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The Complier Pays Principle: The Limits of Fiscal Approaches Toward Sustainable Forest Management

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This paper examines the role and impact of taxation on sustainable forest management. It is shown that fiscal instruments neither reinforce nor substitute for traditional regulatory approaches and can actually undermine sustainability. The paper uses the reasoning at the root of the Faustmann solution to draw conclusions on the incentives for sustainable tropical forest exploitation. It proposes a bond mechanism as an alternative market-based instrument to encourage sustainable forest logging while reducing monitoring costs. [JEL Q23, H39]

Sound natural resource management that takes into account long-term social, ecological, and economic values is an essential component of sustainable development strategies. The fast pace of natural forest depletion worldwide, mostly driven by logging, has been a cause of concern for decades, prompting governments to act to try to reverse the trend.[1] Where they are still found, they often represent the ecologically and economically optimal use of the land, and provide a wide range of nonmarket ecological services in addition to timber and

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[1]In the early 1990s, about 17 million hectares of tropical forests—an area four times the size of Switzerland—were cleared annually.

nontimber products. The forests' degradation through over-exploitation generally implies an economic cost far beyond the loss of timber production potential.[2]

Governments' initial response, namely a strengthening of existing "command and control" management regimes, met with limited success and it soon became apparent that more effective instruments were needed. In the late 1980s, attention focused on economic incentives. Insufficient timber taxation was identified as a leading cause of forest depletion.[3] An effective alternative to "command and control" policy seemed to emerge, exploiting a virtuous (and—if valid—very attractive) complementarity between increased fiscal revenue collection and improved forest management. The resulting policy prescriptions, superficially based on the "polluter pays principle," were embraced by international development institutions.[4] Increased timber taxation became the cornerstone of forest management policy reform packages championed by the World Bank in countries as different as Indonesia, Cambodia, and the Democratic Republic of the Congo.[5] Simply put, it was argued that loggers (cast as polluters) could be induced to internalize the full social cost of their activities through a "Pigovian" tax on timber extraction: the "Pigovian" tax used to counter industrial pollution was being prescribed for tropical forestry.[6] The approach gave respectability to attempts by fiscally beleaguered governments to look toward forests as prime candidates for additional tax revenue.

After more than a decade since they were first adopted, the policies appear to have had very little impact, if any, on forest depletion, which has continued unabated in most countries.[7] On the other hand, the policies have been moderately successful on the fiscal side: although implemented in earnest only after the bulk of accessible areas of forest had disappeared, increased forest taxation has begun to yield significant amounts of fiscal revenue in some countries, even if these revenues still account for only a small percentage of the total. Indonesia, host to one of the world's largest remaining natural forests, and the largest developing country exporter of forestry products for more than two decades, is a case in point. The government introduced numerous taxes and charges, in addition to restrictions already built into logging concession contracts (selective logging rules, a 35-year cutting cycle, minimum diameter provisions, and obligation to undertake certain post-harvest silvicultural activities). "Reforestation fees,"

[2]Where natural forests can give way to superior uses (for example, as agriculture or tree plantations) even when all their external benefits are taken into account, deforestation should be thought of as welfare-enhancing land improvement. Where this is the case, the arguments developed in this paper do not apply.

[3]See Repetto (1988), Hyde and Sedjo (1992), Repetto and Gillis (1988), Vincent (1993a), and Vincent (1993b).

[4]Paris and Ruzicka (1991, 1993) are a dissenting voice while Vincent and Panayotou (1994) offer a detailed account of the evolution of thinking over time.

[5]Other reforms advocated by the World Bank for Indonesia include liberalization of log exports and internal log trade, phasing out of obligatory log processing requirements, extension of concession lease periods and greater lease transferability, and the use of performance bonds and independent performance certification. Although the first two measures are outside the scope of this paper, the other measures are taken up in the analysis.

[6]The Pigovian tax is a tax set as the difference between the marginal social and marginal private cost of an externality-generating activity that restores efficiency in resource allocation.

[7]As shown by the experience in countries as diverse as Cambodia, Congo, or Indonesia, all recent converts to increased timber taxation. See SGS Forestry (1996), World Bank (1999a), and Asian Development Bank (2000).

collected on the basis of harvested volume, were also added, but to no avail.[8] Deforestation rates remained largely unchanged at around 1 percent a year and there are strong indications that the additional taxes fueled corruption.[9]

Many other countries have had similar experiences. In Honduras, state forestry revenue accounted for less than 1 percent of central government revenue in 1994, but stumpage prices increased by a factor of five in two years. In Cameroon, forestry taxes accounted for 3.5 percent of revenue in 1998–99, up from 2.5 percent three years earlier.[10] In the Philippines, total taxes on logs increased from 0.1 percent of revenue in 1989 to 0.4 percent in 1991 (World Bank, 1999b). Yet, in these and other cases, the impact on deforestation has been negligible.

