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Controlling Tropical Deforestation

An Analysis of Alternative Policies

Robert T. Deacon

A simple general equilibrium model — representing salient aspects of the deforestation process — generates first- and second-best policy options for controlling deforestation and helps to assess the environmental consequences of government policies often cited in the literature on deforestation.

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This paper — a product of the Public Economics Division, Country Economics Department — is part of a larger effort in the department to study environmental policies in developing countries. An earlier version of this paper was circulated as "Government Policy and Environmental Quality in Developing Countries: Complements or Substitutes." The research was funded by the Bank's Research Support Budget under research project "Pollution and the Choice of Policy Instruments in Developing Countries" (RPO 676-48). Copies of this paper are available free from the World Bank, 1818 H Street NW, Washington, DC 20433. Please contact Peggy Pender, room N10-067, extension 37851 (November 1992, 38 pages).

After discussing ownership issues related to tropical forests, Deacon develops a simple general equilibrium model to represent — at least in a stylized way — the salient aspects of the deforestation process. He uses the model to generate first- and second-best policy options for controlling deforestation and, later, to assess the environmental consequences of government policies often cited in the literature on deforestation.

Property rights, though important for understanding the process of tropical deforestation, do not necessarily point to a simple or straightforward fix for environmental problems, particularly in developing countries.

The sheer size, communal nature of service flows, and pervasiveness of individual access to tropical forests make monitoring and enforcement costly in some situations and unimaginable in others. Redefining nominal rights in ways that appear to correct inefficiencies may yield gains in some cases, but an approach to environmental protection that leans heavily on this prescription seems aimed more at symptoms than at causes, says Deacon.

Moreover, policy approaches based on the use of Pigovian taxes or marketable permit schemes may yield efficiency gains in some cases, but such approaches generally involve the same monitoring and enforcement problems that prevent the market from solving allocation problems.

Simple, direct solutions to deforestation and other environmental problems are unavailable, but an ability to understand the environmental and welfare consequences of policies adopted for other reasons is useful — if only to help policymakers avoid mistakes that would otherwise go unrecognized.

The model Deacon develops for this purpose is highly stylized and intended primarily to provide a systematic way of thinking about the environmental and welfare effects of government policy — for example, by considering patterns of substitution among inputs and outputs, in cases where an environmental resource to which people have free access is exploited.

If the use of first-best policies is infeasible — whether because of monitoring costs, transboundary effects, or other reasons — then it becomes important to have detailed knowledge of patterns of substitution and complementarity among ordinary inputs and environmental resources, and information on the use of various environmental resources in the production of specific goods and services. Knowledge of such factors can permit policymakers to pursue policy goals in situations where first-best instruments are unavailable.

CONTROLLING TROPICAL DEFORESTATION: AN ANALYSIS OF ALTERNATIVE POLICIES

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An expanded treatment of property rights issues as they relate to tropical deforestation is presented in an earlier working paper, referenced as Deacon, January 6, 1992, in the bibliography. An earlier version of this analysis was circulated under the title "Government Policy and Environmental Quality in Developing Countries: Complements or Substitutes". The World Bank provided support for this research, but bears no responsibility for the views expressed. I benefitted from conversations with Roger Sedjo. Valuable comments from Gunnar Eskeland, William Hyde, Emmanuel Jimenez, Charles Kolstad, Dean Lueck, and seminar participants at the World Bank are gratefully acknowledged.

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CONTROLLING TROPICAL DEFORESTATION: AN ANALYSIS OF ALTERNATIVE POLICIES

Government policies often have environmental consequences that apparently are unintended and unrecognized by policy makers. While this is true generally, the effect of government on tropical forests in developing countries has drawn specific attention. Such familiar economic development strategies as tax incentives for investment and trade protection for domestic industries have been cited as culprits in this process, particularly when the policies favor mines, lumber mills, and land intensive agriculture. Deforestation and other forms of environmental harm are also traced to such seemingly innocuous government actions as road building, flood control, and the structure chosen for taxes and royalties.[1] To date these claims have largely emerged from case studies and descriptive accounts. Systematic empirical analysis, with quantification and hypothesis testing, has been the exception rather than the rule.[2] While the case study approach is useful in identifying issues and formulating hypotheses, the absence of an explicit conceptual framework leaves unclear both the underlying assumptions and the range of application for any conclusions reached.

The present paper takes steps toward such a framework. Following a brief discussion of ownership issues as they relate to tropical forests, a

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[1] Important collections of this work, as it relates to developing countries, are Repetto and Gillis (1988) and Schramm and Warford (1989). Stavins and Jaffe (1990) provide an application to farm policy in the U.S. and Panayotou and Sungsuwan (1990) present an analysis of deforestation in Thailand.

[2] Stavins and Jaffe (1990) and Panayotou and Sungsuwan (1990) are important exceptions. Lopez (1992) reports empirical results for a closely related phenomenon, the effect of common land ownership on land use and agricultural practices.

simple general equilibrium model is developed to represent, at least in a stylized way, the salient aspects of the deforestation process. The model is used to generate first– and second–best policy options for controlling deforestation and, later, to assess the environmental consequences of government policies often cited in the deforestation literature.

Government Policy and Environmental Quality: A Simple Framework

Modern welfare economics connects the attainment of efficiency to the existence of markets. Markets, in turn, require the transfer of ownership and this cannot proceed unless ownership rights are defined and enforced. The nature of many environmental resources and the 'technology' of consuming their services often makes ownership difficult or impossible to practice. Since mutually beneficial trades do not occur in such cases, some of the costs and benefits of using these resources are external to the user.[3]

In the case of tropical forests, the benefits of preservation are poorly reflected in market allocations because many of the services they provide extend far beyond the borders of the host country. The capacity to absorb carbon dioxide is a clear example, and the benefits of biodiversity and the value of the genetic pool in developing new medicines, crops, and pest control agents may fall into this category as well. If transaction costs in such goods and services were negligible, the market equilibrium would be characterized

[3]The literature on tropical deforestation is sprinkled with references to the function of property rights. See, for example, Mendelsohn (1990), Hyde, et al (1990), and Sedjo (1990a and 1990b). An extended discussion of property rights issues and government policy related to tropical deforestation appears in Deacon (1992). Lopez (1992) presents empirical evidence on the degree to which common ownership of land in the Ivory Coast succeeds in avoiding the wastes associated with free access.

by a substantial volume of trade in environmental goods and services, with owners of tropical forests exporting them abroad in return for payment from all who benefit. The fact that such services, once provided, become available for all to consume, rules out such trade — a familiar 'free rider' phenomenon.[4] In such cases, it is customary to recommend a Pigovian tax or subsidy to correct the inefficiency.

Implementing a first-best Pigovian tax to correct an externality requires the regulator to measure use of the resource and to levy a fee to enforce compliance. Yet it is often the difficulty of these tasks that causes market failure and invites government involvement in the first place, so implementation cannot be taken for granted. The following analysis emphasizes second-best policies, instruments that do not require direct measurement or management of the misallocated resource. Rather, they influence its use indirectly, by manipulating the costs of inputs needed to use it and by exploiting patterns of complementarity and substitution. The same general framework is also useful for assessing the environmental impacts of policies adopted for purposes unrelated to the environment.

The following model is related to the contributions of Sandmo (1976) and, particularly, Wijkander (1985).[5] The latter author's simplifying assumptions of separable utility and linear production are largely maintained. The model departs from these predecessors by treating the

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[4]Gillis and Repetto (1988, p.395) briefly acknowledge this point. Fisher and Hanemann (1991) discuss the benefits, both local and global, that standing tropical forests provide. See Peters, et al (1989) for a delineation of "local" benefits.

[5]See Eskeland and Jimenez (1990, pp.24–27) for an efficient summary of this work. As noted in the following discussion, the model presented here is broadly similar to one developed by Lopez and Niklitschek (1991). In their specification, the good characterized by market failure is a factor of production in the local economy, which contrasts with the structure adopted here. Also, Lopez and Niklitschek (1991) explicitly consider dynamic aspects of allocating the communally owned resource.

misallocated good as an environmental resource that can either be left in its natural state, in which case it provides a consumption benefit but is subject to free access, or converted to a market input. Attention is directed toward actions that yield environmental improvements and marginal welfare gains, when starting from an unregulated equilibrium.

Assumptions and Definitions

A brief, stylized description of the model economy will make the analysis that follows more concrete. A tropical forest, when left in its natural state, provides some benefits that are rival in consumption, such as food and shelter, and others that are nonrival, such as absorption of greenhouse gasses. The forest itself is modeled as a free access resource, so those who wish to do so can convert it to a market input, such as cropland for shifting agriculture, pasture for grazing cattle, or timber for lumber production. Deforestation involves private costs for clearing land or harvesting timber. These private costs exclude the foregone consumption benefit the forest provides while standing[6].

