

## Chapter 11

# THE SIMPLE ANALYTICS OF FOREST ECONOMICS

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The allocation of forest resources in the United States is affected by public policy in a variety of ways. Direct control is exercised over public forestlands owned by the federal government and managed by the U.S. Forest Service and the Bureau of Land Management, as well as forests owned by state and local governments. The national forests, under Forest Service administration, account for about 18 percent of the commercial forest acreage in the United States and for over 45 percent of the softwood growing stock, as figures in the first two rows of Table 11-1 show. Holdings of other public agencies amount to an additional 10 percent of forestland acreage and 11 percent of growing softwood inventories.

Public policy also influences timber supplies from private lands by altering the rules and incentives under which private owners operate. Both the magnitudes of tax rates and the form of taxation (i.e., whether levied on yields, property values, or forest products income) affect the relative profitability of alternative rotation and reforestation strategies. Environmental regulations impose direct constraints on the construction of roads and the application of herbicides, and often prescribe both logging and reforestation practices to protect habitats.

Without implicating them for any errors or conclusions this chapter may contain, I wish to thank Margriet Caswell, Perry Shapiro, and John Sonstelie for valuable comments on an earlier draft.

A general economic framework for analyzing allocations of timber resources can be developed in nontechnical terms. The economic decisions of private timber producers are influenced by a wide range of factors including input and output prices, interest rates, tax policy, and environmental and other regulations. To accurately assess the effects of public policy on the decisions of private foresters, an understanding of these economic relationships is clearly important. At the same time, an economic analysis of the costs and benefits of alternative strategies is necessary for evaluating management policy on public forests.

Most treatments of the economics of forestry have been either mathematical in nature, or incorrect in certain important respects.<sup>1</sup> The use of mathematics in the present survey is minimal; rather, important points are demonstrated graphically and explained intuitively wherever possible. The general principle of comparing benefits and costs provides a unifying theme. When benefits and costs are defined to include only factors that enter the profit calculus of the private forest owner, the result is a description of self-interested behavior, a useful guide to the positive analysis of market outcomes. When suitably adapted, the benefit-cost framework also provides a natural vehicle for the analysis of alternative public management strategies.<sup>2</sup> The classic economic problem of when, or at what age, a private owner will harvest a forest is the starting point for the analysis. The concepts and terms developed are then used to examine the sustained-yield forestry practices currently mandated for public lands.

1. Examples of rather mathematical presentations are M. Gaffney, "Concepts of Financial Maturity of Timber and Other Assets," *Agricultural Economics Information Series*, No. 62 (Raleigh: North Carolina State College, 1957); J. Hirshleifer, *Investment, Interest, and Capital* (Englewood Cliffs, N.J.: Prentice-Hall, 1970); C. W. Howe, *Natural Resource Economics* (New York: John Wiley and Sons, 1979), ch. 14; and Paul A. Samuelson, "The Economics of Forestry in an Evolving Society," *Economic Inquiry* 14 (1976): 466-92. Relatively nontechnical accounts may be found in Irving Fisher, *The Theory of Interest* (New York: Macmillan, 1930), pp. 160 ff.; and in G. K. Goundrey, "Forest Management and the Theory of Capital," *Canadian Journal of Economics and Political Science* 62 (1960): 124-42. However, both presentations contain important analytical flaws; see Samuelson, "The Economics of Forestry," for a discussion. For an excellent nontechnical analysis of selected topics, see Y. Levy, "An Economic Alternative to Current Public Forest Policy," in *Economic Review* (San Francisco: Federal Reserve Bank, 1978), pp. 20-39.

2. The benefit-cost approach has been widely applied to public sector decisionmaking and has been legally mandated for the analysis of federal water resource projects. Hence, its potential relevance for public forest policy is clear. See Howe, *Natural Resource Economics*, for further discussion of the uses of benefit-cost analysis.

Table 11-1. Growth, Productivity, and Growing Stocks on Public and Private Forestlands, 1977.

	<i>National Forests</i>	<i>Forest Industry Forests</i>	<i>Total, All Ownership</i>
Land area of commercial timberland (1000 acres) <sup>a</sup>	88,718	68,782	482,486
Softwood growing stock (millions of cubic feet)	207,699	74,382	455,779
Annual net growth of growing stock (millions of cubic feet)	2,465	2,866	12,285
Ratio of growing stock to annual growth	84.25	25.96	37.10
Annual growth per acre (cubic feet)			
actual	35	59	45
potential	74	87	74
actual as percent of potential	47%	68%	61%

a. The other major ownership categories are "other public" and "farmer and other private." The latter group consists primarily of small individual holdings, which, though an important source of commercial timber, are often managed for objectives not compatible with timber harvesting.

Source: USDA, Forest Service, *An Analysis of the Timber Situation in the United States, 1952-2030*, Forest Resource Report no. 23 (Washington, D.C.: Government Printing Office, December 1982).

The same tools are used to study the competitive market supply of timber and the relationships between supply and costs, prices, interest rates, and alternative tax instruments.

### THE HARVESTING DECISION

How long will a private entrepreneur allow a stand of trees to grow before harvest? This is, of course, only one of many economic decisions the owner must make. Other economic choices involve outlays for disease control, for the labor and equipment used in thinning, fire suppression, and reforestation, and for research directed toward genetic enhancement. However, the long-lived nature of the resource

and the long-run character of timber production make the harvest age problem particularly interesting.

Although actual forest harvest decisions result from long-run planning, and are presumably decided well in advance of the actual harvest date, it is useful for expositional purposes to imagine the forest owner re-examining the harvest decision anew each year. When considering whether or not to allow the stand to mature an extra year before harvesting, a rational decision requires a comparison of the benefits and costs of waiting. The benefits to the private forest owner are reflected in the value of salable timber that will be grown during the waiting period. The amount of new growth obtained per year will depend on the age of the stand and will eventually decline as the stand matures.

The costs of delaying the harvest are represented by the value of receipts that are forgone when the stand is allowed to grow for an additional year. The stock of growing timber is a "capital" asset. If, instead of being allowed to grow, it was harvested and the proceeds invested, it would earn interest for the owner. Thus, the forgone return on the stock of standing timber is a cost of allowing the forest to mature. A second cost is associated with the use of forestland to support an additional year of growth in a standing forest. This cost equals the forgone return from the highest valued alternative service the land could have provided during that period.<sup>3</sup> In some cases the highest valued alternative use will be in growing future stands of timber, an activity that requires the existing stand be cut. In other cases the highest valued alternative may lie in some nonforest use such as farming or residential development.

If in a particular period the benefit of waiting an extra year outweighs the cost, then the rational forest owner will postpone the harvest. As the stand matures, the rate of growth will decline, and the benefit from further delays in harvesting will diminish. Eventually, the benefit to waiting an extra year will fall to the point where it just equals the cost of waiting, and no further postponement is profitable. At that age the stand has reached "financial maturity" and will be harvested.

3. The stock of timber capital and the parcel of land the forest occupies may be viewed as two inputs. Use of those inputs for a year is required to produce one year's growth. Accordingly, the marginal cost of waiting is simply the cost of using two inputs for one year.

