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Efficient Management of Biologically Diverse Tropical Forests

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EFFICIENT MANAGEMENT OF BIOLOGICALLY DIVERSE TROPICAL FORESTS

by

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ABSTRACT

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. The model serves as a framework for assessing how various market and tenurial incentives influence both deforestation and the collection of information in tropical forests and other ethno-biologically diverse environments.

INTRODUCTION

Tropical deforestation has become the subject of considerable debate and concern. Experts disagree over how quickly tree-covered land near the equator is being cleared (Myers; Sedjo and Clawson). Likewise, it is difficult to judge whether tropical deforestation affects global climate more or less than do other human activities or natural phenomena (Prance).

Less controversial is the claim that 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 value of species and folk knowledge originating in tree-covered land near the equator.

Until very recently, this omission was of no great consequence. Because nobody forgoing disturbance of tropical forests ever received compensation, there was no need to evaluate ethno-biological information and other services derived from tree-covered land in order to determine efficient compensation levels. Certainly, efficient markets for tropical forests' ethno-biological information remain a remote ideal. However, serious attention is now being given to the idea of offering payments to potential agents of deforestation (Hansen).[1] The need to examine carefully the value of using tropical forests as a repository of ethno-biological information has also been strengthened in recent years by rapid technological change (e.g., dramatic improvements in techniques for biotechnological research). Such change reduces the scarcity value of genetic information that is, for the most part, a substitute for information collected "in the wild." Also, management of ethno-biologically diverse tropical forests is affected by evolving property rights in the fruits of biotechnological and related research (Kloppenburg).

This paper contains an analysis of the trade-offs associated with preserving ethno-biologically diverse tropical forests. 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.[2]

THE MODEL

This paper's model of the costs and benefits of tropical deforestation reflects previous contributions to the literature. Ehui et al. (1988) have used control theory to describe how quickly tropical forests should be cleared so that the soils they cover can be used for agricultural production. Their work, which does not address the problem of ethno-biological information lost as tropical forests are cleared, is not replicated here.

Similarly, the problem of measuring the values society associates with preservation of a species or a natural habitat is not reiterated in this paper (Krutilla and Fisher; Cummings et al.).

The focus, then, is on the trade-offs associated with using tree-covered land near the equator as a repository of ethno-biological information. The model addresses two fundamental and interrelated choices regarding the management of ethno-biologically diverse tropical forests. 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 fundamental and interrelated 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_0 and A_0, 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:

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

Archived information is also subject to loss. Although they would be reflected in a comprehensive model describing management of ethno-biological information, declines in AI are assumed to be nil in this analysis since effort needed to minimize such declines is small relative to effort spent collecting information or clearing trees.

In addition to causing AI to grow, i is, by definition, 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 can be expressed as a concave function, v, of the setting for evolution, F:[3]

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

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.

Arguments of the Objective Function. To specify the model's objective i [illegible]n, the value of ethno-biological information and other services derived from tropical forests must be defined, as must the opportunity costs of information collection and the rental value of deforested land.

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:[4]

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

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,

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

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

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

Optimal Control Problem. 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:

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

subject to

$$dF/dt = -D \ , \qquad F(0) = F_0 \ , \qquad F(T) \geq 0 \ ,$$

$$dA/dt = D \ , \qquad A(0) = A_0 \ , \qquad A(T) \geq 0 \ ,$$

$$dAI/dt = i(N,UI) \ , \qquad AI(0) = AI_0 \ , \qquad AI(T) \geq 0 \ ,$$

$$dUI/dt = v(F) - i(N,UI) \ , \qquad UI(0) = UI_0 \ , \qquad UI(T) \geq 0 \ .$$

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.

Conditions for Efficient Resource Development. 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 and differentiate the following Hamiltonian,

$$H = \{P_i[i(N,UI),AI] + P_B(F) - W(N) + P_W(D) - C(D) + P_A(A)\} e^{-rt}$$
$$+ \lambda_1[-D] + \lambda_2[D] + \lambda_3[i(N,UI)] + \lambda_4[v(F)-i(N,UI)] \quad (12)$$

with respect to the two choice variables:

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

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

The solution is also characterized by four adjoint equations,

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

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

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

$$d\lambda_4/dt = -\partial H/\partial UI = -[\partial P_i/\partial i \ \partial i/\partial UI]e^{-rt} - \lambda_3 \partial i/\partial UI + \lambda_4 \partial i/\partial UI . \quad (18)$$

as well as five transversality conditions,

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

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

$$\lambda_3(T) = \partial Y/\partial AI . \quad (21)$$

$$\lambda_4(T) = \partial Y/\partial UI . \quad (22)$$

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

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:

$$\lambda_1(t) = \lambda_4(t) \ v' + {}_t\int^T P_B'e^{-rs}ds + \partial Y/\partial F . \quad (24)$$