The economy of the country that contains the forest produces two sorts of outputs — those that require the converted forest as an input and those that do not. These differences are captured by two consumption goods, e.g., agriculture, which uses cleared forestland as an input, and manufacturing,

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[6]Many cultures own forestlands in common; see Deacon (1992) for a brief discussion. An important question is whether the equilibrium with common ownership is closer to the open access outcome or the complete markets alternative. Lopez (1992) presents empirical evidence on this general question as it applies to the use of communally owned bush-fallow biomass in the Ivory Coast. According to his estimates, only a fraction of the resource's community-wide value is internalized in decisions regarding its use.

which does not.[7] In addition both consumption goods, plus the process of converting the forest, use the economy's other input, labor, the aggregate supply of which is fixed.

With this metaphor in mind, consider an economy populated by identical individuals, each of whom takes relevant prices as given. Equilibrium allocations in this economy are equivalent to utility maximizing choices of a single representative consumer. The individual gains utility from consumption of three goods, X, Y, and Q. Property rights are defined and enforced for the first two, so markets and prices exist. No market exists for Q, however, the service flow of the free access resource. Although the quality of Q is affected by the aggregate choices of all individuals, the number of agents is sufficiently large that each regards it as given.

The individual's utility is

$$W = U(X) + Y + V(Q) \tag{1}$$

where $U(\cdot)$ and $V(\cdot)$ are strictly concave. If Q is the utility flow from a tropical forest, then V(Q) includes non-excludable benefits of biodiversity, erosion control, and absorption of greenhouse gasses.

Production of X, which may be considered agriculture, requires both labor and an input obtained by converting some of the environmental resource. The amount converted is P, and feasible levels of Q and P are limited by the environmental constraint

$$Q + P = 1. \tag{2}$$

For tropical forests, useful proxies for Q and P might be the amounts of forested and deforested acreage. The production function for X is

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[7]These examples are metaphorical, intended to aid the intuition and to provide concreteness to an otherwise vague distinction. The actual environmental consequences of producing different consumption goods obviously is more complex .

$$X = X(L^X, P) \qquad (3)$$

where L^X is labor used to produce X, and $X(\cdot)$ is concave with positive marginal products. Both L^X and P are assumed to be normal inputs. The production function for Y is

$$Y = \alpha L^Y \qquad (4)$$

where L^Y is labor used to produce Y and α is its marginal product.

The process of converting Q may involve cutting forests, draining wetlands, and so forth, and requires some of the economy's labor. Conversion is described by

$$P = \frac{\alpha}{\beta} L^P \qquad (5)$$

where L^P is labor allocated to converting Q into P and α/β is its marginal product.

The labor available to the economy is limited by

$$L^X + L^Y + L^P = 1 \qquad (6)$$

which implies

$$Y = \alpha - (\alpha L^X + \beta P). \qquad (7)$$

As noted later, the expression in parentheses in (7) is the total 'private' cost of producing X, expressed in units of Y foregone.

Combining equations (1), (2), (3), and (7), the individual's utility is

$$W = U(X(L^X, P)) + \alpha - (\alpha L^X + \beta P) + V(1-P). \qquad (8)$$

The concavity assumptions adopted earlier, together with the linearity of (7), guarantee that (8) is strictly concave and hence has a unique global maximum.

Equilibrium and Efficiency

Those who convert Q to P face no opportunity cost to reflect the fact that this act reduces the environmental quality available to others. The equilibrium allocation in this setting is found by maximizing (8) with respect to L^X and P, treating V(1–P) as fixed. It is useful to break this problem into two parts. Doing so separates the environmental effect of a reallocation of resources into two components, the effect of a change in the mix of inputs used in production and the effect of a change in the mix of final outputs.

First consider the individual's problem of producing X at minimum cost. The Lagrange equation for this problem is

$$L = \alpha L^X + \beta P + \mu(X - X(L^X, P)) \tag{9}$$

and the first-order conditions are

$$\alpha - \mu X_L = 0 \tag{10}$$

$$\beta - \mu X_P = 0, \tag{11}$$

where partial derivatives are denoted with subscripts. Combining these conditions with (3), the private cost minimizing input demands are

$$L^X = L^X(\alpha, \beta, X) \tag{12}$$

$$P = P(\alpha, \beta, X). \tag{13}$$

Inserting these functions into the cost equation (9) yields the 'private' cost function

$$C = C(\alpha, \beta, X). \tag{14}$$

The terms α and β are effective prices for L^X and P, where foregone Y is the unit of account. This private cost of X is less than the social cost, since the price the individual pays for P does not include any charge for environmental damage. The cost function in (14) is concave in the two prices, and derivatives of $C(\cdot)$ with respect to these prices give the cost minimizing input demands. Additionally, the Lagrange multiplier μ in (10) and (11), when evaluated at the prices faced by the individual, equals the marginal private cost of X; that is

$$\mu(\alpha, \beta, X) = C_X(\alpha, \beta, X). \tag{15}$$

Substituting the cost function (14) into (8) gives the following expression for utility

$$W = U(X) + \alpha - C(\alpha, \beta, X) + V(1-P(\alpha, \beta, X)). \tag{16}$$

The individual chooses X to maximize (16), taking V as given. In the unregulated equilibrium, then,

$$U_X = C_X(\alpha, \beta, X), \tag{17}$$

and the marginal benefit of consuming X equals its marginal private cost.

The welfare optimum is found by maximizing (8) with respect to L^X and P. The first-order conditions for this problem are

$$U_X X_L = \alpha \tag{18}$$

$$U_X X_P = \beta + V_Q \tag{19}$$

where V_Q is the marginal utility of the environmental resource.

To allow comparison to the private optimum, substitute μ for C_X in (17) and insert the result into (10) and (11). This yields the following conditions for the private optimum

$$U_X X_L = \alpha \tag{10a}$$

$$U_X X_P = \beta\,. \tag{11a}$$

Comparing (11a) and (19) shows that the competitive solution is inefficient because it causes P to be excessive. This inefficiency is exhibited in the economy in two ways. First, the mix of inputs used to produce X is incorrect; P is used too intensively in the production of X. Second, because P is under-priced, the marginal cost of X relative to Y is too low.

First- and Second-Best Policy Options

The competitive equilibrium is inefficient because no market exists for services provided by the environment. It is well-known that an efficient allocation can be achieved in this circumstance if a properly computed tax is levied on the use of the unmarketed good. In effect, the tax plays the role that would otherwise be filled by the missing price, and restores the allocation that would be achieved if markets were complete.[8] Such 'first-best' policies are seldom adopted, however, and the cost of monitoring that would be needed to enforce a tax policy is one important reason.[9]

This suggests that one examine second–best policies, instruments that do not require direct monitoring of the environmental resource. The second–best instruments considered consist of taxes and subsidies on the inputs and outputs defined in the model economy. Since there are four separate commodities, X, Y, L^X, and P, and hence three relative prices, three separate tax instruments are available.[10]

Tax rates on P, X, and L^X are denoted π, ζ, and λ, respectively. It is convenient to specify these levies as per unit taxes on P and L^X and an ad valorem tax on X; hence

$$R^{\pi} = \pi P; \qquad R^{\lambda} = \lambda L^X; \qquad R^{\zeta} = \zeta C(\cdot). \tag{20}$$

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[8]The same outcome can be obtained by issuing an appropriate number of transferable permits for the use of Q. Competitive trade in permits results in an equilibrium permit price that mimics the corrective tax.

[9] The preceding model does not incorporate monitoring and other transaction costs and is, strictly speaking, applicable for policy analysis only if the implementing agency can monitor the policy's provisions at negligible cost. If the agency is unable to monitor, or can do so only at significant cost, then the first–best tax is infeasible. A tax might still be the best policy available, but one would need to broaden the present model to incorporate monitoring and enforcement costs before deciding.

[10]There are, as well, two additional uses of labor, L^Y and L^P. Since the technologies for producing Y and P are linear, however, taxing these final goods is equivalent to taxing the inputs used to produce them. Subsidies are incorporated into the analysis via negative tax rates. As shown in the following section, the range of policy options to which this analysis applies is broader than the taxes and subsidies explicitly modeled. A quota on production of a good or use of an input is equivalent to a tax on the good accompanied by a particular distribution of tax revenue. Similarly, a price ceiling or floor will cause the same reallocation as a tax on the controlled item, in this case accompanied by a particular distribution of the rent generated by the control.