More radical economic remedies were also envisaged, including outright privatization of forests—perhaps the most tempting, where not specifically precluded by local constitutions. Economists made the case that, presumably, private owners of forests would have a strong incentive to protect their resources. In practice, governments have rightly been reluctant to implement large-scale privatization and no policymaker has seriously advocated it. Where small areas of forest (usually below 2,500 hectares) were sold or granted with few management constraints (as in parts of West Africa), the result has usually been rapid forest liquidation by private owners eager to cash in on the asset and move on to other activities. The fact is that most private owners would be unlikely to manage the asset as a natural forest for timber extraction purposes and instead would convert it to financially more profitable uses such as monocrop tree plantations, grazing land, or agriculture. This can be neglected where the external benefits of natural forests are small, because conversion of forests to other uses would then not only provide ready revenues for the state, but also enhance economic welfare. But this is the exception rather than the rule. Apart from timber, most remaining natural forests provide a wide range of nonmarketed environmental benefits.[11] These

[8]The charges now include, in declining order of importance, the reforestation fee; a royalty levied at 6 percent of the reference price of logs, differentiated by species and province of origin; an export tax on processed wood; forest concession license fee—an area-based tax payable for the 20-year duration of the concession; and minor taxes or charges (scaling and grading fees, training fund, etc.). All told, the combined official taxes averaged $20–25 a cubic meter throughout the mid-1990s (versus free-on-board prices of comparable South East Asia logs of between $81 and $300 a cubic meter during the decade), yielding an annual average total revenue of around $400 million. Obligatory domestic processing of logs, another component of Indonesian policy, has encouraged over-investment in processing capacity and led to strong pressures for increasing log output.

[9]As noted by the World Bank, "only a small portion of the Reforestation Fund has ever been used to finance the replanting of harvested stands or other forms of sustainable forest management. For the most part, the RF has financed secretive and poorly justified investments favoring the elite and with little developmental or poverty-reducing impact. When used for forestry investments, it has often supported conversion of diverse natural forests to artificial plantations." The same document acknowledges that "the introduction of resource taxes may have larger fiscal than deforestation effects" (World Bank, 1999a, p. 11). Contreras-Hermosilla (1997) and Environmental Intelligence Agency (1996) discuss the issue of corruption in more detail.

[10]Based on IMF staff estimates.

[11]There are, furthermore, important nontimber forestry products that can be commercialized (game, medicinal plants, nuts, etc.). If we do not explicitly deal with them here, it is in order to concentrate on the topic of this paper. Readers interested in the subject of the nontimber commercial potential of tropical forests are referred to Godoy and Bawa (1993).

range from the preservation of watershed stability and regulation of hydrological cycles to the provision of habitats to a large number of species.

Stated more analytically, the principal obstacle to privatizing tropical forests is the difficulty of applying a Coasian solution that adequately takes externalities into account. If those benefiting from the environmental services generated by forests could be made to pay for them (in the way that, for example, orchard owners pay bee keepers for the pollination services they provide indirectly), a potential incentive could be found and private loggers could be prevented from imposing costs on downstream economic agents or liquidating the asset.[12]

In practice, many factors make it difficult to envisage this approach, including: the complexity of external environmental services provided by natural forests; the large number of individuals and sectors affected (farmers, users of transport or hydropower, coastal fishing communities, etc.); the lag between the time a forest is degraded and the consequences felt downstream; and the technical difficulty of quantifying the damage caused.

The severe shortages of technical and administrative capacity faced by governments and private sector institutions further compound the difficulties. Experience has shown that the alternative of imposing regulatory constraints on private forest "owners-to-be" at the time of the sale, in order to ensure that their management practices are compatible with the external benefits that forests provide, is equally difficult to put in practice. This is mostly because the scope for bribing forest inspectors to overlook violations is overwhelming. Lastly, efficient privatizations require transparent and competitive allocation mechanisms (for example, auctions). Experience in many developing countries suggests that these ingredients are missing and disposing of state assets then becomes an invitation for wrongdoings.

All these factors combine to make a strong case for keeping natural forests under some form of public control. At the same time, the experience of inefficient state management of commercial activities suggests that logging operations are best left to the private sector. Therefore, the challenge is to devise instruments that provide the government with ready means of enforcing forestry rules, while providing financial rewards to private operators for complying with those rules, thereby minimizing monitoring and enforcement costs.

This paper explores the role and impact of taxation as a mechanism to encourage sustainable management of publicly owned forests by private sector operators. In particular, we review the scope for using fiscal instruments to reconcile private and public interests and foster sustainable natural forest management. We derive a tax-policy-adjusted Faustmann solution to the problem of forest management and show that fiscal instruments neither reinforce nor substitute for traditional regulatory approaches. There are numerous reasons for this. The most

[12]New York City, for example, has set up an elaborate watershed management scheme whereby upstream private land owners are compensated for adopting watershed-friendly land uses. This is complemented by outright purchases of particularly sensitive land and regulatory measures. This innovative scheme provides a way to safeguard drinking water supply, reducing the need for costly downstream infrastructure for water purification and the like. In establishing and managing it, however, New York City has at its disposal human, institutional, and technical capacities far beyond the reach of most developing countries.

fundamental is that the relationship between the negative environmental externalities resulting from logging is weakly and indirectly related to the volume of timber sold and strongly dependent on the management regime in place. A given level of exploitation can lead to very high or very low environmental damage, depending on a complex combination of factors ranging from logging techniques to site-specific characteristics such as topography and proximity to urban centers. Thus, the basic requirement for Pigovian fiscal instruments to work, namely the possibility that a levy on the socially damaging activity could narrow the distortion between the private and social costs of that activity, is not satisfied.

Furthermore, we show that, far from encouraging more sustainable forest management, fiscal instruments can actually undermine it. An inappropriate tax policy could result in more damage to resources and the environment than no tax at all, under any set of real world assumptions. We also point to a number of practical reasons that further undermine the case for fiscal instruments as a means of enforcing logging rules. Based on this analysis, we present a proposal for a performance guarantee bond scheme that assigns both long-term cutting rights and responsibility for forest management to the lessee through competitive bidding. The scheme hinges on the fact that while day-to-day monitoring of forestry rules is difficult and expensive, the impact of compliance—in the form of an ecologically healthy and commercially valuable forest—is readily observed ex-post.

