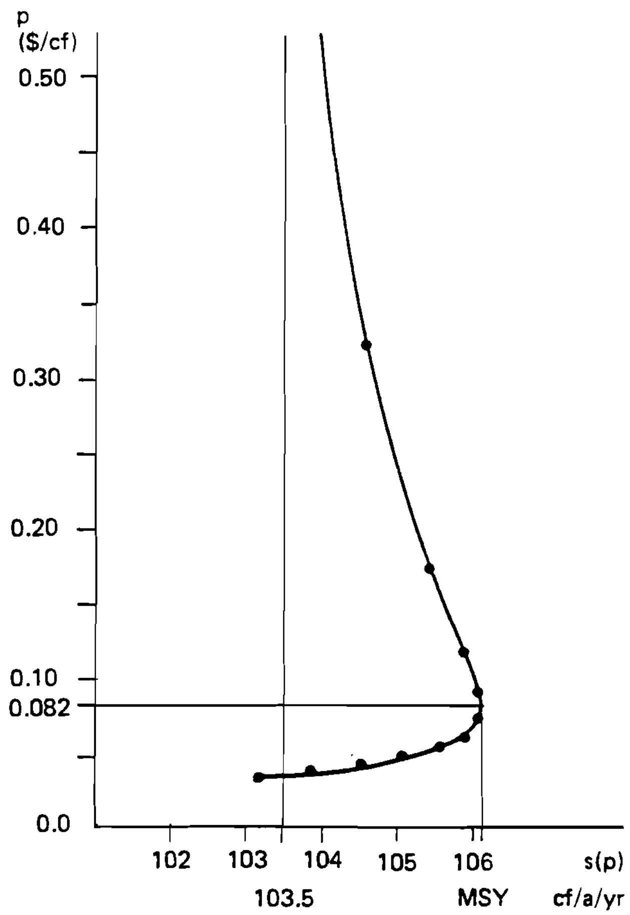

FIGURE 4. Long-run supply, SI 80 Loblolly pine (c = \$50/a, i = 0.025).

Figure 5 plots the price elasticity as a function of price level. This curve was derived numerically from 1.5 and 1.9. Nowhere is the supply curve very elastic. It is perfectly inelastic at MSY and again at the quantity asymptote.

Figure 6 shows the "apparent" inventory elasticity as a function of the rotation age. At the quantity asymptote, the apparent inventory elasticity is 2.88, falling to 0.0 at *MSY* and to −5.7 when timber production is no longer economic. The empirical results from the short-run timber supply studies cited in section 2, above, fall close to the present results near *MSY*.

Finally, Figure 7 shows the capital : output ratio as a function of the rotation age. At *MSY*, the ratio is about 10 and at the quantity asymptote the ratio is about 7. In 1980, the ratio of reproducible fixed assets to value added for all US manufacturing industry was 0.34 (UN, 1981, Tables us 2.15 and us 4.3). Even using the perhaps the most restricted definition of capital possible, timber production requires two orders of magnitude more capital per unit output than does the US industrial sector takes as a whole.

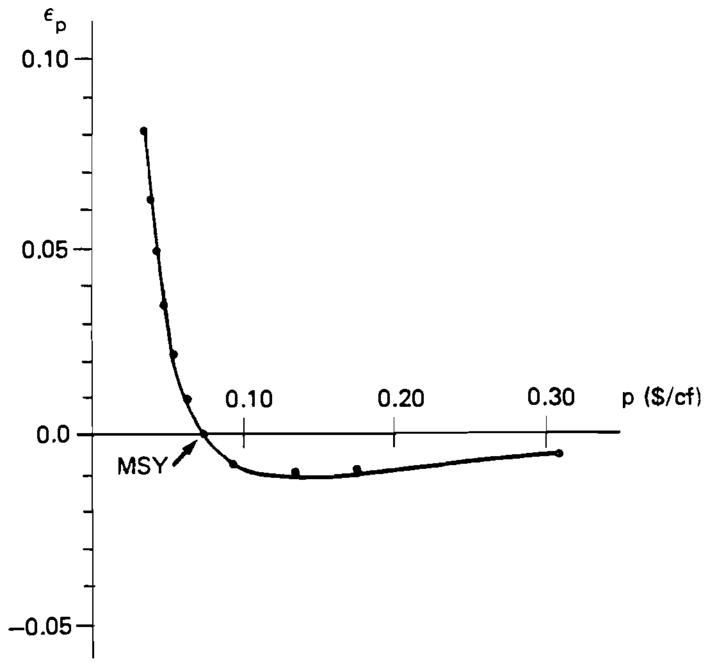

FIGURE 5. Long-run price elasticity, Loblolly pine (c = $50, i = 0.025).

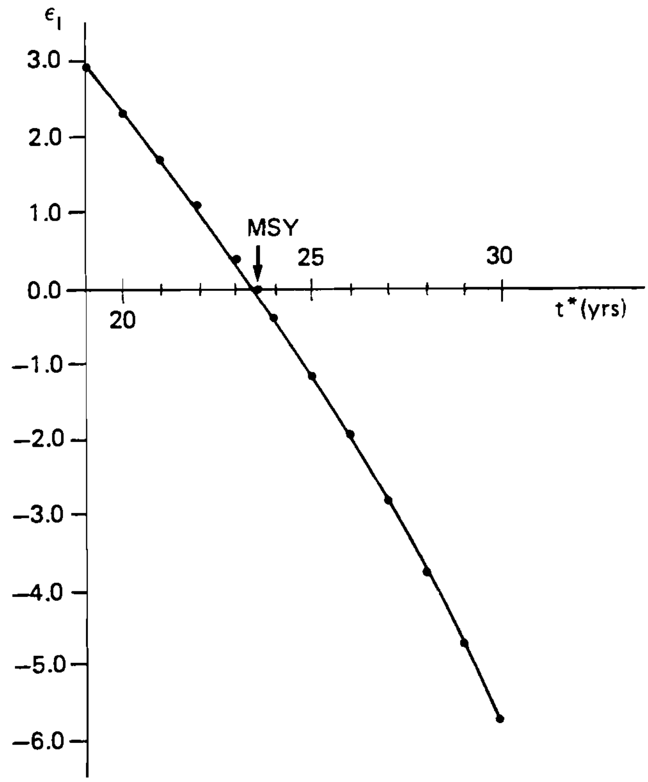

FIGURE 6. Inventory elasticity, Loblolly pine (c = $50/a, i = 0.025).