All tax revenues are rebated to the consumer in lump sum fashion. When these features are incorporated into the utility function, it becomes

$$W = U(X) + \alpha - (1+\zeta)C(\alpha + \lambda, \beta + \pi, X) + V(1-P(\alpha + \lambda, \beta + \pi, X)) + R^{\pi} + R^{\lambda} + R^{\zeta}. \quad (21)$$

First-Best Policy: A Tax on P. It is instructive to demonstrate how the first-best policy of taxing P alone achieves the welfare optimum in this set-up. When π is imposed the individual's choice of X satisfies

$$U_X = C_X(\alpha, \beta + \pi, X), \quad (22)$$

and cost minimizing choices of inputs L^X and P satisfy

$$\alpha/X_L = (\beta + \pi)/X_P = \mu(\alpha, \beta + \pi, X). \quad (23)$$

Recalling that $\mu(\alpha, \beta + \pi, X) = C_X(\alpha, \beta + \pi, X)$, the preceding two conditions imply

$$U_X X_L = \alpha \quad \text{and} \quad U_X X_P = \beta + \pi. \quad (24)$$

Comparing (24) to (18) and (19) it is clear that setting π equal to V_Q achieves the welfare maximum.

Even if the optimal tax rate is unknown, a small positive tax on P necessarily improves welfare over the level reached in the competitive equilibrium. Examining (22), the consumer's choice of X can be written $X = X(\alpha, \beta + \pi)$. Insert this expression into (21), differentiate with respect to π, and evaluate at $\lambda = \zeta = \pi = 0$. The result is

$$\begin{aligned} \partial W/\partial\pi &= (U_X - C_X)\partial X/\partial\pi - \partial C/\partial\pi \\ &\quad - V_Q\{\partial P/\partial\pi + (\partial P/\partial X)\partial X/\partial\pi\} + P \\ &= - V_Q\{\partial P/\partial\pi + (\partial P/\partial X)\partial X/\partial\pi\}, \end{aligned} \quad (25)$$

since $U_X = C_X$ at the untaxed equilibrium and $\partial C/\partial\pi = P$ by duality.

The expression in brackets in (25) can be interpreted more easily by inserting the consumer's optimal choice of X into the demand function for P. The result is

$$P = P(\alpha, \beta + \pi, X(\alpha, \beta + \pi)). \qquad (26)$$

Differentiating with respect to π yields

$$dP/d\pi = \partial P/\partial\pi + (\partial P/\partial X)\partial X/\partial\pi, \qquad (27)$$

which is the expression in brackets in (25). Hence, $\partial W/\partial\pi$ is positive if $dP/d\pi$ is negative. The first term on the right-hand side of (27), $\partial P/\partial\pi$, is the derivative of the demand for P with respect to its own price and is necessarily negative. This is termed an input substitution effect. The remaining terms on the right-hand side of (27) constitute an output substitution effect. Since P is normal $\partial P/\partial X$ is positive, and it is easy to show that normality of P implies $\partial X/\partial\pi$ is negative.[11] Together, then, these results imply $\partial W/\partial\pi > 0$ in a neighborhood of the unregulated equilibrium.

There is an elasticity version of (27) that is useful in applications. This expression, derived in the Appendix, is

$$\frac{dP}{P} = \{\theta_\beta^P + (\phi_X^P)^2\omega_P^X(\frac{\sigma\eta}{(\sigma-\eta)})\}\frac{d\pi}{\beta} \qquad (28)$$

where θ_β^P is the own price elasticity of demand for P, ϕ_X^P is the elasticity of demand for P with respect to output, ω_P^X is the cost share of P in production of X, and σ and η are price elasticities of supply and demand for X. Given any proportionate tax π/β, the proportionate reduction in P is relatively large if: (i) the demand for P is relatively price elastic; (ii) the output elasticity of P in the

[11] Differentiating (22) with respect to π yields $(U_{XX} - C_{XX})\partial X/\partial\pi - C_{X\pi} = 0$, where $C_{X\pi} = \partial^2C/\partial X\partial\pi$. Rearranging, $\partial X/\partial\pi = C_{X\pi}/(U_{XX} - C_{XX})$. From duality, $C_{X\pi} = \partial P(\alpha, \beta, X)/\partial X$, which is positive since P is normal. From concavity, $U_{XX} - C_{XX} < 0$. Hence $\partial X/\partial\pi < 0$.

production of X is relatively large; and (iii) the cost share of P in production of X is relatively large[12]. The term $\sigma\eta/(\sigma-\eta) \leq 0$ is decreasing in σ and increasing in η. Hence, the more price elastic are the supply of X and the demand for X, the larger is the reduction in P for a given tax, π. If either σ or η is zero, the output effect vanishes and only a substitution effect remains.

Second–Best Policy: A Tax on X. If P cannot be monitored so the tax instrument π is unavailable, a natural alternative is to tax X. The salient difference between the two consumption goods is that production of X uses the environmental input while production of Y does not. Taxing X has no effect on relative input prices, so production of X takes place along the same isoquant expansion path as in the untaxed regime. Taxing X discourages its consumption, however, and thereby shifts the demand schedule for P inward. The reduced demand for P then leaves more of the environmental resource in its natural state, to provide the consumption benefit V.

To determine the welfare effect of a marginal ad valorem tax on X, differentiate (21) with respect to ζ, and evaluate where $\zeta = \lambda = \pi = 0$:

$$\partial W/\partial\zeta = (U_X - C_X)\partial X/\partial\zeta - C - V_Q\{(\partial P/\partial X)\partial X/\partial\zeta\} + C,$$

$$= - V_Q\{(\partial P/\partial X)\partial X/\partial\zeta\}. \qquad (29)$$

The expression in brackets is a pure output effect, and the welfare effect of the tax is positive if this output effect is negative. Negativity of the own price elasticity of demand for X implies $\partial X/\partial\zeta < 0$, and $\partial P/\partial X > 0$ since P is normal.[13] Hence, a marginal tax on the consumption good that uses the free access environmental resource as an input is welfare enhancing. As shown later,

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[12]Note that elasticities of demand for P refer to a constant output demand function.

[13]The consumer's choice of X satisfies $U_X - (1 + \zeta)C_X(\alpha,\beta,X) = 0$. Differentiating this equation with respect to ζ and evaluating at $\zeta = 0$ yields, after rearranging, $\partial X/\partial\zeta = C_X/(U_{XX} - C_{XX}) < 0$.

taxing X is equivalent to granting a subsidy for consumption of Y. The policy prescription that emerges thus has intuitive appeal — tax goods that use the unpriced input and grant subsidies to goods that do not.[14]

The elasticity expression for the effect of ζ on conversion of the environmental resource, also derived in the Appendix, is

$$\frac{dP}{P} = \phi_X^P\left(\frac{\sigma\eta}{(\sigma-\eta)}\right)d\zeta. \qquad (30)$$

Since ζ is an ad valorem levy, whereas π was per unit, (30) does not contain a term equivalent to $1/\beta$ in (28).

<u>Second-Best Policy: A Tax on L Used in X.</u> To obtain the welfare effect of a marginal tax on L^X, differentiate (21) with respect to λ and evaluate the derivative at $\pi = \zeta = \lambda = 0$:

$$\partial W/\partial\lambda = (U_X - C_X)\partial X/\partial\lambda - \partial C/\partial\lambda$$
$$- V_Q\{\partial P/\partial\lambda + (\partial P/\partial X)\partial X/\partial\lambda\} + L^X,$$
$$= - V_Q\{\partial P/\partial\lambda + (\partial P/\partial X)\partial X/\partial\lambda\}, \qquad (31)$$

where use has been made of $\partial C/\partial\lambda = L^X$. Imposing a marginal tax on L^X is welfare enhancing if the term in brackets is negative. The term $\partial P/\partial\lambda$ is an input substitution effect, the effect of a change in the price of L^X on demand for P, so its sign depends on whether P and L^X are complements or substitutes in the production of X.[15] The assumption that P and L^X are normal inputs implies $\partial P/\partial X > 0$ and $\partial X/\partial\lambda < 0$.[16]

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[14]Lopez and Niklitschek (1991) reach a similar second-best policy conclusion for the steady state equilibrium in their model.

[15]In the case depicted here, where only two inputs are needed to produce X, the two must necessarily be substitutes. The model can easily be generalized to involve more than two inputs in producing X, in which case complementarity cannot be ruled out.

[16]The explanation for $\partial X/\partial\lambda < 0$ parallels the demonstration for $\partial X/\partial\pi < 0$. Differentiating (22) with respect to λ yields $(U_{XX} - C_{XX})\partial X/\partial\lambda - C_{X\lambda} = 0$, where $C_{X\lambda} = \partial^2C/\partial X\partial\lambda$. Rearranging,

If L^X and P are complements in production, then $\partial W/\partial\lambda > 0$ and imposing a positive tax on L^X is welfare enhancing. The tax has a beneficial input substitution effect ($\partial P/\partial\lambda < 0$), since it causes substitution toward a less damaging mix of inputs for producing each amount of X. It also has a beneficial output substitution effect ($(\partial P/\partial X)\partial X/\partial\lambda < 0$), because it shifts consumption away from the good that uses the polluting input.