Throughout the paper, we concentrate on the general case where commercial-scale timber extraction is potentially compatible with the maintenance of the forest's external benefits in order to focus on how policy instruments can reinforce or undermine this compatibility. Thus, by hypothesis, we exclude cases where the conversion to even-aged plantations would yield socially, economically, and ecologically superior results. Such situations do not pose special policy challenges. At the other extreme, we also exclude situations where forest exploitation is entirely incompatible with the preservation of externality values, and where the public sector must assume forest protection functions. Our focus is exclusively on commercial loggers. Community-based forest management schemes require a completely different set of measures that are not covered.

I. The Model

Consider a natural forest containing a population of trees of varying ages. For simplicity, we assume that all of these trees belong to the same species.[13] Left in a natural state, old-growth forest remains at a physical equilibrium with no net incre-

[13]In reality, forests contain a wide variety of species corresponding to different classes and grades of timber. This has been given much attention in the early literature on the subject (see Page, Pearson, and Leland, 1976). Plotted against unit prices, the composition of each typical area can be organized in descending order, with the most valuable segment of the commercial stock first, followed by the second most valuable, etc. The resulting set of species-specific horizontal demand curves is often referred to, wrongly, as the demand schedule. This schedule is useful, however, for the examination of the impact of changes in the structure of species-specific timber taxes on the mix of species harvested. Although species heterogeneity—like age-heterogeneity—is an important basic fact of natural forest management, taking it into account in our formal model would complicate matters without affecting the results. Hence, while acknowledging the importance of this factor, we have omitted it from the analysis.

ment of timber stock over time. This is because all available nutrients and light are fully utilized. Following an external shock, such as a fire or a storm, the standing stock naturally reverts to equilibrium. Under these conditions, it is possible to harvest trees selectively as they become mature without endangering the forest regenerative capacity and without having to replant the trees felled. The selective logging regimes prescribed in most tropical countries are designed precisely to ensure that the natural reproductive capacity of the forest is preserved.[14]

Sustainable exploitation effectively implies removing the increment of mature timber at each period. Overharvesting can, however, destroy the ability of the forest to regenerate naturally if the stock of remaining trees falls below a certain threshold, causing the forest to completely disappear unless a compensating human intervention, such as replanting, takes place.

We first assume that the stock of wood K_t in the forest at time t evolves between t and $t+1$ according to the general rule:[15]

$$K_{t+1} = \left[K_t\right]^{\alpha(Kt)} ,$$

where the exponent is, in general, not a constant. In one simple, yet realistic, form, this rule yields a law of motion with three equilibria (as represented in Figure 1):

$$[1]\ K_{t+1} = K_t = 1,\ [2]\ K_{t+1} = K_t = 0 \text{ and } [3]\ K_{t+1} = K_t = X,$$

with X given by the implicit equation $X = X^{\alpha(X)}$.

The first equilibrium is stable and corresponds to the long-term equilibrium of a minimally disturbed forest. The second equilibrium is also stable and corresponds to the complete degradation of the forest. The third equilibrium defines the threshold level below which the forest will disappear (converge to the second equilibrium). Provided the stock does not fall below the threshold, the forest will regenerate following natural or man-made disturbances, and eventually regain the first equilibrium.[16]

In practice, the literature has used this formulation to illustrate the risks associated with a stock falling below the threshold (X).[17] Once the point is made, and since our focus is on regulating logging rather than on subsidizing plantations to replace degraded forests, we follow Clark (1990) and many others, and restrict ourselves to the region above the threshold. The model can then be simplified to the case where the law of motion only yields two equilibria, keeping in mind that

[14]These rules are normally translated into limits on the minimum diameter of trees cut. The increasingly common requirement for forest managers to replant trees following felling effectively assumes a violation of selective logging rules.

[15]This functional form has been used by economists in a number of different applications. See, for example, Clark (1990).

[16]Removing aging trees releases light and space for younger ones and actually increases forest productivity. Certain silvicultural operations such as timber stand improvement can also lower the threshold.

[17]There has been considerable work on minimum safe standards of conservation and related issues, see, for example, Anant and Sharma (1985), Cropper (1988), Lewis and Schmalensee (1977), Skiba (1978), or Swallow, Parks, and Wear (1990).

Figure 1. Stock of Wood: Law of Motion with Three Equilibria

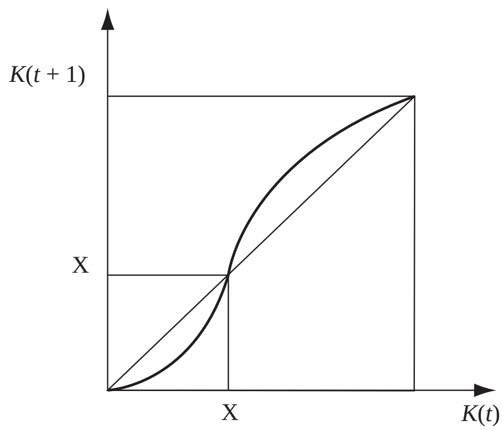
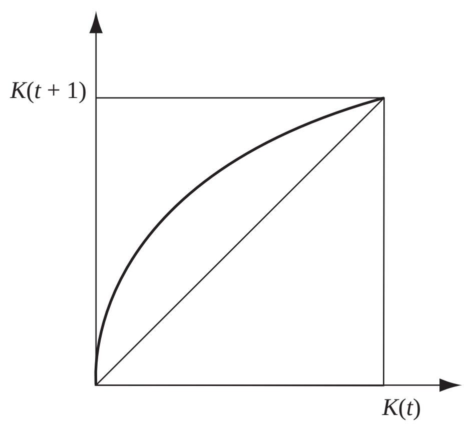


