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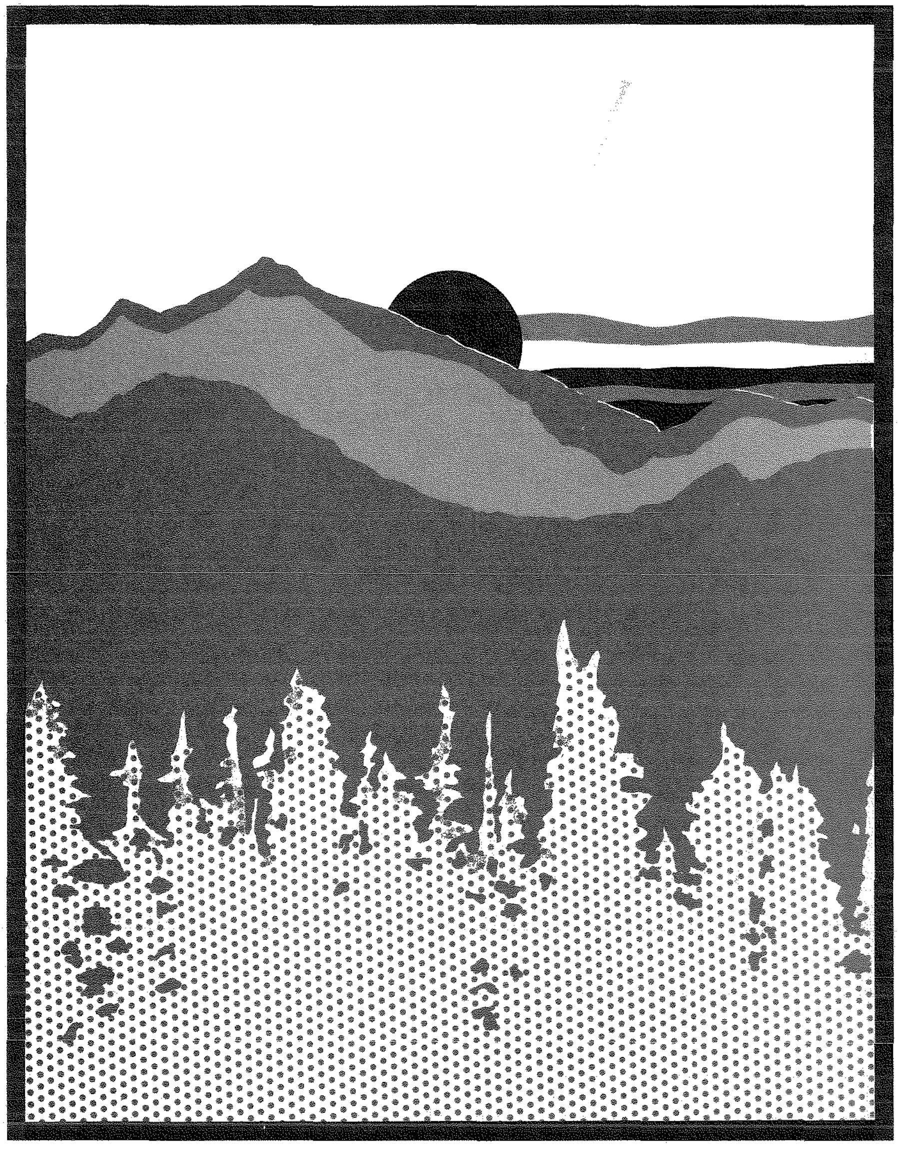

Problems of Resource Utilization

WINTER 1978

An Economic Alternative to Current Public Forest Policy

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A debate is currently raging among foresters as to the appropriate criteria to be used in managing the nation's publicly-owned forest lands, so as to meet the nation's growing demand for timber while also increasing their nontimber outputs. The latter outputs include outdoor recreation, wildlife protection and water storage—uses which sometimes appear to conflict with timber production. The controversy has been sparked by the recent sharp rise in timber prices, and by the expectation that prices will continue to rise in excess of the overall inflation rate if timber supplies continue to be limited by public-forest management policies and environmental pressures. Actions which reduce the supply of timber in the face of rising demand, and thereby raise the price of forest products, can strongly affect the implementation of the nation's housing goals, since nearly one-half of the nation's total output of softwood sawtimber is used for residential construction.

Specifically, the controversy centers around the "non-declining even-flow" harvest policy presently followed by the Forest Service and other governmental agencies in determining the allowable cut on public forest lands. The controversy has important implications with regard to timber supplies, forestry investments, and the allocation of forest land among competing uses. Critics of the even-flow policy argue that it does not accomplish its stated objectives of promoting local forest-community stability and curbing the inflation in lumber prices. Because this policy generates a relatively constant supply of public timber, it can contribute to instability in forest-community employment during periods of declining private harvests and can also aggravate the inflation in timber and lumber prices during periods of sharply rising demand. Again, in the critics' view, the current policy results in an inefficient management of forest lands. They believe that the introduction of economic-efficiency criteria in the harvest and investment decision-making process, as a replacement for the "biological maximization" principles currently followed, might not only increase the financial returns on publicly-owned lands but also permit far greater yields of timber and nontimber outputs than are envisioned under current management strategies.

This article examines the rationale, mechanics and implications of the non-declining even-flow policy presently used in scheduling public timber harvests. Further, it contrasts this policy with an economic approach to harvest and investment determination which seeks to earn the highest net financial return on public holdings consistent with other social objectives. Section I discusses the characteristics of the nation's publicly-owned forest land base and softwood-timber inventory. It contrasts the harvest and growth rates realized on National Forest lands with those realized on private forest-industry lands, which are managed by large integrated forest-product firms operating with a profit-maximization goal. Section II shows that the differences in performance are attributable in part to the biological approach to timber management followed by government agencies on public-forest lands. In this section, the current process of harvest and investment determination on public lands is discussed in detail. Section III outlines an alternative economic approach which seeks to maximize net financial return on public timber holdings. This section demonstrates how it might be possible—through an improved allocation of available land and other resources—to raise timber output yet still accommodate the demands of environmentalists for increased withdrawal of land from timber harvest. The entire analysis—and the entire debate—is confined to softwood timber—the species generally used for construction and paper manufacturing.

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I. Public Forest Characteristics

According to the latest (1970) inventory of U.S. timber resources, the United States contains about 500 million acres of "commercial" forest land, defined by the Forest Service as land which is producing or capable of producing more than 20 cubic feet of industrial wood per acre per year in stands that are not withdrawn from timber harvest.[1] Industrial wood includes wood suitable for lumber, plywood, pulp, paper and all other uses except fuelwood. The phrase "withdrawn from timber harvest" means the exclusion of areas reserved from cutting by law, such as national parks or wilderness areas. Commercial forest land constitutes about one-third of the total land area of the United States, making it a major form of land use.

Only about one-quarter of this land is publicly-owned, but on that land stands 58 percent of the nation's total inventory of softwood growing stock—wood measured in cubic feet, inherent in trees at least five inches in diameter at breast height.[2] The preponderance of this public timber is located on National Forest land owned by the Federal government and managed by the Forest Service (Table 1). The remainder of the publicly-owned timber is located on lands under the jurisdiction of the Bureau of Land Management and other Federal, state and county agencies. The 42 percent of the total softwood inventory under private ownership is about equally divided between the forest-products industry and "other private" owners (such as farmers).

Most of the National Forests and other publicly-owned lands are located in the Pacific Coast and Rocky Mountain states. This Western region contains three-fourths of the nation's total (public and private) softwood growing stock—compared with only 18 percent held by the South, the next most important region. Because of the West's importance both as the leading timber-producing region and as the location of most of the nation's publicly-owned timber, it has provided the focal point for the controversy over forest-management policies. Pressures to increase harvest rates are doubly strong in this region because most of the Western timber is slow-growing old-growth timber, and because harvest rates under present policy are dependent upon growth.

Public vs. private

In the West, National Forests contain nearly two-thirds of the region's total softwood-timber inventory, compared with only 13 percent for forest-industry lands (Table 2). Yet in 1970, National Forests supplied no more timber than forest-industry lands—around 38 percent of the total. Over the entire 1952–70 period, the volume of softwood growing stock in Western National Forests declined by less than 1 percent, com-

Table 1
U.S. Commercial Forest Land and Softwood Growing Stock, by Ownership Class, 1970*

	Commercial Forest Land		Softwood Growing Stock	
Ownership Class	Area (Million acres)	Percent of Total	Volume (Billion cubic ft.)	Percent of Total
National Forest	91.9	18.4	199.8	46.3
Other Public	44.2	8.8	48.4	11.2
Forest Industry	67.3	13.5	73.2	16.9
Other Private	296.3	59.3	110.5	25.6
All Ownerships	499.7	100.0	431.9	100.0

*Note: Western national forests account for 76.9 percent of all national-forest acreage and for 94.5 percent of all national-forest softwood growing stock.
Source: U.S. Department of Agriculture, Forest Service, *Forest Statistics For the United States, by State and Region, 1970.*

pared with a 22-percent decline for forest-industry lands. The annual removals per acre on National Forest lands were only one-fifth those on forest-industry lands, and inventory turnover rates showed similar results.