If L^X and P are substitutes, the welfare effect of a marginal tax on L^X is unclear. In this case, the input substitution effect and output substitution effect work in opposite directions. If the input substitution effect is dominant, then welfare is improved by granting a subsidy for the use of L^X.

The elasticity expression for this tax, as shown in the Appendix, is

$$\frac{dP}{P} = \{\theta^P_\alpha + \phi^P_X \phi^L_X \omega^X_L (\frac{\sigma\eta}{(\sigma-\eta)})\} \frac{d\lambda}{\alpha} \quad (32)$$

where θ^P_α is the cross elasticity of demand for P with respect to the price of L^X, ϕ^L_X is the elasticity of demand for L^X with respect to output, and ω^X_L is the cost share of L^X in the production of X. If L^X and P are complements, a tax on L^X reduces P and the size of the reduction is greater: (i) the less, in algebraic value, is the cross elasticity of demand between P and L^X, (ii) the greater are the elasticities for L^X and P with respect to X, (iii) the greater is the cost share of input X, and (iv) the more price elastic are the demand and supply functions for X.

$\partial X/\partial\lambda = C_{X\lambda}/(U_{XX} - C_{XX})$, the denominator of which is negative by concavity. Since $C_{X\lambda} = \partial L^X(\alpha, \beta, X)/\partial X$, and is positive if L^X is normal, it follows that $\partial X/\partial\lambda < 0$.

Discussion

It is useful at this point to note a number of relationships between alternative tax policies. The linearity of production functions for Y and P imply that taxing L^P is equivalent to taxing P, and taxing L^Y is equivalent to taxing Y. This is a special case of a more general result — imposing equal ad valorem taxes on all inputs used to produce a good achieves the same result as a direct tax on the final product, since marginal cost functions are homogeneous of degree one in input prices. There may be instances in which some or all of the inputs used to convert Q are easily monitored, while the actual conversion process is not. In such cases, monitoring costs favor a policy of taxing the inputs rather than the activity.

A number of additional relationships can be determined quickly, by examining how each policy affects the economy's resource constraint, stated here for convenience as

$$\alpha L^X + Y + \beta P = \alpha. \qquad (7a)$$

A first–best tax on P, expressed as an ad valorem levy at rate γ, changes the budget constraint to

$$\alpha L + Y + (1+\gamma)\beta P = \alpha + R^\gamma \qquad (7b)$$

where R^γ is the revenue the tax generates. Dividing both sides by $(1+\gamma)$, the result is

$$\frac{\alpha L^X}{(1+\gamma)} + \frac{Y}{(1+\gamma)} + \beta P = \frac{\alpha + R^\gamma}{(1+\gamma)}\,. \qquad (7c)$$

Since (7c) and (7b) describe the same opportunity set, they result in the same equilibrium allocation. The policy represented by (7c) involves granting ad valorem subsidies, at rate $1 - 1/(1 + \gamma)$, for consumption of Y and use of input L^X. This is equivalent to subsidizing all inputs except those used in deforestation. While this is presumably unrealistic for any actual economy, understanding this equivalence can be useful in assessing the environmental consequences of broad tax or subsidy policies, such as exchange controls and import protection.

Consider, finally, the effect of a tax on X. Taxing X is the same as imposing equal ad valorem taxes on the inputs used to produce X, L^X and P, which yields the budget constraint

$$(1 + \delta)\alpha L^X + Y + (1 + \delta)\beta P = \alpha + R^\delta, \tag{7d}$$

where δ is the tax rate and $R^\delta = \delta(\alpha L^X + \beta P)$. Dividing both sides by $(1 + \delta)$ yields

$$\alpha L^X + \frac{Y}{(1 + \delta)} + \beta P = \frac{(\alpha + R^\delta)}{(1 + \delta)}, \tag{7e}$$

which characterizes an ad valorem subsidy, at rate $1 - 1/(1 + \delta)$, for consumption of Y, the good that does not use the environmental resource.

These relationships, as well as the results obtained in the examination of first- and second-best policies, are used in the following section to evaluate the environmental consequences of a number of government policies commonly adopted in developing economies. The issue of tropical deforestation is emphasized in the discussions of policy, but implications for other resource issues are examined as well.[17]

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[17]Although the preceding model is static, it can be reinterpreted to shed light on intertemporal issues, at least in certain instances. Consider the example of allocating a reserve of crude oil. Property rights to the *in situ* reserve are often relatively insecure, possibly due to the rule of capture or for reasons of political instability. The reserve can be converted to an owned input, available for use in the present, by extracting it. The resulting allocation is not Pareto efficient; it

The welfare content of the preceding model rests heavily on the assumption that a single unmarketed, and hence misallocated, environmental resource is the only source of inefficiency. When combined with the assumption that the economy is initially in an unregulated equilibrium and the limited welfare goal of identifying marginal welfare improvements, a simple relationship between welfare and changes in the misallocated resource emerges — marginal increases in Q necessarily yield marginal welfare gains. In any actual application, additional areas of market failure may be present, and the economy may suffer other distortions due to taxation, regulation, or an absence of competition. For this reason, welfare implications are downplayed in the applications that follow, and stress is placed on determining the effect of government policy on the environmental resource.

Applications

Several government policies that have received recent attention in the literature on tropical deforestation are surveyed in this section and analyzed in terms of the preceding model. In some cases the environmental effects of these policies are sufficiently obvious that a formal model and detailed analysis is unnecessary. The preceding framework remains useful,

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leaves less of the resource in the ground for future consumption than would be provided if *in situ* property rights were secure. (Johaney (1978) uses this general argument to explain the worldwide crude oil price increase that occurred in the early 1970s. The preceding model implies that welfare will be improved by a policy that raises the private cost of converting (extracting) it, since this increases the amount available in the future. Imposing a royalty or severance tax generally has this effect. On the other hand, policies that further abridge rights to future consumption worsen the misallocation, and property taxes and capital gains taxes on reserves held *in situ* have this effect. Second–best policies that exploit either input or output substitution effects are not difficult to imagine.

however, for sorting these policies into three categories depending on how they affect the environmental resource, whether by altering: the cost of converting it, the relative price of a good that uses it as an input, or the cost of an input that is substitutable or complementary to it.

The Cost of Converting the Environmental Resource

The cost of converting the environmental resource can be affected by policies that tax or subsidize conversion directly, or by policies that change the cost of inputs used in conversion. The policies surveyed in this section have such effects.

The Cost of Gaining Access to Tropical Forests. The pace at which tropical forests are cleared is limited by inaccessibility. An important determinant of the cost of gaining access and removing any products sought is the condition of roads and other transportation facilities. Not surprisingly, direct government provision of roads to and into tropical forests is widely cited as a major cause of deforestation.[18] Construction of a road often leads, eventually, to conversion of the forest to shifting cultivation. This process often begins when a road is built to provide access to a forest for logging. Logging results in a network of logging roads, and the road network attracts peasants seeking land for shifting cultivation. This pattern has been observed in Brazil (Browder, 1988, p.283), Thailand (Panayotou and Sungsuwan, 1989, p.30), the Philippines (Boado, 1988, pp.169,196) and elsewhere.

The preceding model used β to represent the marginal cost of converting the forest, and policies that subsidize this cost naturally lead to

[18]This specific phenomenon has been studied most thoroughly in Brazil; see Browder (1988, pp.251,277–283) and Mahar (1989, pp.91–4, 99–101).

more extensive deforestation. Government provision of access roads and subsidies to other logging inputs are examples; they provide immediate access to timber harvesters and later five access to shifting cultivators.[19] Harvested logs must be shipped to the mill before use and this is costly as well. Government provision of roads and rail lines, if used primarily for hauling logs and other forest products to market, have environmental effects similar to provision of access roads. They reduce the private cost of deforestation and hence hasten the process.[20]

Some observers cite the provision of transportation infrastructure in general, including canals and harbors, as a source of deforestation. If these transportation facilities are also used by sectors that do not use the environmental input, then their environmental effects are ambiguous. Using the language of the preceding section, if the government builds a that road lowers the cost of P but subsidizes production of Y at the same time, the two considerations work in opposite directions. The direction of the net effect cannot be determined without knowledge of relevant elasticities and cost shares. To determine it one would need to compute the implied subsidy rate

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[19]Panayotou and Sungsuwan (1989, pp.4,5) include the price of logging inputs and factors that represent accessibility to the forest among the marginal cost items that determine the rate of logging.