### A Simple Harvesting Problem

To illustrate the preceding concepts and to develop notation that will be useful in subsequent analysis, consider a highly simplified situation in which both the real rate of interest and the real price of timber net of any harvesting cost are expected to remain constant in the future. Furthermore, the only economically scarce input needed to grow timber is the capital embodied in the growing stock. Whatever land is required for growth is assumed to have no opportunity cost.<sup>4</sup> At issue is the age at which a given stand of trees will be harvested by a rational owner. The following notation can be used to address this question:

- $T$  the age of trees in the stand;
- $f(T)$  the volume of timber available for harvest, if left to grow until age  $T$ ;
- $\Delta f(T)$  the annual growth of the stand, at age  $T$ ;
- $r$  the real rate of return (interest) on alternative investments;
- $p$  the real price of timber, net of any harvest costs.

The term  $T$  has been incorporated into the above notation for  $f$  and  $\Delta f$  as a reminder that both the volume of timber in the stand and its annual rate of growth will change as the stand ages. Where no confusion will result, the  $T$  will be dropped to simplify expressions.

With the preceding notation, the benefit from waiting an extra year before harvesting—denoted  $MB$  (waiting)—is simply the value of new growth, the product of annual growth, and the net price of timber,

$$MB(\text{waiting}) = p\Delta f .$$

If the owner decides to wait, the opportunity to earn the market return on the net value of harvested timber will be forgone. Thus, the

4. To the private entrepreneur, an absence of opportunity cost would be reflected in a zero market price for bare timberland. This may have been relevant at some historic time when timberland was so plentiful that it could not command a positive price. At present it may apply, at least approximately, to acreage that is either sufficiently unproductive or remote from market centers that no significant rent can be charged for its use.

marginal cost of waiting is the product of the rate of return and the value of the harvested stand,

$$MC(\text{waiting}) = rpf .$$

If these terms represent the only costs and benefits relevant to the problem, then the rational decisionmaker will continue to postpone harvesting so long as the benefit of doing so exceeds the cost. At some age, however, the two will be equal,

$$p\Delta f = rpf , \quad (1)$$

and the forest will be harvested. Any additional delays beyond that critical age would involve costs that exceed benefits. If the net price  $p$  is cancelled from both sides of this expression, one obtains a benefit-cost condition expressed in physical units,

$$\Delta f = rf . \quad (2)$$

This form of the harvest age criterion is particularly useful for a diagrammatic analysis.

A third representation of this condition can be obtained by dividing both sides of equation (2) by the volume of the stand,  $f$ ,

$$\Delta f/f = r . \quad (3)$$

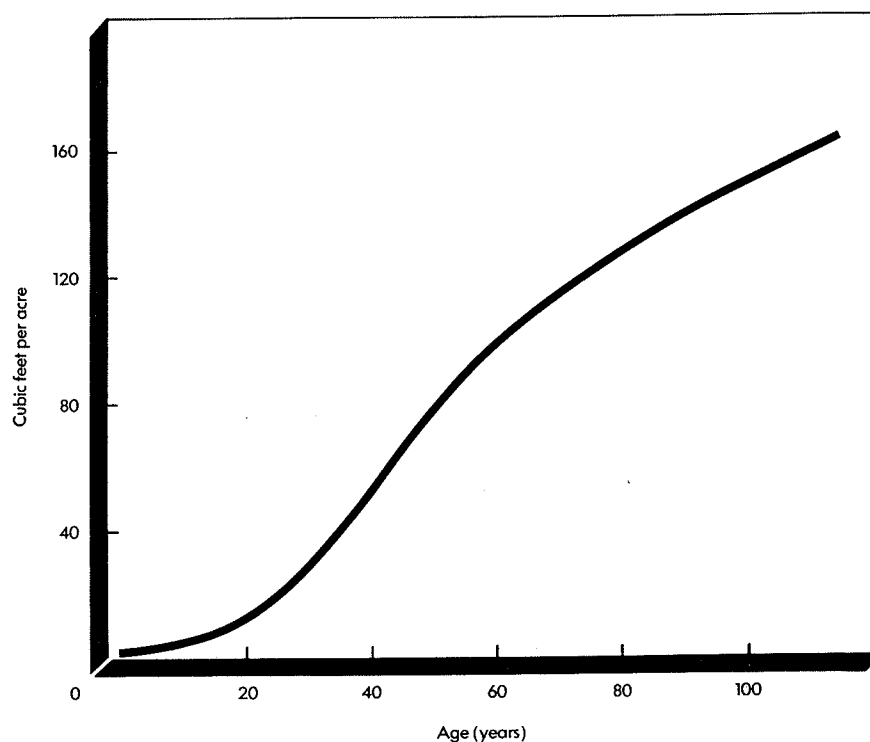
This is a condition that figured prominently in Irving Fisher's analysis of the forest-harvesting decision.<sup>5</sup> The left hand side of equation (3) is the proportionate rate of growth of the forest, and it represents the physical rate of return on the stock of growing timber. With this interpretation, the benefit-cost decision rule indicates that the owner will liquidate the stand when its own rate of return falls to equality with the return available on other investments.

The preceding analysis has a ready diagrammatic interpretation. Figure 11-1 depicts a growth function for the stand of trees in question. On the horizontal axis is the age of the stand ( $T$ ); the volume of timber ( $f$ ), measured in thousands of cubic feet per acre, is shown on the vertical axis. The shape of the curve in Figure 11-1 is representative of growth characteristics for Douglas fir.<sup>6</sup> The exact pat-

5. Fisher, *The Theory of Interest*, pp. 163, 164.

6. See R. McArdle, "The Yield of Douglas Fir in the Pacific Northwest," *U. S. Department of Agriculture Technical Bulletin*, No. 201, Washington, D.C., 1949.

Figure 11-1. Typical Growth for Douglas Fir.



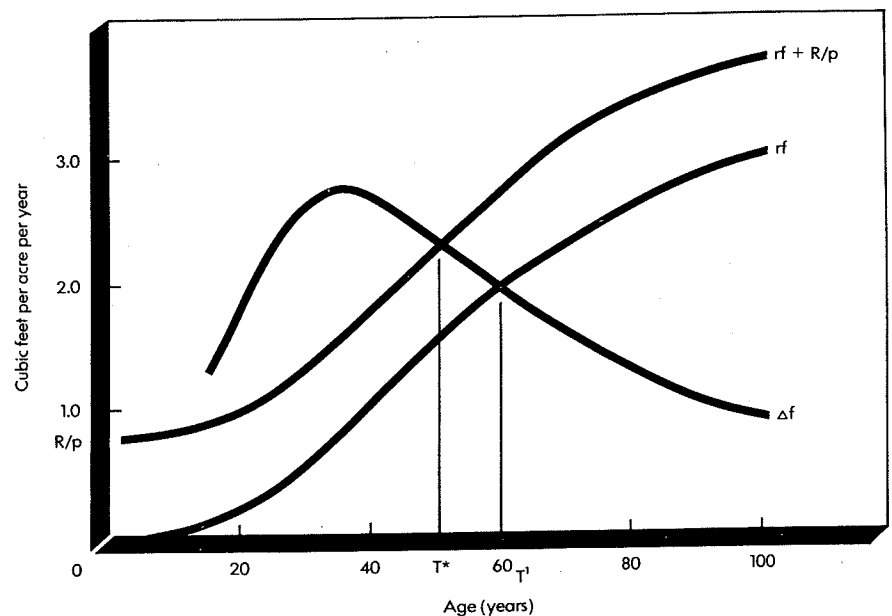
tern of growth for a particular forest would, of course, depend on the species in question and prevailing growing conditions.