The productive potential of Western National Forest lands—measured as the amount of timber the land would be capable of producing per acre per year if fully stocked with natural stands—is considerably below the average for forest-industry lands. This reflects the fact that National Forests were established after private industry had acquired some of the more productive lands. But their annual growth is low even in relation to their own potential growth. In 1970, the actual growth realized on National Forests represented only 31 percent of productive capacity, compared with 52 percent for forest-industry lands. Thus, while neither ownership class is growing wood at anywhere near full potential, the growth rate realized on National Forest lands is particularly low.

This relatively low growth rate partly reflects a conservative harvest policy, which has led to a heavy preponderance of virgin timber on public lands. The old-growth stands on these lands typically show little net growth, partly because of advanced age but also because of high mortality and decay losses. But the difference in growth rates also reflects the fact that National Forests are less intensively managed than industrial lands; that is, less labor and new investment are applied per acre to bring actual growth closer to productive potential. That condition in turn may be due to the fact that the Forest Service not only has less money per acre to spend on timber management, but also allocates those funds in a way that does not maximize productivity gains. For example, National Forests show very little correlation between their management expenditures and their cash receipts from the sale of timber.[3]

Public forest managers argue that their conservative harvest policies are necessary to meet the multiple-use objectives of the public forests, to conserve forest resources for future generations, and to ensure a sustained yield of timber products over the long-run. They argue further that increased timber harvests might conflict with the restrictive goals of environmental protection. Finally, they contend that management of public forest lands for maximum economic return would adversely affect the income of private forest owners.[4]

Critics agree that public forest lands should not be managed solely for profit—that social as well as economic objectives must be satisfied in their management. But they maintain that these objectives are not inconsistent with the applica-

Table 2
Production Indicators For National Forests and Forest-Industry Forests, Western Region*

Wood Production Indicator (1970)	National Forests	Forest-Industry Forests
Inventory (billion cu. ft.)	189.8	41.3
Inventory as percent of regional total	60.4	13.1
Annual removals (billion cu. ft.)	1.9	1.9
Annual removals as percent of regional total	38.0	37.8
Annual harvest as percent of inventory	1.0	4.6
Annual removals per acre (cu. ft.)	27.3	136.2
Estimated productive capacity (cu. ft./acre)	80.0	120.1
Growth achieved in 1970 (cu. ft./acre)	24.6	61.9
Actual growth as percent of productive capacity	30.8	51.5
Change 1952–70		
Annual growth per acre (cu. ft.)	3.6	9.7
Annual removals per acre (cu. ft.)	15.6	−3.1
Inventory (percent)	−0.5	−21.6

*Data refer to softwood growing stock in national forests (containing 71 million acres of commercial forest land) and in forest-industry forests (containing 14 million acres of commercial forest land).
Source: U.S. Department of Agriculture, Forest Service, *Forest Statistics for the United States by State and Region, 1970.*

tion of economic-efficiency criteria to timber management—that, in fact, these criteria should be applied to all management decisions involving alternative outputs and land uses. The use of economic-efficiency criteria would not only increase returns to the public treasury from timber growing and selling, but it would also maximize the timber and non-timber outputs possible with available resources. These critics claim that inefficiencies are involved when the National Forests, with an estimated asset value of $42 billion, are consistently operated at a loss.[5] They argue further that the benefits afforded consumers from increased timber harvests and lower forest-product prices would outweigh the loss of revenues incurred by private forest owners.

II. Current Policies in the Public Forest Sector

Public-forest management policies are guided principally by the Multiple-Use Sustained-Yield Act of 1960, the Forest and Rangeland Renewable Resources Planning Act of 1974, and the National Forest Management Act of 1976. These laws direct the Forest Service to follow the principles of sustained yield, in determining the allowable cut on National Forests. The Multiple-Use Act defines sustained yield as ". . . the achievement and maintenance in perpetuity of a high-level annual or regular periodic output of the various renewable resources of the National Forests without impairment of the productivity of the land." The National Forest Management Act, which amended the Multiple-Use Act but did not materially change the Forest Service's interpretation of sustained yield, states that "the Secretary of Agriculture shall limit sale of timber from each National Forest to a quantity equal to or less than a quantity which can be removed from such a forest annually in perpetuity on a sustained-yield basis."

Harvest determination

In the Forest Service's view, the concept of sustained yield requires that, at the earliest practicable time, an approximate balance be reached between net annual growth and harvest to prevent a decline in the timber inventory. The key to achieving that balance is the establishment of a "regulated forest" with an even distribution of age classes, each of approximately the same acreage. Then, every year, the oldest age class can be cut, with that cut just matching the annual growth of the other classes.

The profile of a fully-regulated forest—the long-term objective of the sustained-yield model—is depicted in Chart I-A and Appendix A. In this example, it is assumed that the forest consists of 210,000 acres of Douglas-fir with the growth characteristics specified later in Table 3. The total forest is divided into seven stands of equal area (30,000 acres), ranging in age from one to seven decades. It is assumed that this type of timber is mature—i.e., ready for cutting—after seven decades under the biological criteria used by the Forest Service. Thus, one-seventh of the total area could be cut every decade, with the growth of the other areas just compensating for that loss of volume. Once harvested, the cutover area would be replanted shortly thereafter and the harvest and replanting cycle continued, leading to a steady periodic output.

The problem with the use of this model in the West is that regulated-forest conditions do not exist in old-growth forests where there is a heavy preponderance of overmature timber. To achieve the desired distribution, large tracts of old-growth timber must be liquidated and restocked with second-growth stands. Under the principle of sustained yield, the key forest-management question concerns the rate at which old-growth timber should be liquidated to convert the forests to a regulated state—a state where growth and cut would be in approximate balance. The U.S. Forest Service has adopted a very conservative harvest policy, based on a non-declining even-flow strategy, which critics contend allows timber to grow far past the point of optimal financial maturity.

Under present Forest Service policy, the first step toward determining the allowable cut for any given National Forest is to determine the appropriate land base upon which the cut would apply. The fundamental unit is not the entire National Forest but rather the segment available for timber production known as "commercial" forest land—that is, the portion remaining after the subtraction of non-forest land, unproductive forest land, "productive deferred" and "productive reserved" lands. The productive reserved component includes designated wilderness and scenic and geologic areas which otherwise would qualify for the commercial component. The productive deferred component includes all areas under study for possible inclusion in the reserved category. Under the present harvest-determination system, the withdrawal of productive land for wilderness or wilderness-study classification thus reduces the area available for determining the allowable annual harvest.

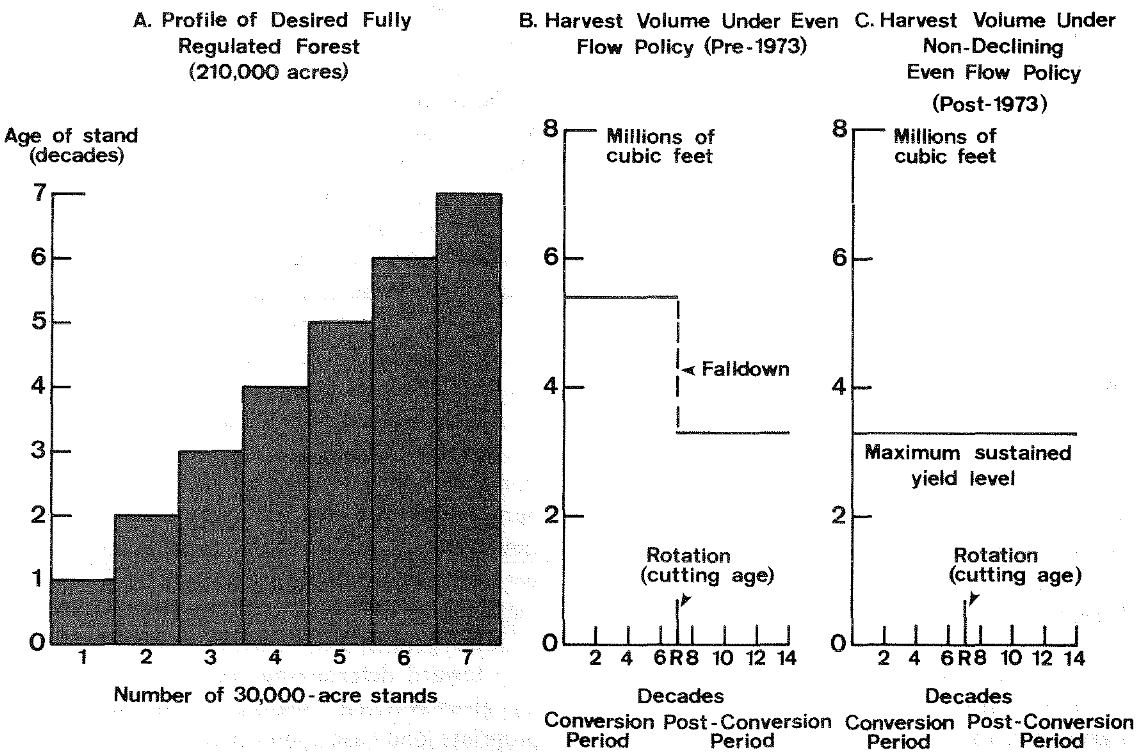
Until recent years, the Forest Service used certain formulas (such as the Hanzlik formula) to determine the allowable cut for each decade in the "commercial" areas of old-growth forests. More recently, it has shifted from the formula approach to the use of a linear programming model—Timber Resources Allocation Method (Timber Ram)—to establish its ten-year allowable cut for each forest. However, this more sophisticated approach has produced similar results to those developed through the old formula approach.

