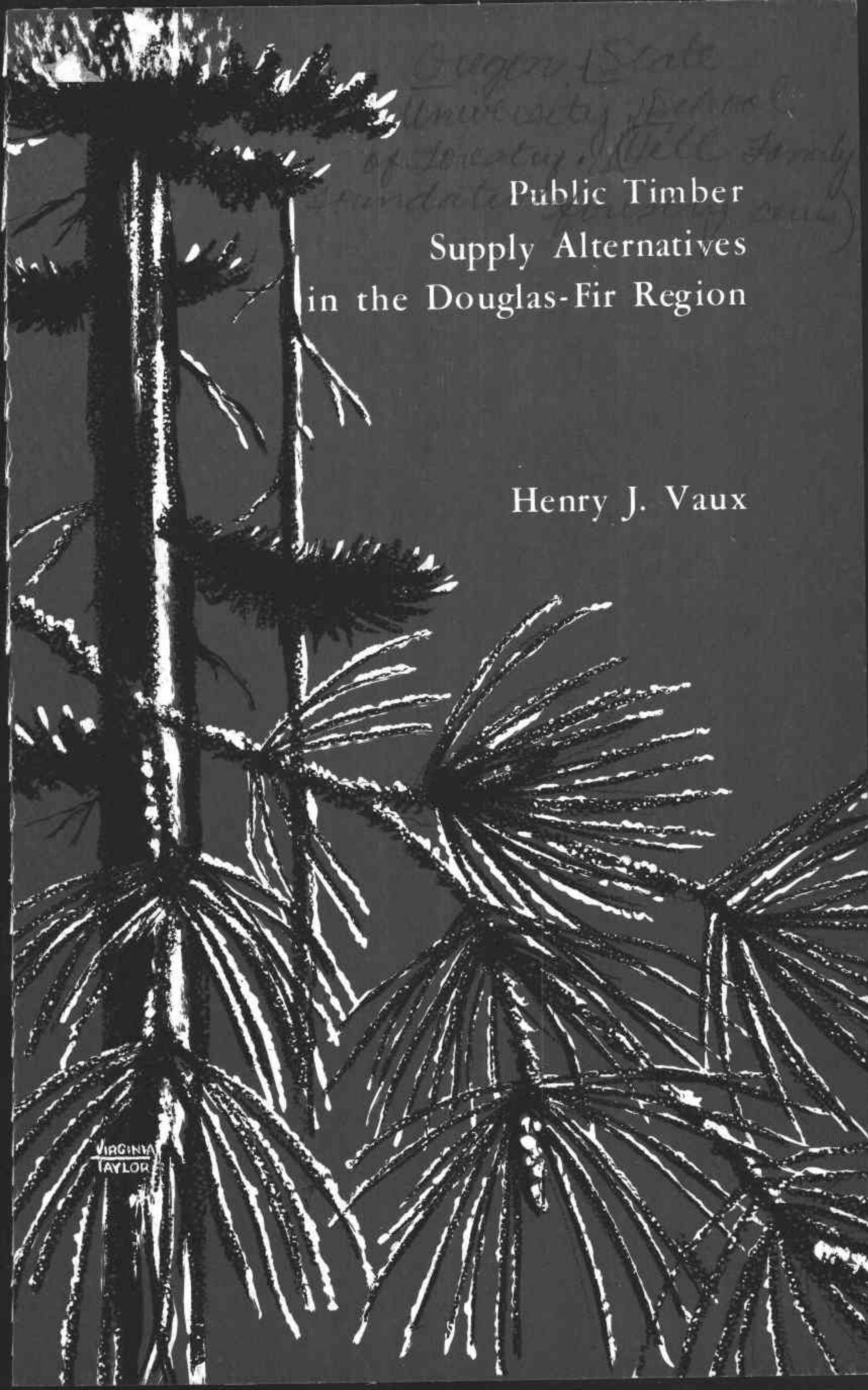
Oregon State University School of Forestry

Public Timber Supply Alternatives in the Douglas-Fir Region

Henry J. Vaux



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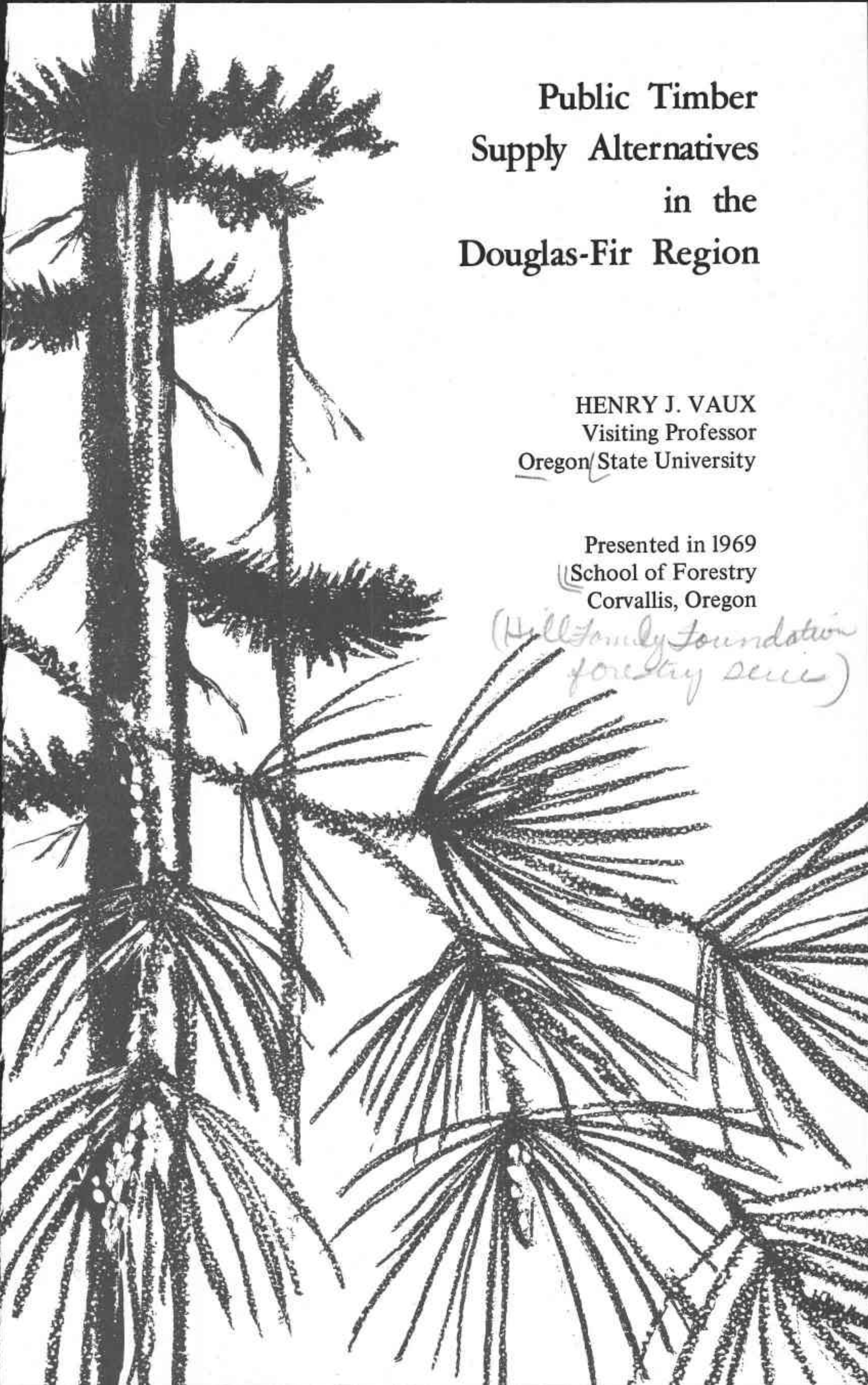