The growth function in Figure 11-1 was used to derive two of the curves in Figure 11-2, those labeled  $\Delta f$  and  $rf$ . (The third curve, denoted  $rf + R/p$ , is discussed in the next section.) The vertical dimension of Figure 11-2 has been expanded to permit easier inspection. The curve labeled  $\Delta f$  is simply the annual rate of growth, that is, the annual change in  $f$  at each age. Consequently, it shows the marginal benefit of waiting expressed in physical units. The curve denoted  $rf$  in Figure 11-2 is proportional in height to the growth function  $f$  in Figure 11-1. If, for example, the real rate of interest ( $r$ ) were 2 percent (the interest rate used in drawing Figure 11-2), the curve would at each age be exactly 2 percent as high as  $f$  in Figure 11-1. In the harvesting decision discussed above,  $rf$  represents the

marginal cost of waiting for the stand to mature, where cost is measured in physical units. The solution to the harvesting problem occurs where the two curves intersect. At this age, denoted  $T^1$ , the benefit-cost condition in equation (2) is satisfied.

Due to the simplifications present in this problem, particularly the assumption that the use of timberland has no opportunity cost, its analysis is of limited interest. Before examining more general cases, however, this simple example may be used to illustrate the sensitivity of the harvest age to the real rate of interest. If  $r$  were higher, the curve labeled  $rf$  in Figure 11-2 would lie above its present position, and the equilibrium harvest age would be lower. The effect of a higher rate of interest is to increase the marginal cost of waiting at all ages and to commensurately reduce the amount of time the owner will find it profitable to wait. Using a symmetric argument it is easy to show that a lower rate of interest would have resulted in a longer waiting time and older age at harvest.

Figure 11-2. Determination of the Harvest Age.





### Harvesting and Reforestation

Land used to support growth of standing forests generally has economic value in alternative uses.<sup>7</sup> These alternatives might range from reforesting and growing a new crop of timber to clearing the land for farming to subdividing into residential parcels. The opportunity cost of allowing a standing forest to occupy the land for an additional year is the value of these forgone uses. In the market, this opportunity cost would be reflected in the rent charged or imputed for use of the land. Letting  $R$  denote this per period cost, the benefit-cost criterion for the optimum harvest age becomes

$$p\Delta f = rpf + R \quad (4)$$

The marginal cost of waiting, represented by the right-hand side of the equation, now has two components. This reflects the fact that two economically scarce inputs, timber capital and timberland, with per period opportunity costs of  $rpf$  and  $R$ , respectively, are required to produce new growth. As before, it is advantageous for graphical analysis to express this benefit-cost condition in physical terms. This is accomplished by dividing both sides of equation (4) by the price of timber to yield

$$\Delta f = rf + R/p \quad (5)$$

The term  $R/p$  now represents the opportunity cost of land expressed in units of timber per period.

At an intuitive level the introduction of an additional component to the marginal cost of waiting reduces the age at which trees are harvested. This is confirmed in Figure 11-2 where the new marginal cost function is drawn as  $rf + R/p$ . The vertical distance between old and new marginal cost curves is  $R/p$ , the opportunity cost of using the land, and the introduction of this cost reduces the equilibrium growing span from  $T^1$  to  $T^*$  years. It is also true that at  $T^*$  the percentage rate of growth of the forest exceeds the real rate of interest. Thus

7. The investment problem addressed in this section was first successfully analyzed by Martin Faustmann, "On the Determination of the Value Which Forestland and Immature Stands Possess for Forestry," 1849, trans. M. Gane, *Oxford Institute Paper* 42 (1968). The following discussion is rather brief, and the reader who wishes more detail or rigor should consult Gaffney, "Concepts of Financial Maturity"; Hirshleifer, *Investment, Interest, and Capital*, ch. 3; and Samuelson, "The Economics of Forestry."

the simple harvesting rule attributed to Irving Fisher does not apply in this more general setting.<sup>8</sup>

How is  $R$  determined, and what economic factors influence it? Consider a parcel of bare timberland just after harvest and assume that the land is expected to remain in foresting over an indefinite sequence of future growing cycles or rotations. (Nontimber uses of the land are temporarily ignored.) The present value of net receipts from these future harvests will clearly be related to the future course of real timber prices, replanting costs, and interest rates. Let this present value be denoted by  $V$ . If the forest was allowed to grow and occupy the parcel for an additional year, the entire stream of future receipts would be delayed by exactly one year. As a result, the opportunity to earn the annual competitive return ( $r$ ) on the value of the stream ( $V$ ) would have been forgone. Consequently, the opportunity cost of allowing the standing forest to occupy the parcel of land for an additional year is

$$R = rV . \quad (6)$$

For clarification, the relationship shown in equation (6) may be viewed from a slightly different perspective. Suppose the timber grower rented the parcel of land from its owner. With land allocated competitively, the equilibrium rent will equal the largest annual charge that any grower would willingly pay. This maximum annual payment is  $rV$ . The present value of an infinite stream of such annual rents would equal  $V$  and hence would just exhaust the net economic profit from foresting.

The general benefit-cost condition stated in equation (5) can be used to analyze how equilibrium land rents and harvest ages will change in response to changes in timber prices, harvesting or reforestation costs, interest rates, taxes, and other economic parameters.<sup>9</sup> For clarification, changes in economic parameters are introduced one at a time, and the parameter changes considered are confined to simple shifts from one constant level to another. Thus, for example,

8. Fisher, *The Theory of Interest*.

9. The value of future forest receipts will also be affected by the harvest age chosen for future stands. With timberland allocated competitively, the rotations used will maximize the present value of future receipts. Moreover, if levels of real price, replanting costs, and interest rates persist indefinitely, then future stands will also be cut at  $T^*$ , the age that maximizes profit from the stand currently growing.

Table 11-2. Qualitative Relationships Between Economic Conditions and Profit-Maximizing Forestry Decisions.

	Net Price of Timber: $p$	Replanting Cost: $c$	Interest Rate: $r$
Land rent from future timbering: $R$	+	-	-
Age at harvest: $T^*$	-	+	-
Long-run supply:			
Acreage in timber	+	-	-
Supply per acre	-	+	-
Net supply effect	?	?	-

Note: The price of timber is net of any harvest costs per unit. All prices, costs, and interest rates are interpreted to be in real (inflation-adjusted) terms.

the effect of price on the rotation age is analyzed by comparing equilibrium rotation ages under different constant price regimes.

