EFFICIENT MANAGEMENT OF BIOLOGICALLY DIVERSE TROPICAL FORESTS

by

Dr. Douglas Southgate, Associate Professor
Department of Agricultural Economics
Ohio State University
Columbus, Ohio 43210

Selected paper, American Agricultural Economics Association annual meetings, August, 1989.

#6844

ABSTRACT

EFFICIENT MANAGEMENT OF BIOLOGICALLY DIVERSE TROPICAL FORESTS

Developed in this paper is an optimal control model of the benefits and costs of using tropical forests as a natural repository of species and folk knowledge. It serves as a framework for assessing how market and tenurial incentives influence both deforestation and the collection of ethnobiological information.

EFFICIENT MANAGEMENT OF BIOLOGICALLY DIVERSE TROPICAL FORESTS

Tree clearing near the equator threatens the world's stock of "ethno-biological information." The high biological diversity of tropical forests is indisputable; although they cover less than ten percent of the Earth's land surface, they contain around half of the world's plant and animal species (Wilson). Furthermore, forest dwellers' environmental knowledge is often lost as tree-covered land is cleared for agricultural production and other purposes. Although precise assessment of tropical deforestation's impacts on biological and cultural diversity is a challenge, no one doubts that those impacts are severe.

In spite of this, economic evaluation of ethno-biological information lost as tropical forests are removed remains at an incipient stage. The uses humankind has made of species and folk knowledge originating in tropical forests have been emphasized, as has the potentially high cost of denying species and folk knowledge to future generations (Myers). Also, it has been observed that ethno-biological information, like other environmental services provided by tropical forests, is undervalued because it is not exchanged in markets (Sedjo). Beyond these observations, the literature contains virtually no analysis of the trade-offs associated with development of tree-covered land near the equator.

Until very recently, this omission was of no great consequence. Now, however, proposals to compensate individuals and governments that protect tropical forests are being given serious consideration (Hansen). As a consequence, there is a need to evaluate the benefits and costs of using tropical forests as a natural repository of species and folk knowledge.

Those benefits and costs are the subject of this paper. A model describing the costs and benefits of both land clearing and information collection is developed to explain how various market and institutional incentives influence the development of tree-covered land near the equator. This paper's analysis is general, addressing the economics of using any natural environment as a storehouse of ethno-biological information.

The Model

This paper's model of the trade-offs involved in the management of ethno-biologically diverse tropical forests addresses two fundamental and interrelated choices. One, of course, is the rate at which land is cleared. The other choice, the rate at which information is collected, arises because information can be stored not only in tropical forests but also in the outside world's gene banks and libraries. This paper's model provides a framework for assessing how both of these decisions are influenced by the value of information collected in tropical forests, biological and cultural evolution in that environment, the opportunity cost of inputs (primarily scientists' time) required to collect ethno-biological information, uses of tropical forests that do not impinge on biological diversity, and the agricultural rental value of deforested land.

At the beginning of this section, the model's state variables and arguments of its objective function are defined. Then, the model is used to characterize efficient clearing of tree-covered land as well as efficient collection of ethno-biological information.

state variables. Initial forested and deforested (or, agricultural) area can be labeled F_o and A_o, respectively. Once cleared, a large share of land formerly covered with trees stays cleared because of sustained human pressure. Much of the remaining deforested land never returns to its original state or does so only after a very long time. For these two reasons, converting F into A is treated as irreversible:

$$dF/dt = -D \text{ and} \tag{1}$$

$$dA/dt = D , \tag{2}$$

where D is the deforestation rate.

Let AI_o and UI_o represent initial stocks of archived (or previously collected) and uncollected ethno-biological information, respectively. Temporal change in the former depends on the rate at which species and folk knowledge are collected in tropical forests. That rate, I, is an increasing and concave function of both UI and inputs to information gathering, N:

$$I = I(N,UI) , \qquad \partial I/\partial UI \text{ and } \partial I/\partial N > 0 . \tag{3}$$

Although archived information is also subject to loss, declines in AI are assumed to be nil in this analysis.