[20]The model in the preceding section considered only policies that affect the prices of all inputs used in converting the forest. If there are two inputs, e.g., roads and labor for harvesting timber, and the price of only one of these is affected, then the effect on marginal conversion cost is given by $d\beta/\beta = \phi^i_P \omega^P_i \, d\varepsilon_i/\varepsilon_i$. Here, $\beta(\varepsilon_1, \varepsilon_2)$ is the marginal cost of conversion, assumed independent of output, ε_1 and ε_2 are prices of inputs used in conversion, i signifies the input whose price is changed, ϕ^i_P is the elasticity of demand for input i with respect to P, and ω^P_i is the cost share of input i in the conversion process. Thus, the effect on marginal cost of subsidizing a given input depends on the input's cost share and output elasticity in the conversion process.

for P and for Y, and then combine equations (28) and (30) to determine the effect on P.[21]

Royalties and Taxes. The most common form of payment specified in contracts to harvest timber from government forests is the royalty, assessed either on a per unit or ad valorem basis. The severance tax, in either per unit or ad valorem forms, is another common revenue instrument and its incentive effects are identical.[22] If the environmental damage that results from timber harvests is uniquely related to the amount of wood harvested, so P can be represented by the size of the harvest, then both royalties and severance taxes act as first-best policies. Both lower the profit earned on any logs harvested, and hence reduce pressure to extend deforestation.

Royalties, whether expressed as a fraction of the value of the log at the mill or as a fixed charge per cubic foot removed, eliminate the incentive to remove stems that would be on the margin of profitability absent the royalty. Since the timber left behind is of relatively low quality, this phenomenon known as 'high-grading'.[23] High-grading increases the area of forestland disturbed per unit of timber harvested. This disturbance can lead to the scarring of unharvested stems and to damage in the form of erosion and siltation.

Several authors have argued that royalties and taxes, by causing high-grading, are important sources of deforestation. Repetto (1988a, pp.

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[21] Assessing the effect on welfare seems particularly difficult in this case, in part because the facilities involved may have public good attributes.

[22] Royalties and severance taxes are commonly levied on mineral extraction as well.

[23] Vincent (1990) provides empirical evidence on the importance of royalties in inducing high-grading in Indonesia. A severance tax obviously has the same effect and tax-induced high-grading has been noted in the general literature on the economics of forestry; see, for example, Gaffney (1975) and Deacon (1985, pp. 299–300).

18, 24) provides a general statement, Boado (1988, pp. 180–181) gives evidence regarding the Philippines, and Gillis (1988a, p. 59, 1988b, p. 128, and 1988c, pp. 322–332) applies this reasoning to Indonesia, Malaysia, and Liberia.

While a royalty can induce high–grading, and high–grading increases the acreage of forestland disturbed for each unit of wood harvested, it does not follow that a royalty causes deforestation.[24] A royalty has the same effect on the harvesting decision as a reduction in the mill value of *each* stem in the forest. If the harvesting decision for each stem is motivated by harvesting profits, then the effective price reduction cannot increase the number of stems harvested. If the demand for logs is highly elastic, as is likely if they are harvested for export, then the harvester's price net of royalty will fall by roughly the amount of the royalty, reducing the incentive to harvest all stems.[25] If demand is relatively inelastic, on the other hand, the royalty will simply be passed through to buyers, and have no effect on the price net of royalty or the harvesting decision.[26] In either case, stems that would be left unharvested absent the royalty remain unharvested when the royalty is imposed.

One can imagine alternative revenue instruments that avoid the high–grading phenomenon. One might define the base for royalty payments as the mill value of logs less all costs of harvest. If perfectly implemented, the resulting royalty base equals the stumpage value of standing timber, and any

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[24]Repetto (1988a, p.24) seems to conclude that royalties cause deforestation and Gillis (1988b, p. 130) argues that royalties worsen logging damage and accentuate forest depletion in Malaysia.
[25]Panayotou and Sungsuwan (1989) confirm this negative price effect empirically and quantify the responsiveness of deforestation to changes in timber prices in northeast Thailand.
[26]Repetto (1988a, p. 24) and Gillis (1988b, p. 130) seem to have the inelastic demand case in mind when they speak of the harvest required to fulfill demand or obtain a given output.

stem worth harvesting absent the royalty remains profitable to harvest with the levy. Such a royalty has no effect on the choice of stems actually cut, and is not a source of high-grading. Computing eligible harvest costs would presumably be difficult. An alternative is to sell rights to harvest particular tracts of timber through a competitive bidding process, where bidders offer lump sum payments rather than charges per unit of timber removed. Again, the process of collecting revenue would not be a source of high-grading.

By avoiding high-grading, these neutral revenue instruments would reduce the area of land disturbed per unit wood removed. This does not imply that they would slow deforestation, however. If perfectly implemented they would leave unaffected the profit-maximizing harvest decision for each stem. Hence, *all* stems harvested in the absence any royalty would remain profitable to harvest with either of these neutral revenue instruments. As noted earlier, a simple ad valorem or per unit royalty renders subeconomic some stems that would be harvested with a neutral scheme, and thus reduces the volume cut.[27]

Log Export Controls. Developing countries often limit log exports to promote domestic processing of tropical timber. Some have argued that this *accelerates* deforestation and the reasoning used has two parts. First, an export ban causes timber to be processed in domestic rather than foreign mills, and domestic mills tend to be relatively inefficient in the sense that they require more timber to produce a given output of wood products. Second,

[27]The choice of royalty rates and instruments also affects the distribution of the rent that forest harvesting can provide. Gillis and Repetto (1988) conclude that increasing the share of rent going to the nominal government owner is desirable per se. Hyde and Sedjo (1992) argue that it is an empirical question whether the national economy and local populations gain more from government or private capture of this rent.

once domestic mills are established, the host government tends to maintain timber harvests at whatever level is needed to keep the mills running, regardless of costs and benefits. Gillis has applied this argument to Malaysia (Gillis, 1988b, p. 138), Indonesia (Gillis, 1988a, pp. 69–71), the Ivory Coast, and to Liberia and Ghana in lesser degrees (Gillis, 1988c, pp. 337–341). Gillis (1988a, p. 69) reaches a similar conclusion for log export taxes, arguing that a 20 percent export tax on logs, with no export tax on wood products, significantly increases the rate of deforestation in Indonesia. Repetto (1988a, p. 18, and 1989, pp. 81–82) provides concise summary statements of this view.

Prohibiting log exports eliminates foreign mills as a source of log demand. This lowers the stumpage value of timber in much the same way a tax would. Sedjo and Wiseman (1983, pp.113–4) and Parks and Cox (1985, p. 250) reach the same conclusion in their analysis of export prohibitions on logs taken from federal land in the U.S. So long as the pressure to harvest is positively related to the profit from harvesting, the export ban should reduce, not increase, the pace of logging and deforestation.[28]

Political pressure to keep employment high at inefficient domestic mills evidently exists and might be strong enough to outweigh the economic pressure for a lower harvest that comes from the reduction in stumpage value.[29] If so, the export ban would accelerate deforestation. It is fruitless to argue this point on conceptual grounds, however, since the question is

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[28]If banning exports caused an unchanged volume of *lumber* to be produced in inefficient domestic mills rather than efficient foreign ones, then the rate of deforestation clearly would rise. This would not be the market response to an export ban, however. The ban reduces the total demand for *logs* and reduces in the total volume of lumber produced.

[29]Once built, the cost of such mills is sunk and becomes irrelevant in short run decisions of whether and at what rate to keep them operating, a consideration that adds plausibility to the argument.

essentially empirical, and to date the necessary empirical analysis has not been performed.

Policies That Alter the Mix of Final Products

Conversion of the environmental resource is discouraged by policies that retard production of the good that uses the environmental input. The same end can be reached by subsidizing consumption of the good that does not use the environmental input. While this is a useful generalization, the first of the following examples indicates that it must be applied with care.

General Agricultural Policies. Governments in developing countries commonly adopt policies that keep farm prices low relative to prices of other outputs; see Repetto (1988b, p. 171), Schramm and Warford (1989a, p. 14), and Warford (August 1987, p. 19). This end can be accomplished by direct price control, by high tax rates on farm products or, as noted later, by overvaluing a country's currency or protecting its manufacturing sector. An obvious effect is to reduce the demand for agricultural inputs, particularly farmland. If conversion of land to agriculture is inimical to the environment, as is widely claimed for conversion of tropical forests, then such policies are environmentally benign, at least along this dimension.

In some developing countries the net force of government policy runs in the opposite direction, and subsidizes production of at least some agricultural products. The leading example is the system of tax credits, tax exemptions, and credit subsidies provided by the Brazilian government for cattle ranching in the Amazon; see Browder (1988, pp. 251–255, 257 ff.), Repetto (1989, p. 83), and Binswanger (1989, pp. 3,6,11). These policies are credited with almost three-fourths of the Brazilian deforestation that had taken place by the early 1980s (Browder, 1988, p. 251 ff.). Gillis (1988, p. 347) reaches a similar conclusion regarding government incentives for rice production in Liberia. In a nonagricultural example, Mahar (1989) argues against subsidies to mining in Brazil, which use charcoal made by harvesting wood from the forest, as an input.