The Hanzlik formula distributes the harvest of old-growth (overmature) timber over one-rotation age—i.e., the cutting age based upon biological maximization—and then adds the expected growth in the decade for which the harvest is being determined.[6] Accordingly:

$$\text{Allowable Cut Per Decade} = (Vm/R) + I$$

Chart 1

FOREST REGULATION UNDER SUSTAINED YIELD (BIOLOGICAL) MODEL[1]



[1] Assumes biological rotation age of seven decades

Sources: See Appendix A

where: Vm = Volume of mature timber, i.e., timber at or beyond cutting age
R = Length of rotation, i.e., cutting age in decades
I = Increment in total volume, i.e., net new timber growth expected in current decade

This system is designed to convert old-growth timber stands to a regulated state while at the same time providing a regular flow of harvested timber during the conversion period, usually one rotation in length.

Strict adherence to the Hanzlik formula results in a decline, or "falldown," in the average timber harvest level during the post-conversion period, as the inventory of mature timber declines (Chart I-B). To prevent this falldown, the Forest Service in 1973 thus added another constraint to its allowable cut calculation—non-declining even flow—which requires that the allowable cut for any given ten-year period be no higher than can be maintained in perpetuity. That harvest in turn is the maximum sustained yield, i.e., the harvest for a fully regulated forest in the post-conversion period (Chart I-C). The implementation of this regulation caused a sharp decline in the allowable cut on most National Forest lands. The Forest Service's inability to cut overmature timber more rapidly also meant that those forests might never be transformed to a regulated state.

Sustained yield connotes perpetual maintenance of the productive capacity of a forest, without reference to variations in harvest within or among decades. But the Forest Service has interpreted the concept to mean small variations in annual cut, which on average for a ten-year period do not deviate significantly from the long-term average. Moreover, since 1973 it has applied an extreme version of the even flow constraint—non-declining even flow—which forbids significant differences in harvests from one decade to the next. The same philosophy governs the management of other publicly-owned forest lands, such as those administered by the Bureau of Land Management.

The supply of Federal timber under the Forest Service's present policy is depicted by the supply schedule, S_O, shown in Chart 2-A. The most important aspect of this supply function is its unresponsiveness to bid prices, since it is determined on the basis of biological factors which are independent of any cost considerations. It shows that the Forest Service will not sell timber for less than the appraised price, Pc—a price that is not predicated upon its own costs but rather upon the amount it estimates forest-product firms can pay and still earn a satisfactory profit. The Forest Service would be willing to sell up to the full amount of the allowable cut, Qo, for the appraised price, if that price were in fact all that forest product firms were willing to offer. But no matter how much extra purchasers bid for the timber, the quantity offered would remain the same at Qo. In other words, the supply is perfectly inelastic for prices beyond the appraised price Pc. During the past decade, the prices offered for Federal timber typically have been far greater than the appraised price, indicating excess demand for timber at that price. Indeed, empirical studies have verified that the total supply of softwood timber in important Western timber regions—which are heavily influenced by such public policies—is very price inelastic.[7]

The rationale for the Forest Service's non-declining even-flow policy is the maintenance of stable timber prices and stable forest-community employment. Throughout most of this century Forest Service literature has stressed the need to stabilize dependent communities by providing equal or near-equal timber offerings at all times. But many commentators have pointed out that, in a dynamic world of changing technologies and changing economic conditions, an even flow of public timber does not necessarily ensure the realization of those objectives.[8] Employment can be stabilized only if harvests are kept unchanged in both the public and private sectors—an unlikely eventuality when shifts occur in demand. In reality, if demand declines and public harvests are maintained at an even flow, the private sector will be required to make the entire supply adjustment.

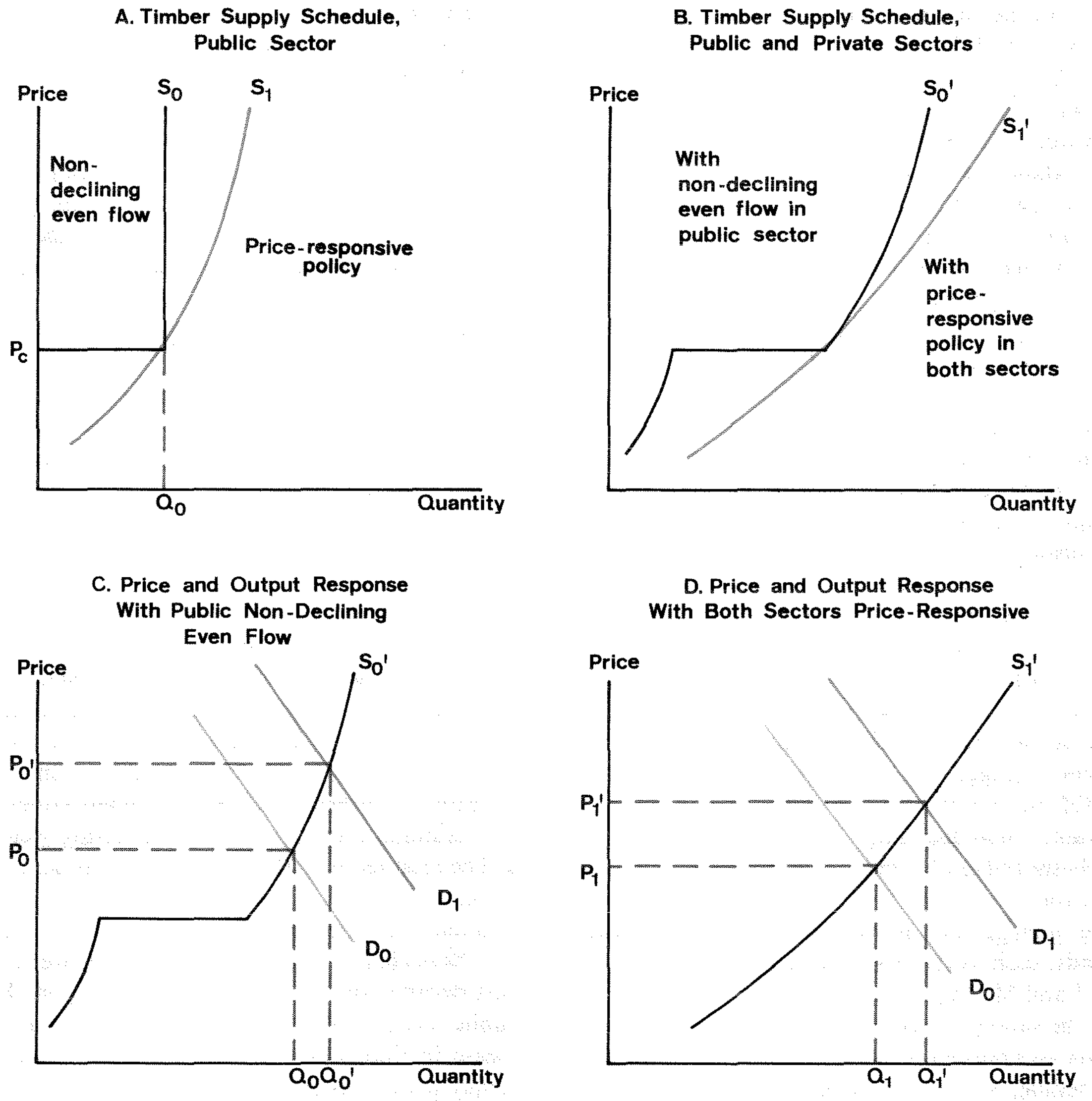
In the context of the strong demand conditions that have characterized timber markets over the past decade, an even-flow harvest policy in the public sector may actually result in a greater increase in timber prices than a price-responsive supply policy. As shown in Charts 2-C and 2-D respectively, an upward shift in demand from Do to D_1 with a public even-flow policy would have greater impact on timber prices (Po to Po') than would a shift with a price-responsive harvest policy (P_1 to P_1'). Again, in reality, the private sector is likely to react to an increase in public timber supplies by reducing its own harvest. But unless its actions totally offset those of the public sector—which is unlikely—rising demand will exert a smaller inflationary impact on timber prices with a price-responsive public harvest policy than with an even-flow policy.