In addition to causing AI to grow, I is a negative argument of temporal change in UI. That stock also grows because of biological and cultural evolution taking place in remaining tree-covered land, a newly evolved species or a new indigenous insight into the environment generally being part of UI. Evolutionary growth in UI is expressed in this model as a concave function, V, of the natural setting for evolution, F:

$$V(F) , \qquad V' > 0 . \tag{4}$$

As primary tropical forests dwindle to zero, V can become negative (e.g., because unknown species become extinct due to limited habitat). However, it is assumed here that, because F is never smaller than some minimum critical area, V is always positive.

<u>arguments of the objective function</u>. A function, P_I, can be used to evaluate environmental and cultural secrets yielded up by tropical forests. The marginal value of newly acquired information is undoubtedly stochastic since a selected species might either be useless to humankind or contribute greatly to human health or agricultural production around the world.

Recognizing this stochasticity, we can say that P_I, which is an increasing and concave function of I, is the expected utility of newly acquired information. In addition to including a risk premium society is willing to pay because it is uncertain about I's value, P_I is also a decreasing function of AI since a new addition to AI is typically a substitute for a gene or folk tale drawn randomly from the cumulative stock of past discoveries:

$$P_I = P_I(I, AI) \ , \qquad \partial P_I/\partial I > 0 \text{ and } \partial P_I/\partial AI < 0 \ . \qquad (5)$$

An increasing and concave function, P_B, can be used to express forests' watershed management and climatic benefits. While the collection of ethno-biological information does not impinge on P_B, those benefits are sacrificed as F is converted into A:

$$P_B = P_B(F) \ , \qquad P_B' > 0 \ . \qquad (6)$$

The opportunity cost, W, of inputs to the collection of ethno-biological information is an increasing and convex function of those inputs:

$$W = W(N) \ , \qquad W' > 0 \ . \qquad (7)$$

Finally, the rental value of deforested land depends on timber prices, clearing costs, and the net returns to agricultural production. The value of timber removed from cleared parcels is generally an increasing and concave function of deforestation,

$$P_W = P_W(D) \ , \qquad P_W' > 0 \ , \qquad (8)$$

just as clearing costs, C, are an increasing and convex function of D,

$$C = C(D) \ , \qquad C' > 0 \ . \qquad (9)$$

Net agricultural returns, P_A, are an increasing and concave function of A:

$$P_A = P_A(A) \ , \qquad P_A' > 0 \ . \qquad (10)$$

<u>optimal control problem</u>. Given the preceding definitions of land use, stocks of information, and net returns to resource development options, the optimal control model describing efficient management of tropical forests is:

$$\text{maximize} \ {}_0\!\int^T \{P_I[I(N,UI),AI] + P_B(F) - W(N) + P_W(D) - C(D) + P_A(A)\}\ e^{-rt}dt + Y[F(T),A(T),T] \qquad (11)$$

subject to
$$dF/dt = -D\ , \qquad F(0) = F_o\ , \qquad F(T) \geq 0\ ,$$
$$dA/dt = D\ , \qquad A(0) = A_o\ , \qquad A(T) \geq 0\ ,$$
$$dAI/dt = I(N,UI)\ , \qquad AI(0) = AI_o\ , \qquad AI(T) \geq 0\ ,$$
$$dUI/dt = V(F) - I(N,UI)\ , \qquad UI(0) = UI_o\ , \text{ and } UI(T) \geq 0\ .$$

In this problem, r is the real discount rate and T is the endogenously determined terminal date.

Unless evolution of new ethno-biological information in a natural setting is very rapid, which is a possibility not investigated here, it can be expected that the marginal value product of inputs to information collection, N, will eventually fall below the marginal cost of those inputs for all positive levels of N. In the context of this model, that point is reached at the endogenously determined terminal date, T. Given how T is defined, Y, which is the net present value of natural resource development after the terminal date, depends on neither AI nor UI and control variable N is positive throughout the period, 0 through T. It will also be assumed that deforestation, control variable D, is positive during the same timespan.