Public Timber Supply Alternatives in the Douglas-Fir Region

HENRY J. VAUX
Visiting Professor
Oregon State University

Presented in 1969
School of Forestry
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Preface

The forests of the Pacific Northwest contain 40 percent of the nation's sawtimber inventory and provide 35 percent of the sawtimber harvest. Federal forests of the region account for more than 70 percent of this inventory and 50 percent of the cut. There is, thus, good reason for intense public interest in policies related to the management of these federal forests and inventory.

In response to such interest, a Seminar on Public Forestry Issues was sponsored by Oregon State University in July, 1969. Leader of the seminar was Jenry J. Vaux, South Santiam Visiting Professor of Forestry for the University's Natural Resource Economics Institute.

The seminar permitted forestry students, foresters, and economists to discuss the role of economics in determining optimum public forest management policies in the Douglas-fir subregion of the Pacific Northwest. Special attention was given to the *Douglas-fir Supply Study* (7) and alternative analyses.

This booklet contains one of the thought-provoking lectures Dr. Vaux presented as a basis for his seminar discussions. The paper suggests another means of determining optimum long-term levels of sustained yield for federal forests and optimum rates of harvest in the transitional period. The analysis suggests public benefits might be greater if both optima were determined by giving greater attention to the needs of wood consumers, which are reflected through stumpage prices, as compared with current policies which stress an undiminished, even flow of timber harvest from public forests.

One of the world's most respected forest economists, Henry Vaux speaks from a background of private and public forestry experience and as a distinguished scholar. Dr. Vaux is

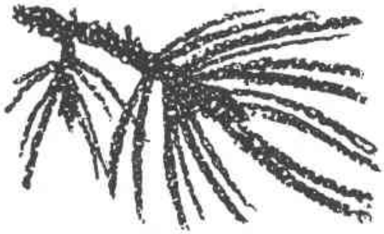
Professor of Forestry in the School of Forestry and Conservation, University of California at Berkeley. His analysis is based on studies conducted as a part of California Agricultural Experiment Station Project F 2350, supported by McIntire-Stennis and U.S. Forest Service Cooperative Aid funds.

This paper is published as one of the Hill Family Foundation Series of lectures by Visiting Professors, not as an endorsement of the ideas presented, but to enable all of those concerned with the management of these important resources to study another of several alternatives to current management policies. Only through the systematic study of such alternatives can the optimum policies by identified and adopted.

Carl Stoltenberg
Corvallis, Oregon
September, 1970

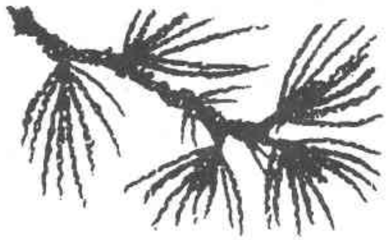
Contents

Public Timber Supply Alternatives in the Douglas-Fir Region



INTRODUCTION

Public policy on timber management now requires that plans for disposal of timber from national forests be based on the principle of sustained yield; it further provides, as far as possible, for an even flow of such timber (6). This sustained yield-even flow policy of timber output from public lands in the western United States, after several decades of acceptance, has come under increasing scrutiny recently. The publication by the Forest Service of its *Douglas-fir Supply Study* (7) provides an overview of some alternatives for future supply of timber that the sustained yield-even flow policy could produce on the national forests of the Douglas-fir region. For the first time, foresters can consider quantitatively many of the economic and social consequences of the sustained yield-even flow policy in our most important timber-growing region. This paper contributes to that consideration. It will argue, first, that the sustained-yield goal of national forest policy should be based on much more intensive programs of timber management than have yet been proposed; and, second, that in the decades just ahead the even-flow policy should be moderated to check the long-term rise in the price of stumpage.



SUPPLY STUDY

The *Douglas-fir Supply Study* "examined the effects which three intensities of timber management, two rates of road construction, and five lengths of rotation would have upon timber harvests and other values in the region" (7, p.*v*.) The published evaluation is complete for six programs representative of these 30 alternatives. The major economic characteristics of these six programs are summarized in Table 1. Ultimate sustained-yield capacity shown in column 5 of the Table is the average annual yield provided by a program for the period that begins at the end of the tenth decade and presumably continues indefinitely. The transitional average flow (column 6) provided by a program is the average annual yield during the transitional 10 decades beginning in 1967. At the end of the first rotation, yields from all programs fall sharply, as comparison of columns 5 and 6 indicates. Liquidation of surplus growing stock now embodied in old-growth stands is spread relatively uniformly over the first rotation in all programs with only minor variations in annual output before the end of that period. This practice of spreading the liquidation of surplus growing stock over a full rotation is called "the even flow policy."

Study data provide estimates of costs and returns from each of the six programs. These estimates are limited to costs and returns experienced during the first 12 decades of any program. Costs and returns can be ignored after the twelfth decade, because their effects on present decisions would be far less than the uncertainties inherent in nearer-term portions of the analysis. Data on production and costs and returns for the first 12 decades of the six programs are shown in Table 2.

Yields for transitional periods are not entirely "even" under any of the programs; deviations from even flow of up to 14 percent appear in some programs.

If one accepts maximum present net worth as the criterion for program selection and 5 percent as the appropriate rate of interest, Table 2 might suggest that Program VI is the preferable alternative economically. Program VI has a higher net worth

Table 1. Characteristics of Six Alternative Programs for Timber Management in National Forests of the Douglas-fir Region (7).