Rotation age

Under any harvest policy, the rotation age—the age at which timber is cut—is a prime determinant of the allowable cut. It determines the

Chart 2

EFFECT OF SHIFTING DEMAND ON TIMBER PRICES AND OUTPUT UNDER ALTERNATIVE PUBLIC SUPPLY STRATEGIES



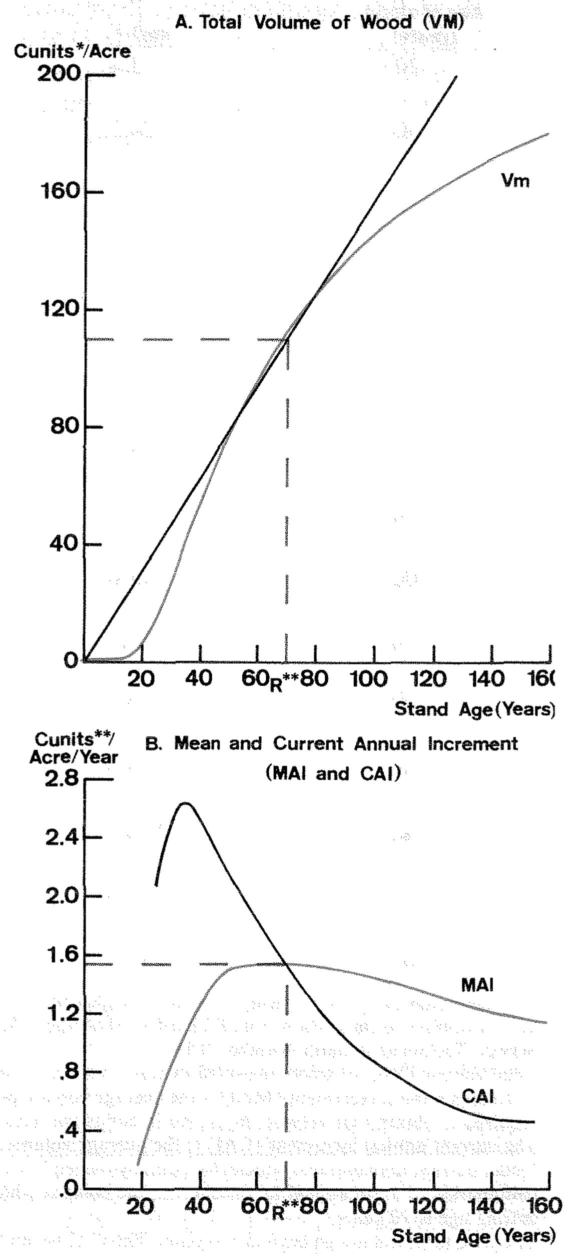
timber that is potentially available for harvest, whether the criteria be biological or economic, although the actual allowable cut may depend upon other constraints such as even flow or maximum economic return. The rotation age is also a key determinant of the rate of return earned on forest capital. Forest growing stock is forest capital: as a stand of trees grows in volume, it also appreciates in value. The period of time that a stand of trees is permitted to grow before the asset is converted to cash determines the economic return to the owner.

Nonetheless, the Forest Service establishes the appropriate rotation age for National Forest timber without reference to economic criteria. The objective is not to maximize economic return but rather the biological yield of the forest at a given level of management intensity. Consider the typical pattern of growth of a natural fully-stocked Douglas-fir stand on a one-acre parcel of land of medium fertility (Table 3). The table shows the relationship between stand age and volume of wood, known as a biological production function or yield curve. This production function also appears in Chart 3-A. The table also shows two other key factors necessary for determining the maximum sustained yield—the program which maximized the harvest of wood over the long-run. The first determinant, the mean annual increment (MAI), is the total capital stock or volume of wood divided by the number of years required to obtain that volume. The second determinant, the current annual increment (CAI), is the change in volume over a given time interval divided by the number of years in that interval. MAI is equivalent to the average physical product, and CAI to the marginal physical product (Chart 3-B).

The appropriate rotation (cutting) age for achieving maximum sustained yield is the age at which the current annual increment is equal to the mean annual increment, that is, where the mean annual increment is at a maximum. In the example shown, the appropriate rotation age is 70 years. This can be clearly seen if a long period, say 420 years, is considered. Cutting every 70 years would give six harvests of approximately 110 cunits each or a total of 660 cunits. (One cunit equals one hundred cubic feet.) No other rotation age would result in as much wood over

Chart 3

DETERMINATION OF CUTTING AGE FOR A ONE-ACRE DOUGLAS-FIR STAND UNDER BIOLOGICAL CRITERIA



*One cunit equals 100 cubic feet.

**R, rotation or cutting age, equals 70 years in this example.

Table 3
Determination of Cutting Age for a One-Acre Douglas-Fir Stand Under Biological Criteria

Age of stand (years)	Vm[1,2]	MAI[3]	CAI[4]
20	3.4	0.17	
			2.08
30	24.2	0.81	
			2.62
40	50.4	1.26	
			2.36
50	74.0	1.48	
			1.98
60	93.8	1.56	
			1.64
70	110.2	1.57[5]	
			1.38
80	124.0	1.55	
			1.10
90	135.0	1.50	
			0.96
100	144.6	1.45	
			0.83
110	152.9	1.39	
			0.70
120	160.0	1.33	
			0.57
130	165.6	1.27	
			0.53
140	170.9	1.22	
			0.47
150	175.6	1.17	
			0.45[6]
160	180.1	1.13	

[1] Normal biological growth (yield) curve for Douglas-fir trees 7 inches in diameter or larger at breast height on fully stocked acre, medium site class. Data from Richard E. McArdle, *The Yield of Douglas Fir in the Pacific Northwest,* U.S.D.A. Forest Service Technical Bulletin Number 201.

[2] Total volume (Vm) of wood measured in cunits per acre. One cunit equals 100 cubic feet.

[3] The mean annual increment (MAI) is the average volume per year—that is, the total volume divided by the number of years required to obtain that volume, measured in cunits per acre per year.

[4] The current annual increment (CAI) is the average volume added each year, measured in cunits per acre per year.

[5] Under current management policies for publicly-owned forest lands, the appropriate cutting (rotation) age is determined at the culmination of mean annual increment, i.e., the point at which the total volume/age is greatest. In this example, appropriate cutting age is 70 years.

[6] The yield table did not go beyond 160 years. The CAI beyond that age is assumed to be zero to simplify the harvest determination example shown in Appendix A.

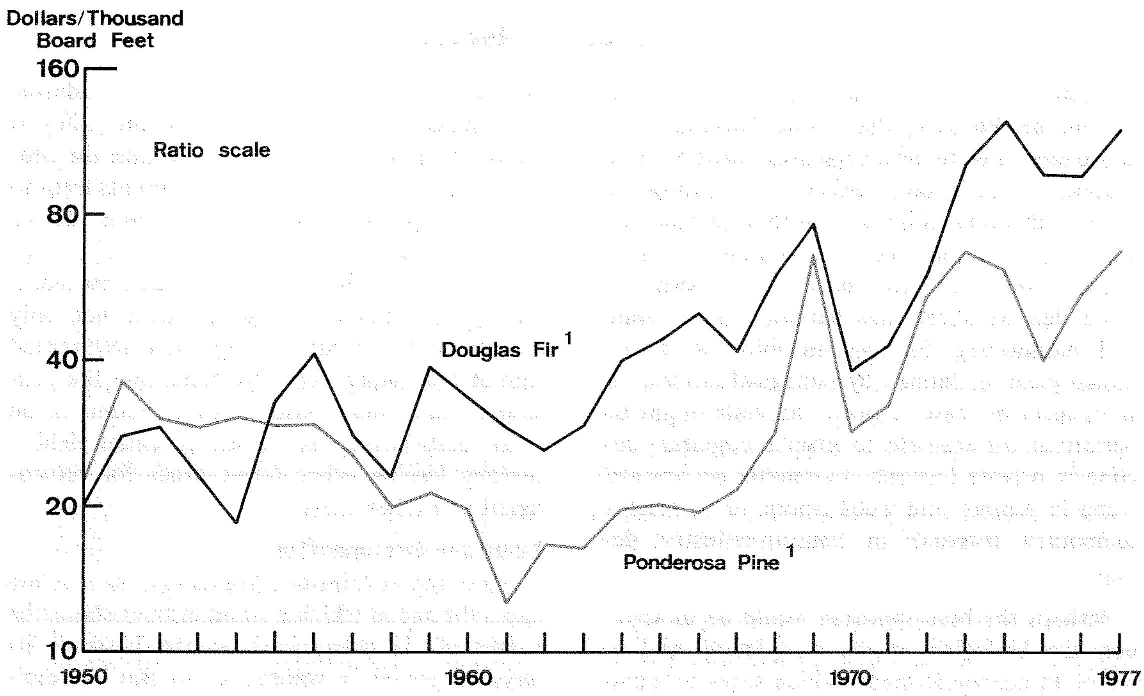
the period. For example, a rotation age of 140 years would give three harvests of 171 cunits each or a total of 514 cunits.

For any given National Forest, the allowable-cut calculation is predicated upon a given intensity of forest management. This refers to a given application of capital and labor to each acre of commercial forest land. The allowable cut can be increased if it can be shown that a more capital- and labor-intensive management "regime" is being introduced as a means of raising prospective forest productivity, i.e., timber growth per acre per year (CAI). For example, "good" management may involve fire protection and seeding and planting to fill in gaps in natural regeneration.[10] "Highest-order" management may involve those practices plus others, such as weeding, fertilization, thinning and genetic stand improvement.

Under current Forest Service policy, the intensification of management practices to bring actual productivity closer to that potentially realizable with fully-stocked natural stands would permit an immediate acceleration in the rate of liquidation of old-growth timber, even though the returns in terms of added growth would not immediately be obtained. This increase in the current allowable cut attributable to increased investment—known as the allowable-cut effect (ACE)—represents a shift to the right in the supply function under a non-declining even-flow policy (Chart 2-A). The approach has been severely criticized by the proponents of an economic approach to public timber management.[11] They argue that it leads to inefficient investment decisions, because the return on a new investment is determined not on the basis of its own growth and revenue potential, but rather on the basis of the increased revenue to be derived from cutting existing old-growth timber.