<u>conditions for efficient resource development</u>. To solve the optimal control problem, we define λ_1, λ_2, λ_3, and λ_4 as the costate variables of F, A, AI, and UI, respectively, and differentiate the following Hamiltonian,

$$H = \{P_I[I(N,UI),AI] + P_B(F) - W(N) + P_W(D) - C(D) + P_A(A)\}\ e^{-rt} + \lambda_1[-D] + \lambda_2[D] + \lambda_3[I(N,UI)] + \lambda_4[V(F)-I(N,UI)]\ . \qquad (12)$$

with respect to the two choice variables:

$$\partial H/\partial D = \{P_W' - C'\}e^{-rt} - \lambda_1 + \lambda_2 = 0 \text{ and} \qquad (13)$$

$$\partial H/\partial N = \{[\partial P_I/\partial I\ \partial I/\partial N] - W'\}e^{-rt} + \lambda_3\ \partial I/\partial N - \lambda_4\ \partial I/\partial N = 0\ . \qquad (14)$$

The solution is also characterized by four adjoint equations,

$$d\lambda_1/dt = -\partial H/\partial F = -P_B{}'e^{-rt} - \lambda_4 V' , \qquad (15)$$

$$d\lambda_2/dt = -\partial H/\partial A = -P_A{}'e^{-rt} , \qquad (16)$$

$$d\lambda_3/dt = -\partial H/\partial AI = -\partial P_I/\partial AI \; e^{-rt} , \text{ and} \qquad (17)$$

$$d\lambda_4/dt = -\partial H/\partial UI = -[\partial P_I/\partial I \; \partial I/\partial UI]e^{-rt} - \lambda_3 \partial I/\partial UI + \lambda_4 \partial I/\partial UI , \qquad (18)$$

as well as five transversality conditions,

$$\lambda_1(T) = \partial Y/\partial F , \qquad (19)$$

$$\lambda_2(T) = \partial Y/\partial A , \qquad (20)$$

$$\lambda_3(T) = \partial Y/\partial AI , \qquad (21)$$

$$\lambda_4(T) = \partial Y/\partial UI , \text{ and} \qquad (22)$$

$$H(T) + \partial Y/\partial T = 0 . \qquad (23)$$

Given the definitions of T and Y, $\lambda_3(T)$ and $\lambda_4(T)$ equal zero.

The solution to differential equations (15) through (18) together with the five terminal conditions, equations (19) through (23), give time paths for the four shadow prices. The returns associated with a marginal addition to F at date t comprise three parts. First, by arresting deforestation at that time, UI is increased, the value of which depends on $\lambda_4(t)$. Second, watershed management and climatic benefits are enhanced during the period, t through T. Third, the same benefits are increased after T. Each impact is represented, in order, on the following equation's right-hand side:

$$\lambda_1(t) = \lambda_4(t) V' + \int_t^T P_B{}'e^{-rs}ds + \partial Y/\partial F . \qquad (24)$$

Similarly, the benefits of marginally increasing A at the same time comprise the present value of subsequent agricultural production on deforested land:

$$\lambda_2(t) = \int_t^T P_A{}'e^{-rs}ds + \partial Y/\partial A . \qquad (25)$$

Marginally increasing AI at date t reduces the scarcity value of ethnobiological information collected subsequently:

$$\lambda_3(t) = \int_t^T \partial P_I/\partial AI \; e^{-rs}ds \qquad (26)$$

Finally, a marginal increase in UI improves the productivity of effort subsequently devoted to information collection. Information collection, in turn, augments AI and reduces UI. Each of these changes affects λ_4:

$$\lambda_4(t) = {}_t\int^T [\partial P_I/\partial I \; \partial I/\partial UI]e^{-rs}ds + \lambda_3 \partial I/\partial UI - \lambda_4(t) \; \partial I/\partial UI$$

$$= [\partial I/\partial UI][1 + \partial I/\partial UI]^{-1} \; {}_t\int^T [\partial P_I/\partial I + \partial P_I/\partial AI]e^{-rs}ds$$

$$= R \; {}_t\int^T [\partial P_I/\partial I + \partial P_I/\partial AI]e^{-rs}ds \; . \qquad (27)$$

Since the partial derivative, $\partial I/\partial UI$, is in all likelihood a positive fraction of one, the maximum plausible value of the coefficient, R, is one-half. Of course, if a large stock of uncollected information has a negligible impact on the "success" of information collection, then R and, by implication, λ_4 approach zero. In addition, $\lambda_4(t)$ is an increasing function of the marginal value of I. As explained in equation (5), that marginal value depends positively on I and negatively on archived information, AI.