1 Program	2 Management intensity[1]	3 Rate of road construction[2]	4 Rotation[3]	5 Ultimate sustained yield capacity	6 Transitional even flow[4]	7 First decade allowable cut
				Billions fbm/yr	*Billions fbm/yr*	*Billions fbm/yr*
I	Low	Current	Current	1.80	2.90	2.93
II	Medium	Accelerated	Current	2.15	3.56	3.77
III	High	Accelerated	Current	2.68	3.87	3.99
IV	Low	Current	Current (-30 yr)	1.62	3.25	3.99
V	Medium	Accelerated	Current (-30 yr)	1.75	3.67	4.85
VI	High	Accelerated	Current (-30 yr)	2.42	4.09	5.22

[1] **Low** represents about the amount of management practiced on national forests in the region in 1966.
Medium increases sawlog harvests by programmed commercial thinning, mortality salvage, and prelogging.
High-intensity management increases yields by programmed restocking of cutovers within 1 year, reforesting nonproducing areas, and noncommercial thinning in 20-year-old stands.

[2] **Current** road construction includes existing roads and those to be constructed under present Forest Service programs.
Accelerated road construction provides, within 20 years, roads needed to all stands eligible for commercial thinning.

[3] **Current** rotation is the one now practiced in Forest Service timber management planning; it varies, by working circles, from 90 to 105 years.

[4] Average annual harvests for the next 10 decades.

Table 2. Production and Present Worth of Costs and Returns over 12 Decades for Six Alternative Programs of Timber Management for National Forests of the Douglas-fir Region (7).

1 Program	2 Management intensity and rotation	3 Ultimate sustained yield capacity	4 Transitional average even flow	5 Present worth of program costs at 5%	6 Present net worth at 5%[1]
		Billions fbm/yr	*Billions fbm/yr*	*Millions of $*	*Millions of $*
I	Low:Current	1.80	2.90	985.5	1,468
II	Medium:Current	2.15	3.56	1,111.2	2,052
III	High:Current	2.68	3.87	1,195.1	2,190
IV	Low:Current less 30 years	1.62	3.25	1,118.9	2,157
V	Medium:Current less 30 years	1.75	3.67	1,185.7	2,720
VI	High:Current less 30 years	2.42	4.09	1,337.9	2,887

[1]The *Study* priced prospective stumpage yields as follows:

Decade 1 (1967-76)	$34.32/M
Decade 2 (1977-86)	42.23/M
Decade 3 (1987-96)	50.16/M
After 1996	50.16/M

than any of the others and produces more wood for at least the next 180 years. So, apparently, it more than justifies the somewhat higher costs involved. Its lower ultimate capacity for sustained yield than Program III, although a negative feature, is a rather remote disadvantage.

But such a conclusion appears misleading. Table 2, and the *Study* on which it is based, assumed that future stumpage prices in the Douglas-fir region will be independent of whatever program of timber management is applied to the national forests. We believe that this assumption is unwarranted. And if national forest allowable cut policy *has* a significant influence on the future trend of regional stumpage prices, then something quite different from Program VI may be needed to secure maximum benefits from the management of public forests.

PAST INFLUENCE OF NATIONAL FOREST OUTPUT ON PRICE

To test the *Study's* assumption that regional output of timber is independent of stumpage prices in national forests, we took the average annual price paid for Douglas-fir from national forests as an index of prices (8), and Forest Service estimates of annual production of logs in the region as an index of output (2). For the 20-year period from 1948 to 1967, the coefficient of correlation between the index of stumpage price and the index of timber output was $r = 0.718$ (The coefficient is significant at the level $P = 0.001$.). In contrast, Teeguarden (13) found no significant relation between production and lumber prices in the central Sierra region, which apparently reflects the fact that limitations on allowable cut were much more constraining on production from national forests in the central Sierra region than they were in the Douglas-fir region before 1960.

With the same index of stumpage prices, we next separated regional log production of national forests from the production of sources other than national forests, based on Forest Service estimates (2). The resulting correlations between stumpage prices of Douglas-fir and regional log output by source are shown in Figure 1.

The net regression of annual log production from national forests on average stumpage price of Douglas fir from national forests and time is shown by curves *A* and *B* in the figure. The coefficient of multiple correlation is 0.94, and the regression coefficients between price and production and between time and production are both highly significant. In contrast, curve *C* shows the relation between national forest stumpage price, time, and the output from land other than national forests. The coefficient of multiple correlation is 0.29 and the regression coefficients are not significant.

Although national forest stumpage is not a perfect substitute for stumpage on other ownerships, the two commodities seem reasonably comparable in market value. Accordingly, we have accepted the average annual price of national forest stumpage as an estimate of the average annual

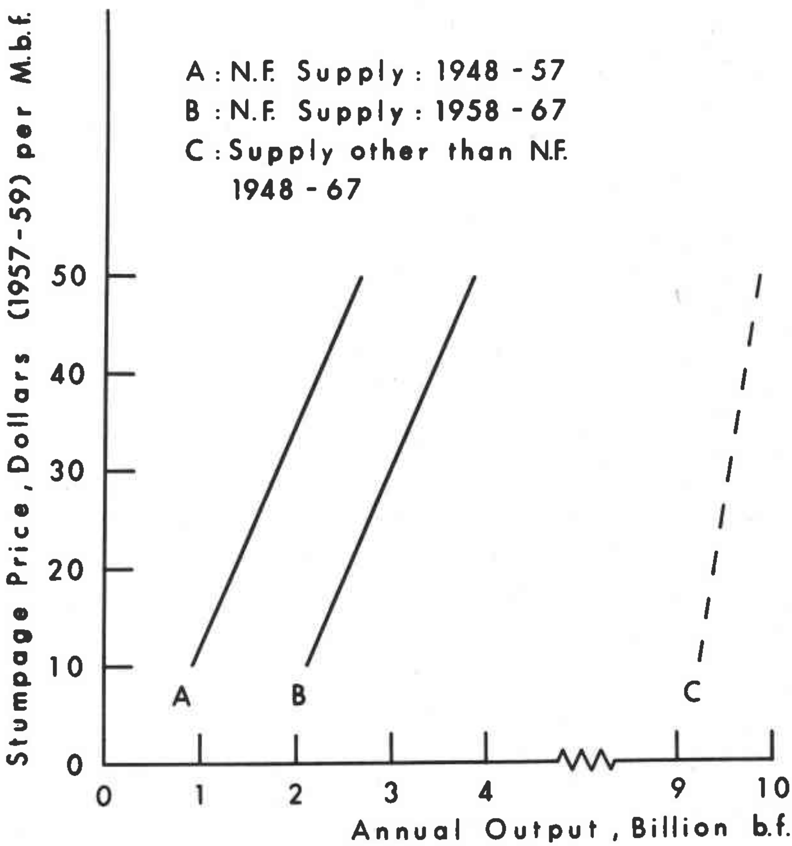


Figure 1. Net relation between average price of Douglas-fir stumpage and annual production in the region from national forests and from other sources, 1947 to 1966.

price of other stumpage. With this assumption, the data in Figure 1 lead to two conclusions. First, regional stumpage supply from lands other than national forests (curve *C*) has shown no significant net response to changes in stumpage price throughout the post-World War II era. This result conforms to the conclusion reached on theoretical grounds by Duerr and others that marketings of timber by private forest owners (who, in 1953, held *73* percent of sawtimber not on national forests) are relatively insensitive to changes in price (1, 4).

