Working Paper Series

WORKING PAPER NO. 576

VALUATION OF TROPICAL FORESTS

by

Anthony C. Fisher and W. Michael Hanemann

DEPARTMENT OF AGRICULTURAL AND
RESOURCE ECONOMICS

BERKELEY

CALIFORNIA AGRICULTURAL EXPERIMENT STATION

University of California

DEPARTMENT OF AGRICULTURAL AND RESOURCE ECONOMICS
DIVISION OF AGRICULTURE AND NATURAL RESOURCES
UNIVERSITY OF CALIFORNIA AT BERKELEY

WORKING PAPER NO. 576

VALUATION OF TROPICAL FORESTS

by

Anthony C. Fisher and W. Michael Hanemann

California Agricultural Experiment Station
Giannini Foundation of Agricultural Economics
January, 1991

Draft
July, 1990

VALUATION OF TROPICAL FORESTS

by

Anthony C. Fisher
W. Michael Hanemann

Department of Agricultural and Resource Economics
University of California at Berkeley

Paper prepared for the United Nations University, World Institute for Development Economics Research conference on "The Environment and Emerging Development Issues," September 3-7, 1990, Helsinki, Finland.

VALUATION OF TROPICAL FORESTS

1. Introduction

As noted in the WIDER program on the environment and development, specifically in the section on this paper, tropical forests provide a wide variety of services to humankind. Yet, as documented in countless books, articles, and other media presentations, the forests are under threat. Repetto (1988, pp. 2-15) observes that, since World War II, deforestation has shifted from temperate to tropical forests and that, in most developing countries today, deforestation is accelerating. Table 1 shows that, at 1981-1985 annual rates of deforestation, there are a number of countries where forests will disappear within 30 years. Others, having larger reserves, are losing vast areas every year. A question that naturally arises is, given the value of the tropical forest resource, why is it being destroyed? The answer, it seems to us, is that a very substantial part of the value simply does not get counted, either because it is hard to measure or because it is not captured by those who make the decisions on deforestation. The purpose of this paper is to help in redressing the balance by providing a framework for a more complete valuation of tropical forests. Our focus is not on the causes of deforestation, which have been addressed at length by Repetto and, indeed, by many others as well. Rather, we seek to identify the goods and services produced by the forests, to develop a framework for valuation, and to offer some suggestions concerning measurement techniques.

We begin in the next section with a discussion of the major uses of tropical forests, paying particular attention to the relationships among uses. For example, are they compatible with forest preservation? Are they sustainable? Section 3 provides the elements of a framework for valuation, taking account of the varied uses. The time dimension will be important here. One issue is, of course, sustainability. Another is feasibility of a sequential pattern of use; livestock ranching may follow the clearing of land for a timber harvest but not vice versa. Also, the values associated with different uses may grow at different rates. Finally, as we shall see, the present value of a tract of land will depend on how uncertainty about future values is resolved. Section 4 is about issues that arise in empirically estimating values or benefits, and section 5 offers some concluding thoughts.

2. The Uses of Tropical Forests

Uses and Utilitarianism: A Caveat

When we talk about uses of the forest, we have in mind human uses. This is an important distinction, since some would argue that human uses and the values to which they give rise are not deserving of any special consideration when it comes to a decision on whether to preserve a tropical forest. According to one interpretation of this view, nature has rights; to exploit nature is just as wrong as to exploit people (Nash, 1989). Another interpretation is that nonhuman species are intrinsically valuable, independent of any use they may be to humans (Callicott, 1986). We would prefer not to take issue directly with this view. Rather, we would observe that economics is about the human use and valuation of resources. As such, it is embedded in utilitarianism. In the larger philosophical universe, utilitarianism is, of course, only one of many possible approaches to questions of ethics and choice. Advocates of conservation for its own sake are presumably appealing to an alternative to philosophical utilitarianism. In this paper, we confine our focus to what we understand to be the subject matter of economics—the uses and values of resources to humans. At the same time, we recognize that decisions, especially public decisions, affecting tropical forests may be made on the basis of a variety of other considerations as well—including, perhaps, inherent rights or intrinsic values.

There is an important point to note in this connection. Often in environmental economics, we speak of intrinsic or "non-use values," referring to the benefits some people derive from the mere existence of a natural environment (such as, for example, the Amazon rain forest) even though they make no use of it. In our judgment these benefits are likely to be quite significant for many environmental resources and are legitimately included in our notion of economic value. However, as Batie (1989) points out, this is still a utilitarian view in that the resources, although not used, have value in relation to human welfare. Taking into account this extension of the notion of economic value, a better title for this section of the paper might be: "The Goods and Services Provided by Tropical Forests," with the understanding that among these services is the existence of the forests, apart from any use to which they may be put by humans.

There is a further, and equally important, point to be made here. We shall very shortly be talking about local and global environmental services provided by standing tropical forests. These environmental services are, as we shall see, quite tangible and, indeed, impinge quite directly on human activities. Existence value, as just defined, does not. It is derived from the knowledge that the forests or other environmental resources are alive and well, again, apart from any human activity affected by them.

Uses Compatible With Preservation

Several kinds of human activities in and around the forests appear to be reasonably compatible with preservation: hunting and fishing; gathering of food such as nuts and fruits; gathering of forest products such as rubber, oils and medicines; and even traditional shifting agriculture. By definition, the setting up of parks and preserves also falls within this category. We observe in passing that all of these uses are sustainable, almost by definition.

It may be objected that shifting cultivation is, in fact, a major cause of deforestation and, as such, hardly qualifies as compatible with preservation or even as sustainable. A study by the National Academy of Sciences (1982, p. 13), for example, concludes that at least half of current deforestation results from shifting cultivation. But by traditional shifting agriculture, we have in mind the kind of activity that involves little disturbance to the forest cover and root systems outside the small plot under cultivation, and that allows the plot to regenerate for 20-30 years before a new round of cutting and burning. As noted by Gradwohl and Greenberg (1988, p. 102), many forested areas once considered "virgin" are now believed to have been occupied for centuries by people practicing shifting agriculture. The difficulty arises when population pressures—and perverse incentives as, for example, the linking of ownership rights to the clearing of land—result in the cutting of what had been protective buffer zones and a shortening or even elimination of the fallow period. It is this "nontraditional" agriculture that is implicated in deforestation.

Standing tropical forests are also associated with the provision of environmental services, as distinguished from the uses just noted. There are no doubt a number of ways in which these services can be classified, but one that in our judgment will be helpful in discussing valuation issues is as local and global. What we are calling local environmental services are, perhaps, best understood by considering some of the consequences of deforestation. For example, the loss of forest cover leads to soil erosion which, in turn, aggravates flooding and contributes to premature silting of reservoirs for irrigation and electric power production. Though local, these impacts are not trivial. It is estimated that revenue losses from sedimentation behind just one dam in Costa Rica have reached a level of \$133-\$274 million (Postel and Heise, 1988, p. 92).