Substituting equations (24) through (27) into equation (13), one obtains the condition for efficient deforestation at date t:

$$P_W' - C' + {}_t\int^T P_A' e^{-r(s-t)}ds + \partial Y/\partial A \; e^{rt} = {}_t\int^T P_B' e^{-r(s-t)}ds + \partial Y/\partial F \; e^{rt}$$

$$+ V' \; R \; {}_t\int^T [\partial P_I/\partial I + \partial P_I/\partial AI]e^{-rs}ds \; . \qquad (28)$$

Deforestation should increase up to the point where deforestation's marginal benefits, represented by the left-hand side of equation (28), equal forest preservation's marginal benefits, indicated in the same equation's right-hand side. The former consist of timber revenues plus the present value of future agricultural rents less clearing costs. The latter include values unrelated to ethno-biological diversity, represented by the right-hand side's first two terms. The remaining right-hand side term in equation (28) indicates the present value of additional ethno-biological information collected by future generations because more forest area remains untouched. In addition to depending on λ_4, the present value of additional information is influenced by

V′, which is the additional cultural and biological evolution made possible by an increase in forest area.

Efficient collection of ethno-biological information in tropical forests can be characterized by substituting equations (26) and (27) into equation (14) and then dividing through by N′s marginal physical product, $\partial I/\partial N$:

$$\partial P_I/\partial I - MC = R \int_t^T [\partial P_I/\partial I + \partial P_I/\partial AI]e^{-rs}ds + \int_t^T \partial P_I/\partial AI\ e^{-rs}ds \ , \qquad (29)$$

where MC, equal to W′ multiplied by $\partial N/\partial I$, represents the current marginal cost of newly collected ethno-biological information. Equation (29) indicates that the difference between the marginal value of newly collected information, $\partial P_I/\partial I$, and MC should equal UI′s shadow price plus AI′s shadow price. That is, efficiency requires that information collection at one date be influenced by the impacts of that activity both on subsequent rates of information collection and on the value of future additions to AI.

Efficient Trade-Offs in Deforestation and Information Collection

Equations (28) and (29) express the conditions for socially efficient land use change and information collection. That is, they suggest how, at any given date, human and natural resources should be allocated to maximize the present value of ethno-biological information, agricultural production, and other commodities obtained from land now covered with trees.

Of course, these conditions are never observed because people who live and work in tropical forests as well as national governments keen to develop tree-covered hinterlands do not consider all the economic impacts of their activities. The severity of misallocation induced by individual agents′ failure to internalize depends on economic incentives, technology, and the degree to which tropical forests′ ethno-biological information substitutes for information generated or stored outside tropical forests.

economic incentives. Intertemporal allocation is, of course, always affected by the real discount rate, r. Tropical forest management is no exception. Inspection of the left-hand and right-hand sides of equation (28) reveals that an increase in the discount rate reduces the marginal benefits of both deforestation and forest preservation. One should bear in mind, however, that the agricultural productivity of deforested land in the tropics falls off quickly after clearing (Lal) while the value of services obtained from tree-covered land exhibits less temporal decline (and might even increase over time). Consequently, the present value of future agricultural production on deforested land, which is represented by the second and third terms on the left-hand side of equation (28), is generally less sensitive to changes in the discount rate than are the marginal benefits of forest preservation, the same equation's right-hand side. An increase in that rate, then, accelerates socially efficient deforestation and reduces the discrepancy between socially efficient and privately efficient deforestation.

At the same time, a higher discount rate causes the present value of future welfare losses associated with collecting ethno-biological information now, the right-hand side of equation (29), to fall. This encourages current information collection. Reducing the opportunity cost of inputs to information collection, W, has the same effect.

Socially efficient forest preservation and the difference between socially efficient and privately efficient deforestation are increasing functions of the climatic and watershed management values derived from tree-covered land, which are represented by the first two terms on the right-hand side of equation (28), and decreasing functions of the rental value of agricultural land, expressed in equation (28)'s left-hand side.