The second conclusion is that over the 20-year period, the volume of timber marketings from national forests did relate significantly to changes in stumpage prices. Apparently, had the Forest Service not followed an expansionist policy with respect to output during the past 2 decades, stumpage prices would have increased substantially more than they actually did. More generally, we conclude that national forest allowable cut will influence regional stumpage prices in the future. The data of Table 2, therefore, do not provide an adequate basis for evaluating program alternatives.

THE PRODUCTION GOAL APPROACH TO PROGRAM EVALUATION

The economic production-goal theory elaborated over the past 20 years by various forest economists (9, 12, 14, 17) provides a method for assessing the price effects that were ignored in Table 2. In brief, production goal theory suggests that, one, the target for ultimate sustained-yield capacity should be set where the marginal long-run cost of producing additional timber just equals the price that such additional output is expected to command, and, two, the output during the period of transition between the present and the sustained-yield target should be established at rates that will provide maximum present worth of future net benefits, subject to the constraint that stumpage prices should move smoothly during the transitional period from present to expected long-run rates. With this theory, I have made a preliminary assessment of the six program alternatives in the *Study*.

Table 3 presents estimates of long-run unit costs of production under each of the six programs. The concept of average long-run unit cost is discussed fully in the Appendix.

The average long-run cost of yields (Table 3, column 3) follows the familiar U-shaped cost curve, as the intensity of management and volume of output increase, both with current rotations and with shorter rotations.

For any of the *Study* programs, the average long-run costs of growing timber on the national forests of the Douglas-fir region (column 3) are far below both present stumpage prices and the *Study's* own projections of future prices. This suggests that none of the *Study's* program alternatives includes sufficient intensity of timber management to achieve economically optimum growth and yield on national forests of the Douglas fir region.

The costs of Table 3 represent true long-run average costs on the assumption that the programs represent the most efficient way of producing specified rates of production. The *Study* itself indicates that certain units of supply have been included where costs exceed returns (7, p. 29). My assumption is conservative for the present purpose, however, because correction of the *Study* figures in the interest of efficiency would tend to lower the cost estimates. The point may be clarified by Figure 2, which shows the relation of average long-run unit cost of timber yields of each current rotation program (from Table 3) to the average production for the transitional period of that program (curve *AC*). From this

Table 3. Long-Run Average and Marginal Costs of Timber Production on National Forests in the Douglas-fir Region, for Six Alternative Management Programs (7).

1 Program	2 Management intensity	3 Long-run avg cost of yields	4 Ten-decade output	5 Subsequent sustained yield	6 Long-run marginal costs of additional yields
		$ per M fbm	*Billions fbm*	*Billions fbm/yr*	*$ per M fbm*
CURRENT ROTATION					
I	Low	$16.93	290.31	1.80	
					5.11
II	Medium	$14.76	355.57	2.15	
					16.10
III	High	$14.87	387.26	2.68	
CURRENT ROTATION LESS 30 YEARS					
IV	Low	$14.34	324.58	1.62	
					-0.01
V	Medium	$12.68	367.03	1.75	
					18.23
VI	High	$13.24	408.22	2.42	

average cost curve, the related marginal costs have been calculated and plotted as curve *MC*.

Production-goal theory tells us that a timber-growing program should be selected that will equate marginal costs of production with expected price. Figure 2 indicates that the marginal-cost curves calculated from *Study* programs (solid portion of curve *MC*) would have to be extended to rates of timber production substantially greater than those the *Study* has reported before marginal costs approach the prices forecast.

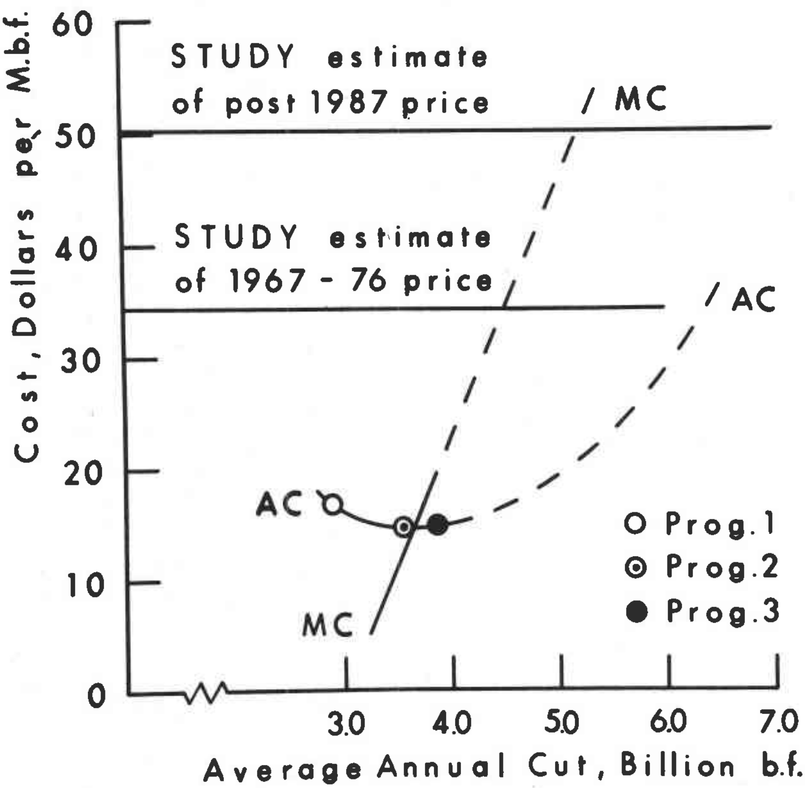
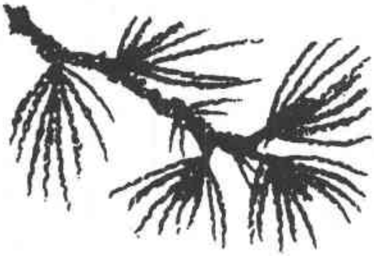


Figure 2. Long-run average and marginal cost of growing timber on national forests in the Douglas-fir region at average rates of production in the transitional period for Programs I, II, and III at current rotations (7).