Figure 2. Stock of Wood: Law of Motion with Two Equilibria



this relies on the implicit assumption that at no time will the stock fall under an unspecified threshold. Hence, the rule can be written as:

$$K_{t+1} = \left[K_t\right]^{\alpha},$$

where α is a constant < 1. This rule is shown in Figure 2.
As mentioned, this simplified rule yields only two equilibria:

$$[1]\ K_{t+1} = K_t = 1 \text{ and } [2]\ K_{t+1} = K_t = 0.$$

The first equilibrium corresponds to the long-run stable equilibrium. The second equilibrium is not stable but the absence of stability has no effect on the analysis because any deviation from it, no matter how small, results in the forest regenerating itself.

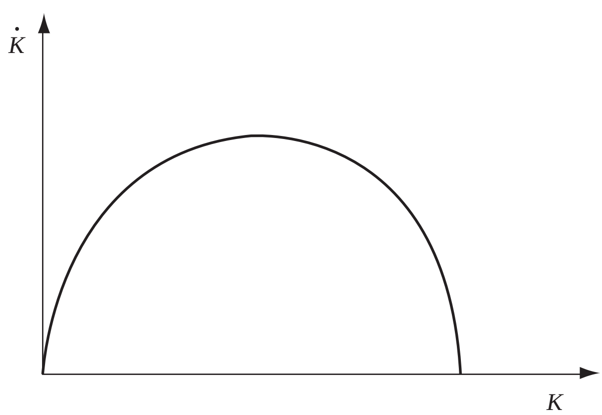
Another way to look at this law of motion is to plot the level of the stock with the speed at which it regenerates itself, which is given by $K_{t+1} – K_t$ or, in continuous time (which we use later to solve the Euler problem), by K. This is done in Figure 3, which corresponds to the same law of motion as that presented in Figure 2.

Consider now the case of an agent (the forest manager, or the lessee) who is granted by the principal (the government, or the lessor) the right to manage a given area of forest for a period of time assumed to span several rotation cycles.[18] The agent is granted the right to cut trees from the existing stock in exchange for an initial fee, D, paid in full at the beginning of the lease. At the end of the tenure, the agent will receive a terminal payment F. Both D and F are introduced right from the outset even if their importance emerges only later and although they have typically been absent from the forest policy armory.[19] Finally, we shall assume that, during his tenure, the agent will cut wood and sell it on the world market where he will be a price taker.[20]

Our task now is to explore the relationship between the terms of the lease, notably the lessor's fiscal policies, and the agent's behavior.

In order to fell the trees, the agent must create physical access to them. In an age-heterogeneous forest and under a selective logging system, creating physical

Figure 3. Stock of Wood: Law of Motion in the (K, K) Space



[18]Rotation cycles will be defined here as the ideal length of time separating consecutive harvests of the same timber stand.

[19]At this stage, the reader might think of D as the amount offered by the winner in an auction set up to award the right to manage the forest. Similarly, F could be the result of an auction held at the end of the lease period for new prospective lessees intent on taking over the management of the forest concession.

[20]This important assumption is consistent with the situation prevailing in the world timber industry as well as most national markets, where producers are small relative to the market as a whole.

access to the forest, and felling and transporting logs out of it, inevitably results in some damage to the residual stand (immature trees that are not meant to be harvested).[21] In other words, each unit of timber sold results in a greater reduction in the stock of timber remaining in the forest.

The extent of this collateral damage depends on the harvesting and transport technology used.[22] The overall cost of bringing a unit of timber to the market rises with the efforts made to reduce the damage to unharvested trees. The negative environmental externalities associated with logging are also strongly related to the damage inflicted to unharvested trees.

In general, the agent has a choice between a technology that is costly per tree sold, but which inflicts relatively little damage on unharvested trees and the environment ("helicopter logging"), or another technology that is relatively cheaper per unit sold, but entails a bigger waste because more trees are effectively destroyed for each one actually sold ("bulldozer logging"). We shall assume that each tree cut to be sold costs c per unit and that the felling process generates some damage to the forest.[23] Let Q^{sold} be the *quantity of wood effectively sold* on the market and Q^{cut} be the *quantity of wood cut* (the sum of the quantity sold plus the amount of wood wasted in the process). As argued above, the choice of technology implies that:

(i) there is a link between Q^{cut} and Q^{sold}, and therefore

$$Q^{cut} = Q^{cut}\left(Q^{sold}\right), \text{ with } \partial Q^{cut} / \partial Q^{sold} > 0; \text{ and}$$

(ii) for a given quantity of wood sold, the unit cost of felling a tree decreases if more wood is wasted. Hence,

$$\partial c / \partial Q^{cut} \rfloor Q^{sold} < 0, \text{ that is, if } Q^{sold} = \text{constant.}$$

Thus, for any given quantity of wood sold, it is possible to decrease the unit cost by inflicting increased damage to the forest (increasing Q^{cut}). To preserve the tractability of our model, we will assume that:

$$Q^{cut} = \gamma * Q^{sold}, \text{ with } \partial c / \partial \gamma < 0.$$

[21]See, for instance, Borhan, Johari, and Quash (1987); and Cassels (1992).