At a global level, tropical deforestation appears to be related to what may well be the gravest environmental issues of our time: the "greenhouse effect" and the wholesale extinction of species. As is well known, the buildup of several trace gases in the atmosphere (most importantly, carbon dioxide) is expected to lead to a substantial warming over the next several decades with an attendant rise in sea level and change in patterns of precipitation. Potential consequences, to coastal settlements, to agriculture, and to other activities, have been discussed at length in many places (for a brief overview, see Brown and Flavin, 1988). What is important to note here is that deforestation, almost entirely tropical deforestation, is estimated to account currently for a very substantial fraction of global carbon emissions—between one-fifth and one-half as much as the burning of fossil fuels (Postel and Heise, p. 94).

The second global environmental issue we noted is the threatened loss of species. Although this is the popular perception of the issue, it would be more accurate to speak of the threatened loss of biodiversity. The point of the distinction is that biodiversity, as well as being the source of potentially valuable individual species, is an input to such ecological processes as nutrient and water cycling, soil generation, erosion control, pest control, and climate regulation—all essential to human survival (Reid and Miller, 1989, p. 88). With respect to individual species, wild relatives of economically important crops, trees, and livestock often carry unique genes that can be used to improve the characteristics of the domesticated stocks or just help them survive changes in the environment. Plants, animals, and micro-organisms found in the wild are also major sources of medicines and industrial substances. Reid and Miller note that tropical species have been particularly important sources of medicines because many active medical compounds are derived from the toxins that they have evolved to combat predation (p. 27). More generally, tropical forests are important to the conservation of biodiversity because it is believed that they contain more than half of the world's species, though only 7 percent of the land surface. About half of all vertebrates and vascular plant species occur in tropical forests, and recent discoveries of great insect species richness there suggest tropical forests may account for as much as 90 percent of all of the world's species (Erwin, 1982). Although one cannot predict with a high degree of confidence that a particular tract of tropical forestland will be the source of a cure for cancer, or a liquid hydrocarbon, or a key crop pest control, the chances of finding any or all of these are surely greater, the greater is the preservation of tropical forests generally.

Commercial Forestry

Particularly in Africa and Southeast Asia, the first step in the conversion of tropical forests is typically opening an area to logging. Commercial forestry covers a variety of activities—including selective culling of highly valued woods; clear-cutting for timber or pulp production; and plantation harvesting of an introduced, non-native species. Of course, there is also cutting for fuel, but this is more prevalent in relatively arid areas as opposed to tropical moist forests (Gradwohl and Greenberg, p. 37).

The difficulty with any of these activities is that they may not be sustainable. Without intensive (and probably also expensive) management, the forests may not regenerate the harvested species successfully. The chief problem is the loss of nutrients once the trees are cut since, in tropical forests, the soil is relatively poor, with most of the nutrients stored in the vegetation (Gradwohl and Greenberg, p. 31). Another reason why it may be difficult to practice a sustainable forestry is that, especially without intensive management, the harvested species do not regenerate quickly enough to compete with other uses of the cleared forestland. As Gradwohl and Greenberg put it, "if the timbering system is only marginally profitable, or becomes unprofitable, it simply sets the stage for a more intense form of forest destruction" (p. 31). Of course, this is a matter of choice—or economics—rather than a physical constraint on the system of the sort imposed by loss of nutrients.

Commercial Agriculture

One example of the "more intense form of forest destruction" might be commercial agriculture, which involves presumably irreversible conversion of forests.

Commercial agriculture includes both plantation farming (of such crops as bananas, sugarcane, rubber, and pineapple) and livestock production, especially (in the Amazon and other tropical American forests) beef cattle ranching. To these activities, one might add intensive subsistence agriculture, involving both shifting and continuous cultivation (the latter, primarily irrigated paddy rice).

Like commercial forestry, large-scale or intensive agriculture may not be sustainable. Long-term, continuous cultivation or grazing leads to soil erosion and loss of nutrients and, at least in the case of cultivation, tends also to involve heavy application of fertilizers and pesticides. The buildup and dispersal of these substances, in turn, interferes with the provision of local environmental services. As with forestry, (costly) management inputs can make an agricultural operation relatively sustainable. Mulching, the use of careful cultivating techniques, long fallow periods, and avoidance of poorer soils can all contribute to this objective (Gradwohl and Greenberg, p. 32).

Other Extractive Activities: Mining, Water Resource Development, and Transportation

To some extent, extractive activities are just an extension of the hunting and gathering that is consistent with forest preservation. For example, medicinal substances, meat, skins, plumage, and even live animals may be taken for export rather than subsistence. Additionally, however, fairly large areas may be affected by mining, water resource, and transportation projects. Of all of the uses discussed thus far, these are probably the most disruptive of the forest ecosystem and their consequences almost certainly the most difficult to reverse. By definition, a mining project cannot be sustainable, though it can, of course, produce great wealth over the life of the mine. Water impoundments (the construction of large dams for irrigation or hydroelectric power) will also have finite lives as reservoirs silt up over several decades. Moreover, as we have seen, the silting process is accelerated by deforestation and resulting soil erosion.

3. A Framework for Valuation

We start by making a distinction between valuing the specific services provided by a rain forest (such as those described on the preceding pages) and valuing the forest itself, viewed as an asset generating a stream of services over time. The methodological issues associated with valuing specific services provided by a rain forest will be discussed in the following section. Here, we focus on the valuation of the forest. Mapping from the valuation of service flows to the valuation of the asset raises two important issues. The first is discounting and the way in which current and future values are counted. This is, of course, an old issue in welfare economics, and we simply observe that it remains controversial, both in theory and application.

One point worth noting here, perhaps, is that environmentalists and advocates of sustainable development have recently joined the debate, generally to argue for a low or even a zero discount rate, on the grounds that this favors resource conservation and, more broadly, the interests of future generations. What might be called the "environmentalist critique of discounting" is presented—and discussed—at some length in the recent volume on sustainable development by Pearce, Barbier, and Markandya (1990). A similar discussion is beyond the scope of the present paper, but we note the conclusions of Pearce *et al.* With respect to the choice of a social discount rate different from private market rates, (1) calculating the appropriate rate is difficult; (2) lowering the overall rate will stimulate resource-using investment (and thus be counterproductive from the environmentalist's standpoint); and (3) a selective lowering of the rate for environmental projects is inefficient, cumbersome, and difficult. Instead of adjusting discount rates, they therefore recommend that efforts to take account of environmental concerns be concentrated on (1) improving valuation techniques (including future costs and benefits more carefully), (2) integrating environmental considerations into economic decisions, and (3) incorporating a sustainability constraint, as developed in their study. We might note that all of these conclusions except the last are consistent with earlier discussions by environmental economists (see, for example, Krutilla and Fisher, 1975). The last, the sustainability constraint, is novel.

The second issue is the allocation of forestland among alternative uses. As indicated in the preceding discussion, there are a great many different kinds of goods and services provided by the forest, not all of them compatible with each other. In the circumstances, a choice among them is required, and this choice will dictate the value of the forest. In effect, the forest can be regarded not as a single asset but rather as a portfolio of assets, whose composition can be varied over time (subject to some constraints). Thus, the forest cannot be valued without regard to future choices about how it will be managed: Valuation cannot be divorced from decision making. The issue of choice is particularly relevant in the tropical forest setting, given the wide range of uses and activities relative to those supported by temperate forests in developed countries.