Armed with such examples it is tempting to conclude that promotion of agriculture harms tropical forests, because it leads to their conversion. Such broad generalizations ignore differences in the production technologies and inputs used by different crops and farming practices, however. A subtle observation on this point was made by Panayotou and Sungsuwan (1989, p.31 ff), who studied the causes of deforestation in Thailand. Land converted from tropical forest typically is used for agriculture, which seemingly supports the preceding generalization. The authors found, however, that while high prices for upland crops promote deforestation, higher rice prices impede it. Upland crops (cassava, maize, and kenap) are more intensive than rice in their use of converted forestland, so a shift toward growing rice draws farm labor away from upland crops and thereby the reduces the extent of deforestation. Lopez (1992, pp. 24–25) makes essentially the same point when commenting on the possibility of differentially taxing agricultural outputs as a second-best way to correct for inefficiency in agricultural land use.

Policies that discriminate against agriculture may also influence the method of farming. Imposing price controls or taxes could shift farm production toward food grown for home consumption and for sale in black markets to escape taxation or regulation. This possibility is speculative since it has not been examined in detail in the literature. It seems likely, however, that farm products grown for home consumption or illegal markets are more frequently produced by shifting agriculture, a practice that is particularly damaging to forests, than those produced for legal trade.[30]

Trade Policy. Developing countries often overvalue their currencies, reducing the prices domestic producers receive for sales abroad and thus depressing exports. The comparative advantage of most developing countries lies in agriculture and natural resource products, so exchange controls typically discourage these sectors relative to manufacturing. Evidence and further elaboration are provided by Repetto (1988a, p. 23), Gillis (1988a, pp. 78–81), Gillis (1988c, pp. 305,343), and Gillis and Repetto (1988, p. 403). If the primary environmental concern is deforestation, then the model presented earlier allows a useful generalization. If agriculture and natural resource industries rely on inputs acquires by converting forestlands, while manufacturing does not, then exchange controls tend to reduce the pace of deforestation.[31]

Trade patterns in developing countries also are influenced by tariffs and quotas. Quotas and taxes on log exports, intended to protect domestic processors, were examined earlier and found to retard deforestation.

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[30]It is also argued that policies that depress agriculture, such as taxes, price controls, and exchange controls, lower incentives to invest in farmland improvement, and thereby cause erosion, salinization, and nutrient depletion (Warford, August 1987, p. 19). If so, then at least some kinds of agricultural inputs, e.g., those related to soil conservation, are environmentally beneficial. Again, the net relationship between the pace of agriculture and the condition of the environment is difficult to determine. It depends on the crops that are farmed, the nature of the local environment, and the kinds of environmental damages one measures.

[31]Gillis (1988a, pp. 78–81) argues that *overvaluation* of the Indonesian rupiah accelerated the rate of tropical deforestation in that country by depressing prices of export crops harvested from uncut forests, thereby reducing the incentive to leave these forests standing. In Malaysia, on the other hand, Gillis (1988b, p. 101) concludes that tropical deforestation was hastened by *undervaluation* of the Malaysian dollar (or ringget), because it accelerated log exports. For both claims to be accurate it must be true that forest crop exports, not logs, are the main source of profit and hence the primary factor in the harvesting decision for Indonesia's forests, while logging is of primary importance in Malaysia.

Other measures used to protect domestic manufacturers and raw materials processors include tariffs on imports of finished manufactured goods and subsidies for domestic manufacturers and processors, such as lumber mills and petroleum refineries. Subsidizing a sector that does not use inputs from forest conversion diverts the economy's labor away from deforestation. Some manufacturing industries seem to satisfy this condition, but others clearly do not.

Developing countries use both log export controls and subsidies to protect domestic processors from foreign competition. Subsidies to processors take the form of tax credits, tax holidays, and subsidized loans (Repetto 1988a, pp. 17–18). While processing subsidies and log export bans both offer protection from foreign competition, their implications for deforestation are completely different. A subsidy to domestic processors leaves the foreign demand for logs unaffected, but increases the profits of domestic processors and thereby increases their demand for logs. This intensifies the incentive to harvest and hastens deforestation. A log export ban, on the other hand, reduces the overall demand for logs.

Employment Opportunities. General poverty among landless peasants has been cited as an important cause of deforestation. Lacking other employment opportunities, such workers often turn to converting forestland to shifting cultivation, particularly after it has been logged. One way to relieve this pressure on forests is to subsidize or otherwise promote employment and production in industries that do not convert forestlands to obtain inputs. In commenting on deforestation in Brazil, Mahar (1989, p.12) essentially makes the same point when recommending that the Brazilian government increase employment opportunities in sectors and geographic areas unconnected to the Amazon forests.

Policies That Alter the Mix of Inputs

Changing the price of an input generally changes both the mix of inputs used to produce a given level of output and the mix of final outputs consumed. Subsidizing a substitute for an input obtained by deforestation may cause use of the forest-related input, and hence deforestation, to rise or fall, depending on the relevant elasticities and cost shares. Subsidizing a complement, on the other hand, necessarily hastens deforestation.

Substitution Among Fuels. A leading cause of forest degradation in densely populated tropical regions is the gathering of fuelwood for heating, cooking, and lighting. The problem is particularly acute in Nepal and on Java, where it leads to soil depletion and erosion (Pitt, 1985, p. 201); it has also been noted by Panayotou and Sungsuwan (1989) in Thailand. Elsewhere, Warford (1987, p. 4) notes that the use of dung for fuel also depletes the soil. There are a number of substitutes for these natural fuels such as electricity, coal, and refined petroleum. Granting subsidies for one or more substitute energy sources would induce desirable input substitution, and reduce fuelwood use per unit of final output.[32] If this input substitution effect were not outweighed by an adverse output substitution effect, the rate of deforestation would fall as a result.

The Indonesian government subsidized kerosene for many years, and the possibility of a beneficial effect on deforestation was offered as one

[32] In this case the relevant 'outputs' are residential heat, light, and cooked food.

rationale. Pitt (1985) and Dick (1980) conclude that the subsidy did little to prevent deforestation, however, since the two fuels are not highly substitutable among those populations who inhabit the rural areas where deforestation occurs. Panayotou and Sungsuwan (1989), on the other hand, found the extent of "forest cover" in Thailand to be negatively related to the price of kerosene, which agrees with the general line of reasoning advanced here.[33] The disparity in these findings highlights the value of information on relevant elasticities in forming policy. Ideally, policy formulation would proceed by empirically assessing the most important uses of fuelwood, quantifying substitution possibilities, and targeting specific alternative energy sources for subsidies.[34]

Substitution Among Agricultural Inputs. Changing the price of an input that is complementary to the forest-related input can be examined symmetrically. Stavins and Jaffe (1990) have applied this reasoning to the conversion of forested wetlands in the U.S. to agriculture. They point out that forested wetlands provide unmarketed services, such as wildlife habitat and

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[33]The presence of collinearity if their econometric model made it difficult to separate the effect of kerosene price from the influence of other variables that determine deforestation.

[34]A similar analysis could be applied to examine the effects of taxes or subsidies for capital used in processing logs, mineral ores, and other natural resources. Milling capital and logs appear substitutable in the production of finished lumber. When milling capital is cheap production seems capital intensive and 'efficient' in the sense of requiring a small volume of timber to produce a given output. A subsidy to milling capital would, by this reasoning, reduce the use of logs relative to milling capital, a favorable input substitution effect. It would also cause an opposing output substitution effect, so a careful determination of relevant cost shares and elasticities would be needed to determine the net outcome. As the logic of equation (32) implies, a subsidy to milling capital might actually hasten deforestation if the output effect is dominant. The same reasoning applies to processing mined ores in cases where the environmental harm of concern is directly related to the volume of ore removed. It is useful to reiterate the difference between a subsidy to processing capital and a general subsidy to the processing activity. The latter has no beneficial input substitution effect, and hence unambiguously increases extraction of the raw material.

visual amenities. Agricultural crops are produced with cleared land and other farm inputs. Most of these other inputs appear complementary to land, such as irrigation water, fertilizers, pest control agents, and flood protection for farmland. Hence subsidies for these inputs imply a pattern of input and output substitution effects that hastens deforestation.[35] Stavins and Jaffe's (1990) empirical analysis focuses on the effect of free flood protection for farmland, and their simulations indicate that this policy has been a significant cause of deforestation and wetland conversion. Their empirical analysis also examines subsidies to irrigation water, which tends to enhance forest conversion, and controls on the use of agricultural pesticides, which appear to retard it.