[22]The term "technology" is a simplification. The cost of harvesting and the resulting damage to the residual stand will be determined not only by the choice of equipment used to reach, fell, and remove the trees (helicopters versus bulldozers) but also by the way logging operations are planned and executed. Clearly, two different managers using the same technology may have a different impact on the forest stock according to their know-how and their approach. This means that each agent's flexibility of response is far greater than suggested by the mere changes of technology more narrowly conceived. It also means that the imposition of qualitative logging rules as part of selective logging systems cannot be reduced to the prescriptions of specific types of equipment to be used. In the longer run, the choice of technology will also affect the magnitude of the environmental cost, notably in the form of soil erosion. See Weidelt and Banaag (1982), Bruenig (1996), Munoz-Braz and d'Oliveira (1997), or ITTO (1996, 1997).

[23]This cost variable is a simplification. It amalgamates pre-harvest, harvest, and post-harvest costs without distinguishing between their variable and fixed components. This point is addressed in a later section.

In other words, γ can be seen as a waste factor which increases (decreases) as the cost of felling a tree decreases (increases). The cost function (written in general here as $c(\gamma)$, but which will be specified later) is different from that generally used in models of renewable resources management where costs are associated with the effort required to extract the resources (Clark, 1990). Here, we focus on the amount of damage inflicted on the forest in order to extract a given quantity of timber for sale on the market. In other words, Clark considers a cost function where the cost of extracting one fish increases if there are fewer fish in the sea. Here, the cost of felling one tree decreases if more trees are wasted (and, therefore, there are fewer remaining trees). This distinction has important implications that are spelled out a little later.

We now consider fiscal interventions. Let us postulate that, as part of his lease, the lessee must also pay a number of logging-related taxes, in addition to an up-front lump sum fee D mentioned earlier. We shall assume two different types of taxes: a stumpage fee t^s levied on the quantity of timber sold Q^{sold}, and a waste tax t^w on the volume actually removed from the stock through collateral damage but not sold ($Q^{cut} - Q^{sold}$).[24]

The other variables introduced in the model are to be interpreted as follows:

Q^{sold}, the quantity of timber sold, represents a homogeneous commodity, namely marketable-sized trees, and is readily observable. Furthermore, it is easy to attribute an indisputable monetary value to Q^{sold} at any point in time, by reference to an observed market price which is independent of the origin of the trees concerned.

Q^{cut}, which includes Q^{sold} as well as the quantity of timber removed or otherwise destroyed in the course of extracting Q^{sold}, is a heterogeneous mix: it includes marketable trees damaged in the course of the harvest as well as immature trees damaged during or after the harvest. Some of these immature trees may be very far from maturity at the time they are destroyed.[25]

Q^{cut} is not readily observable but, even if it were, it would not be possible to attribute a ready money value to the quantity actually cut, because this would require a perfect knowledge of the age and diameter of all trees damaged, their future volume growth rate, their market price at marketable age, and the rate of interest in the intervening period. For the same reason, it is not possible to attribute a market value to the stock of wood K discussed at the beginning of the section.[26] The value of the environmental externalities associated with Q^{cut} is likewise very difficult to assess, but may exceed the value of the timber destroyed by a large factor.

II. The Agent's Problem

We shall pursue the analysis in the context of a principal-agent's problem. The principal (the owner), who has imperfect information, sets incentives to which the agent (the lessee) reacts as he maximizes profits. In this case, the principal cannot observe γ or Q^{cut} because the cost would be prohibitive. Hence, the problem can

[24]Assuming that a waste tax can be levied effectively. Extending the analysis to also embrace a tax on income would not affect the results in any way.

[25]And some of these could well be destined for death through natural competition, not logging.

[26]Recall that we have considerably simplified matters by assuming a single species. More realistic assumptions would make it even more difficult to assign a market value to Q^{sold} and K.

be seen as a two-stage game where incentives are fixed in the first stage by the principal (here, these incentives take the form of tax rates) while the volume of trees cut is decided by the lessee in the second stage. Of course, the lessee has perfect information on γ.

We shall first assume that γ, reflecting the technology used, is fixed. For a given technology—and associated cost structure and Q^{cut}/Q^{sold} ratio—the problem of the lessee is to maximize the discounted flow of profits during the period of the lease. For the sake of simplicity, we shall first write the problem for an infinite lease. Unless otherwise specified, we assume that both Q^{cut} and Q^{sold} are calculated at time t. We have:

$$\max \prod = \max \int_0^\infty e^{-\delta t}\left[\left(p_t - c - t^s\right)Q^{sold} - t^w\left(Q^{cut} - Q^{sold}\right)\right]dt - D,$$

which, since for any time t, $Q^{cut} = \gamma^* Q^{sold}$, can be written as:

$$\max \prod = \max \int_0^\infty e^{-\delta t}\left(\mu/\gamma\right)Q^{cut}dt - D,$$

where $\mu = p_t - c - t^s + t^w\,(1 - \gamma)$ is the net margin.

In order to solve this problem, we use the law of motion of K at time t given by:

$$\dot{K} = \Delta K = \left[K_t\right]^\alpha - K_t - Q^{cut}.$$

This will allow us to rewrite the profit maximization problem as an Euler equation:

$$\max \prod = \max \int_0^\infty e^{-\delta t}\left(\mu/\gamma\right)\left(\left[K_t\right]^\alpha - K_t - \dot{K}\right)dt - D = \max \int_0^\infty \Phi\left(t, K, \dot{K}\right)dt - D.$$

Thus we know that the optimal harvesting policy in the steady state must follow:

$$\frac{\partial \Phi}{\partial K} = \frac{d}{dt}\,\frac{\partial \Phi}{\partial\left(\frac{dK}{dt}\right)},$$

which leads to the well-known Faustmann rule (see also Mitra and Wan, 1986; Faustmann, 1849, Gane ed.), according to which the agent cuts wood in such a way that the rate at which the remaining stock regenerates is equal to the interest rate (adjusted for risk and other factors):

$$\alpha K^{\alpha-1} = 1 + \delta.$$

We will now provide some intuition on Bellman equations, the Faustmann solution, and dynamic programming techniques, which are at the root of the bond proposal discussed later.