In this section we lay out a framework for valuing a tract of tropical forestland, allowing for different choices about the uses of the forest and the role of time discounting and taking into account constraints on the sequencing of uses. We are deliberately vague about the size of the tract: It may be anything from the one hectare sample of Amazon rain forest considered in a recent study by Peters, Gentry, and Mendelsohn (1989) to some much larger area. About the only restriction is that it not be so large that choice among uses is not meaningful because, on a large enough tract, one might reasonably expect to find a little of everything. Our framework, in contrast, is designed to exhibit the consequences, for the value of the tract, of a particular set of choices (for example, indigenous gathering, followed by logging, followed, in turn, by beef cattle ranching). Of course, in applying this framework to an appropriately delimited tract, the analyst would need to know (or assume) something about what is going on elsewhere in the forest, as well. Spatial relationships may be quite important here. For example, the benefits of preservation will be a non-concave function of area if there is some critical minimum habitat size. Also, as noted earlier in the discussion of shifting cultivation, preservation benefits will be affected by the intensity of activities in adjacent tracts and by the configuration of the tracts. In what follows, we assume that information of this sort can be developed in an empirical case study or policy analysis and indicate how it might be fit into a larger framework—one that is readily adapted to show the consequences of different choices and sequences of uses and assumptions about such things as time discounting, sustainability, and the benefits of particular uses in particular periods.

Our point of departure is the work on choices between just two alternative uses of a natural environment, development, and preservation; work begun in the Natural Environments Program at Resources for the Future (RFF) in the 1970s (see, for example, Fisher, Krutilla, and Cicchetti, 1972, and Krutilla and Fisher, 1975, 1985). The focus of that work was on methods of estimating time profiles of benefits of the alternative uses, strategies for choosing between uses when information about benefits (especially the future benefits of preservation) is unavailable, and implications for efficient choices when one of the alternatives (development) is irreversible. Another aspect of the analysis of the choice between development and preservation was (and continues to be) an explicit treatment of the implications of irreversibility coupled with uncertainty in the form of a Bayesian information structure in which information about future benefits improves with the passage of time (see, for example, Arrow and Fisher, 1974; Henry, 1974; Hanemann, 1989; and Fisher and Hanemann, 1986, 1987, 1990).

The focus of this paper is on laying out a broader framework for valuation and decision, drawing on results in the earlier literature where relevant. One important way in which the current framework is broadened is by consideration of more than two alternative uses of the land. In the preceding section, we distinguished uses compatible with preservation, commercial forestry, commercial agriculture, and other extractive activities. To make the conceptual transition from just two uses (one irreversible) to several, it will be sufficient to specify three generic uses with appropriate constraints on feasible sequences. Thus, we consider preservation, P; development, D; and an intermediate use, M. We assume that it is possible to go from P to P, M, or D; from M to M or D; and that D is a trapping state. The relationship of the generic uses to those discussed in the preceding section would need to be specified in a particular empirical setting. For example, indigenous gathering (a use compatible with preservation) could be P, commercial timber harvesting could be M, and large-scale beef cattle ranching or mining could be D. In some settings, it might be helpful to specify more than one intermediate state as, for example, M_1 for low-intensity shifting cultivation and M_2 for high-intensity, or fuelwood gathering. However, for purposes of discussion here, the three states should suffice.

Another way in which we broaden the focus of the earlier work is in giving explicit attention to the sustainability of alternative land uses. For example, it will be important to indicate, in our valuation framework, that (say) beef cattle ranching might not be expected to be sustainable beyond a single planning period of one, two, or five years. Our object here will be not to take a stand on this issue (i.e., to argue for or against a sustainability criterion, as suggested by Pearce *et al.*), but rather to lay out a framework for valuing sequences of uses of a tropical forest that can accommodate differing views—as well, of course, as differing assumptions about the feasibility of moving from one state to another, discounting, and rates of growth in benefit streams.

An Illustration

The framework is best understood in the context of an illustration, or example, involving the three uses of a tropical forest tract: P, M, and D. The relationships among them can be represented in a decision tree format as in Figure 1. To keep the figure from becoming too cumbersome, we specify just three periods. These may be individual years, conventional five-year economic planning periods, or even something like (optimal) timber rotation periods in the problem at hand. We note in passing that determination of an optimal rotation cycle is not a concern of ours in the present paper. The original Faustmann solution is well known, and a comprehensive theory of extensions to account for the influence of non-timber uses has been provided most recently by Bowes and Krutilla (1989).

Associated with each use, or state, of the tract in each period is a figure of merit, the benefit of the use, indicated in Table 2. We shall initially assume that the benefits in periods "1" and "2" are discounted back to period "0" at a rate of 10 percent. This is simply a convenient number, and its use here should not be taken as a considered judgment about an appropriate social discount rate. We also assume, for now, that the (expected) benefits of each use in future periods ("1" and "2") are known and that no information that would lead to a change in expectations will be forthcoming. An implication of this assumption is that it is possible to value any feasible three-period sequence on a once-and-for-all basis. Later on, we shall relax this "open-loop" assumption and consider a more realistic, though more complex, "closed-loop" format in which information is forthcoming over time and valuation depends on a sequence of choices about uses made on the basis of the new information.

With this (open-loop) framework, and the associated benefit figures, we can readily calculate the value of each of the feasible sequences of uses. To avoid cluttering the discussion, we shall consider here just of few of these. Suppose that the development alternative is the extraction of an exhaustible resource; in the simplest case, theory tells us that the discounted (marginal) benefit should be the same in each period. This is represented in the specification of $D_t = 100$, all t, where D_t is the benefit of D in period t (and, similarly, for P and M). Let us assume that the benefits of uses associated with preservation, P, are growing over time, even relative to the benefits of development, as some of the early RFF work suggested (though not specifically with reference to tropical forests). Thus, we have P_t growing at a rate of 20 percent to 25 percent. With these assumptions, development exhibits the greatest value in the first period, but its advantage diminishes over time as, say, the local and global benefits of preserving the forest environment loom larger. It is still true that the development sequence yields the greatest discounted value over all periods ($\sum D_t =$ 300 *vs.* $\sum P_t = 298$), but this would cease to be true if our time horizon were extended by just one period and relative rates of growth of benefits in P and D persist. It would also cease to be true even in the three-period case if benefits were not discounted; then, as shown in Table 2, $\sum D_t = 331$ and $\sum P_t = 333$. Note that the potential problem of unbounded values is dealt with in this example by ignoring benefits that accrue after the third or fourth period, in effect discounting them at an infinite rate. Finally, note that, if development were postponed beyond the first period, the value of the development sequence would fall. That is, the sequences P_0, D_1, D_2 and M_0, D_1, D_2 both exhibit values below $\sum D_t = 300$ and, indeed, below $\sum P_t =$ 298.