As the shape of the curves cannot be extrapolated beyond the available data, the broken portions of the average and marginal cost curves of Figure 2 are purely hypothetical. They suggest, however, that plans for timber management by the Forest Service should include information about program, cost, and production for intensities of national forest management that would produce sustained and transitional yields at least 20 to 30 percent larger than those projected for the highest yielding program in the *Study*.

Although the *Study* presents only a narrow range of information on the effects of rotation changes, the available data (Table 3) show that, for a given intensity of management, average long-run costs are reduced 11-15 percent by a 30-year shortening of rotation. The cost advantage of a 30-year shortening of rotations is quite small, however ($1.63 per M fbm under high-intensity management). Moreover, the marginal cost of expanding production rises almost twice as rapidly with shorter rotations as it does with present ones. This is a point of some significance that appears to have been largely ignored in recent discussions of the rotation issue. If shorter rotations are adopted now and if in the future we wish to expand sustained yield production of national forests above the one governing current policy, it may be more costly to do so if we are on the shorter rotations than if we remain on the current ones. Whether or not relevant long-term marginal costs for the shorter rotations are higher than for present ones remains an open question, partly because *Study* data do not cover the relevant range of program intensities and partly because *Study* costs do not appear to include any cost for the use of forest capital. The possibility of added costs, coupled with the lower sustained-yield rates produced on shorter rotations (Table 3, column 5), suggests that the full economic effects of shorter rotations should be carefully explored before any decision to change present national forest rotations is adopted.

Some of the pressure to shorten rotations is based on a desire to increase allowable cuts in the decades just ahead. Under the even-flow constraint, shortening rotation permits an immediate increase in allowable cut. Because of the possible adverse effect of such a shortening on ultimate sustained-yield production and costs of expansion, however, confronting the problem of increases in allowable cut directly by reconsidering the even-flow constraint itself would seem more sensible. If an increase in allowable cut is desirable, better ways to achieve it may be possible than reducing sustained-yield capacity through shortening rotations.



AVAILABLE SURPLUS OF GROWING STOCK

Firm treatment of the policy aspects of alternatives to even flow during the transitional period is hampered by the fact that the *Study* did not probe the critical rates of output around which policy discussion ought to focus. A preliminary assessment is possible, however, with Program III data for illustration. Under Program III (Table 2), transitional yields exceed the ultimate rate of sustained yield by 1.19 billion fbm per year. Thus, Program III results in the liquidation over the first 100 years of an existing growing stock "surplus" of about 119 billion fbm. (The precise amount of surplus will of course be a function of the rate at which existing growing stock is liquidated. If the period of liquidation were halved, the available volume of surplus might be different. But as more rapid cutting of old growth will increase net growth in the region, the 119 billion fbm figure seems to represent a conservative first approximation of the growing-stock surplus.)

Several policy goals possible in the marketing of this surplus have been suggested as alternatives to even flow. It could be converted as rapidly as possible for the maximum return on capital. It could serve as a counter to cyclical or secular movement in stumpage prices or stumpage production. It could be used, in certain situations, to stimulate growth and development in underdeveloped forest areas of the region. The details of what might be accomplished in pursuit of any one of these objectives are complex and cannot be evaluated exhaustively here. But a preliminary evaluation of substituting for even flow a policy of countering the long-term rise in stumpage prices is possible.

POTENTIAL EFFECTS ON STUMPAGE PRICES OF ALLOWABLE CUT POLICY

First, we need to know something about the demand for Douglas-fir, a subject on which the *Study* is, for the most part, properly silent. *Timber Trends in the U.S.* (5) forecast a continuing future shift in the national demand function for forest products amounting to an increase of about 6.7 billion fbm per decade between 1962 and 1980 and about 10.3 billion fbm per decade between 1980 and 2000. If the Douglas-fir region were to continue to supply the same proportion of national wood consumption that it did in 1962, the estimates of national demand suggest that the demand schedule for the region may increase about 4.7 billion fbm by 1980, and an additional 6 billion fbm by A.D. 2000.

Factors such as the southern "third forest" development and increasing substitution of other materials for wood may temper this demand expansion. For purposes of the present analysis, we will assume a lesser shift in the demand for Douglas-fir stumpage of 2.5 billion fbm per decade from now until 2000.

The elasticity of long-run demand for stumpage has never been thoroughly examined. A study in 1952 of long-run demand for sugar pine stumpage (15) indicated a price elasticity for that species of about -1.0. In general, the long-run elasticity of demand for lumber has been estimated as about -2.0. If so, the theory of derived demand would suggest an elasticity of about -0.8 for Douglas-fir stumpage (if stumpage price is about 40 percent of the price of lumber). Figure 3 shows prospective demand curves for stumpage in the Douglas-fir region for the decades 1967-76, 1977-1986, 1987-1996 and 1997-2006, based on these demand shift projections and a constant elasticity of -0.8. (A demand curve for 1962 is also shown for comparison, based on the 5-year average price centered on 1962.)

With these demand curves in mind, let us assume that supply from other than national forest sources is inelastic and continues at the average for 1947-1966 of 9.38 billion fbm per year. (This may be an unduly optimistic assumption. The *Study* predicts a significant decline in harvest of private timber in the region, but does not publish data on which we could base a firmer assumption.) Total regional supply for each of the next 4 decades may then be projected onto the demand functions of