Government subsidies for agricultural inputs are also observed in the developing world and the items typically favored include pesticides, fertilizers, irrigation water, and farm machinery; see Repetto (1989, pp. 73–77), Schramm and Warford (1989, p. 15), and Warford (1987, pp. 20–22). The subsidies take various forms: direct payments to users of pesticides, below cost sales of irrigation water by government agencies, and favorable tariff treatment for farm machinery.[36] Such policies cause output substitution that hastens deforestation — they reduce the marginal cost of an activity, agriculture, that often uses converted forestland as an input. They also cause substitution between farmland and other agricultural inputs, however, and this effect could either augment or offset the output substitution effect. While some empirical information on the direction and magnitudes of these effects is available, e.g., Stavins and Jaffe (1990) for the U.S. and Panayotou and

[35]Panayotou and Sungsuwan (1989), in their study of northeast Thailand, find a similar deforestation effect from government provision of irrigation improvements.
[36]Warford (1987, p. 20) reports a median subsidy rate of 44 percent of cost for pesticides used in a sample of developing countries.

Sungsuwan (1989) for Thailand, knowledge on this subject of relatively incomplete.[37]

Conclusions

The importance of property rights, though important for understanding the process of tropical deforestation, does not necessarily point to a simple or straightforward fix for environmental problems, particularly in developing countries. Regarding tropical forests specifically, their sheer size, the communal nature of their service flows, and the pervasiveness of individual access to them, make monitoring and enforcement very costly in some situations and virtually unimaginable in others. Redefining nominal rights in ways that appear to correct inefficiencies may yield gains in some instances, but an approach to environmental protection that leans heavily on this prescription seems aimed more at symptoms than causes. Furthermore, while policy approaches based on the use of Pigovian taxes or marketable permit schemes may yield efficiency gains in some instances, they generally encounter the same monitoring and enforcement problems that prevent the market from solving these allocation problems.

If simple, direct solutions to deforestation and other environmental problems in developing countries are unavailable, an ability to understand the environmental and welfare consequences of policies adopted for other

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[37]The use of fossil fuels as a source of energy to produce manufactured goods provides an additional application of this general framework. The use of fossil fuels degrades an environmental resource, clean air. In effect, clean air, or the waste-receptive capacity of the atmosphere, is an input to the production of manufactured goods. Fossil fuels are complementary to the use of this environmental input; hence the typical government policy of subsidizing use of fossil fuels promotes air pollution and lowers welfare. Kosmo (1989) provides information on air pollution and energy price policy in several developing nations.

reasons is useful, if only to help policy makers avoid mistakes that might otherwise go unrecognized. The model developed for this purpose is highly stylized, and is intended primarily to provide a systematic way of thinking about the environmental and welfare effects of government policy, e.g., by considering patterns of substitution among inputs and outputs, in cases where an environmental resource is exploited under conditions of free access. The policy applications examined were not studied in any detail, and sometimes were stated in terms so simple that a model seems unnecessary. In any actual situation, however, pursuing a specific government policy can affect a variety of industries to different degrees and may reallocate resources in a way that protects some environmental resources and simultaneously degrades others. If the use of first-best policies is infeasible, whether due to monitoring costs, transboundary effects, or other reasons, then detailed knowledge of patterns of substitution and complementarity among ordinary inputs and environmental resources, and information on the use of various environmental resources in the production of specific goods and services become important. Knowledge of such factors can permit policy makers to pursue policy goals in situations where first-best instruments are unavailable.

Appendix

When taxes on P, L^X, and X are considered, the demand for P is expressed

$$P = P(\alpha + \lambda, \beta + \pi, X). \tag{A.1}$$

The consumer's choice of X satisfies

$$U_X = (1 + \zeta)C_X(\alpha + \lambda, \beta + \pi, X), \tag{A.2}$$

which implies

$$X = X(\alpha + \lambda, \beta + \pi). \tag{A.3}$$

The effect of a marginal tax on P, levied at rate π, on the equilibrium value of P is found by incorporating (A.3) in (A.1) and differentiating with respect to π

$$\frac{dP}{d\pi} = \frac{\partial P}{\partial \pi} + \left(\frac{\partial P}{\partial X}\right)\frac{\partial X}{\partial \pi}. \tag{A.4}$$

To evaluate the term $\frac{\partial X}{\partial \pi}$, insert (A.3) into (A.2) and differentiate with respect to π. Evaluating at $\pi = \lambda = \zeta = 0$ yields

$$\begin{aligned} \frac{\partial X}{\partial \pi} &= \frac{C_{X\pi}}{U_{XX} - C_{XX}} \\ &= \frac{\partial P}{\partial X}\left(\frac{1}{U_{XX} - C_{XX}}\right). \end{aligned} \tag{A.5}$$

It is useful to relate the expression $1/(U_{XX} - C_{XX})$ to ordinary price elasticities of demand and supply. Suppose the consumer's utility maximization problem were intermediated by a market, so output X is sold competitively at price R and is bought be a price–taking consumer. The necessary conditions for utility and profit maximization become

$$U_X(X) = R \tag{A.6}$$

$$C_X(\alpha, \beta, X) = R. \tag{A.7}$$

These conditions can be inverted to yield $X = X^D(R)$ and $X = X^S(\alpha, \beta, R)$, respectively, which are competitive demand and supply functions.

Incorporating these demand and supply functions into (A.6) and (A.7) respectively, and differentiating with respect to R, yields

$$\frac{1}{U_{XX}} = \frac{\partial X^D(R)}{\partial R} \tag{A.8}$$

$$\frac{1}{C_{XX}} = \frac{\partial X^S(\alpha, \beta, R)}{\partial R}. \tag{A.8}$$

With some manipulation, it can be shown that

$$\frac{1}{U_{XX} - C_{XX}} = \frac{X}{R}\left(\frac{\sigma\eta}{\sigma - \eta}\right) \tag{A.9}$$

where η and σ are price elasticities of demand and supply of X.

It is now possible to combine (A.4), (A.5) and (A.9) to obtain

$$\frac{dP}{d\pi} = \frac{\partial P}{\partial \pi} + \left(\frac{\partial P}{\partial X}\right)\left(\frac{\partial P}{\partial X}\right)\left(\frac{X}{R}\right)\left(\frac{\sigma\eta}{\sigma - \eta}\right). \tag{A.10}$$

This can be expressed in a form involving elasticities which yields the proportionate change in P for a marginal tax π

$$\frac{1}{P}dP = \left\{\frac{(\beta + \pi)}{P}\left(\frac{\partial P}{\partial \pi}\right) + \left[\frac{X\partial P}{P\partial X}\right]^2\left[\frac{(\beta+\pi)P}{C_X X}\right]\left[\frac{\sigma\eta}{\sigma - \eta}\right]\right\}\frac{d\pi}{(\beta + \pi)}. \tag{A.11}$$

Evaluating at $\pi = 0$, and simplifying, this becomes

$$\frac{1}{P}dP = \left\{\theta_P^\beta + (\phi_P^X)^2\omega_X^P\left(\frac{\sigma\eta}{\sigma - \eta}\right)\right\}\frac{d\pi}{\beta} \tag{A.12}$$

where θ_P^β is the own price elasticity of demand for P, ϕ_P^X is the elasticity of demand for P with respect to output, and ω_X^P is the cost share of input P in the production of X.

Taking a parallel approach, the effect of a tax on L^X levied at rate λ can be shown to equal

$$\frac{1}{P}dP = \left\{\theta_P^\alpha + \phi_P^X\phi_L^X\omega_X^L\left(\frac{\sigma\eta}{\sigma - \eta}\right)\right\}\frac{d\lambda}{\alpha} \tag{A.13}$$

where θ_P^{α} is the cross elasticity of demand for P with respect to α, ϕ_L^X is the elasticity of demand for L^X with respect to output, and ω_X^L is the cost share of L_X in production of X.

Finally, the effect on P of a marginal tax on X, levied at rate ζ, can be derived in similar fashion. Inserting (A.3) into (A.1), differentiating with respect to ζ, and evaluating where $\zeta = \pi = \lambda = 0$ gives

$$\frac{\partial P}{\partial \zeta} = \frac{\partial P \partial X}{\partial X \partial \zeta}. \qquad \text{(A.14)}$$

The term $\partial X/\partial \zeta$ is evaluated by plugging (A.3) into (A.2) and differentiating. After rearranging, the result is

$$\frac{\partial X}{\partial \zeta} = \frac{C_X}{U_{XX} - C_{XX}}. \qquad \text{(A.15)}$$

Combining (A.9), (A.14) and (A.15) gives

$$\frac{\partial P}{\partial \zeta} = \left(\frac{\partial P}{\partial X}\right)\frac{C_X X}{R}\left(\frac{\sigma\eta}{\sigma - \eta}\right). \qquad \text{(A.16)}$$

This can be arranged to yield an elasticity expression similar to those provided earlier

$$\frac{\partial P}{P} = \phi_P^X\left(\frac{\sigma\eta}{\sigma - \eta}\right)d\zeta. \qquad \text{(A.17)}$$

Recall that ζ is an advalorem levy, whereas π and λ are per unit taxes. Hence the form of (A.17) does not contain a term similar to $1/\alpha$ or $1/\beta$ in (A.13) and (A.12).