We have thus illustrated in a simple but plausible example how valuation of a tract of tropical forestland depends on (1) constraints on feasible sequences of uses (D is a trapping state, and one can only get to P from P), (2) the time horizon and the choice of a discount rate or, indeed, of whether or not to discount, and (3) relative rates of growth of benefits of the alternative uses as well as current-period benefits. In the next section, we shall discuss methods of current-period benefit estimation.

The point here is simply that fine-tuning the estimation may be less important than laying out a framework for valuation that takes into account constraints and parameters of the decision problem and, indeed, allows decision makers to explore the consequences of differing assumptions about them.

In this spirit, let us change one other key assumption in the example: that development is sustainable. Accordingly, we assume that the mine will be exhausted after the second period, leaving a wasteland not suited to the production of any other valued goods and services. Up to this point, we have said nothing about the intermediate use, M. Suppose that this is some sort of sustainable forestry—the selective cutting (and replanting) of trees for a commercial lumber operation. This is consistent with the specification, in Table 2, of an even flow of (undiscounted) benefits from M. Of course, if D is not sustainable, then even the present discounted value of the preservation sequence exceeds that of the development sequence which is now just $D_0 + D_1 = 200$. But development benefits are now exceeded also by those of the intermediate activity (the sustainable timber harvest) which displays discounted benefits of $M_0 + M_1 + M_2 = 246$.

The possibility of some intermediate state can play a still more important role in a valuation exercise. Suppose, in addition to being sustainable, that the harvest in our example is conducted with minimal disruption of the surrounding forest environment. As we have noted earlier, this is not likely where the avoidance of disruption is expensive and the benefits of avoidance are not captured by the harvester. From a social point of view, though, the benefits are certainly relevant; the question is, are they worth the cost? Let us further suppose that, if the harvest is conducted in this minimally disruptive fashion, something like the original forest ecosystem can be regenerated, perhaps with a lag of one or more periods after the harvest is stopped. To this end, let us change the example a bit, as in Figure 2, where the relevant sequences are traced.

In the modified example, a harvest takes place in the first period, yielding somewhat lower net benefits—say, $M_0 = 80$—to reflect the costs of environmental controls. Now we assume that the forest is allowed to regenerate in the second period (indicated on the figure as R_1, where $R_1 = 0$) and that, in consequence, preservation-related benefits (including local and global environmental services) can be obtained in the next and succeeding periods. As shown on the figure, the discounted present value of this sequence, over four periods, is 347 as compared to just 314 over four "normal" harvests. What this example suggests is the importance, in an empirical application, of exploring the technical and economic feasibility of a sequence involving recovery from an extractive activity to the point where preservation-related benefits can, again, be obtained.

The Value of Flexibility

To this point, our analysis has been based on the assumption that no further information about future benefits is forthcoming. A hypothetical decision maker would simply look, as we have done, at the expected benefits over a feasible sequence with all choices (of P, M, or D—or R) specified at the outset. Thus, for example, the maximum expected present value associated with putting the forest tract to the preservation use in the first period is computed as

$$V_P^* = P_0 + \max\{E[P_1] + \max\{E[P_2], E[M_2], E[D_2]\}, E[M_1] + \max\{E[M_2], E[D_2]\}, E[D_1] + E[D_2]\}, \quad (1a)$$

where the expectation is with respect to the information set available in the first period. Similarly, the discounted present value associated with intermediate and development uses are

$$V_M^* = M_0 + \max\{E[M_1] + \max\{E[M_2], E[D_2]\}, E[D_1] + E[D_2]\} \quad (1b)$$

(1c) $$V_D^* = D_0 + E[D_1] + E[D_2].$$

In these formulas, while it is recognized that the discounted present value associated with a current use depends partly on decisions about future uses, the current anticipation of those decisions is based entirely on current information about future benefits and costs.

However, this overlooks the possibility that better information about future benefits and costs will be forthcoming in such a way as to influence the future decisions about the uses of the forest tract. Let us now make the more realistic assumption that such information is forthcoming. Specifically, we assume that, at the start of each period, the decision maker learns what the benefits of each of the alternative uses of the tract will be in that period (though not in future periods) and then chooses the highest-yielding alternative. This affects how one computes the present values associated with the various uses; it corresponds to a closed-loop type of control rule. Under this control scenario, the maximum expected present value associated with preservation in the first period is computed as

(2a) $$\hat{V}_P = P_0 + E[\max\{P_1 + \max\{P_2, M_2, D_2\}, M_1 + \max\{M_2, D_2\}, D_1 + D_2\}].$$

Similarly, the present values associated with the intermediate and development uses are

(2b) $$\hat{V}_M = M_0 + E[\max\{M_1 + \max\{M_2, D_2\}, D_1 + D_2\}]$$

(2c) $$\hat{V}_D = D_0 + E[D_1 + D_2].$$

Observe that, in the case of the development use, there is <u>no</u> difference between the values associated with the two information scenarios: $\hat{V}_D - V_D^* = 0$. For the other two uses, however, there <u>is</u> a difference, given by

$$
(3) \quad \begin{aligned} \hat{V}_P - V_P^* = {} & E[\max\{P_1 + \max\{P_2, M_2, D_2\}, M_1 + \max\{M_2, D_2\}, D_1 + D_2] \\ & - \max\{E[P_1] + \max\{E[P_2], E[M_2], E[D_2]\}, E[M_1] \\ & + \max\{E[M_2], E[D_2], \ E[D_1] + E[D_2]\} \end{aligned}
$$

and

$$
(4) \quad \begin{aligned} \hat{V}_M - V_M^* = {} & E[\max\{M_1 + \max\{M_2, D_2\}, D_1 + D_2\}] \\ & - \max\{E[M_1] + \max\{E[M_2], E[D_2]\}, E[D_1] + E[D_2]\}. \end{aligned}
$$

By making repeated use of the convexity of the maximum operator and Jensen's Inequality, it can be shown (see Appendix) that these expressions are non-negative:

$$
(5) \qquad \hat{V}_P - V_P^* \geq 0; \qquad \hat{V}_M - V_M^* \geq 0.
$$

That is, the present value associated with the preservation or intermediate uses is larger when one recognizes the prospect of being able to use better information in making future decisions than when one disregards this prospect. The difference is what is known in decision theory as the expected value of information; that is, $\hat{V}_P - V_P^*$ measures the expected value of future information conditional on allocating the forest tract to a preservation use in period zero. Similarly, $\hat{V}_M - V_M^*$ is the expected value of information conditional on intermediate use. With regard to development, the conditional expected value of information, $\hat{V}_D - V_D^*$, is zero because allocating the tract to development at time zero eliminates all options with respect to alternative future uses of the forest and thus deprives the decision maker of the freedom to take advantage of any future information. That is why the information has no economic value.