Chart 4

RELATIVE STUMPAGE PRICES FOR SAWTIMBER
SOLD FROM NATIONAL FORESTS



1 Actual prices divided by wholesale-price index (1967=100).
Source: U.S. Department of Agriculture, Forest Service, **The Demand and Price Situation for Forest Products.**

Effects on timber prices

The recent movement for change has been motivated by a growing concern over the future cost and availability of public timber if current management policies are continued. In the face of a sharp increase in demand over the 1963–77 period, the competition for available domestic softwood timber supplies has led to an intense price rise, relative to the overall wholesale price index (Chart 4). During that period, the average price for Douglas-fir sawtimber sold on the National Forests in western Washington and western Oregon rose nearly ten-fold, from $27.90 to $230.25 per thousand board feet. Deflated by the wholesale price index, the price of Douglas fir still quadrupled—and a similar pattern was evident in the price of ponderosa-pine sawtimber.

More importantly, U.S. Forest Service projections of softwood timber demand and supply to the year 2000 indicate a continuation of this severe inflation in timber prices.[12] The Forest Service study argues that, with current silvicultural practices and timber harvesting policies, demand is likely to be brought into balance with supply only under the assumption of "rising relative prices," compared with the overall wholesale price index.

The supply forecast suggests that a sharp decline in Western timber harvests will tend to offset an increase in supplies from private lands in the South.[13] This Western decline is expected to occur primarily on private lands, on the basis of the Forest Service's belief—under its biological conception of harvest determination—that private industrial owners will attempt to maintain a closer balance between growth and removals after a period of heavy inventory liquidation. Of course, if these owners respond to rising timber prices, private supplies (and total supplies) from the West could be higher than predicted. Nevertheless, the expected rapid growth in timber demand, together with the past behavior of prices, suggests that price pressures will remain strong if the Forest Service's present harvest policy is continued.

III. An Economic Alternative

Numerous strategies have been suggested to expand the Western public timber harvest, in order to ease upward price pressures. Most of these proposals have involved either 1) increasing the level of silvicultural investment to raise expected annual growth and thus the allowable cut, or 2) relaxing the even-flow constraint to permit a more flexible short-term harvest policy, while still maintaining the long-run objective of sustained-yield as defined by biological criteria. A short-term increase in public harvests might be permitted, for example, to offset a temporary decline in private harvests, to counter an upward trend in lumber and wood prices, or to meet a temporary increase in housing-industry demand.[14]

Perhaps the best approach would be to abandon the biological model completely, and to adopt an economic model which seeks to maximize net financial return, more specifically the present value of future net cash flows. This alternative in effect would subject all forest-management decisions to economic efficiency standards. Economists maintain that the present policy is inefficient in that it does not maximize the economic value of output. Rather, it permits trees to grow far past their point of maximum economic maturity, and thus results in irrational investment decisions. Proper management, by maximizing net financial return, would not only dictate a shorter rotation age and accelerated rate of harvesting—thereby benefiting the consumer—but would also focus investments on those lands having the highest potential yield—thereby freeing other forest areas for recreational and other uses.

Economic determination

Under the sustained-yield concept, the rotation age—the age at which a stand of trees should be harvested—is determined on the basis of its physical growth in volume terms. But by determining the rotation age at the point of maximum "mean annual increment," the biological model ignores the major cost of timber production—the opportunity cost of tying up the owner's capital for the next period. By failing to take account of interest on capital investment this "zero interest model" permits trees to grow past their point of maximum economic maturity.

With timber production, time is one of the chief inputs. Time is required before the timber reaches marketability. Yet timber cut and sold in the future is worth less to its owners than an equal amount available today. For that reason, investors must be ensured of an acceptable rate of return on invested capital to compensate them for foregoing benefits until a later date. Yet in the Forest Service model, timber cut 70 years from now is assumed equal in value with timber cut this year, without any consideration of the housing and other services which this year's cut will provide for the next 70 years.

What rate of return should be used in evaluating public investments? Economists generally agree that resources committed to the public sector should earn as great a return as they would earn in the private sector for investments of comparable risk—the so-called "opportunity cost of capital."[15] But there is less agreement about the amount of risk inherent in the public sector, and about the proper private sector rates to be used in comparing private and public investments.[16] In any case, some interest rate clearly should be included in the investment decision, and future income then should be discounted by that rate to make it comparable to present income.

But what should the investor attempt to maximize to determine the optimum rotation? Different foresters and economists—such as Fernow (1902), Fisher (1930) and Boulding (1935)—have offered various solutions, including forest rent, present net worth over one harvest cycle, and internal rate of return.[17] But Samuelson showed in 1976 that the appropriate economic model for determining timber maturity is the soil- or land-expectation model developed by German forester Martin Faustmann in 1849.[18]

The Faustmann approach to rotation-age determination is basically a "present-value model" that seeks to maximize the present value of the land devoted to timber production. It begins by asking, "How much could an investor afford to pay for an acre of bare land if he intended to use it for timber production? Rather than determining the present value on the basis of the discounted net income resulting from a single harvest, it determines the present value on the basis of an infinitely long series of expected discounted net periodic incomes from the timber. The optimum rotation age thus is the age at which the present value of a perpetual net income stream earned on the land is maximized.

The basic Faustmann formula reads:

Present Value of Bare Forest Land =

$$\frac{\sum_{t=o}^{r} R_t(1+i)^{r-t} - \sum_{t=o}^{r} C_t(1+i)^{r-t}}{(1+i)^r - 1}$$

where: R_t = revenue received at time t
C_t = costs incurred at time t
r = rotation age
i = interest rate

The formula (Appendix B) does not in itself determine the optimum rotation age. Instead, it

Table 4
Douglas-Fir Cutting (Rotation) Ages
Site Index 150 (Medium)

Criteria	**Cutting Age (years)**
Biological Model: Maximize Mean Annual Increment (Table 3)	70
Economic Model: Maximize Land Expectation Value	
Case I (6% and zero)—Table 5*	50
Case II (6% and 2%)—Table 5*	55
Case III (10% and zero)—Appendix C*	41
Case IV (10% and 2%)—Appendix C*	45

*Figures in parentheses refer, respectively, to real rate of interest and annual stumpage price appreciation after adjustment for inflation.

is necessary to calculate present values for perpetual income streams corresponding to various rotation ages, and then to select that age at which the present value is maximized. Two examples illustrate the present-value method of rotation-age determination, using the same yield data for a one-acre Douglas-fir stand as was used in the biological model. The examples illustrate a key point: by introducing an interest rate into the computations, the economic model provides a shorter optimal rotation age than does the biological model.

The calculations are made under several different interest-rate and price assumptions. If we assume a 6-percent real interest rate and no timber (stumpage) price appreciation (after inflation adjustment), we obtain an optimum cutting age of 50 years (Table 4). With a 2-percent annual rise in relative prices, we obtain an optimum cutting age of 55 years—still far less than the 70-year solution derived by applying the biological model. If we use a 10-percent real rate of interest, we shorten the rotation age still further. Indeed, in 1968 hearings of the Congressional Joint Economic Committee, most of the economists testifying advocated an 8-to-10 percent rate of discount for public investment.[19]

In determining the optimal rotation age under economic criteria, the forest manager needs information on the timber inventory and the vol-

Table 5

Determination of Cutting Age for a One-Acre Douglas-Fir Stand Under Economic Criteria*
6% Real Rate of Interest

(R) Age of Stand[1] (years)	Vol. of Wood (Cunits/ acre)	Current Stumpage Price[2] ($ per cunit)	Current Value of Wood ($ per acre)	6% Present Value of Revenue w/no Appreciation[3] ($)	6% Present Value of Revenue w/2% Appreciation[4] ($)	6% Present Value of Costs[5] ($)	6% Land Expectation Value w/no Appreciation ($)	6% Land Expectation Value w/2% Appreciation ($)
20	3.4	0	.00	.00	.00	62.39	−62.39	−62.39
30	24.2	27	653.40	137.85	301.11	57.55	80.30	243.56
40	50.4	43	2,167.20	233.28	592.13	55.48	177.80	536.65
50	74.0	64	4,736.00	271.87	810.96	54.48	217.39[6]	756.48[7]
60	93.8	77	7,222.60	225.78	798.08	53.96	171.82	744.12
70	110.2	87	9,587.40	165.07	696.25	53.67	111.40	642.58
80	124.0	95	11,780.00	112.40	567.16	53.52	58.88	513.64
90	135.0	98	13,230.00	70.20	528.43	53.44	16.76	374.99
100	144.6	99	14,315.40	42.32	312.36	53.39	−11.07	258.97
110	152.9	100	15,290.00	25.20	225.48	53.36	−28.16	172.12
120	159.9	100	15,990.00	14.71	159.77	53.35	−38.64	106.42
130	165.6	100	16,560.00	8.50	112.77	53.34	−44.84	58.93
140	170.9	100	17,090.00	4.90	78.69	53.34	−48.44	25.35
150	175.6	100	17,600.00	2.81	54.96	53.33	−50.52	1.63
160	180.1	100	18,100.00	1.61	38.33	53.33	−51.72	−15.00

*See Appendix D for revenue and cost assumptions.