<u>technology and substitution</u>. Certainly, technological change can enhance the value of newly collected ethno-biological information, P_I. For

example, P_I rises when new uses are identified for tropical species. Interpretation of equation (28) suggests that socially efficient deforestation declines as a result. An increase in P_I also augments equation (29)'s right-hand side as well as the current marginal returns to information collection, $\partial P_I/\partial I$. However, because the former is discounted while the latter is not, a higher P_I causes information collection in the present to increase. Of course, neither privately efficient information collection nor privately efficient deforestation is greatly affected by changes in P_I, which is, for the most part, a non-market value.

Technological change also enhances the outside world's ability to collect ethno-biological information in tropical forests. This impact is represented in this paper's model by reductions in $\partial I/\partial UI$ and R (i.e., by successful information collection becoming less dependent on the existing stock of uncollected information) or by an increase in $\partial I/\partial N$ (i.e., by a reduction in the current marginal cost of newly collected information, MC). If $\partial I/\partial UI$ and R fall, the incentive to reduce current land clearing in order to facilitate future information collection in tropical forests is weakened. [In the context of the model, the third right-hand side term of equation (28) is diminished.] In addition, current information collection increases because of declines both in MC and in equation (29)'s right-hand side.

Technological change outside of tropical forests also affects socially efficient management of that resource. For example, it is possible for improvements in laboratory techniques to enhance the value of "missing genetic blueprints" collected in tropical forests. This would be an exception, however, to the rule that information generated or collected outside of natural environments is typically a substitute for information gathered in the wild. Consequently, technological change that increases the supply of the former diminishes P_I, thereby weakening the incentive to preserve tropical forests and other ethno-biologically diverse habitats.

property rights in ethno-biological information. Weak tenure in services provided by tropical forests is clearly a major cause of inefficient development of that environment (Sedjo). However, since any existing or potential market value of ethno-biological information originating in tropical forests depends on the performance of markets for information generated or collected elsewhere, changing property rights in the latter information also has an impact on the development of tree-covered land near the equator. In general, property rights in information generated outside tropical forests are becoming more secure (Schmid). Institutional evolution of this type should have the same effect as technological innovation. That is, biotechnological and related research should be stimulated, thereby depressing whatever market value is attached to tropical forests' ethno-biological information.

Summary and Conclusions

Improvements in this paper's model of trade-offs associated with the development of ethno-biologically diverse tropical forests are certainly possible. A stochastic (and considerably more complex) optimal control model could be developed rather than a deterministic one. Doing so, one would be able to comment about how uncertainty regarding the impacts of land clearing should influence the use of tropical forests as a repository of species and folk knowledge. Without a doubt, those impacts are considerable. In addition, because this paper's model lacks a geographic dimension, the insights it yields into where to try to collect ethno-biological information and which tropical forests are most deserving of protection are highly general.

Nevertheless, this paper's model comprises a satisfactory framework for evaluating how a variety of market and tenurial incentives influence development of tree-covered land near the equator. Not addressed in this paper is the vexing problem of presenting agents of tropical deforestation with a set of economic incentives that will induce them to use natural resources in a socially efficient manner. However, the economic rationale for addressing that problem, which is to enhance tropical forests' watershed management and climatic benefits as well as to retain a natural storehouse of ethno-biological information, is clarified in this paper.

REFERENCES

Hansen, S. "Debt for Nature Swaps." Environment Department Working Paper, World Bank, 1988.

Lal, R. "Effects of Soil Erosion on Crop Productivity." _CRC Critical Reviews in Plant Sciences_ 5(1987): 303-367.

Myers, N. _The Primary Source_. New York: Norton, 1984.

Schmid, A. "Biotechnology, Plant Variety Protection, and Changing Property Institutions in Agriculture." _North Central Journal of Agricultural Economics_ 7(1985): 129-183.

Sedjo, R. "Deforestation and the Value of Biological Diversity." Invited paper presented at the Annual Meetings of the Association of Environmental and Resource Economists, New York, 1985.

Wilson, E. "The Current State of Biological Diversity." In E. Wilson, ed. _Biodiversity_. Washington: National Academy Press, 1988.