In the terminology of the literature on environmental valuation, the quantities $\hat{V}_P - V_P^*$ and $\hat{V}_M - V_M^*$ represent the quasi-option value associated with preservation and intermediate uses in period-zero. They measure the value of these uses' flexibility with respect to exploiting new information in later decisions. There is another related, but distinct, element of flexibility: Part of the benefit associated with preservation or intermediate uses arises from the breadth of choice that these uses permit in future decisions. Intuitively, preservation affords more flexibility than intermediate uses—the reason being that it bequeaths a larger choice set to decision makers in periods 1 and 2. This is true under both the open- and closed-loop controls; from (1a, b, c) and (2a, b, c), we have

$$(\hat{V}_P - P_0) \geq (\hat{V}_M - M_0) \geq (\hat{V}_D - D_0) \tag{6}$$

and

$$(V_P^* - P_0) \geq (V_M^* - M_0) \geq (V_D^* - D_0). \tag{7}$$

By way of proof, observe that the first inequality in (6) yields

$$\begin{aligned}(\hat{V}_P - P_0) - (\hat{V}_M - M_0) = E[&\max\{P_1 + \max\{P_2, M_2, D_2\}, M_1 + \max\{M_2, D_2\}, D_1 + D_2\} \\ &- \max\{M_1 + \max\{M_2, D_2\}, D_1 + D_2\}] \geq 0\end{aligned} \tag{8}$$

while the first inequality in (7) yields

$$\begin{aligned}(V_P^* - P_0) - (V_M^* - M_0) = {} & \max\{E[P_1] + \max\{E[P_2], E[M_2], E[D_2]\}, E[M_1] \\ & + \max\{E[M_2], E[D_2]\}, E[D_1] + E[D_2]\} - \max\{E[M_1] \\ & + \max\{E[M_2], E[D_2]\}, E[D_1] + E[D_2]\} \geq 0.\end{aligned} \tag{9}$$

The result follows because the right-hand side of (8) takes the form E[max{X, Y, Z} - max{Y, Z}] $\geq$ 0, while (9) takes the form max{E[X], E[Y], E[Z]} - max{E[Y], E[Z]} $\geq$ 0. The basic principle is: the greater the number of elements in a maximization, the greater the maximum.

Thus, in terms of impact on the breadth of future choices, preservation in period zero outranks intermediate use (and development). Does the same ranking apply to the value of information associated with these two uses? In other words, what is the relationship between the two kinds of flexibility; does the prospect of a larger choice set make information more valuable so that $(\hat{V}_P - V_P^*) - (\hat{V}_M - V_M^*) \geq 0$? Perhaps contrary to one's intuition, a simple counter-example shows that this is not true in general. Consider, first, two alternatives (Y and Z) and two states of nature (S_1 and S_2), each with a probability of occurring of one-half. Suppose that the benefits of Y and Z are distributed over the states as follows: Y = 5 in S_1 and 15 in S_2, and Z = 10 in S_1 and 12 in S_2. Then max{E[Y], E[Z]} and E[max{Y, Z}] are readily computed as

$$\max\{E[Y], E[Z]\} = \max\left\{\frac{1}{2}(5) + \frac{1}{2}(15), \frac{1}{2}(10) + \frac{1}{2}(12)\right\} = 11$$

and

$$E[\max\{Y,Z\}] = \frac{1}{2}(10) + \frac{1}{2}(15) = 12.5,$$

respectively. Now add a third alternative, X, where the benefit of X is 9 in S_1 and 14 in S_2. Clearly, E[max{X, Y, Z}] = E[max{Y, Z}], since the maximum benefit obtainable in S_1 and S_2 is unchanged. However, max{E[X], E[Y], E[Z]} > max{E[Y], E[Z]}, since E[X] = 11.5. In this example, having a larger choice set raises V* more than it raises $\hat{V}$ so that the conditional value of information is lowered.

Of course, in a particular empirical application, it may turn out that the use which bequeaths the larger future choice set does have the larger quasi-option value. We have simply shown that this need not be so (see also Hilton, 1981). Also, we do not mean to suggest that the optimal initial choice can never be M or D. We have argued that P and M both provide more flexibility than D with regard to both the breadth of future choice sets and the value of future information and that P outranks M by at least the first of these criteria. But M or D might still be the optimal action in period zero, depending on the relative magnitudes of P_0, M_0, and D_0.

4. Empirical Issues

It should be noted at the outset that the empirical techniques for valuing the alternative uses of tropical forestland have been developed and applied almost exclusively in the industrialized countries: Placing an economic value on the natural environment has so far been a pastime of the rich. Clearly, however, it is highly relevant to developing countries since, as suggested earlier, one reason for deforestation in these countries is that a substantial part of the tropical forests' value is being overlooked when forest land-use decisions are made.

The goods and services generated by a tropical forest may be viewed as intermediate goods (e.g., timber, watershed protection) or as final goods for some set of people (e.g., fuelwood, fruit, recreation, intrinsic values). The contribution of the tropical forest use may be seen as making available something that would otherwise be unavailable or improving the supply (lowering the cost or raising the quality) of an existing commodity. To the extent that marketed commodities are involved, these benefits can be measured using standard techniques based on shifts in demand and supply functions or related concepts (value of the marginal product, avoided cost, preventive expenditures saved, etc.). There may be practical problems in modeling the market correctly—for example, marketing channels that impose constraints on the seller's ability to dispose of an increased supply of tropical fruits and nuts, or price effects that spill over to other markets and call for a general equilibrium analysis. Also, if there are distortions arising from government actions or imperfect competition, shadow prices will be needed to correct for divergences from true opportunity cost or willingness to pay. In general, though, these marketed services of tropical forest raise no new conceptual issues.

However, many of the services provided by a tropical forest are not supplied through a market. These would include most of the environmental services such as protection of habitat, promotion of genetic diversity, protection against the greenhouse effect, provision of parks and wilderness preserves, etc. This is because these aspects of the natural environment are, to a large degree, public goods (or public inputs) that cannot be divided up and sold. The absence of markets poses a challenge to conventional valuation techniques. In response, two approaches have been adopted. One approach is to identify commodities that are marketed and whose consumption is related in some manner to the enjoyment of the natural environment—for example, commodities that are complements or substitutes for the natural environment. The classic example is the travel cost method of valuing the recreational use of the environment; the hedonic property value, hedonic wage, and hedonic travel cost models are other examples. In these cases one uses conventional techniques to recover individuals' preferences for the market goods from their observed market demand behavior; and, since their enjoyment of the natural environment is bound up with their enjoyment of these marketed goods, their preferences for the natural environment are recovered at the same time.

These "indirect" techniques of valuing non-market goods are, by definition, subject to two limitations. First, for some environmental attributes, there simply may be no substitute or complementary market goods that can serve to reveal a person's preferences for the natural environment. Second, to the extent that substitute or complementary market goods do exist, there can be no assurance that these capture all of the person's preferences for the natural environment: In addition to caring for nature in connection with his use of the related market commodities, a person may also care about nature for reasons unconnected with them. For example, a hunter may want to protect the forest because it provides habitat for the animals that he hunts; but he may also wish to see the forest protected for motives that have nothing to do with his own or others' hunting. This additional component of a person's preferences may not be reflected in his demand function for any market commodities and, thus, it cannot be recovered by the indirect valuation techniques.