Intuition

The agent takes a decision on the amount of wood to cut by weighing the benefits of keeping a stock that will grow in value over time and the interest he gets from selling the wood he cuts at the current period (and depositing the money in the bank). This is possible because the logger can internalize the transfer of value from one period to the next during the lease. This is the so-called transversality condition which constitutes the basis for the Bellman equations. On the other hand if, for whatever reason, the logger is not able to make that transfer of value, he will cut all of the wood in the forest as fast as he possibly can.

For the same reason, if the transfer value of the forest can be passed on to the next logger at the end of the lease (or if the current logger receives a corresponding amount from the owner if the lease was granted on the basis of a refundable deposit), there is no reason why the current logger should not remain on the sustainable path until the end of the lease. At that time, the new logger will take over and pursue the same policy. If the transfer value is inadequate or, in the worst possible case, if there is no transfer at the end of the lease, however, the logger will not follow the sustainable path until the end, but will make sure he cuts everything by the time the lease expires. Just as it is essential that the current logger is able to internally pass on to the next period the value of the stock of wood (by which we mean, of course, the discounted value of the flow of benefits it will generate) in order to obtain a sustainable path, it must also be the case that this transfer of value to the next logger occurs at the end of the lease.

If we solve this equation, we obtain the equilibrium harvesting solution given by:[27]

$$Q^{cut} = K^{\alpha} - K;\ K = \left(\frac{1+\delta}{\alpha}\right)^{\frac{1}{\alpha-1}};\ \text{or}\ Q^{cut} = \left[\left(\frac{1+\delta}{\alpha}\right)^{\frac{\alpha}{\alpha-1}} - \left(\frac{1+\delta}{\alpha}\right)^{\frac{1}{\alpha-1}}\right].$$

The solution obtained above applies only in the steady state. In general, however, the lease does not start with a stock of wood just equal to the equilibrium stock

$$K^{\wedge} = \left(\frac{1+\delta}{\alpha}\right)^{\frac{1}{\alpha-1}}.$$

If the stock is higher, the agent will be able to extract more wood during the first period than during the subsequent ones.[28] If the stock of wood is lower, the agent will have to wait for the number of periods $T^{\wedge}$ required to bring it up to the equilibrium level $K^{\wedge}$. This time lag is given by

[27]Note that the Euler equation obtained here is a special case of the more general solution where the effort made to harvest the stock has an impact on costs (for example, where *c* increases with the quantity cut). The interested reader should refer to Clark (1990) p. 40.

[28]Actually, faster harvesting could extend for several periods if the technology does not allow undertaking harvesting operations throughout the lease area. We rule out this possibility in the formal model, but will briefly discuss it later.

$$T^{\wedge} = \frac{1}{\alpha} * \ln\left(\left(\frac{1+\delta}{\alpha}\right)^{\frac{1}{\alpha-1}} - K_0\right).$$[29]

Let us now consider the case of a lease running from 0 to $t = T$.[30] The previous discussion suggests that for tractability, it is easier to assume $T > T^{\wedge}$ so that the agent has a possibility to reach the equilibrium harvest.[31]

The agent's problem now becomes:

$$\max \prod = \max \int_0^T e^{-\delta t}(\mu/\gamma)Q^{cut}dt\left[-D + \frac{F}{(1+\delta)^T}\right],$$

where F is the amount received by the agent at the end of the lease, if any, and D is the amount paid at the beginning. One should note that the amount D associated with the next logger is equal to the amount F paid to the current one. We use two different letters because these payments correspond to two different loggers.

Let us recall the variable F introduced earlier. First note that unless F is linked to the value of the stock remaining in the forest at time $t = T$, the logger will cut the entire stock of wood during the last period.[32] This is true, in particular, if $F = 0$, which can happen (and has happened) when the government is the owner and does not pay the lessee. Thus, unless there is an effective enforcement mechanism by a public body, a profit-maximizing agent will not leave a positive stock of wood at the end of the lease without financial compensation. On the other hand, if there is a mechanism that properly values the remaining stock, not only will the logger have an incentive to leave the forest at equilibrium, there will also be no need for an enforcement agency. This is one immediate, simple, and yet very important policy implication of the model. If the lessor wants the agent to behave in a sustainable manner (such that the latter harvests the increment only throughout the lease), the end-of-lease transfer fee must correspond to the value of the concession at the end of the lease, which is the discounted flow of profits for the new logger under competitive bidding.

[29]The easiest way to compute the amount of time required to reach the equilibrium starting from K_0 (as shown in Clark, 1990) is to use a discrete approach and compute the number of periods n required as satisfying:

$$K_0^{n\alpha} = \left(\frac{1+\delta}{\alpha}\right)^{\frac{1}{\alpha-1}} = K^{\wedge}, \text{ thus, } n = \frac{1}{\alpha} * \ln\left(\left(\frac{1+\delta}{\alpha}\right)^{\frac{1}{\alpha-1}} - K_0\right).$$

The same result applies in the continuous case.

[30]The duration of forest leases must also be consistent with the exceptionally long rotation periods involved. Many timber species mature only after 20 years or more.

[31]Clark (1990) presents a detailed discussion of what happens when the length of the lease is such that the equilibrium harvest is never reached.