Consider first how changes in prices, costs, and other factors would alter  $R$ , the equilibrium rent on land devoted to growing timber. Clearly, a higher timber price would increase the annual return to land devoted to forestry, and increases in costs would tend to reduce it. Changes in the interest rate,  $r$ , would also affect  $R$ , though the direction of this relationship is less straightforward. Here it is useful to view  $R$  as the maximum amount a potential user would be willing to bid for use of the land for one year. If the interest rate is increased, the discounted value of future receipts from any given harvest and reforestation plan will decline. Accordingly, the amount of current income a forester would pay to obtain this stream of receipts falls, as well.<sup>10</sup>

The preceding qualitative relationships are listed in Table 11-2. In this table the column headings are economic parameters that influence returns to forestry and the harvest-replanting decision. The term  $c$  is defined to be a per acre replanting or reforestation cost incurred at the beginning of each growing cycle. The row headings

10. Recall that  $R = rV$  in equation (6). The argument in the text only demonstrates that an increase in  $r$  will cause  $V$  to decline. To conclude that it causes  $R$  to decline, it must be shown that the fall in  $V$  more than offsets the associated increase in  $r$ . This follows from the fact that the effect of  $r$  on  $V$  is more than proportionate, due to the compounding of interest in the present value relation. A formal demonstration of this point is available from the author on request.

are variables that result from forest management decisions, such as the rent on forestland and the rotation age. The signs in the first row of cells in this table indicate directions of relationships between the equilibrium rent on forestland and the price of timber, the replanting cost, and the interest rate. Thus, the first row of entries indicates that  $R$  responds positively to increases in price and negatively to both increases in replanting cost and increases in the interest rate. Recall that price is defined net of harvesting costs (i. e., it is a stumpage price). Hence, increases in harvest costs will, *ceteris paribus*, reduce  $p$  and cause  $R$  to decline.

Examine next how economic conditions will influence the rotation age,  $T^*$ .<sup>11</sup> As shown in Figure 11-2 (and in equation (5)),  $T^*$  is determined by the rate of growth ( $\Delta f$ ) and by the opportunity cost of using both the stock of timber and land to support growth ( $rf$  and  $R/p$ , respectively). Consider first the relationship between  $c$ , the initial reforestation cost, and the optimum harvest age. From the results represented in the first row of Table 11-2, an increase in  $c$  will reduce  $R$ . From Figure 11-2, a reduction in  $R$  would cause the curve labeled  $rf + R/p$  to shift down, increasing the equilibrium rotation age. Hence, the relationship between  $c$  and  $T^*$  is positive, as shown in the second row of Table 11-2. At a more intuitive level, the forest manager can mitigate the impact of increased reforestation costs by reducing the number of replantings undertaken in any given time period. To do so, the length of each rotation must, of course, be increased.

The relationship between  $p$  and  $T^*$  is somewhat more complicated. The net price,  $p$ , enters the benefit cost condition in Figure 11-2 through its effect on  $R/p$ . Because  $p$  is positively related to both the numerator and the denominator, it is not immediately clear how this expression would change if  $p$  were increased. To clarify this question, it is useful to write out the present value of a single rotation's net receipts, denoted  $N$ , where discounting is to the initial period of the rotation,

$$N = \frac{pf}{(1+r)^T} - c . \quad (7)$$

11. An analysis of the effects of prices and costs on the length of rotations is also presented in Howe, *Natural Resource Economics*, pp. 225 ff.

In this expression,

$c$  is the cost of reforestation incurred at the beginning of each rotation;

$1/(1+r)^T$  is the present value of a receipt received  $T$  periods in the future.

The terms  $p$ ,  $f$ ,  $r$ , and  $T$  were defined earlier. From equation (7) it can be seen that, so long as  $c$  is positive, a change in  $p$  will cause a more than proportionate change in profit per rotation ( $N$ ) and hence a more than proportionate change in  $R$ . For example, a 10 percent increase in price will increase *gross* receipts by exactly 10 percent. If replanting costs are positive, however, the resulting rise in *net* receipts, and hence  $R$ , will exceed 10 percent. Thus, increases in  $p$  will cause  $R/p$  to rise, since the numerator is increased relative to the denominator. From Figure 11-2, an increase in  $p$  will shift the curve  $rf + R/p$  upward, and a shorter rotation time will result.

For a less mechanical and more intuitive explanation of this relationship, recall the monetary expression of the harvesting condition in equation (4). There it may be seen that a given increase in price causes proportionate increases in both  $p\Delta f$ , the marginal benefit of waiting (since any timber grown will be worth more), and  $rpf$ , the opportunity cost of allowing the stand to mature an extra period (since the return would be greater if the stand was harvested and the proceeds invested). If the opportunity cost of land ( $R$ ) also increased in proportion, then both marginal benefit and marginal cost would be increased proportionately, and no change in rotation times would be indicated. With positive replanting costs, however, the increase in land cost is more than proportionate, and the costs of waiting rise relative to the benefits. As a result, the rotation time is reduced.

Regarding the last entry in the second row of Table 11-2, note that the real rate of interest enters the marginal cost of waiting in two ways. An increase in  $r$  will raise  $rf$ , the opportunity cost of using "timber capital" to produce new growth. At the same time, however, a higher interest rate reduces the present value of future harvests and hence lowers the opportunity cost of occupying the land. (Recall the relationship between  $r$  and  $R$  in the first row of Table 11-2.)

Hence, the net effect of a change in the interest rate on the marginal cost of waiting and the chosen rotation age would seem ambiguous. It can be shown, however, that the change in  $rf$  dominates, so

that higher interest rates increase the marginal cost of waiting and reduce the rotation age.<sup>12</sup> Without delving extensively into the algebra of the present value relation, it may be noted that increases in interest rates signal increases in the premium that current consumption commands over future consumption. Forest management decisions respond to that signal by reducing rotation times and thus moving future consumption closer to the present.

### FORESTRY AND PUBLIC POLICY

The analysis to this point has been exclusively concerned with private forest management practices. However, the general benefit-cost framework developed earlier can be applied, with suitable modification, to questions of public policy, as well. The competitive outcomes analyzed previously may well diverge from an appropriately defined social norm, due perhaps to the presence of externalities. However, the market solution still provides a very useful benchmark for policy analysis since, as Arrow and others have pointed out, if markets existed for all goods and services that affect society's welfare, then equilibrium-competitive outcomes would be socially efficient.<sup>13</sup> In this case, application of the private benefit-cost criterion developed above would yield results that pass a social benefit-cost test, as well.

An understanding of the relationship between competitive outcomes and socially efficient forest resource allocations may be gained by reinterpreting terms in the private benefit-cost framework developed earlier in order to transform that rule into an appropriate criterion for social policy. To do this, it is most convenient to work with the monetary form of the condition stated in equation (4) as  $p\Delta f = rpf + R$ . First, the price of timber,  $p$ , must be reinterpreted as the marginal benefit society receives from the use of timber in housing, paper products, and so forth. Any postulated difference between

12. As in the case of the relationship between  $r$  and  $R$ , this result follows from the effect of compounding in the present value relation. A formal demonstration will be provided by the author upon request.