The other approach is "direct" valuation using surveys to elicit from respondents measures of their willingness to accept or willingness to pay for the services provided by a tropical forest (the contingent valuation approach). This approach has attracted much interest recently and is the subject of much current research with regard to its statistical and survey research aspects. By construction, it offers the prospect of recovering those components of preferences that elude the indirect measurement techniques.

The recent books by Smith and Desvousges (1986), Johannson (1987), and Mitchell and Carson (1989) provide excellent introductions to the various valuation techniques; some applications to developing countries are described by Hufschmidt *et al.* (1983). Rather than giving more details here, we propose to comment on some of the lessons to be learned from experiences with non-market valuation to date.

7 First, it must be emphasized that framing can be very important to the success of the exercise—how one conceptualizes the consequences of a change in the flow of services from a tropical forest greatly affects the form of the subsequent analysis.

Whether the natural environment is seen as an input or as a final good, or whether the change is seen as primarily entailing a change in income, a change in choice sets, or a change in prices, inevitably shapes the economic analysis to be performed. The framing is inherently a subjective decision on the part of the analyst; asking the right questions is a key to her success.

Our second point concerns the influence of the availability of tools and data on what gets measured. A few years ago, there was a popular song with lyrics that ran: "If you can't be with the one you love, then love the one you're with." It seems to us that economists too often embrace a similarly pragmatic morality: If you can't measure what you want, then be satisfied with what you can measure. Data limitations obviously matter; but an effective analyst must demonstrate a good sense of what aspects of the tropical forest are important even if they cannot readily be quantified. The substance of the issues, not the techniques, should drive the analysis.

Third, before proceeding to the technical details, the analyst should start with a balance sheet listing the various groups of people (including future as well as present generations) that may be affected by a change in uses of tropical forests and indicating the nature of this impact in physical (non-monetary) terms. This is an essential prelude to the economic valuation exercise. In addition to providing an overall perspective, the balance sheet delineates the distinct groups that have standing in the analysis and need to be considered from a distributional point of view.

Many of the recent applications of non-market valuation techniques in the USA have been relatively unconcerned with distributional issues and have concentrated instead on whether the aggregate benefits of, say, a proposed regulatory action, outweigh the aggregate costs. The focus on aggregate benefits stems from two sources, one philosophical and the other political. The philosophical source is the Kaldor-Hicks potential compensation criterion for assessing welfare changes which implicitly de-emphasizes questions such as how benefits differ among distinct sub-groups of the population and concentrates, instead, on the overall population mean. The political source, at least in the United States, is a distrust of estimates of regional impacts and a belief that agencies such as the Army Corps of Engineers have abused them in the past in order to justify unwarranted projects.

However, both the emphasis on aggregate benefits and the Kaldor-Hicks criterion may be inappropriate when applied to the valuation of tropical forests. For some forest services, the benefits clearly transcend national and temporal boundaries—e.g., prevention of the greenhouse effect, protection of species diversity. To ensure a proper accounting, it is necessary to look beyond the current preferences of individuals in countries in which the tropical forests are located and include the values that people in other parts of the world, and in future times, would place on these services. In that case, however, it would be meaningless to summarize the results in terms of an average per capita benefit. For example, with respect to current benefits, one would surely want to break the total down into benefits accruing to residents of the country where the tropical forest is located, benefits accruing to residents of industrialized countries, and benefits accruing to residents of other third-world countries. Moreover, since regional impacts are important in the economic development process, one cannot avoid paying explicit attention to them.

When the benefits involve the natural environment as a final good, there is an additional reason for wanting to identify the values associated with distinct sub-groups of the population—namely, the diversity of people's preferences for the natural environment. To be sure, observed differences in monetary values attached to environmental resources can be linked in part to differences in income; protecting the environment is likely to be quite income elastic not only within countries but also among them. Beyond this, there appear to be genuine differences in tastes with regard to both use and non-use values for the natural environment. Differences in tastes—not differences in income or prices—are surely the key factor determining participation versus non-participation in outdoor recreation. Similarly, there is much more variation in the willingness to pay values elicited by contingent valuation surveys in the USA than can be explained by income alone. Different people clearly have different interests: Some people—perhaps a small number—place a very high monetary value on the given environmental resource; other people care for the resource, but not as passionately and with lower monetary values; and there are some people who place no value at all on the resource.

Therefore, for the population as a whole, the aggregate value can be thought of as depending on (1) the fraction of the population falling into each distinct preference group, including the zero-value group and (2) the typical value (e.g., median, mean) associated with that group. Approaching the aggregate value in this way is useful when it comes to extrapolating from the responses to a contingent valuation survey (or an outdoor recreation survey) to the overall population, since the distribution over preference groups in the sample may be different from that in the population. It may also be useful when dealing with the crucial but awesome task of projecting the values that future generations place on the environmental resource. To the extent that future generations have entirely different preferences from the present generation, there is no way to predict them. But, to the extent that future generations are composed of the same preferences groups as the current generation, albeit in different proportions, one has some hope of making a prediction by using information about the values currently associated with distinct preference groups combined with projections of their future population shares. Projecting future population shares, as opposed to future preferences, may be associated with a manageable degree of uncertainty, since we currently have information about the relationship between preferences for the environment, on the one hand, and readily measured and projected variables such as income and education levels on the other.

Predicting future benefits is probably the single most challenging aspect of valuing tropical forests. More than for some other resources, current decisions about managing tropical forests can have significant long-term impacts. Dealing with these in a sensible manner is crucial to the success of the valuation exercise. Unfortunately, little guidance can be obtained by looking at the experience with environmental valuation in the industrial countries. Almost all of these exercises have been static in nature. They employ data—whether housing market data or data from contingent valuation or recreation surveys—that are collected at a single point in time and convey no information about secular trends in environmental behavior or attitudes. Of course, collecting time-series data on environmental behavior or attitudes requires a greater commitment of resources and takes much more time than cross-section data, which is why such data bases are scarce. But, having data from a single point in time greatly limits one's ability to make projections about the future. In fact, this has not been seriously attempted in most recent valuation exercises: Current per capita values are projected to future populations.

Our suggestion above about projecting sub-group values separately from their population shares is intended as an improvement, but it is by no means a complete solution. Krutilla and Fisher (1975) have stressed the need for "second-best" approaches to estimating time profiles of future benefits in the absence of good information—for example, by using current estimates of preservation benefits and postulating a future growth rate for the ratio of these benefits to those associated with the alternative uses of the resource. In both cases, there is a substantial degree of uncertainty associated with the projections of future population shares or future growth rates in benefits. This could be handled by developing alternative scenarios for these future outcomes and attaching probabilities to them. Such an exercise would certainly be subjective and "soft," but that cannot be avoided. The alternative—to treat the future as known with certainty and a replication of the present—is unacceptable.

5. Concluding Remarks

Throughout this paper, we have sought to emphasize the link between the valuation of tropical forests and decisions about their uses. We firmly believe that the valuation exercise cannot be designed effectively without reference to the types of decisions that are being made. The framing of the decisions determines the valuation strategy. To this end, we have reviewed alternative uses with a view toward identifying feasible sequences that, in turn, affect the value of some initial choice of use or activity.