Throughout the range shown in Figure 7, $\frac{d\frac{k}{y}}{dt}$ is positive. As one would expect, increases in capital costs will lead to less capital used per unit of output. Until age 7 the converse is true, however.

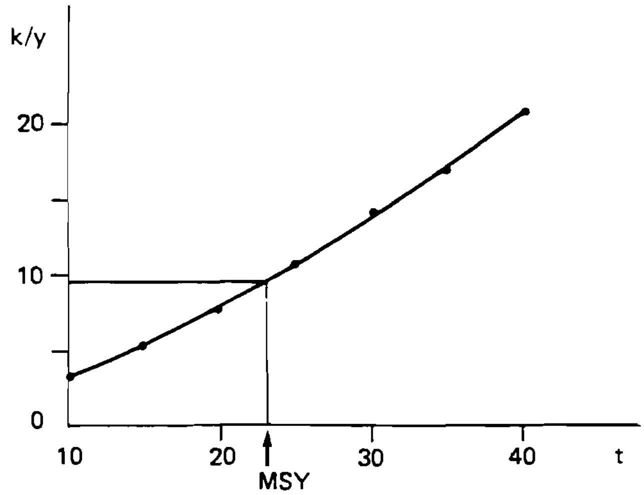

FIGURE 7. Capital : output ratio, SI 80 Loblolly pine (c = \$50/a, i = 0.025).

5. CONCLUSION

Capital is a major component of forest production costs. By determining the amount of growing stock inventory, the rotation length largely determines the quantity of capital used in a timber enterprise. The rotation age also strongly influences the average output from the forest. High stumpage prices imply not only that the output from the forest has a high value, but also that capital in the form of growing stock has a high opportunity cost. At high prices it is optimal to conserve on the use of capital, and therefore to reduce the growing stock inventory by reducing the rotation age. This kind of capital conservation can also reduce forest growth. In the long run, timber supply can therefore fall as a consequence of higher timber prices. Higher output prices inevitably mean higher capital costs, and the timber supply curve bends backward as a result of the necessity to reduce these costs. Market instability may result from this unusual cost structure for timber production.

These conclusions are of course strictly correct only under the many assumptions necessary for such concise and unambiguous results. Two important market adjustments have been ignored in the analysis: changes in management intensity and changes in the area of land devoted to timber production. Both kinds of adjustments make timber supply more elastic than found here, particularly at low prices where there is much latitude for intensifying silvicultural practices or for extending the intensive and extensive margins of timber production. As a forest sector develops, however, the opportunity for these adjustments will diminish, and capital will tend to dominate the timber production cost structure. The structural problems for the sector associated with inelastic or backward bending supply will then appear.

REFERENCES

Adams, D., and R. Haynes. 1980. The 1980 Softwood Timber Assessment Market Model: Structure, Projections, and Policy Simulations. *For. Sci.* Mono 22.

Binkley, C.S. 1983. Long Run Timber Supply for the Spruce-Fir Region of Maine. Prepared for the James Sewall Co., Old Town, ME.

Binkley, C.S. and P.A. Cardellichio. 1985. The US Hardwood Assessment Market Model. draft ms.

Bowes, M.D., J.V. Krutilla, and P.B. Sherman. 1984. Forest Management for Increased Timber and Water Yield. *Water Resources Research* 20:655-663.

Chang, S.J. 1983. Rotation Age, Management Intensity and the Economic Factors of Timber Production: Do Changes in Stumpage Price, Interest Rate, Regeneration Cost and Forest Taxation Matter. *Forest Science* 29:267-277.

Clark, C.W. 1976. *Mathematical Bioeconomics*. New York: John Wiley & Sons.

Davis. K. 1974. *Forest Management*. New York: McGraw-Hill.

Hantman, R. 1976. Harvesting Decision When a Standing Forest Has Value. *Economic Inquiry* 14:52-58.

Hyde, W.F. 1980. *Timber Supply, Land Allocation and Economic Efficiency*. Baltimore: Johns Hopkins Press.

Jackson, D.W. 1980. *Microeconomics of the Timber Industry*. Boulder: Westview Press.

Robinson, V.S., A.A. Montogomery, and J.D. Strange. 1981. Economic Growth Goal for Timber in the Southeast. *For. Prod. J.*, 31:69-76.

Samuelson, P.A. 1976. Economics of Forestry in an Evolving Society. *Economic Inquiry* 14:466-492.

Schumachon, F.X. and T.S. Coile. 1960. *Growth and Yield of Natural Stands of the Southern Pines*. Durham, NC: T.S. Coile, Inc.

United Nations. 1981. *1981 Yearbook of National Accounts*, v. II. New York: UN Publications.

USDA Forest Service. 1963. Timber Trends in Western Oregon and Western Washington. Pac. N.W. Forest & Range Exp. Stat. Res. Pap. PNW-5.

Vaux, H.J. 1954. Economics of Young-Growth Sugar Pine Resources. Univ. Calif./Berkeley, Div. of Ag. Sci. Bull. 78.