1 R = rotation (cutting) age.

2 Today's prices for trees of various ages. Assumes no appreciation in the price of timber relative to the wholesale price of other goods.

3 Six-percent present value of current value of wood per acre every R years in perpetuity.

4 Six-percent present value of appreciating value of wood per acre every R years in perpetuity, using an interest rate adjusted for appreciation (1.06 ÷ 1.02 = 1.039216).

5 Costs = Aerial seeding for regeneration = $20/acre, with annual management costs $2/acre/year. Six-percent present value of $20 every R years beginning today and $2 per year in perpetuity.

6 Under economic criteria, the appropriate cutting age is the age at which land expectation value (net present value) is maximized. Under the assumption of no stumpage price appreciation, appropriate cutting age is 50 years.

7 With stumpage price appreciation, land expectation value is maximized at age 55.

ume of wood per acre at various ages—just as he does when operating with the biological model. But the manager also needs estimates of the expected price of trees at different ages, including the price appreciation in excess of the overall inflation rate. He can then convert the biological growth curve to a revenue function by multiplying the volume of wood per acre by the assumed price for timber at each rotation age. Eventually he will be able to calculate the "land-expectation values"—the present discounted value of all net cash receipts, with and without price appreciation, calculated over the infinite chain of cycles of planting and cutting on the given acre of land (Table 5, Appendix C, and Chart 5).

For each interest rate, the age at which the land-expectation value is maximized under each price assumption is the appropriate cutting age. Those values represent the amount investors would be willing to pay for the bare land, under alternative price assumptions, to earn (say) 6- and 10-percent rates of return annually on their investment.

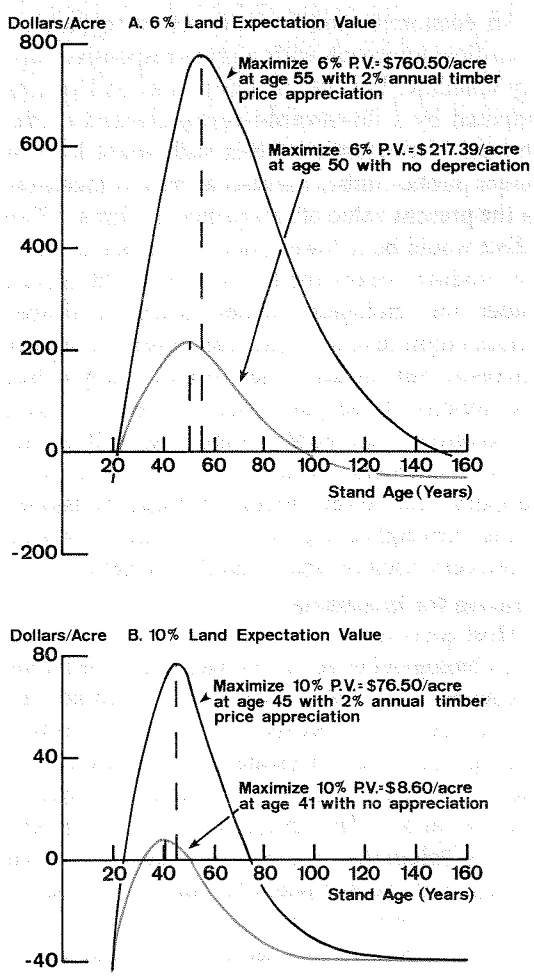
Harvest scheduling

The land-expectation formula might show that most trees on the National Forests are past their point of maximum economic return, but that does not mean that the Forest Service should begin harvesting its entire stock of overmature timber. For a small forest owner, the economic rotation age is the most important element in the harvest-determination process, because it tells him just when his timber should be harvested. In any given year, to maximize the present value of his forest, the small owner should cut all the trees he owns that are at or above the economic rotation age. But for the National Forests and other very large ownerships, which are large enough to affect the price of timber, such a drastic increase in harvests could seriously depress the price of timber, so that both private forest owners and public agencies would soon be growing timber at a loss.

In imperfectly competitive markets, where large owners can affect the market price, additional data are needed to determine that harvest schedule which will maximize present net worth. In this case, where the forest manager faces a downward-sloping demand curve—i.e., can only

Chart 5

DETERMINATION OF CUTTING AGE FOR A ONE-ACRE DOUGLAS-FIR STAND UNDER ECONOMIC CRITERIA



sell increased quantities at lower prices—demand forecasts and extraction-cost estimates are even more important than the appropriate rotation age in the harvest-determination process. Given such estimates, we can calculate the present value of net income that would be obtained under various timber harvest schedules, and can select that harvest schedule which produces the highest present value of future net timber returns selected. To calculate present values for a large number of alternative harvest schedules, the assistance of a computer is required. At least one model—The Economic Model for Optimizing The Rate of Timber Harvesting, known as ECHO—has been developed incorporating these economic-maximization principles.[20]

An economic model would act to replace an even-flow approach with a price-responsive supply schedule. Despite the limitations on harvests imposed by a downward-sloping demand curve, the use of economic criteria still would lead to larger public-timber harvests as well as increases in the present value of future income flows.[21] The effect would be to lower prices of timber and forest products below the levels that would prevail under the biological model. Reduced timber prices might lead to reductions in private timber harvests, but unless those cutbacks fully offset the actions of the public sector, forest product firms reliant upon public timber—as well as ultimate consumers—would gain from increased supplies and lower prices. If those consumer gains outweighed the loss of revenue to private producers, society would stand to benefit.[22]

Criteria for investment

Most economists agree that policies based solely on biological criteria will lead to irrational investment decisions. Under the allowable cut effect (ACE), the prospect of increased growth arising from a new investment is a sufficient condition for raising the current allowable cut of mature timber. The return on a new investment thus is calculated not on the basis of its own growth and revenue potential but on the basis of the value derived from cutting existing old-growth timber. Given a decision to replant a non-stocked area of a given National Forest, the allowable cut of old-growth timber could immediately be increased, because it would raise the expected growth of the forest taken as a unit. But under current policy, the returns on that investment would be measured, not by comparing the costs and expected returns on the land where the investment took place, but by comparing those costs with the increased revenues to be derived from cutting more old-growth timber elsewhere in the forest.

In contrast, the economic approach would relate the increased costs associated with a given investment to the value of the increased harvests resulting from the investment. This analysis suggests that investments in better, more accessible sites, should be undertaken first. As prices rise, poorer-quality and less-accessible land should be subjected to more intense management, but at every price some lands would not be worth the investment. Thus, under an economic model, supplies of timber from publicly-owned lands, as well as the intensity of management, would be responsive to price.

Economic criteria thus dictate the removal of unprofitable areas from timber management and production, resulting in a net saving to the public treasury and to society. But since such areas frequently have the physical attributes that are most desirable for wilderness designation—scenic vistas, alpine meadows, lakes and streams—an economic approach to timber management might ensure both more wilderness and more timber production. In those cases where the best timberland possesses desirable, even unique, wilderness characteristics, efficiency criteria would require that the timberland be allocated to its highest valued use—which might be for wilderness preservation when the latter value exceeds foregone timber value.

In essence, then, an economic approach would lead to the segregation of land into two classes. One class would consist of prime timber-growing land, on which timber would be managed to maximize present value. The second class would include those lands less valuable for timber production and/or those with characteristics which could compete with timber in social value. This approach would probably lead to more of both timber production and other forest outputs—including wilderness—because of 1) the accelerated harvesting called for under the economic-efficiency criteria and 2) the concentration of investments on the most productive sites.

IV. Summary and Conclusions

According to Forest Service forecasts, the U.S. demand for softwood timber can be brought into balance with supply over the next several decades only at substantially higher relative prices for forest products—assuming the continuation of current timber-harvesting policies and levels of timber investment. The agency believes that conservation efforts designed to slow down the growth of demand cannot significantly affect the upward pressure on prices. Rather, solutions will have to be sought on the supply side.

Many resource economists, as well as forest-product consumers, believe that National Forests offer an important opportunity for raising total supplies above projected levels in the face of only modest increases in private timber harvests. They argue that the current non-declining even-flow harvest policy places unnecessarily severe constraints on annual harvests from National Forest lands, and fails to accomplish its stated objective of fostering local-community stability. Moreover, that policy leads to an inefficient allocation of available capital and labor for forest management. A more flexible harvest strategy, better tailored to meet the requirements of the market, is needed to alleviate upward pressures on timber and forest-product prices. The solution, in the view of these economists, lies in the use of economic criteria to determine appropriate harvest rates and investments on National Forests. Through this approach, society should be able to obtain both a greater economic return on timber production and a greater set-aside of land for recreation and other uses. Thus, an unduly restrictive and inefficient harvest strategy, rather than environmental pressure, is the true cause of today's apparent shortage of reasonably-priced timber.