Beyond the link between valuation and decision, perhaps always important, in the case of tropical forests in particular it seems to us that key features of the valuation problem are the long time horizon and the great uncertainties associated with the future consequences of current management decisions. As our illustrative example shows, it may be more important to take account of feasible sequences, the sustainability of a given use, the choice of discount rate, and the planning horizon, than to fine-tune the estimates of current benefits.

The economic literature contains a number of treatments of tropical forest management which de-emphasize the uncertainty and treat the future costs and benefits of alternative forest uses as known with certainty. (A recent example in the leading journal of environmental and resource economics [JEEM] frames the problem of managing a tropical forest as a deterministic optimal depletion problem; at what rate should the tropical forest land be converted to agricultural use so as to maximize the discounted stream of net benefits, when the benefit functions themselves are taken as known and stationary over time?) We believe that this is an inappropriate way to frame the problem, even as a first approximation. For an economic analysis to be useful, it must find a strategy for coming to grips with uncertainty with regard to both how one approaches the decision problem and how one approaches the valuation of alternative uses.

The decision problem has to be seen as one of stochastic control, in which information acquisition and flexibility rank more highly than nicely determining the allocation of land based solely on current estimates of benefits and costs. The valuation problem becomes one of guessing how the future may be different from the present and identifying blind spots as much as fine-tuning the estimates of what is known.

Both as a means of eliminating gaps in the analysis and also as an aid to predicting how the future may be different from the present, we have suggested that the analyst develop a "balance sheet" of affected parties, both present and future. The balance sheet should take account of all significant impacts, including those that cannot readily be quantified. Valuation in monetary terms is desirable in order to ensure a common yardstick—but it must yield to the goal of comprehensiveness with regard to covering the things that matter in the real world. The balance sheet forces the analyst to be explicit about who has standing and what are the distributional implications of alternative uses of the tropical forest—both of which tend to be treated with some skittishness by researchers in the industrialized countries. Finally, the balance sheet provides a framework for extrapolating future values: We have suggested that changes in people's preferences may be a powerful force affecting the value of environmental resources over time, and one way to project this is to identify the distinct preference groups, or "market segments," in the current population and then project changes in their future population shares. We concede that this type of approach is somewhat fuzzy but judge that the alternative—assuming the future to be the same as the present—is spuriously precise.

Appendix: Proof that $\hat{V}_P \geq V_P^*$

Define $E_{t/t-1}$ as an expectation held in period t, based on observation through period t - 1. We begin by noting that

$$E_{1/0}[\max\{P_2, M_2, D_2\}] \geq \max\{E_{1/0} P_2, E_{1/0} M_2, E_{1/0} D_2\}$$

from the convexity of the maximum operator and Jensen's Inequality. Thus,

$$E_{1/0}[P_1 + \max\{P_2, M_2, D_2\}] \geq E_{1/0}[P_1] + \max\{E_{1/0} P_2, E_{1/0} M_2, E_{1/0} D_2\}.$$

Similarly, one can prove that

$$E_{1/0}[M_1 + \max\{M_2, D_2\}] \geq E_{1/0}[M_1] + \max\{E_{1/0} M_2, E_{1/0} D_2\}.$$

Let

$$\hat{a} = P_1 + \max\{P_2, M_2, D_2\},\ a^* = E_{1/0}[P_1] + \max\{E_{1/0} P_2, E_{1/0} M_2, E_{1/0} P_2\},$$
$$\hat{b} = M_1 + \max\{M_2, D_2\},\ \text{and}\ \ b^* = E_{1/0}[M_1] + \max\{E_{1/0} M_2, E_{1/0} D_2\}.$$

Since

$$E_{1/0}[\hat{a}] \geq a^* \ \text{and}\ \ E_{1/0}[\hat{b}] \geq b^*,$$

it follows that

$$E_{1/0} \max\{\hat{a}, \hat{b}, D_1 + D_2\} \geq \max\{E_{1/0}[\hat{a}], E_{1/0}[\hat{b}], E_{1/0}[D_1 + D_2]\}$$
$$\geq \max\{a^*, b^*, E_{1/0}[D_1 + D_2]\}.$$

Thus,

$$E_0 [\max\{P_1 + \max\{P_2, M_2, D_2\}, M_1 + \max\{M_2, D_2\}, D_1 + D_2\}] = E_0[E_{1/0} \max\{\hat{a}, \hat{b}, D_1 + D_2\}]$$

$$\geq E_0 \max\{a^*, b^*, E_{1/0}[D_1 + D_2]\}$$

$$\geq \max\{E_0[a^*], E_0[b^*], E_0 E_{1/0}[D_1 + D_2]\}$$

$$= \max\{E_0 E_{1/0}[P_1] + E_0 \max\{E_{1/0} P_2, E_{1/0} M_2, E_{1/0} D_2\}, \quad E_0 E_{1/0}[M_1] + E_0 \max\{E_{1/0} M_2, E_{1/0} D_2\}, E_0 E_{1/0}[D_1 + D_2]\}$$

$$= \max\{E_0[P_1] + E_0 \max\{E_{1/0} P_2, E_{1/0} M_2, E_{1/0} D_2\}, \quad E_0[M_1] + E_0 \max\{E_{1/0} M_2, E_{1/0} D_2\}, E_0[D_1 + D_2]\}$$

$$\geq \max\{E_0[P_1] + \max\{E_0 E_{1/0} P_2, E_0 E_{1/0} M_2, E_0 E_{1/0} D_2\}, \quad E_0[M_1] + \max\{E_0 E_{1/0} M_2, E_0 E_{1/0} D_2\}, E_0[D_1 + D_2]\}$$

$$= \max\{E_0[P_1] + \max\{E_0 P_2, E_0 M_2, E_0 D_2\}, \quad E_0[M_1] + \max\{E_0 M_2, E_0 D_2\}, E_0[D_1 + D_2]\}.$$

TABLE 1

Tropical Deforestation

Country	Closed forest area, 1980	Annual rate of deforestation, 1981-1985	Area deforested annually
	thousand hectares	percent	thousand hectares
With high rates of deforestation (≥ 3.0% annually)			
Ivory Coast	4,907	5.9	290
Paraguay	4,100	4.6	190
Nigeria	7,583	4.0	300
Costa Rica	1,664	3.9	65
Nepal	2,128	3.9	84
Haiti	58	3.4	2
El Salvador	155	3.2	5
With large absolute losses (≥ 500,000 hectares annually)			
Brazil	396,030	0.4	1,480
Colombia	47,351	1.7	820
Indonesia	123,235	0.5	600
Mexico	47,840	1.2	595

Source: Repetto (1988, pp. 7-8).