13. K. J. Arrow, "The Organization of Economic Activity," in Haveman and Margolis, eds., *Public Expenditures and Policy Analysis* (Chicago: Markham, 1970), pp. 59-73. By "socially efficient" it is meant that the competitive equilibrium would be a Pareto optimum, an allocation from which any departure will necessarily make one or more members of society worse off.

this marginal benefit and the competitive price would imply socially optimal rotations that diverge, in a predictable fashion, from those chosen by private forest managers. Second, it might be necessary to modify  $r$ , the real rate of interest relevant for competitive investment decisions, in order to reflect the socially appropriate rate for discounting future consumption. Third, the opportunity cost of land used to grow timber ( $R$ ) might need to be altered to allow for possible nonmarket benefits (or costs) that the presence of standing forests confer.

One potential reason for a divergence between price and the marginal benefit of consuming timber products arises from external damages imposed in harvesting timber or in processing it into paper and wood products. On the one hand, if these external effects are large relative to the externalities associated with other forms of consumption, then the market price revealed to forest managers would be too high from a social point of view. On the other hand, favorable tax treatment of income earned from growing timber might result in timber supplies that are excessive in a social sense, and market prices that are accordingly too low. If the net difference between price and marginal benefit could be determined, then the preceding analysis and the qualitative relationships shown in Table 11-2 could be used to determine the direction of bias in privately chosen rotation ages. Clearly, however, careful empirical analysis in several areas would be needed to determine the presence and magnitude of any discrepancies between market prices and social benefits, and hence an appropriate policy toward private rotation practices.

The possibility of divergences between social and market rates of discount has been debated for decades in the academic literature.<sup>14</sup> Some noted economists have asserted that, due either to the effects of corporate income taxation or to a public good aspect of bequests to future generations, the discount rates applied to private investment decisions are too high from a social perspective. Others, most notably Hirshleifer, have argued against any such distinction between private and social rates of discount.<sup>15</sup>

If one agrees with the proponents of a lower discount rate for evaluating private investments, the implications of this position for pri-

14. For a brief discussion of this literature, see Samuelson, "The Economics of Forestry," p. 488.

15. J. Hirshleifer, "Investment Decisions Under Uncertainty," *Quarterly Journal of Economics* 80 (1966): 252-77.

vate forestry are not entirely clear. The ambiguity arises because the social discount rate reasoning offers a prescription to subsidize all private investment. To apply it to forestry decisions alone would result in a misallocation of capital between forestry and other sectors of the economy. As a result of these considerations, Samuelson was led to conclude, "It is not necessarily an argument for programming . . . [the choice of timber rotations] with a hypothetical interest rate much lower than interest rates that prevail elsewhere."<sup>16</sup>

Possible divergences between social and private measures of the opportunity cost of occupying land with standing timber ( $R$  in the benefit-cost equations) might arise from a variety of sources. In the forest policy literature, references to external benefits from recreation, watershed enhancement, and habitat protection are very common, though attempts at actual measurement appear to be rare.<sup>17</sup> If these external benefits are important at the margin, then a market allocation system will tend to overstate the opportunity costs of occupying land with standing timber. Here it is important to stress that it is the marginal effect, the contribution of an extra acre of standing timber to these nonmarket benefits, that is significant for policy. On the one hand, if these nonmarket demands were already largely satisfied by private allocations of forest resources, then the divergence between social and private opportunity costs might be quite small.<sup>18</sup> On the other hand, if this divergence was significant, then the benefit-cost rule stated in equation (4) would indicate the nature of the difference between competitive and socially efficient rotation plans.

This brief survey is not the appropriate context for a full discussion of the externality issue or application of the benefit-cost approach to actual policy problems. Even from this limited discussion, however, it should be clear that the comparison of benefits and

16. Samuelson, "The Economics of Forestry," p. 488.

17. For discussions regarding the claim that standing forests promote flood protection and commercial fisheries, see Nelson and Grobey, Chapters 2 and 7, respectively, in this volume. As Hartman has shown, the presence of such nonmarket considerations tends to lengthen optimum rotation times, a result that confirms the relationship between  $R$  and  $T^*$  in Table 11-2. See R. Hartman, "The Harvesting Decision When a Standing Forest Has Value," *Economic Inquiry* 14 (1976): 52-58.

18. Grobey (Chapter 7 in this volume) has made precisely the same point regarding the importance of marginal values for policy analysis in the area of fishery enhancement. He also points out that the average benefits are often used for actual policy recommendations, while marginal benefits are generally lower.



costs is an essential part of any acceptable public policy toward forests. To approach public policy problems by simply placing forests in the public sector and then relying on the good intentions of public managers is clearly not adequate, as a growing body of research has demonstrated.<sup>19</sup> Rather than confront the difficult economic comparisons that must be made in allocating such resources, public forest managers have traditionally attempted to base policy solely on physical criteria.

A general neglect of economic considerations is exemplified by policy concerning choices among alternative uses of public forestlands. In recognition of the fact that forests can often serve a variety of purposes, current public forest policy stresses the principle of multiple use. A formal mandate for this policy was first stated in the Multiple-Use Sustained-Yield Act of 1960. This act also provided that "due consideration shall be given to the relative values of the various resources in particular areas, . . . latitude for periodic adjustments in use to conform to changing needs and conditions; that some lands will be used for less than all the resources."<sup>20</sup> Despite the economic guidance in this clause, the Forest Service's implementation of the multiple-use philosophy has often resembled an attempt to require all uses to be represented on all public forestlands. Such a practice accentuates conflicts between uses and often has the effect of unnecessarily reducing the levels of important forest outputs. Any economically efficient policy of public forest management would require an examination of conflicts among alternative uses and a determination of the economic merits of alternative uses in situations where conflicts exist. In general, a correct benefit-cost analysis would not prescribe the coexistence of all uses on all forestlands. As is common in other contexts, certain forest resources would best serve society's interests if they were specialized, for example, for either timbering or recreation, rather than managed to accommodate all uses simultaneously.

19. See, for example, Marion Clawson, *The Economics of National Forest Management* (Baltimore: Johns Hopkins University Press, 1976). In the present volume, see Nelson (Chapter 2), Johnson (Chapter 4), Nelson and Pugliaresi (Chapter 6), Grobey (Chapter 7), and Muraoka and Watson (Chapter 8).

20. Quoted from Howe, *Natural Resource Economics*, p. 225. More recent statements of policy for national forests appear in the Forest and Rangeland Renewable Resources Planning Act of 1974 and the National Forest Management Act of 1976.

Clawson has found that the Forest Service does not allocate management expenditures among forests in a way that maximizes the value of services produced.<sup>21</sup> Rather, expenses for promoting timber growth are often directed toward forests that are relatively unproductive at growing wood, thus short-changing the more productive national forests. Accordingly, Clawson has recommended a policy of dominant use, really an application of the principle of specialization, that would allocate the least productive timber growing forests to wilderness and recreation use and concentrate timber management efforts on the most productive sites. The result, according to Clawson, would be a two to threefold increase in annual timber growth, and a two to fourfold increase in recreational and wilderness opportunities.