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

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

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

$$\lambda_3(t) = {}_t\int^T \partial P_i/\partial AI \; e^{-rs} ds \tag{26}$$

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:

$$\begin{aligned} \lambda_4(t) &= {}_t\int^T [\partial P_i/\partial i \; \partial i/\partial UI] e^{-rs} ds + \lambda_3 \partial i/\partial UI - \lambda_4(t) \; \partial i/\partial UI \\ &= [\partial i/\partial UI][1 + \partial i/\partial UI]^{-1} \; {}_t\int^T [\partial P_i/\partial i + \partial P_i/\partial AI] e^{-rs} ds \\ &= R \; {}_t\int^T [\partial P_i/\partial i + \partial P_i/\partial AI] e^{-rs} ds \, . \end{aligned} \tag{27}$$

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:

$$P_W' - C' + {}_t\int^T P_A' e^{-r(s-t)} ds + \partial Y/\partial A \; e^{rt} = {}_t\int^T P_B' e^{-r(s-t)} ds + \partial Y/\partial B \; e^{rt} + v' R \; {}_t\int^T [\partial P_i/\partial i + \partial P_i/\partial AI] e^{-rs} ds \, . \tag{28}$$

Deforestation should increase up to the [illegible] 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, $\partial i/\partial N$:

$$\partial P_i/\partial i - MC = R \,{}_t\!\int^T [\partial P_i/\partial i + \partial P_i/\partial AI]e^{-rs}ds + {}_t\!\int^T \partial P_i/\partial AI \; e^{-rs}ds \,, \quad (29)$$

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 do not consider all the economic impacts of their activities. At an extreme, many agricultural colonists face tenure regimes that prevent them from capturing any benefit of forest management. Consequently, they never refrain from clearing any parcel immediately if agricultural rents can be captured by doing so (Southgate and Pearce). In the context of this paper's model, deforestation continues until the left-hand side of equation (28) falls to zero.

Individuals who clear tropical forests are responding to market forces and tenurial conditions that are partly or fully determined by national governments. Those incentives are inconsistent with efficient resource allocation in tropical forests because national governments, like individual agricultural colonists, do not internalize all the benefits of forest conservation. For example, a government might help to contain nonpoint source water pollution in a neighboring country by inducing its citizens not to clear land. However, it will probably not receive any compensation for doing so. Likewise, no country has been able to collect from the rest of the world the value of climatic stability and ethno-biological information provided by tropical forests. Consequently, deforestation's adverse impacts on global climate and biological diversity are, from a national perspective, an external cost.

Of course, misallocation induced by national governments' and private individuals' failure to internalize the full social costs of deforestation is small if the marginal rents captured by agents of deforestation -- the left-hand side of equation (28) -- are so small that privately efficient deforestation is negligible.[6] The severity of resource misallocation in tropical forests also depends on prices, technology, and the degree to which tropical forests' ethno-biological information substitutes for information generated or stored outside tropical forests. Indicated in the paragraphs that follow are the impacts on deforestation and information collection of changes in those factors. Discussed at the end of the section is the influence of property rights in ethno-biological information and uncertainty about the costs of land clearing on the development of tropical forests.

Prices. 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. Under tenure regimes facing agricultural colonists, an increase in the value of marketable timber removed from deforested land, P_W, or a decrease in clearing costs, C, encourages that group to clear land (Southgate and Pearce). However, if P_W rises enough, tenure regimes favorable to forest management should evolve.

Technology and Substitution. 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 results. 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 links" 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 ρ_i, thereby weakening the incentive to preserve tropical forests and other ethno-biologically diverse habitats.

Property Rights in Ethno-Biological Information. Earlier in this section, agricultural colonists' reluctance to manage tropical forests efficiently was explained by the clearing of trees being a prerequisite for property rights under the typical frontier tenure regime. Indeed, the observation that property rights attenuation is a major cause of inefficient development of tree-covered land in the tropics is not unique to this paper. Sedjo (1985), for one, stresses that tropical deforestation is excessive because property rights do not exist in ethno-biological information.

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, which affects its production and allocation, should have an impact on the development of tree-covered land near the equator. Proposals to declare all genetic information, be it collected in a natural environment or generated in a laboratory, the "common heritage of mankind" (in effect, to match attenuated rights in natural environments' ethno-biological information with attenuated rights in other information) are being mooted in some international fora (Kloppenburg). In general, however, property rights in information generated outside tropical forests are becoming more secure (Schmid).[7] At least over the long run, 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.

The Uncertain Costs of Tropical Deforestation. As acknowledged at the beginning of this paper, the climatic impacts of tropical deforestation remain the subject of debate (Prance). Similarly, by no means is the value of ethno-biological information collected in tropical forests easy to determine, for which reason the function, P_i, in this paper's deterministic model is defined as the expected utility of newly collected information.

Increasing uncertainty about the value of ethno-biological information augments the risk premium that a risk-averse society counts as a part of $\partial P_i/\partial i$. As interpretation of equations (28) and (29) suggests, such a change should discourage land clearing while stimulating information collection. Uncertain information about some of the other factors influencing the costs of deforestation has the same effect. For example, estimation of v', which is the additional cultural and biological evolution made possible by an increase in forest area, is very difficult. Recognizing this induces a risk-averse society to refrain from a certain amount of land clearing.