TABLE 2

Values of Alternative Uses and Sequences

(a) Discounted at 10 percent

Use \ Period	0	1	2	
P	80	98	120	$\sum_t P_t = 298$
M	90	82	74	$\sum M_t = 246$
D	100	100	100	$\sum D_t = 300$

(b) Undiscounted

Use \ Period	0	1	2	
P	80	108	145	$\sum P_t = 333$
M	90	90	90	$\sum M_t = 270$
D	100	110	121	$\sum D_t = 331$

Figure 1

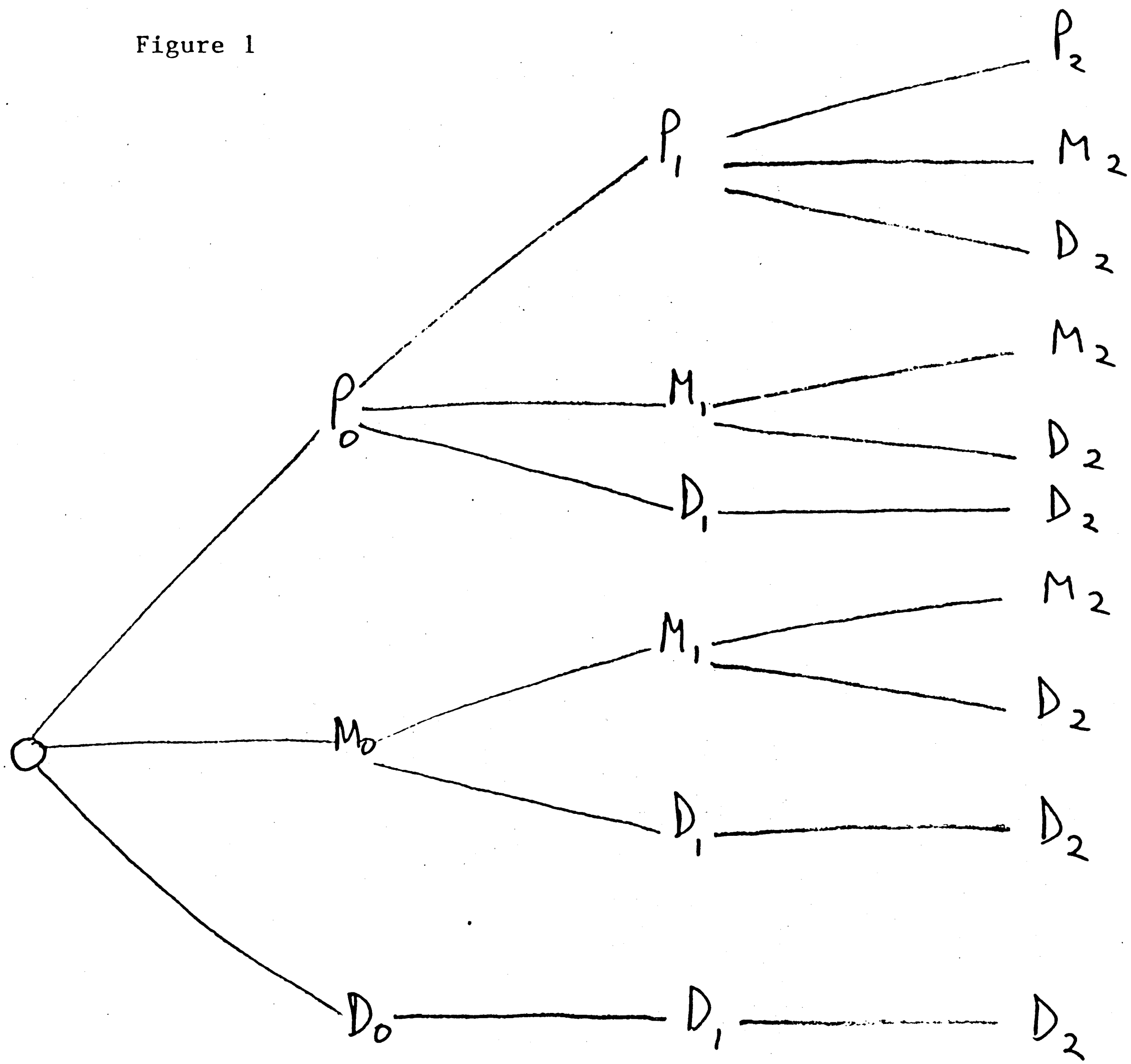
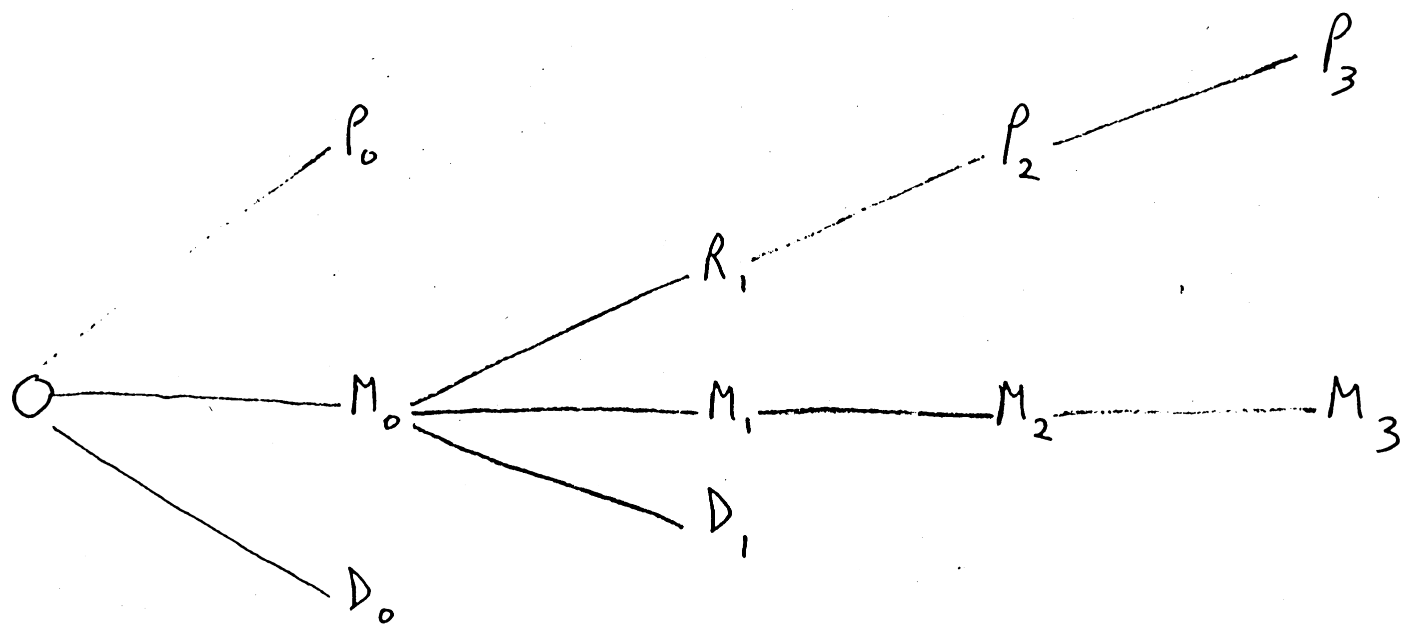


Figure 2



$$M_0 + R_1 + P_2 + P_3 = 80 + 0 + 120 + 147 = 347$$

$$\sum_{t=0}^{3} M_t = 90 + 82 + 74 + 68 = 314$$