Another area where public forest management has largely ignored economic considerations and attempted to base policy on physical principles is in the choice of rotation ages and harvest schedules. Here the dictum of maximizing sustained yield and the more recent requirement for nondeclining even-flow harvest schedules have formed the basis for public forest policy. Citing again the Multiple-Use Sustained-Yield Act of 1960, the goal in planning harvests is "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."<sup>22</sup> In practice, this directive has been interpreted to call for rotation schedules that would maximize the sustainable yield of timber from public forestlands.

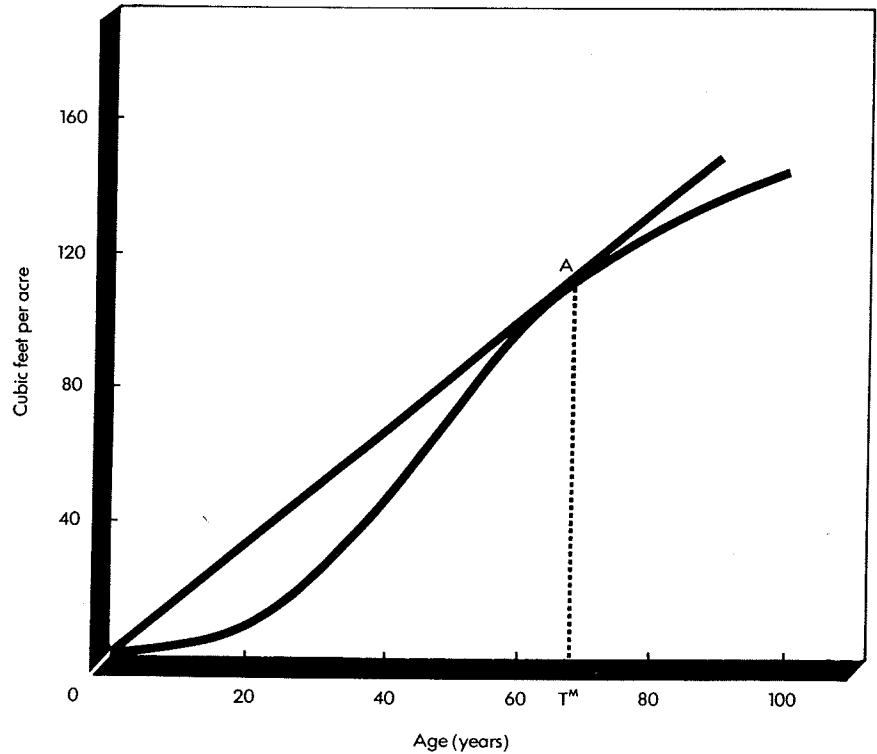
If harvest ages are chosen to maximize sustainable yields, then forests will be cut when cumulative growth per year of growing time is largest. This age has been described as the "culmination of the mean annual increment" of growth, and harvesting at this age is explicitly mandated by the National Forest Management Act of 1976. In terms of the notation developed earlier, a maximum sustainable yield policy amounts to setting the harvest age to maximize  $f/T$ , the mean annual increment or average growth per year. This policy has a ready graphic interpretation from the growth curves used earlier.

In Figure 11-3 the growth function from Figure 11-1 has been reproduced, and a line segment has been drawn between point *A* on

21. Clawson, *The Economics of National Forest Management*.

22. Quoted from Levy, "An Economic Alternative," p. 23.

Figure 11-3. Maximum Sustainable-Yield Harvest Age.



the growth curve and the origin. The slope of line  $OA$  equals the ratio of the volume of wood grown by that age ( $AT^M$ ) and the age of the stand ( $OT^M$ ). The slope of this line is, therefore, the mean annual increment for a stand of age  $T^M$ . There will, of course, be a different mean annual increment for each harvest age. The mean annual increment is maximized, however, at age  $T^M$ . Thus, a policy that specified rotations at intervals of  $T^M$  years would maximize the sustainable yield from the forest shown in Figure 11-3.

This criterion has no economic content and is completely independent of such economic considerations as prices, costs, and interest rates. Only in a very special set of circumstances, where the real rate of interest is zero and replanting costs are nonexistent, would such a

policy coincide with an economic optimum.<sup>23</sup> If the rate of interest was zero, society would be indifferent regarding the timing of forest outputs. That is, a dollar's worth of present or future benefits would have equal value, and a socially efficient policy need simply maximize the average annual value of net benefits. If replanting costs were also zero, then net benefits would be dependent only on the average annual volume of wood produced.

Accordingly, a policy that maximizes  $f/T$  would also maximize net benefits in this case.<sup>24</sup> However, in a world where the interest rates and replanting costs are positive, a forest management policy that maximizes annual timber output will not maximize the net present value of the resource to society. Likewise, a socially efficient forest policy will not maximize the long-term undiscounted volume of wood produced. Though this may seem anomalous at first glance, it simply reflects a social preference for present to future consumption and a recognition that the process of growing timber uses socially valuable resources.

Although it is clear that the maximum sustainable-yield criterion will not, except coincidentally, result in a social optimum, it cannot be determined from theoretical considerations alone whether the disregard for economic values results in rotation schedules that are too long or too short. To see this, recall from Table 11-2 that positive replanting costs tend to extend the present value maximizing rotation age, while positive interest rates tend to reduce it. As an empirical question, however, it is widely agreed that rotation ages adopted by the U.S. Forest Service for softwood timber substantially exceed those employed on industry forestlands, and most economic analysts

23. In keeping with the practice of comparing alternative steady state equilibria, it is assumed that all economic variables (prices, costs, and interest rates) are expected to remain constant over time.

24. The result can also be shown using the benefit-cost condition stated earlier in equation (4). Interpreting  $p$  as the marginal social value of timber,  $(pf - c)/T$  is the undiscounted average value of net receipts per period. If the interest rate were zero, this would equal  $R$ , the rental payment required to occupy the land with standing timber for one period. Incorporating this into the benefit-cost condition of equation (4), with  $r$  set equal to zero, results in the harvest criterion

$$p \Delta f = (pf - c)/T .$$

If  $c = 0$  also, this reduces to  $\Delta f = f/T$ . This rule indicates that the forest should be cut when the last year's growth ( $\Delta f$ ) just equals the average annual growth of the stand over the entire rotation ( $f/T$ ). In terms of Figure 11-3, this occurs at age  $T^M$ .

have concluded that these rotation ages are excessive from a social viewpoint as well.<sup>25</sup>

An indication of the divergence between harvest practices on public and private forestlands may be obtained from Table 11-1. Figures in the fourth row show the ratio of growing stock to annual growth under different ownership regimes. As shown, this ratio is over three times as high in national forests as in industry forestlands. In a fully regulated forest this ratio would equal the rotation age.<sup>26</sup> Because actual forests are not fully regulated, this finding is best interpreted as indicating only the relative magnitudes of rotation ages under different ownership regimes.