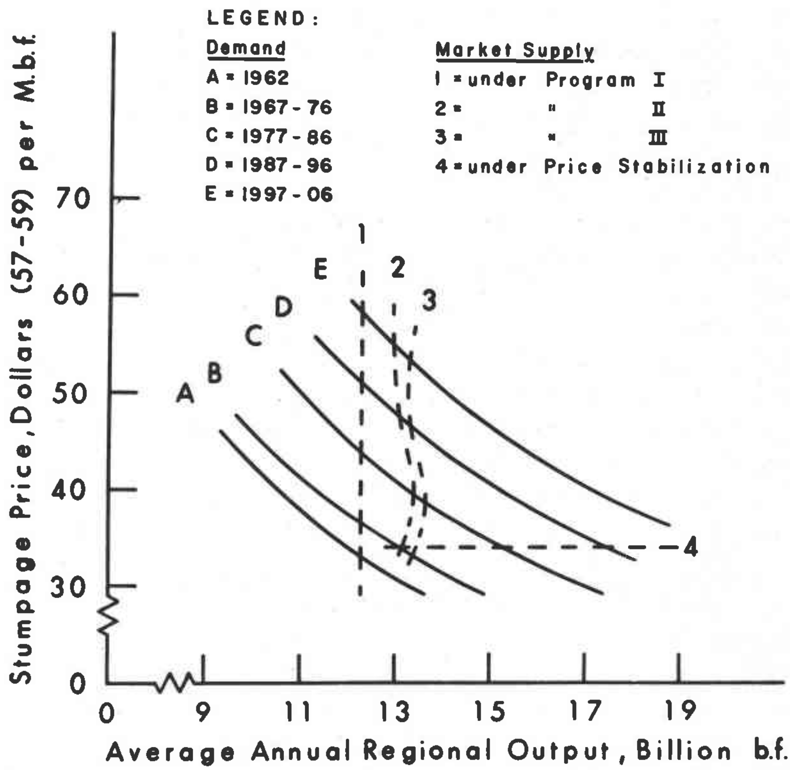


Figure 3. Projected demand, supply, and price for stumpage in the Douglas-fir region by decades, 1967-2006, under selected programs (7) and under a program of price stabilization.

Figure 3. The projections of supply under each of the alternatives for current rotations from the *Study* are also shown. These intersections of supply and demand show estimates of Douglas-fir stumpage price for each of the next 4 decades under each of the three programs for national forest management based on current rotations. The resulting estimates of stumpage prices are shown in Table 4, along with the *Study's* own price projections.

The average of the three price estimates for each decade from Figure 3 agrees fairly well with the *Study's* projections for 1967-1976, 1977-1986, and 1987-1996, but after that date prices seem likely to experience further strong increases rather than level off as the *Study* predicts. Moreover, within each decade, the Figure 3 projections show that stumpage price will be responsive to the rate of national forest production. Prices vary by nearly 10 percent even with the limited range of production alternatives included in the *Study*. If we relax the even-flow assumptions of the *Study*, Forest Service policy on allowable cut may exert an even more powerful influence on stumpage prices.

For example, suppose we adopt a policy of using the 119 billion fbm of growing stock surplus estimated earlier as available under Program III to check the long-term rise in stumpage prices at the 1967-1976 level. The goal of determining

Table 4. Comparison of Douglas-fir Stumpage Prices Projected by the Production Goal Approach with Prices Projected in the *Study* (7).

Management intensity	Average price per M fbm for decade			
	1967-1976	1977-1986	1987-1996	1997-2006
Study projection	$34.31	$42.23	$50.16	$50.16
Production goal projection[1]				
Low	36.50	43.90	50.90	58.20
Medium	33.90	39.40	47.40	55.00
High	33.20	38.70	46.60	53.40
Average	34.40	40.67	48.30	55.50

[1]With current rotation.

Table 5. Regional Stumpage Supply Required in Billions of Board Feet a Year to Maintain Douglas-fir Price at $34 per M fbm, by Decades to 1996.[1]

Decade	Average stumpage price	Required average regional log supply[2]	Source of supply: National forest: Sustained yield	Source of supply: National forest: Growing stock surplus	Source of supply: Other
	$ per M fbm				
1967-1976	34.00	13.10	3.14	0.58	9.38
1977-1986	34.00	15.30	3.14	2.78	9.38
1987-1996	34.00	17.60	3.14	5.08	9.38

[1] Assuming current rotations, "High intensity" management as defined in the *Study* (7), and a sustained-yield target for the national forests of 3.14 billion fbm per year.

[2] Read from Figure 3.

allowable cut would then be to market enough national forest stumpage over the 1967-1996 decades to *prevent* the prospective rise in stumpage price projected in Table 4 and Figure 3. Table 5 shows the estimated cut from national forests that would be needed to meet this objective. Table 6 compares the results of such a price stabilization policy with those of Program III for the next 3 decades.

During 1967-1976, stumpage prices in the region would be about the same, and the growing-stock surplus would be slightly greater under price stabilization than under Program III. During 1977-1986, stumpage prices would be 12 percent lower under the price stabilization policy; at the end of the decade, the stock surplus would be 14 percent lower than under Program III. During 1987-1996, stumpage prices would be 27 percent lower and at the end of the decade, the stock surplus would be 40 percent of Program III. At the same date, the stock surplus would have been reduced to 90 billion fbm under Program III, and to 36 billion under the price stabilization policy.

Table 6. Comparison of Projected Stumpage Prices of Douglas-fir in Dollars per M Fbm, Regional Timber Supply, and National Forest Growing Stock Surplus in Billions Fbm under Program III (7) and under a Policy to Stabilize Price at $34 per M Fbm.

	Study program III				Price stabilization program			
Decade	Stumpage price	Regional supply	National forest cut	Growing stock surplus	Stumpage price	Regional yearly supply	National forest cut	Growing stock surplus
	$/M fbm	*10^6 fbm*	*10^6 fbm*	*10^6 fbm*	*$/M fbm*	*10^6 fbm*	*10^6 fbm*	*10^6 fbm*
				119				119
1967-76	33.20	13.37	3.99		34.00	13.10	3.72	
				110				113
1977-86	38.70	13.66	4.28		34.00	15.30	5.92	
				99				85
1987-96	46.60	13.37	3.99		34.00	17.60	8.22	
				90				36

CONCLUSIONS

I believe that a policy of checking the rising trend of stumpage prices in the Douglas-fir region for at least the next 20 years is a feasible economic objective for national forest policy on allowable cut. The stabilization policy would have the following advantages: the historic trend of rising stumpage prices would be significantly checked; such a curtailment of the rising price trend would help to stabilize, for the next 20 years, the cost structure of dependent industries; it would at least curtail the rising trend of wood product costs and the consequent displacement of wood in many major markets—a displacement that is socially undesirable to the extent that it requires nonrenewable resources where renewable wood could serve as well; it would sustain continuing growth of the wood economy in the Pacific Northwest and of the structure dependent on it for at least another 20 years, without sacrificing ultimate sustained-yield potentials; and it would significantly increase the efficiency of use of surplus forest capital.

There are, of course, disadvantages to the price stabilization policy. Abandonment of even flow during the transition will complicate the task of achieving a fully regulated growing stock. If not properly constrained, this could preclude ultimate achievement of sustained yield. I believe this is unlikely to happen, however, if accelerated liquidation of surplus is confined to the magnitude discussed here and limited to the next 3 decades.