BIBLIOGRAPHY

Binswanger, Hans P., "Brazilian Policies That Encourage Deforestation in the Amazon", Environment Department Working Paper No. 16, World Bank, WAshington, DC, April 1989.

Boado, Eufresina L., "Incentive Policies and Forest Use in the Philippines" in Robert Repetto and Malcolm Gillis, eds., *Public Policies and the Misuse of Forest Resources*, Cambridge University Press, Cambridge, UK 1988.

Browder, John O., "Public Policy and Deforestation in the Brazilian Amazon", in Robert Repetto and Malcolm Gillis, eds., *Public Policies and the Misuse of Forest Resources*, Cambridge University Press, Cambridge, UK 1988.

Deacon, Robert T., "The Simple Analytics of Forest Economics", in Robert T. Deacon and M. Bruce Johnson, eds., *Forestlands: Public and Private*, Ballinger Publishing Co., Cambridge MA, 1985.

Deacon, Robert T., "Controlling Tropical Deforestation: An Analysis of Alternative Policies", unpublished working paper, Department of Economics, University of California, Santa Barbara, January 6, 1992.

Dick, H., "The Oil Price Subsidy, Deforestation, and Equity", *Bulletin of Indonesian Economic Studies*, (1980), Vol 13, No. 3, 32–60.

Eskeland, Gunnar, S., and Jimenez, Emmanuel, "Choosing Among Policy Instruments in Pollution Control: A Review", unpublished, Public Economics Division, Country Economics Department, World Bank, Washington, D.C, 1990.

Fisher, A.C., and W.M. Hanemann, "Valuation of Tropical Forests", Working paper No. 576, Dept. of Agricultural and Resource Economics, University of California, Berkeley, CA. 1991.

Gaffney, Mason, "Taxes on Yield, Property, Income, and Site: Effects on Forest Revenues and Management", Mimeo, Institute for Policy Analysis, University of Victoria, Victoria, Canada, 1975.

Gillis, Malcolm, "Indonesia: Public Policies, Resource Management, and the Tropical Forest", in in Robert Repetto and Malcolm Gillis, eds., *Public Policies and the Misuse of Forest Resources*, Cambridge University Press, Cambridge, UK 1988.

Gillis, Malcolm, "Malaysia: Public Policies and the Tropical Forest", in Robert Repetto and Malcolm Gillis, eds., *Public Policies and the Misuse of Forest Resources*, Cambridge University Press, Cambridge, UK 1988.

Gillis, Malcolm, "West Africa: Resource Management Policies and the Tropical Forest", in Robert Repetto and Malcolm Gillis, eds., *Public Policies and the Misuse of Forest Resources*, Cambridge University Press, Cambridge, UK 1988.

Gillis, Malcolm, and Robert Repetto, "Conclusions: Findings and Policy Implications", in Robert Repetto and Malcolm Gillis, eds., *Public Policies and the Misuse of Forest Resources*, Cambridge University Press, Cambridge, UK 1988.

Hyde, William F., and Roger Sedjo, "Managing Tropical Forests: Reflections on the Rent Distribution Discussion", *Land Economics*, forthcoming.

Hyde, William, Robert Mendelsohn, and Roger Sedjo, "The Applied Economics of Tropical Deforestation". Paper presented at AERE session of American Economics Association Annual Meetings, Washington, DC, December, 1990.

Johaney, A. D., "OPEC is Not a Cartel: A Property Rights Explanation of the Rise in Crude Oil Prices", unpublished Ph.D. dissertation, University of California, Santa Barbara, June 1978,

Kosmo, Mark, "Economic Incentives and Industrial Pollution in Developing Countries", Environment Department, Policy and Research Division Working Paper No. 1989-2, July 1989.

Lopez, Ramon, and Mario Niklitschek, "Dual Economic Growth in Poor Tropical Areas", *Journal of Development Economics* (1991) Vol. 36, 189-211.

Lopez, Ramon, "Resource Degradation, Community Controls and Agricultural Productivity in Tropical Areas", Mimeo, University of Maryland, College Park (1992).

Mahar, Dennis J., "Deforestation in Brazil's Amazon Region: Magnitude, Rate, and Causes", in Gunter Schramm and Jeremy J. Warford, eds., *Environmental Management and Economic Development*, The Johns Hopkins University Press for the World Bank, Baltimore MD, 1989.

Mendelsohn, Robert, "Property Rights and Tropical Deforestation". Paper presented at AERE session of American Economics Association Annual Meetings, Washington, DC, December, 1990.

Panayotou, Theodore, and Sungsuwan, Somthawin, "An Econometric Study of the Causes of Tropical Deforestation: The Case of Northeast Thailand",Discussion Paper No. 284, Harvard Institute for International Development, Cambridge, MA, March 1989.

Parks, Richard W., and Cox, Judith, "The Economic Implications of Log Export Restrictions: Analysis of Existing and Proposed Legislation", in Robert T. Deacon and M. Bruce Johnson, eds., *Forestlands: Public and Private*, Ballinger Publishing Co., Cambridge MA, 1985.

Peters, Charles M. , Gentry, Alwyn J., and Mendelsohn, Robert O., "Valuation of an Amazonian Rainforest", *Nature*, June 29, 1989, *339*, 655–656.

Pitt, Mark, "Equity, Externalities and Energy Subsidies: The Case of Kerosene in Indonesia", *Journal of Development Economics*, 1985, 201–217.

Repetto, Robert, "Economic Incentives for Sustainable Production", in Gunter Schramm and Jeremy J. Warford, eds., *Environmental Management and Economic Development*, The Johns Hopkins University Press for the World Bank, Baltimore MD, 1989.

Repetto, Robert, "Overview", in Robert Repetto and Malcolm Gillis, eds., *Public Policies and the Misuse of Forest Resources*, Cambridge University Press, Cambridge, UK 1988a.

Repetto, Robert, "Subsidized Timber Sales from National Forest Lands in the United States", in Robert Repetto and Malcolm Gillis, eds., *Public Policies and the Misuse of Forest Resources*, Cambridge University Press, Cambridge, UK 1988b.

Repetto, Robert, and Gillis, Malcolm, eds. *Public Policies and the Misuse of Forest Resources*, Cambridge University Press, Cambridge, UK 1988.

Sandmo, Agnar, "Direct Versus Indirect Pigovian Taxation", *European Economic Review*, 1976, *7*, 337–349.

Schramm, Gunter, and Warford, Jeremy J., eds. *Environmental Management and Economic Development*, The Johns Hopkins University Press for the World Bank, Baltimore MD, 1989.

Schramm, Gunter, and Jeremy J. Warford, "Introduction", in Gunter Schramm and Jeremy J. Warford, eds., *Environmental Management and Economic Development*, The Johns Hopkins University Press for the World Bank, Baltimore MD, 1989.

Sedjo, Roger A., "Book Reviews" of: Robert S. Anderson and Walter Huber, *The Hour of the Fox: Tropical Forests, the World Bank, and Indigenous People in Central India*, University of Washington Press, Seattle, WA, 1988; and *The Forest for the Trees? Government Policies and the Misuse of Forest Resources*, World Resources Institute, Washington, May 1988; in *Economic Development and Cultural Change*, 1990a.

Sedjo, Roger, "Tropical Forests, Land Use and Environmental Values: Economic Concepts and Real World Complexities". Paper presented at AERE session of American Economics Association Annual Meetings, Washington, DC, December, 1990b.

Sedjo, Roger A., and Wiseman, Clark, "The Effectiveness of an Export Restriction on Logs", American Journal of Agricultural Economics, Vol. 65, no. 1 (1983) 113–6.

Stavins, Robert N. and Jaffe, Adam B., "Unintended Impacts of Public Investments on Private Decisions: The Depletion of Forested Wetlands", *American Economic Review*, June 1990, *80*, 337–351.

Vincent, Jeffrey R., "Rent Capture and the Feasibility of Tropical Forest Management", *Land Economics*, May 1990, *66*, 212–223.

Warford, Jeremy, "Environmental Management and Economic Policy in Developing Countries", in Gunter Schramm and Jeremy J. Warford, eds., *Environmental Management and Economic Development*, The Johns Hopkins University Press for the World Bank, Baltimore MD, 1989.

Warford, Jeremy J., "Environment, Growth, and Development", Development Committee Report No. 14, World Bank, Washington DC, August 1987.

Wijkander, Hans, "Correcting Externalities Through Taxes On/Subsidies To Related Goods", *Journal of Public Economics*, 1985, *28*, 111–125.

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