[32]That is, if, as mentioned earlier, the technology makes this possible. If not, the logger will deplete as fast as possible toward the end of the lease so that K_t vanishes at time $t = T$.

In fact, the same mechanism underlies the Faustmann equation at the steady state: it is because he knows that he will extract some profits during the remaining period of the lease that the logger does not cut the whole stock at time $t < T$.[33] Again, while we have assumed that T exceeds the time required to reach the equilibrium for tractability reasons, the same reasoning applies for a shorter period of time.

We shall therefore assume from now on that the value of F is given by:

$$F = \int_0^{\infty} e^{-\delta t}(\mu'/\gamma) Q^{cut}\, dt,$$

where μ' denotes the unit profit that the next logger is able to realize. Although we have not made it explicit, the technology used could also be different, and we could have $\gamma' \neq \gamma$ for another logger. If the current logger leaves the stock of wood at equilibrium at time $t = T$, the value of F will be:

$$F = \frac{\mu'}{\gamma\delta} * \left[\left(\frac{1+\delta}{\alpha}\right)^{\frac{\alpha}{\alpha-1}} - \left(\frac{1+\delta}{\alpha}\right)^{\frac{1}{\alpha-1}}\right] * e^{-\delta T}.$$

As mentioned earlier, however, the current logger need not necessarily leave a stock of wood equal to $K^\wedge$. Assuming that the logger leaves a stock $K_T < K^\wedge$, we know that the next logger would then have to wait for a period of time given by $\{\ln(K^\wedge - K_T)\}/\alpha$ and therefore we would have:

$$F = \frac{\mu'}{\gamma\delta} * \left[\left(\frac{1+\delta}{\alpha}\right)^{\frac{\alpha}{\alpha-1}} - \left(\frac{1+\delta}{\alpha}\right)^{\frac{1}{\alpha-1}}\right] * e^{-\delta\left(T+\frac{1}{\alpha}*\ln\left(K^\wedge - K_T\right)\right)}.$$

And, we observe, as expected, that $\partial F/\partial K_T > 0$: the higher the stock of wood left by the previous logger, the higher the volume of wood that can be cut by the new logger and, hence, the higher the down payment.

On the other hand, by leaving a stock below equilibrium, the logger benefits from a large harvest at the end of his lease. Thus, he must make an arbitrage between this extra income and the forgone amount it induces on F. In fact, at time $t = T$, the logger must maximize with respect to K_T the following expression:

$$\mu * \left[\left(\frac{1+\delta}{\alpha}\right)^{\frac{\alpha}{\alpha-1}} - K_T\right] + \frac{\mu'}{(1+\delta)\gamma\delta} * \left[\left(\frac{1+\delta}{\alpha}\right)^{\frac{\alpha}{\alpha-1}} - \left(\frac{1+\delta}{\alpha}\right)^{\frac{1}{\alpha-1}}\right] * e^{-\delta\left(T+\frac{1}{\alpha}*\ln\left(K^\wedge - K_T\right)\right)}.$$

The first term expresses the extra benefit from over-logging during the last period (it increases if K_T decreases), while the second represents the forgone lump

[33]We refer here to the Bellman equations that are at the root of the Faustmann solution. Indeed, at every period t in $[0, T]$, the logger follows the same path (for example, he weighs the returns from his logging activities at time t and the returns from all remaining periods). For a detailed account, see Bellman (1957) or Clark (1990).

sum F (which decreases if K_T decreases). The expression above has two extrema: one in $K_T = 0$, and one in

$$K_T = \left[\left(\frac{1+\delta}{\alpha} \right)^{\frac{\alpha}{\alpha-1}} \right].$$

Once again, this result has important implications, discussed in the next section. If, at the end of the lease, there is a high uncertainty regarding F, or a certainty of low payment (one where the immediate benefits from over-logging exceed the expected benefit from keeping the forest in a sustainable state), the current agent will have a strong incentive to over-harvest the forest, namely to cut trees that would become mature only after the lease has expired so long as they can be sold on the market.[34] If the probability of repayment falls to zero, the forest will necessarily be exhausted at the end of the lease.[35] This outcome is quite consistent with frequently observed situations where forest leases neither provide a long-term security of tenure, allowing the operator to benefit directly from sustainable management practices during the lease period, nor reward for compliance with prescribed selected logging rules (in the form of a terminal payment). Conversely, if future timber prices are expected to be high, and the government is not expected to default, the agent may voluntarily leave behind a better stocked forest than at the beginning of the lease, and be rewarded through a higher value of the F collected. In any case, as explained earlier, a similar arbitrage is carried out at each period of the lease and, as long as F reflects the true value of the stock, the same sustainable solution will obtain, whether it is during the lease or at the end of it.

III. The Effect of Taxes on Forest Management

We now move to the first stage of the game where the principal (the state) sets the incentives (the taxes).[36] The previous section suggests that by levying taxes, thereby affecting profits (since $\mu = p_t - c - t^s + t^w(1 - \gamma)$), the government has an impact on forestry management through two different, yet mutually reinforcing, mechanisms: the amount harvested by the logger changes, and the value of the remaining stock of wood, which determines the long-term sustainability of the forest, also changes. Note, however, that the two taxes considered here do not have the same impact. An increase in t^s, the royalty, decreases the margin irrespective of the technology used by the logger, while a tax on the amount wasted, if it could

[34]Generally, immature trees are salable at a discount, reflecting their smaller diameter. Note that these trees grow at a rate higher than the interest rate.