The other growth indicators in Table 11-1 show that, at least in terms of timber yields, private forestlands vastly outproduce national forests, even if corrections are made for differences in natural productivity. These disparities in growth are no doubt due to a variety of factors, including differences in the use of such high-yield practices as thinning, weed and disease control, and genetic improvement, plus differences in the allocation of such efforts among individual forests. But important causes of low growth on public lands remain the choice of harvesting schedules and the Forest Service practice of retaining extensive volumes of old growth timber until even the age of maximizing physical yields is exceeded. As Clawson points out,

The only way in which more timber can be grown on many national forest areas is to cut the timber now standing. . . . [Few] people seem to realize that growth of timber cannot proceed indefinitely unless timber harvest also goes forward, since inventory cannot accumulate beyond some maximum volume per acre.<sup>27</sup>

### TIMBER SUPPLY IN THE SHORT AND LONG RUN

The supply of timber over the long run may be expressed as the product of yield per acre and the number of acres in commercial for-

25. See Clawson, *The Economics of National Forest Management*, and Nelson and Pugliaresi (Chapter 6 in this volume).

26. Annual growth in a regulated forest would be  $f/T$  per acre, and the size of the growing stock per acre would be  $f$ . Hence the ratio of growing stock to annual growth would be  $T$ , the rotation age.

27. Clawson, *Man, Land, and the Forest Environment* (Baltimore: Johns Hopkins University Press, 1976).

ests. Changes in economic conditions in timber markets will, in general, cause private timber producers to alter both components of supply. The per acre yield on forestlands can be altered by changing the rotation schedule or by varying the intensity with which certain growth-enhancing activities are pursued. The amount of acreage in commercial timbering is sensitive to decisions of whether to continue harvests and reforestation on marginal timberlands and to the possibility of reforesting lands that are currently used in other ways. In total, then, there are three sources of potential timber supply response: choices of rotations, growth enhancement, and land use. The rotation problem has already been treated in some detail, though the implications of alternative rotations for short- and long-run timber supply levels has not been stressed. This section incorporates the results of the rotation problem with a simple treatment of the land use component of timber supply. The growth enhancement aspect of supply is not directly addressed.

The possibility of nontimber uses of the land can affect both the choice of harvest ages for current stands of timber and the decision of whether or not to reforest after harvest. To address these questions let all possible uses be collapsed into two categories: the growth of forests and some nonforestry alternative such as residential development, denoted  $F$  and  $A$ , respectively. The opportunity cost of allowing a standing forest to mature an extra year now depends on the future use to which the land will be allocated. Let  $R^F$  denote the forgone return if the future use is growing new forests and let  $R^A$  represent the return the land could earn if allocated to the nonforestry activity. Then the true opportunity cost of allowing a standing forest to grow an extra year will be the higher of these foregone returns:

$$R = \text{maximum}(R^F, R^A) .$$

In this broader context,  $R$  enters the decision of when to harvest a standing forest in exactly the same way that it did in equations (4) and (5).

Recall the benefit-cost rule developed earlier for the decision of when to harvest,  $\Delta f = rf + R/p$ . This rule continues to apply for the choice of harvest ages, even in the case where the nonforest alternative will occupy the land in the future (i.e., where  $R^F < R^A$ ). Although the land will not be reforested in such instances, the qualitative relationships shown in the second row of Table 11-2 still indi-

cate the age at which the current stand will be harvested. Although it has not been included as a separate parameter in Table 11-2, the per period value of nontimber outputs the land could produce ( $R^A$ ) also is important in determining forest management decisions. For example, an increase in  $R^A$  on land that is occupied by an economically marginal stand will tend to increase  $R$ . As a result (using the apparatus in Figure 11-2), the age at which this forest will be cut is reduced, and once cleared the land will be withdrawn from timber production and devoted to the nonforestry alternative.

When analyzing the effects of shifts in prices, costs, or interest rates on timber supplies, the steady state characterization adopted earlier is retained. Thus, for example, a price change refers to a discontinuous shift in price from one level to another, with the new level expected to remain in effect indefinitely. Such movements will cause changes in long-run rotation ages and land use decisions. They will also give rise to transitory or short-run changes in harvests and timber supplies as inventories of standing timber shift from one long-run equilibrium level to another. These short-run supply impacts are discussed further later.

With land allocated to forest and nonforest uses in a competitive fashion, any change in economic conditions that increases  $R^F$  (*ceteris paribus*) will tend to increase the amount of acreage devoted to growing timber. Likewise, changes that reduce  $R^F$  will cause some marginal forestland to be withdrawn from production in the long run. Consequently, the qualitative relationships shown in the third row of Table 11-2 coincide with those shown in the first row. If, for example, net price ( $p$ ) were to increase, it would tend to bring more acreage into production and thereby increase long-run supply.

Over the long run, the per period volume of timber grown on an acre of forestland will equal  $f/T$ . Accordingly, long-run supply per acre will depend on the rotation age chosen. The qualitative relationship between the rotation age ( $T^*$ ) and  $f/T$  depends on whether present value of maximizing rotation periods tends to exceed or fall short of  $T^M$ , the rotation that would maximize sustainable yield. It is evident from Figure 11-3 that if  $T^*$  exceeded  $T^M$ , then a small decrease in  $T^*$  would cause  $f/T$  to rise. On the other hand, if  $T^* < T^M$ , then a reduction in the rotation age would decrease timber grown per period.

As noted earlier, the relationship between  $T^*$  and  $T^M$  cannot be determined on theoretical grounds alone. Rather, it depends on the

force of discounting and replanting costs, and these two factors tend to pull the privately chosen rotation age in opposite directions. It was also noted, however, that private harvest decisions tend to result in rotation ages that are far below those found on national forests. Since the latter are at least nominally guided by yield maximization, it seems reasonable to conclude that  $T^* < T^M$  in most situations.<sup>28</sup> Correspondingly, the qualitative effect of changes in economic parameters upon long-run timber supplies per acre coincides with their effect on  $T^*$ , that is, increases in  $T^*$  tend to increase supply per acre, and vice versa. For this reason, the signs in the fourth row in Table 11-2 are the same as those reported for  $T^*$ .

The last row of relationships in Table 11-2 shows the net qualitative relationships between economic parameters and the long-run supply of timber. Surprisingly, perhaps, the effects of permanent changes in net price and replanting costs on long-run supply are ambiguous. That is, they cannot be predicted on theoretical grounds alone; rather, empirical analysis would be required to determine the directions of these effects in specific cases. If, for example, the net price level rises, more land will be brought into production and long-run supplies will tend to increase. The anomaly arises, however, because this increase may be more than offset by the lower long-run yields per acre caused by shorter rotations. Exactly the same kind of ambiguity surrounds the effect of replanting costs on long-run supply. Only in the case of interest rate changes is the qualitative shift in long-run timber supply determinate. An increase in the interest rate will, *ceteris paribus*, force some marginal land out of production and induce private foresters to liquidate future stands at earlier ages. It is appropriate to recall that one dimension of supply response, the enhancement of growth per acre through disease control, genetic improvement, and other means, has been omitted from the preceding analysis. It is expected that such efforts, and the additional supplies

28. For additional evidence in support of this conclusion, see P. Berck, "The Economics of Timber," *Bell Journal of Economics* 10 (1979): 447-62. This relationship is, of course, dependent upon replanting costs and may therefore be different for different forests. Interestingly, Clawson has found that the Forest Service sometimes spends resources actively replanting land on which private investment in reforestation would be unprofitable. If the absence of private reforestation is interpreted as a very long private rotation period, then the Forest Service practice may reflect a situation in which its yield-maximization policy leads to shorter rotations than present value maximization. In this case, it is the neglect of replanting costs that is crucial in determining the relationship between  $T^*$  and  $T^M$ . See Clawson, *The Economics of National Forest Management*.



they bring forth, would respond positively to price and negatively to replanting costs. If so, this would reinforce the land use component of long-run supply and thus make the anomalous supply response cases less likely.