Appendix A: A Simplified Example of Forest Regulation in the Public Sector

Problem:

Using the Forest Service's biological criteria for harvest determination, develop a harvest schedule for an old-growth Douglas-fir forest that will convert the existing forest into one with an even distribution of age classes yet still provide a regular flow of harvested timber over time. Assume a simple hypothetical forest with the following characteristics:

Profile of Existing Forest:

Area: 210,000 acres

Age of stands: all trees, 16 decades old

Cutting, or rotation age (R), determined on basis of biological criteria: 7 decades, as shown in Table 3

Growth: assume no growth increment after age 160 years

Profile of Desired Fully Regulated Forest (As shown in Chart 1-A)

Area: 210,000 acres

Age of stands: 1 to 7 decades old, with each age class occupying an equal area of the forest, namely 30,000 acres

Cutting, or rotation age (R), determined on basis of biological criteria, 7 decades, as shown in Table 3

Harvest Determination:

1. *Even-Flow Policy,* Pre-1973 (As shown in Chart 1-B)

   a. Conversion Period:

   In this simplified example—where all stands are assumed to be of equal age (even-aged), growth in all the ensuing decades is assumed to be zero, and the cutting age is 7 decades—the appropriate cutting policy to achieve a regulated forest is to cut 1/7th of the total forest area each decade—a so-called area-control approach. Indeed, the Hanzlik formula $\frac{Vm}{R} + I$, discussed in the text, reduces to an area control formula when there is a large proportion of mature timber, and when I therefore approaches zero. The harvest schedule for each decade of the conversion period would be calculated as follows:

$$\frac{\text{Total area}}{\text{Decades in rotation}} \times \text{Volume per}$$

acre for mature timber (160 years)

Solution:

$$\frac{210{,}000 \text{ acres}}{7 \text{ decades}} \times 180.1 \text{ cunits per}$$

acre = 5.4 million cunits/decade

(Note: Volume per acre as shown in Table 3; one cunit equals 100 cubic feet.)

b. Post-Conversion Period:

In the post-conversion period, when the forest is regulated and there are 7 stands of equal area, ranging from 1 to 7 decades in age, 1/7th of the forest area also can be cut, namely that stand containing the trees 7 decades old. Using this same formula, the harvest schedule for each decade of the post-conversion period would be calculated as follows:

$$\frac{\text{Total area}}{\text{Decades in rotation}} \times \text{Volume per}$$

acre for mature timber (70 years)

Solution:

$$\frac{210{,}000 \text{ acres}}{7 \text{ decades}} \times 110.2 \text{ cunits per}$$

acre = 3.3 million cunits/decade

(Note: Volume per acre as shown in Table 3.)

2. *Current Non-Declining Even-Flow Policy* (As shown in Chart 1-C)

The allowable cut under a non-declining even-flow policy is that harvest that can be sustained in perpetuity, i.e., the maximum sustained yield. That volume in turn is the harvest for a fully regulated forest, that is, the cut in the post-conversion period. In this example, the cut would be 3.3 million cunits per decade, assuming a given level of management intensity.

Appendix B: Derivation of the Faustmann Present Value Formula

In the article, the objective of the empirical examples was to identify that rotation age, under each set of conditions, at which the present value of the land was maximized. Present values were calculated for net income streams corresponding to various rotation ages. A graph of these values, with corresponding ages on the ordinate, gave an inverted parabola (Chart 5). The highest point on this curve—the point tangential to the horizontal—was identified as the optimum rotation age.

The Faustmann formula, which gives the present value of a perpetual net income stream is derived as follows:

$$\text{Present Value} = \sum_{t=o}^{\infty} \frac{R_t - C_t}{(1+i)^t}$$

where R_t represents revenues at time t

C_t represents costs at time t and

i is the exogenously given interest rate for discounting future income streams.

To introduce rotation age r explicitly, we break up the series on the righthand side, as follows:

$$\text{Present Value} = \sum_{t=o}^{r} \frac{R_t - C_t}{(1+i)^t} + \sum_{t=r+1}^{2r} \frac{R_t - C_t}{(1+i)^t} + \ldots + \sum_{t=(n-1)r+1}^{nr} \frac{R_t - C_t}{(1+i)^t} + \ldots + \ldots$$

$$= \sum_{t=o}^{r} \frac{(R_t - C_t)(1+i)^{r-t}}{(1+i)^r} + \ldots + \frac{\sum_{t=(n-r)+1}^{nr} (R_t - C_t)(1+i)^{r-t}}{(1+i)^{nr}} + \ldots + \ldots$$

$$= \left[\sum_{t=o}^{r} (R_t - C_t)(1+i)^{r-t} \right] * \sum_{n=1}^{\infty} \frac{1}{(1+i)^n}$$

Assuming that the level of cash flows in each rotation cycle is a constant (the assumption may be relaxed if this level increases at some compounded rate over time) as given by

$$\left[\sum_{t=o}^{r} (R_t-C_t)(1+i)^{r-t}\right],$$

we can use the series property

$$\sum_{n=o}^{\infty} \frac{1}{(1+m)^n} = \frac{1}{1-(1+m)^{-n}} =$$

$$1 + \frac{1}{(1+m)^n-1}$$

Therefore, $\sum_{n=1}^{\infty} \frac{1}{(1+m)^n} = \frac{1}{(1+m)^n-1}$,

which gives us:

$$\text{Present Value} = \frac{\sum_{t=o}^{r} (R_t-C_t)(1+i)^{r-t}}{(1+i)^r-1}$$

Conceptually, the numerator may be seen as a future-value term. All cash flows within a cycle are transformed to their future values at the end of each cycle. We then have a financial asset which pays a constant amount every r periods in perpetuity.

Appendix C

Determination of Cutting Age for a One-Acre Douglas-Fir Stand Under Economic Criteria (10% Real Rate of Interest)

(R) Age of Stand[1] (years)	Vol. of Wood (Cunits/acre)	Current Stumpage Price[2] ($ per cunit)	Current Value of Wood ($ per acre)	10% Present Value of Revenue w/no Appreciation[3] ($)	10% Present Value of Revenue w/2% Appreciation[4] ($)	10% Present Value of Costs[5] ($)	10% Land Expectation Value w/no Appreciation ($)	10% Land Expectation Value w/2% Appreciation ($)
20	3.4	0	.00	.00	.00	43.49	−43.49	−43.49
30	24.2	27	653.40	39.72	75.69	41.22	−1.50	34.47
40	50.4	43	2,167.20	48.97	111.16	40.45	8.52[6]	70.71
50	74.0	64	4,736.00	40.69	111.14	40.17	.52	70.97[7]
60	93.8	77	7,222.60	23.80	78.68	40.07	−16.17	38.61
70	110.2	87	9,587.40	12.16	48.41	40.03	−27.87	8.78
80	124.0	95	11,780.00	5.75	28.11	40.01	−34.26	−11.90
90	135.0	98	13,230.00	2.49	14.82	40.00	−37.51	−25.18
100	144.6	99	14,315.40	1.04	7.53	40.00	−38.96	−32.47
110	152.9	100	15,290.00	.43	3.78	40.00	−39.57	−36.22
120	159.9	100	15,990.00	.17	1.86	40.00	−39.83	−38.14
130	165.6	100	16,560.00	.07	.90	40.00	−39.93	−39.10
140	170.9	100	17,090.00	.03	.44	40.00	−39.97	−39.56
150	175.6	100	17,600.00	.01	.21	40.00	−39.99	−39.79
160	180.1	100	18,100.00	.00	.10	40.00	−40.00	−39.90

*See Appendix D for revenue and cost assumptions.

[1] R = rotation (cutting) age.

[2] Today's prices for trees of various ages. Assumes no appreciation in the price of timber relative to the wholesale price of other goods.

[3] Ten-percent present value of current value of wood per acre every R years in perpetuity.

[4] Ten-percent present value of appreciating value of wood per acre every R years in perpetuity, using an interest rate adjusted for appreciation (1.1 ÷ 1.02 = 1.07843).

[5] Costs = Aerial seeding for regeneration = $20/acre, with annual management costs $2/acre/year. Ten-percent present value of $20 every R years beginning today and $2 per year in perpetuity.

[6] Under economic criteria, the appropriate cutting age is the age at which land expectation value (net present value) is maximized. Under the assumption of no stumpage price appreciation, appropriate cutting age is 41 years.

[7] With stumpage price appreciation, land expectation value is maximized at age 45.

Appendix D: Revenue and Cost Assumptions (Economic Model)

Revenue Assumptions

Age of Stand (Years)	Current Stumpage Price[1] (Dollars/cunit)	End of First Rotation Price[2] (Dollars/cunit)
20	0	0
30	27	49
40	43	95
50	64	172
60	77	253
70	87	348
80	95	463
90	98	582
100	99	717
110	100	883
120	100	1,077
130	100	1,312
140	100	1,600
150	100	1,950
160	100	2,377

Cost Assumptions

Aerial seeding for regeneration = \$20/acre
Annual management costs = \$2/acre/year

[1] At current (today's) prices, timber 110 years old would sell for \$100/cunit; \$100/cunit = \$200/thousand board feet Scribner. Current stumpage prices are assumed to remain constant after adjustment for inflation.

[2] End of rotation price (with 2% annual appreciation) = Current price x $(1.02)^R$ where R = rotation age.

FOOTNOTES

1. The last comprehensive inventory of U.S. timber resources was conducted by the Forest Service in 1970. Results, as well as an assessment of the long-term supply and demand outlook, appeared in U.S. Department of Agriculture, Forest Service, **The Outlook for Timber in the United States,** Forest Resource Report 20 (Washington, D.C.: U.S. Government Printing Office, 1973). See page 310 for the definition of "commercial forest land." More detailed forest resource statistics, by ownership class and geographical area, are available in the Forest Service publication, **Forest Statistics for the United States, By State and Region, 1970** (Washington, D.C.: U.S. Government Printing Office, 1973).