A more telling objection is that the stabilization policy could not be pursued for more than 4 decades without exhausting the existing surplus of growing stock. What would be gained, however, by holding the surplus over a prolonged period, if the future markets such a surplus might serve have been lost as a result of unchecked long-run price increases? Finally, total elimination of the rising trend of timber values could drastically reduce or eliminate the existing incentives to private investment in timber growing in the region. Hence, before final judgments are made as to public policy on allowable cut, careful study needs to be given to the possible influence of alternative allowable cuts on private forest investments as a result of the price effects outlined above.

In the absence of such studies, my preliminary judgment would be that even flow during the transition might well be replaced by a policy aimed at ultimate levels of sustained yield justified by long-run relations of cost to price and well above those discussed in the *Study*, coupled with release of the resulting surplus of growing stock at a rate designed to limit the long-run rise in stumpage prices to not more than 1 percent per year.

The preceding analysis has made bold use of admittedly sketchy and, in some respects, inadequate data. My conclusions, it should be stressed, are merely preliminary and indicative. The issues they raise are so important, however, that every effort should be made forthwith to complete in definitive fashion the analysis I have sketched. This will require detailed research attention to programs, outputs, and costs of much more intensive national forest management; more reliable estimates of the price elasticity of the long-run demand for timber in the region; an assessment of the impact of long-run increases in stumpage price on future shifts in the demand for wood; and some evaluation of the relation between long-run increases in stumpage price and incentives to timber growing investment in the private sector.

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APPENDIX

LONG-RUN UNIT COST UNDER SUSTAINED YIELD

A rigorous interpretation of what the principle of sustained yield means in economic terms is perhaps overdue. Francois has pointed out that "sustained yield is the ideal objective of a forest policy. One can only aim at a sustained yield" (3, p. 30). In economic analysis, then, the policy of sustained yield defines the goal or target that timber management should aim to achieve. In management, this goal is described as a normally regulated growing stock. In economics, the goal is a forest capital capable of producing equal, periodic outputs of wood in perpetuity.

An adequate specification of the goal of forest management policy, however, must also answer the question: at what level should ultimate yields be sustained? A range of possible sustained-yield alternatives exists, depending on the amount of growing stock and the level of other production factors that are chosen. This range is limited at the upper end by maximum site capacity and at the lower end by such minimum "volunteer" production as a forest might generate with no management whatsoever. Practical implementation of a sustained-yield policy therefore requires that a single rate of sustained yield production be chosen from among these various alternatives. This is necessary before sustained yield can be used as a goal or target of specific management planning. How does one choose the optimum rate of sustained yield for this purpose?

In national or regional forest policy, the neo-classical economic concept of long-run normal equilibrium provides a set of analytical tools for making this choice. The rate of sustained yield that will achieve equilibrium between long-run demand for and long-run supply of timber production is the optimum rate that should serve as the target for long-run management planning (14). Concepts and methods for empirical estimates of long-run demand functions for timber have been reasonably well developed through Forest Service timber requirements studies and related evaluations (for example, see 1, Chapter 31). The long-run supply function has been developed empirically for a limited situation (15), but never for an entire forest region. The theory and procedures for developing such empirical long-run supply functions are, however, available (16).

The long-run timber supply is a function showing the relation between various rates of sustained-yield timber production and the total costs of producing them. Because costs of production are spread over an infinite period of time, their total can best be measured by their present worth. Because the resulting outputs of timber are also spread over an infinite period, the unit costs of these outputs may best be measured by their present worth. Thus, if X_A equals the average long-run cost per unit of production at sustained-yield rate A, Y_A is the annual production at that rate, and i is the rate of interest.

The present worth of unit long-run costs of output is $(X_A Y_A)/\ i$ and the present worth of costs of producing this output is

$$\frac{e}{i} + \sum_{n=1}^{n=\infty} \frac{k_n}{(1+i)^n}$$

where e is the constant annual costs of production, and k_n is the nonrecurring cost of production in year n. Because the unit cost of production is, by definition, the same as the cost of producing this amount,

$$\frac{X_A\ Y_A}{i} = \frac{e}{i} + \sum_{n=1}^{n=\infty} \frac{k_n}{(1+i)^n} \qquad 1$$

and the average long-run unit cost of production, X_A, is

$$\left[\frac{e}{i} + \sum_{n=1}^{n=\infty} \frac{k_n}{(1+i)^n} \right] \frac{i}{Y_A} \qquad 2$$

Equation 2 thus permits measuring the long-run average costs of production (X_A) under a management program that will produce a sustained yield of Y_A, provided we know the magnitude and timing of costs required to operate the program. Similar evaluation of a variety of management programs, each with a different rate of sustained yield, provides the data for constructing a functional relation between various rates of sustained-yield production and their average long-run costs, provided each management program is the most efficient one for that rate of production (that is, the program for Y_A has a lower average long-run unit cost than any other program that produces Y_A). Such a curve showing average long-run unit costs appears as *AC* in Figure 4.

For an entire industry or forest region, the long-run supply function for timber production is the curve marginal to curve *AC*. This is shown in Figure 4 as *MC* and may be calculated directly from *AC* by conventional methods.

The long-run equilibrium rate of sustained yield is shown by the intersection of the supply function, *MC*, with the appropriate long-run demand function, *DD*; that is, at sustained-yield rate *OQ*. We can readily see that this is the optimum target rate of sustained yield because, at any rate of sustained yield lower than *OQ*, such as OQ', demand price DP' will exceed supply price SP'; and at any rate of sustained yield larger than OQ', such as OQ'', demand price DP'' will be insufficient to cover supply price SP''.

Up to this point, discussion has concerned only the static condition where sustained yield has already been achieved. We may now adapt the analysis to the practical condition, in which sustained yield is the goal of policy, an aim not yet achieved. Yields will not be constant for all future time, but may be greater or less than the sustained-yield rate during some transitional period, p. Let Y_c equal the yield in the c^{th} year of period p, with other symbols retaining the same meaning as previously indicated.