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 more precisely about how uncertainty regarding the impacts of land clearing should influence the use of tropical forests as a repository of species and folk knowledge. In addition, because this paper's model lacks a geographic dimension, the insights it yields into <u>where</u> to try to collect ethno-biological information and <u>which</u> tropical forests are most deserving of protection are highly general.[8]

Nevertheless, as indicated in the preceding section, the 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 potential 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 confronting the incentives 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.

FOOTNOTES

1. Indeed, transnational compensation to preserve tropical forests has already occurred. In July of 1987, Conservation International gave the Bolivian government $650,000 of the latter's debt, obtained in international financial markets for about $100,000, in exchange for the government's promise to protect 1.5 million hectares of primary forest in northeastern Bolivia.

2. Though tropical forests are more biologically diverse than most other environments, maintaining biological diversity is almost always one of the arguments for preserving "undeveloped" land in any part of the world. For example, management of parks and wilderness areas in the United States has recently been criticized on the grounds that biological diversity has not been preserved (Newmark).

3. To describe temporal change in UI more fully, one would have to relate the evolution of new ethno-biological information not only to F but also to unarchived ethno-biological information and on archived plants, animals, and indigenous cultures that continue to exist in the wild. Unfortunately, plausible mathematical descriptions of evolution's dependence on the latter are, in general, intractable.

4. Watershed management and climatic benefits lost as land is deforested, P_B, are not always great. Many agricultural land uses are not very erosive and farmers can use conservation techniques. Also, while a hectare of agricultural land contains considerably less living biomass than a hectare of primary forest, differences between primary forests' and secondary forests' biomass concentrations can be negligible.

5. Settlers' tendency to raise crops and livestock where trees used to stand instead of to manage forests is partly explained by frontier

tenure regimes, which vest property rights only in those who clear land (Southgate and Pearce). However, the slow rate at which high-valued species, which typically account for a small portion of forest biomass in the tropics, mature often dictates that timber extraction leading to land use conversion is rational (Clark).

6. In many countries, agricultural rents captured by those who settle in forested hinterlands are greatly enhanced by government subsidies (Pearce and Myers; Mahar). Where that is the case, cutting those subsidies inhibits deforestation.

7. In the United States, for example, the Supreme Court extended patent protection for breeders, codified in Sec. 101 of the 1970 Plant Variety Protection Act, to microorganisms bred in laboratories in the 1980 case, Diamond v. Chakrabarty (100 S. Ct. 2204).

8. These topics are explored by Sedjo (1985).

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BOOKS

Edward B Barbier,

Economics, Natural-Resource Scarcity and Development: Conventional and Alternative Views. Earthscan Publications Limited, London, 1989. Paperback - £15

The history of environmental and resource economics is reviewd, then using insights provided by environmentalism, ecology and thermodynamics, Barbier begins the construction of a new economic approach to the use of natural resources and particularly to the problem of environmental degradation. With examples from the global greenhouse effect, Amazonian deforestation and upland degradation on Java, Barbier develops a major theoretical advance and shows how it can be applied. This book breaks new ground in the search for an economics of sustainable developement.

David W Pearce, Edward B Barbier and Anil Markandya,

Sustainable Development: Economics and Environment in the Third World, Edward Elgar Publishing Limited, London 1989.

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The authors attempt to give some structure to the concept of sustainable development and to illustrate ways in which environmental economics can be applied to the developing world. Beginning with an overview of the sustainable development concept, the authors indicate its implications for discounting and economic appraisal. Core studies on natural resource management are drawn from Indonesia, Sudan, Botswana, Nepal and the Amazon.

David W Pearce, Anil Markandya and Edward B Barbier
<u>Blueprint for a Green Economy</u>, Earthscan, September 1989, £6.95 (third printing)

This book by the London Environmental Economics Centre was prepared as a report for the Department of Environment, as a follow up to the UK government's response to the Brundtland Report. Here it stated that: '...the UK fully intends to continue building on this approach (environmental improvement) and further to develop policies consistent with the concept of sustainable development.'
The book attempts to assist that process.

Gordon R. Conway and Edward B. Barbier
<u>After the Green Revolution: Sustainable Agriculture for Development</u>
Earthscan, London 1990 £8.95

The Green Revolution has been successful in greatly improving agricultural productivity in many parts of the developing world. But these successes may be limited to specific favourable agro-ecological and economic conditions. This book discusses how more sustainable and equitable forms of agricultural development need to be promoted. The key is developing appropriate techniques and participatory approaches at the local level, advocating complementary policy reforms at the national level and working within the constraints imposed by the international economic system.

David W. Pearce and R. Kerry Turner
*** <u>Economics of Natural Resources and the Environment</u>, Harvester-Wheatsheaf, London and Johns Hopkins University Press, Baltimore, 1989.*

This is a major textbook covering the elements of environmental economics in theory and practice. It is aimed at undergraduates and inlcudes chapters on sustainable development, environmental ethics, pollution taxes and permits, environmental policy in the West and East, recycling, and optimal resource use.

*Copies of the above publications (except those marked with **) are available from:*

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