2. Softwood "growing stock" is more comprehensive than the volume of sawtimber in that it includes trees that are too small for lumber production but suitable for paper. Sawtimber trees must contain at least one 12-foot sawlog or two non-contiguous 8-foot logs, and meet regional specifications for freedom from defect. Unless otherwise specified, the timber inventory, growth and harvest rates discussed in this study refer to growing stock.

3. Marion Clawson, "The National Forests: A Great National Asset is Poorly Managed and Unproductive," **Science** (February 1976), pp. 762-767.

4. For a good summary of this position see, H.R. Josephsen, "Economics and National Forest Timber Harvests," **Journal of Forestry** (September 1976), pp. 605-611.

5. Asset value of standing timber, forest lands and man-made improvements, 1974, as estimated by Marion Clawson, **op. cit.,** pp. 762-764. Charges of inefficiency in public forest management also were made by John Walker in, "Economic Efficiency and the National Forest Management Act of 1976," **Journal of Forestry** (November 1977), pp. 715-718.

6. In determining the allowable cut for a given forest for the first decade, V_m, the volume of mature merchantable timber at or beyond rotation age, is calculated by multiplying the number of acres in each age class at or beyond the rotation age by the volume per acre for each age class at or beyond the rotation age and summing to obtain a grand total. I, current increment (net new timber growth) expected in the first decade, is calculated by multiplying the number of acres in each age class where significant growth is expected by the growth per acre expected in that decade and summing to obtain a grand total. R= number of decades per rotation.

For a description of the traditional methods of determining the allowable cut on National Forests, see LeRoy Hennes, Michael J. Irving, and Daniel I. Navon, **Forest Control and Regulation, A Comparison of Traditional Methods and Alternatives,** U.S. Department of Agriculture, Forest Service Research Note PSW—231 (Berkeley: Pacific Southwest Forest and Range Experiment Station, 1971).

7. For an analysis of the supply response in the Douglas-fir region see, U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station, **Timber Trends in Western Oregon and Western Washington,** Research Paper PNW5 (Portland: Pacific Northwest Forest and Range Experiment Station, October 1963), page 75.

8. See, for example, Emmett F. Thompson, "Traditional Forest Regulation Model: An Economic Critique, **Journal of Forestry** (November, 1966), pp. 750-752. Also, Thomas R. Waggener, **Some Economic Implications of Sustained Yield As a Forest Regulation Model,** Contemporary Forestry Paper Number 6 (Seattle, Washington: Institute of Forest Products, May 1969); and John T. Keane, "Even Flow—Yes or No?" **American Forests** (June 1972), pp. 32-37.

9. The total volume of wood, or timber inventory, in this example has been labelled Vm rather than K, i.e., capital stock, to distinguish the biological model from the economic model, where physical volumes are converted to values.

10. There are many gradations in intensity of forest management when wood production is the primary objective. Staebler has distinguished six management levels: 1) average management, 2) good management, 3) high-order management, 4) high-order management plus fertilization, 5) high-order management plus fertilization plus thinning, 6) strategy 5 plus genetic improvement. High-intensity management usually refers to at least strategy 6. For definitions of these levels, see George R. Staebler, "Concentrating Timber Production Efforts," **Society of American Foresters, Proceedings 1972** (Washington, D.C.: Society of American Foresters, 1973), pp. 74-76.

11. For an explanation and critique of the "allowable cut effect"

(AEC), see Dennis L. Schweitzer, Robert W. Sassaman and Con H. Schallau, "Allowable Cut Effect: Some Physical and Economic Implications," **Journal of Forestry** (July 1972), pp. 415-418. Also, Dennis E. Teeguarden, "The Allowable Cut Effect: A Comment," **Journal of Forestry** (April 1973), pp. 224-226; Dennis L. Schweitzer et al, "The Allowable Cut Effect: A Reply," **Journal of Forestry** (April 1973), pp. 227, 357, and 360; Barnie Dowdle, "Some Further Comments on the Allowable Cut Effect," **Forest Industries** (November 1976), page 52.

12. The Forest Service timber supply-demand forecast to the year 2000 first appeared in U.S. Department of Agriculture, Forest Service, **The Outlook for Timber in the United States.** That forecast was later updated by the Forest Service in U.S. Department of Agriculture, Forest Service, **The Nation's Renewable Resources—An Assessment, 1975.** The forecast incorporated in this study is the updated version.

13. Numerous studies in addition to **The Outlook for Timber in the United States** have attested to the decline in Western timber harvests expected over the next few decades. See, for example, Donald R. Gedney, Daniel D. Oswald and Roger D. Flight, **Two Projections of Timber Supply in the Pacific Coast States,** U.S.D.A. Forest Service Resource Bulletin, PNW-60 (Portland: Pacific Northwest Forest and Range Experiment Station, 1975) and John Beuter, K. Norman Johnson and H. Lynn Scheurman, **Timber for Oregon's Tomorrow: An Analysis of Reasonably Possible Occurrences,** Research Bulletin 19 (Corvallis: Forest Research Laboratory, School of Forestry, Oregon State University, 1976).

14. For an example of the first proposal see, Robert J. Marty, "Economic Effectiveness of Silvicultural Investments for Softwood Timber Production," Appendix D, **Report of the President's Advisory Panel on Timber and the Environment** (Washington, D.C.: U.S. Government Printing Office, 1973), pp. 145-55, and U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station, **Douglas-Fir Supply Study, Alternative Programs for Increasing Timber Supplies from National Forest Lands** (Washington, D.C.: U.S. Government Printing Office, 1969). For an analysis of various short-term flexible harvest strategies and their application to public-forest lands in Oregon under the management of the Bureau of Land Management, see Robert Nelson and Lou Pugliaresi, **Timber Harvest Policy Issues on the O & C Lands** (Washington, D.C.: U.S. Department of the Interior, Office of Policy Analysis, March 1977). The "price control" option also has been analyzed by Darius M. Adams, in his study, **Effects of National Forest Timber Harvest on Softwood Stumpage, Lumber and Plywood Markets, An Econometric Analysis,** Research Bulletin 15 (Corvallis: Forest Research Laboratory, Oregon State University, 1977), pp. 41-44.

15. For a clear analysis of this point see, William J. Baumol, "On the Social Rate of Discount," **The American Economic Review** (September 1968), pp. 788-802. Also see his presentation, "On the Discount Rate for Public Projects," in **The Analysis of Evaluation of Public Expenditures: The PPB System,** A Compendium of Papers Submitted to the Subcommittee on Economy of the Joint Economic Committee, 91st Congress, 1st Session (Washington, D.C.: U.S. Government Printing Office, 1969), pp. 489-503.

16. For a good summary of this debate see, John V. Krutilla and Anthony C. Fisher, **The Economics of Natural Environments, Studies in the Valuation of Commodity and Amenity Resources** (Baltimore: John Hopkins University Press for Resources for the Future, 1975), pp. 60-65.

17. B. E. Fernow, **Economics of Forestry** (New York: Thomas Y. Crowell and Company, 1902); Irving Fisher, **The Theory of Interest** (New York: Macmillan, 1930), particularly pp. 161-165; Kenneth Boulding, "The Theory of a Single Investment," **Quarterly Journal of Economics** (1935), pp. 475-494.

18. Paul Samuelson, "Economics of Forestry in an Evolving Society," **Economic Inquiry** (December, 1976), pp. 466-492. For other analyses of the application of financial maturity models to timber harvesting, see William A. Duerr, John Fedwik and Sam Guttenberg, **Financial Maturity: A Guide to Profitable Timber Growing,** Technical Bulletin Number 1146, U.S. Department of Agriculture (Washington, D.C.: U.S. Government Printing Office, August 1956); Mason Gaffney, "Concepts of Financial Maturity of Timber and Other Assets, **Agricultural Economics Information Series 62** (Raleigh: North Carolina State College, 1957). Also William B. Bentley and Dennis Teeguarden, "Financial Maturity: A Theoretical Review," **Forest Science** (1965), pp. 75-87 and Harold Bierman, Jr., "The Growth Period Decision," **Management Science** (February, 1963), pp. B303-B309.

19. This conclusion appeared in Subcommittee on Economy in Government of the Joint Economic Committee, Congress of the United States, **Economic Analysis of Public Investment Decisions: Interest Rate Policy and Discounting Analysis** (Washington D.C.: U.S. Government Printing Office, 1968), page 16.

20. The basic concepts for this model were developed by John Walker, **An Economic Model for Optimizing the Rate of Timber Harvesting,** Ph.D. Dissertation (Seattle: College of Forest Resources, University of Washington, 1971).

21. This result is discussed by George A. Craig and John T. Keane, "Economic Analysis: A Better Way to Guide Federal Timber Programs," **Forest Industries** (November, 1977), pp. 80-81.

22. For an analysis of this concept see, Hans M. Gregersen and Thomas W. Houghtaling, "Economics and National Forest Timber Harvests-Additional Considerations," **Journal of Forestry** (January, 1977), pp. 28-29.