The preceding discussion has focused exclusively on timber supplies in the long run by comparing the attributes of different long-run equilibria. Accompanying any actual shift, however, will be a period of transition from one steady state to another, a short-run situation in which timber supplies may move in a direction that differs from the long-run shift. Suppose, for example, that price increased and rotation times were lowered as a result. A portion of the growing stock that was previously below the optimum harvest age would now be above the new optimum harvest age. In the transition period between long-run equilibria, there would be an increase in short-run supplies as standing forests are placed on the new rotation schedule. This short-run impact may also be viewed as an inventory adjustment. A reduction in  $T^*$  is equivalent to a reduction in the optimum inventory of standing timber. The liquidation of this timber inventory increases the supplies of timber that reach the market in the short run. Similarly, increases in  $T^*$  tend to increase equilibrium inventories and to decrease supplies in the short-run transition period.

### TAXATION AND TIMBER SUPPLY

By employing the relationships developed in Table 11-2 and retaining the long-run, partial equilibrium approach applied above, it is possible to explore the resource allocation effects of alternative forest taxation policies.<sup>29</sup> Consider first a severance tax levied as a fixed percentage of the *net* price of timber. In terms of the preceding supply analysis, imposition of this tax has the same effect as a reduction in  $p$ . That is, rotation times are lengthened and the return to marginal land is reduced. From Table 11-2 the net effect of the tax on long-run supply is ambiguous. By reducing  $R^F$ , the tax leads to the withdrawal of marginal land from future production. Gaffney has

29. The effects of alternative tax instruments on forest management decisions have also been examined by M. Gaffney, "Taxes on Yield, Property, Income, and Site" (University of Victoria, B.C.: Institute for Policy Analysis, 1975). (Mimeo.)

termed this phenomenon "invisible high grading," that is, only high grade forestland will be restocked.<sup>30</sup> It occurs principally because the present value of reforestation costs cannot be deducted from the forester's tax liability. In practice, it appears more common for severance taxes to be levied against the *gross* price of timber, that is, the price at the mill rather than on the stump. In these cases where harvest costs are not deductible, the severance tax has the additional effect of discriminating against the harvest of marginal resources, stands for which net price is low. In this case, the high grading would be quite visible, and marginal stands would remain uncut.

Consider next a property tax levied annually as a fixed percentage of the market value of standing timber on a parcel of land. The effects of such a tax on rotations and timber supply are symmetric to those accompanying an increase in the interest rate.<sup>31</sup> The tax imposes a per period cost on standing timber in much the same way the interest rate does, and thus encourages shorter rotations.<sup>32</sup> A property tax also lowers the equilibrium return to foresting and thus reduces  $R^F$  and the incentive to employ land in growing timber. Assuming that the tax does not have an equivalent effect on the return to alternative uses of the land, the effect of this reduction in  $R^F$  would be to remove some land from growing timber. Qualitatively, then, the property tax affects the long-run supply of timber in the same way as an increase in the interest rate.

Finally, consider a tax levied as a fraction of the value of forestland alone, or the annual rent received from its use. So long as the tax is levied on the land only and is independent of the use in which the land is employed or the amount of capital (standing timber or otherwise) that occupies it, it will be impossible to avoid the tax by altering the pattern of resource allocation. As a result, such a tax would have no effect on rotation times, the choice of activity that occupies the land, or long-run timber supply. In other words, it would be perfectly neutral.

Although completely neutral taxes are possible, all commonly applied taxes distort investment and production decisions and there-

30. Ibid.

31. They are not, however, identical, as V. Gamponia and R. Mendelsohn have shown in "The Economics of Forest Taxation" (Seattle: University of Washington, Department of Economics, 1983). (Mimeo.)

32. Gamponia and Mendelsohn provide a formal demonstration of this effect in "The Economics of Forest Taxation."

fore reduce the present value of forest outputs. In general, the magnitudes of such losses will depend on the type of tax levied and the price, reforestation cost, and growth characteristics of the taxed species. An important policy issue is the choice of taxes to minimize such losses.

Tax-induced shifts in rotation age have been examined empirically by Gamponia and Mendelsohn.<sup>33</sup> They compared the social losses that result from alternative property and severance taxes designed to produce equal tax revenues. For the tax rates and timber species they examined, their analysis indicated that severance taxes were vastly preferred to equal yielding property taxes. To complete the analysis it would be necessary to examine the magnitude of land use distortions as well, and perhaps to extend the comparison to a multitude of different species and economic conditions. Nevertheless, Gamponia and Mendelsohn's approach clearly indicates the role of economic analysis in answering important policy questions.

### CONCLUSIONS

In the private sector, the choice of profitable management strategies was seen to depend on prices, costs, and interest rates. A potential use of the private decisionmaking model presented in this chapter lies in the choice of alternative tax instruments and a comparison of their potential impacts on private rotation decisions. The same approach could also be extended to permit analysis of the impact of public regulations on private management decisions. Elsewhere, it was noted that any public management policy designed to maximize the net benefits that society receives from public forestlands will also be sensitive to values, costs, and interest rates. The optimizing decisions reached by unregulated private entrepreneurs and enlightened public managers may well differ due to the presence of nonmarket costs and benefits, but the principle of comparing benefits and costs, and even the structure of the benefit-cost calculus, is common to both settings.

In actuality, the management practices applied to public and private forestlands differ dramatically, and the divergence does not appear to arise from any careful application of economic principles to treat externalities or market failure. Rather it seems to stem from

33. Gamponia and Mendelsohn, "The Economics of Forest Taxation."

an unwillingness on the part of public forest managers to confront economic issues and the difficult choices and tradeoffs they often imply. Disparities in public and private management practices might not be remarkable if they were confined to such nontimber uses of forestlands as recreation or watershed protection. However, most of the criticism directed toward federal forest management, including the multiple-use philosophy, maximum sustained-yield harvest policies (cutting at the culmination of mean annual increment), and the nondeclining even-flow constraint on harvest schedules, has regarded the way public forests are used to grow timber. As several analysts have shown, these policies unnecessarily constrain the production of timber on public lands without generating offsetting increases in nontimber benefits. The public forests of the United States are a great national asset. Without a management strategy based on careful consideration of costs and benefits, however, the return society receives from this asset will remain below its full potential.