Then, the present worth of the costs of future production is as before

$$\frac{e}{i} + \sum_{n=1}^{n=\infty} \frac{k_n}{(1+i)^n}$$

and the present worth of average long-run unit costs is

$$\frac{X_A\ Y_A}{i(1+i)^p} + \sum_{c=1}^{c=p} \frac{Y_c X_A}{(1+i)^c}$$

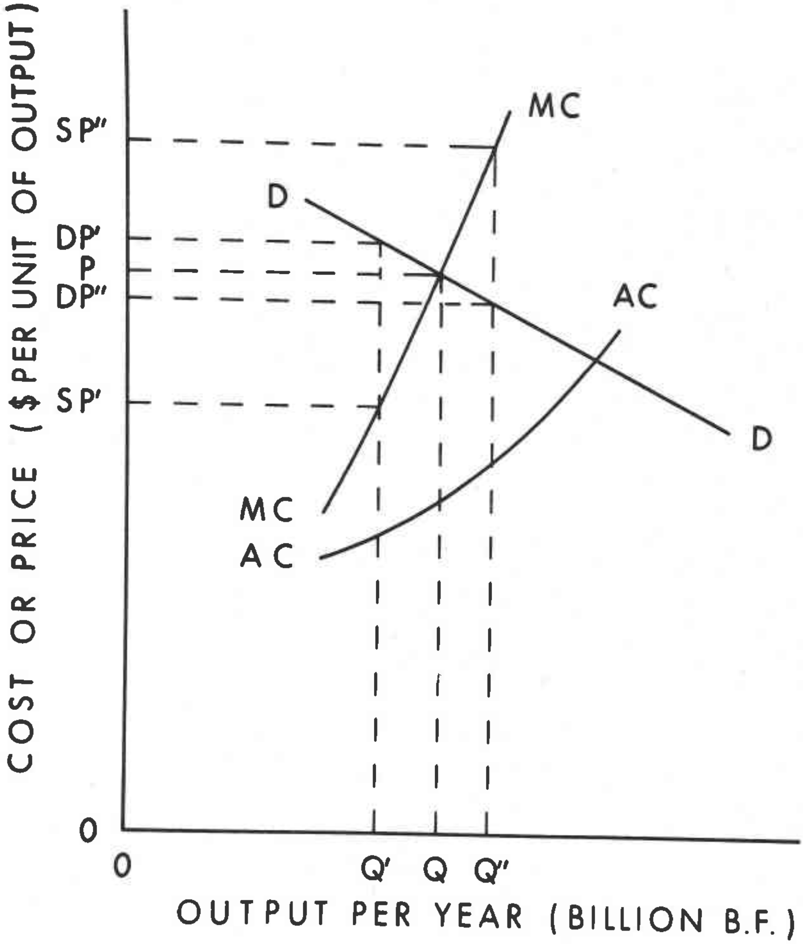

Figure 4. Long-run equilibrium output (*Q*) equalizes demand price (*D-D*) with supply price (*MC-MC*).

Equating present worth of costs of future production with the present worth of average long-run unit costs of output, we have

$$\frac{X_A\ Y_A}{i(1+i)^p} + \sum_{c=1}^{c=p} \frac{X_A\ Y_c}{(1+i)^c} = \frac{e}{i} + \sum_{n=1}^{n=\infty} \frac{k_n}{(1+i)^n} \qquad 3$$

or

$$X_A = \frac{\dfrac{e}{i} + \displaystyle\sum_{n=1}^{n=\infty} \frac{k_n}{(1+n)^n}}{\dfrac{Y_A}{i(1+i)^p} + \displaystyle\sum_{c=1}^{c=p} \frac{Y_c}{(1+i)^c}} \qquad 4$$

Costs and yields incurred at distant dates will have little or no significant effect on X_A at customary interest rates. In practice, such costs and yields can be ignored. In the *Study*, they were specified for 12 decades. Equation 4, modified to include only costs and yields of a finite number of decades, d, becomes

$$X_A = \frac{\dfrac{e[(1+i)^{10d}-1]}{i(1+i)^{10d}} + \displaystyle\sum_{n=1}^{n=10d} \frac{k_n}{(1+i)^n}}{\displaystyle\sum_{d=1}^{d=12} \frac{Y_d(\overline{1+i}^{10}-1)}{i(1+i)^{10d}}} \qquad 5$$

where Y_d is the average annual yield in the d'th decade.

Equation 5 formulates the solution to the problem of average long-run unit costs where the length of the conversion period and the length of the sustained-yield rotation have already been determined. The formulation applies whether or not the transitional period is characterized by even flow and does not require that the transitional period and rotation be of equal length. Thus, the equation can be readily adapted for determining costs where (unlike the *Study*) the transitional period differs from the rotation length and the even-flow constraint is not imposed on the transition.

Given the cost and yield data published in the *Study*, application of Equation 5 to a particular management program is simple, as shown in Table 7. It illustrates the calculation of average long-run unit costs for the particular plan of Program III. This average long-run unit cost, $14.87 per M fbm,

Table 7. Calculation of Average Long-Run Unit Cost of Production during Twelve Decades under Sustained Yield for Program III (7).

1	2[1]	3[2]	4[3]	5[4]	6[5]
Decade	Yearly program cost	Valuation factor at 5%	Present net worth of program costs	Yearly output	Present net worth of costs of output[6]
	Millions dollars		*Millions dollars*	*Billions fbm*	*Millions dollars*
1	78.16	7.723	603.63	3.99	30.84X
2	75.26	4.742	356.88	4.28	20.31X
3	36.96	2.911	107.59	3.99	11.60X
4	33.26	1.788	59.47	3.94	7.05X
5	24.16	1.097	26.50	3.93	4.31X
6	24.16	0.673	16.26	3.91	2.63X
7	24.46	0.413	10.10	3.89	1.60X
8	24.46	0.254	6.26	3.87	0.98X
9	24.46	0.156	3.82	3.81	0.59X
10	24.16	0.096	2.32	3.14	0.30X
11	24.06	0.059	1.42	2.68	0.16X
12	23.76	0.036	0.86	2.68	0.10X
All			1,195.11		80.47X

[1] Accumulation from *Study* tabulations (p. 21-24) showing costs by decade for each program component in program III.
[2] Present worth of a payment of $1 per year made each year during the decade.
[3] (Column 2) x (Column 3).
[4] Accumulated from *Study* tabulations (p. 12-13) showing yields by decade for each category of cut in program III.
[5] (Column 5) x (Column 3).
[6] X = long-run average unit cost of output in dollars per M fbm.
Present net worth of production costs (sum of column 4) = present net worth of costs of output (sum of column 6)X,
or 1,195.11 = 80.47X
X = $1,195.11/80.47 = $14.87 per M fbm.

corresponds to a sustained-yield rate of 2.68 billion fbm per year and an average transitional even flow of 3.87 billion fbm per year. Comparable calculations for other programs produce estimates of average long-run costs for the specific rates of sustained yield and transitional production characteristic of such programs.

As noted, these estimates lead to formulation of the long-run average cost curve appropriate for deriving the supply function for the Douglas-fir region only if the *Study* programs are efficient.