[35]In practice, rising logging and transport costs owing to topographical factors and increased distance from the forest gate would eventually result in increasing the marginal cost of logging. The more remote parts of the lease area may thus not be worth logging and some marketable timber stock would still remain unharvested. These complexities do not affect our basic results.

[36]We only consider the impact of taxes on profit-maximization. A welfare maximizing approach could also be considered but would be more relevant in a model where externalities are explicitly taken into account.

be implemented, would penalize wasteful management. We also note that the equilibrium value obtained for the quantity cut, given by:

$$Q^{cut} = \left[\left(\frac{1+\delta}{\alpha} \right)^{\frac{\alpha}{\alpha-1}} - \left(\frac{1+\delta}{\alpha} \right)^{\frac{1}{\alpha-1}} \right],$$

is not dependent on μ as long as the logger has an incentive to pursue sustainable management (that is, as long as the Faustmann solution applies, although this may not be true with another law of motion). We will show that this is not the case for Q^{sold}. However, we shall first consider the long-term impact of taxes on the value of the stock.

We have already shown that, toward the end of the lease, the logger will weigh the benefits of leaving a sustainable stock in the forest against the expected terminal payment. If the value of such payment falls below a certain level, the agent will deplete the forest. Among other factors (such as the rate of discount, the technology used, or the probability of default), taxes play a critical role because they clearly affect future profits by reducing the value of the discounted flow of profits for the current agent as well as the transfer F at the end of the lease. If taxes imposed today exceed a critical amount (defined as the level beyond which the Faustmann solution does not apply because there is no way to pass on to the next period a stock of wood of sufficient value), there is no scope for sustainable forest management.

In fact, if the level of taxation is such that the Faustmann solution no longer applies, there will even be an *increase* in the quantity sold as the logger optimizes his income along the unsustainable path of forest depletion. We also note that the same conclusion would apply if sufficiently high new taxes were suddenly imposed during the lease: the logger would simply liquidate the forest asset, which would have become no longer worth maintaining, at the least cost possible and give up on the possibility of receiving $F > 0$ at the end of the lease.[37]

The impact of higher taxes on short-term forestry management where the level of profits remains compatible with the Faustmann solution is a little more complex to describe. First, since the equilibrium quantity of wood cut (not the quantity sold) in the forest remains unaffected by the level of the tax (as we have seen earlier), the only possible impact of a change in taxes is on the quantity sold in the market. This occurs through the strategic choice of technology by the logger (γ) because $Q^{cut} = \gamma Q^{sold}$. The logger will adopt the technology that maximizes the margin for a given quantity cut. Thus, the agent actually maximizes with respect to γ:

$$\frac{\mu}{\gamma} = \frac{p_t - c - t^s + t^w * (1-\gamma)}{\gamma},$$

where $c = c(\gamma)$ and $\partial c / \partial \gamma < 0$. To analyze more precisely the link between tax policy and forest management, we therefore need to introduce explicitly the link between cost and technology. For simplicity, let us now assume that

[37]As already emphasized, preventing this is possible only with rigorous (and therefore costly) monitoring.

$c(\gamma) = \lambda/\gamma$, with $\lambda > 0$.[38]

The value of γ that maximizes the ratio μ/γ is given by γ^* such that:

$$\gamma^* = \frac{2\lambda}{p - t^s + t^w}$$

and

$$c(\gamma^*) = \frac{\lambda}{\gamma} = \frac{p - t^s + t^w}{2}.$$

This relationship shows that a profit-maximizing agent compensates for increases in the stumpage tax by adopting cheaper but more wasteful technology. The reduction in volume harvested and sold as a result of the tax is actually accompanied by increased forest destruction. Only lessees whose intentions are to comply with logging rules (environmentally conscious lessees) will fail to avail of this ready means of increasing profits. In other words, the tax burden falls on compliers rather than violators. Assuming a fixed technology, which excludes this key adjustment mechanism, is untenable. Once again, only the expectation of a terminal payment can counterbalance the incentive to reducing costs.[39] Note that the process of intensified forest degradation can coexist with increased collection of stumpage taxes and an observed reduction in the volume of timber reaching sawmills or harbors.[40] All these results remain valid for any cost function such that $\partial c/\partial\gamma < 0$, although the algebra is tedious.

Increased stumpage taxes t^s would have the desired effect of reducing volumes cut if, and only if, the lessor could control qualitative logging methods—a task even more demanding than monitoring the agent's observance of quantitative (for example, diameter limit) cutting rules. Concerning fiscal policy, note that a stumpage tax expected to remain permanent would reduce the effectiveness of a terminal payment and, therefore, the effect of the tax would be similar to an increase in the probability of default by the lessor. Thus, even with renewable leases and terminal payments F, increased timber taxes would encourage forest degradation.

This leaves the waste tax t^w as the only potentially effective fiscal instrument to foster sustainable logging practices. However, this possibility is theoretical only. Assessing the waste tax (that is, attributing a ready monetary value to K), is excessively demanding, as mentioned above, and most unlikely to be a practical option, let alone a cost-effective one.

The practical difficulty of setting and collecting a "waste tax" would be compounded if the externalities associated with Q^{cut}, including a whole array of

[38]This is done strictly for tractability.

[39]Export taxes or bans, and any other measure reducing the market price of logs, have the same negative impact. Conversely, ecolabeling or export certification schemes that allow certified loggers to obtain higher prices for sustainably harvested timber encourage good logging practices.

[40]Typically, timber taxes are assessed not at the logging site, an expensive procedure, but at mill-gate. This further weakens the argument that these taxes encourage the enforcement of quantitative logging rules.

nonmarketed negative externalities both internal and external to the area, were also to be taken into account. A forest administration that has the capacity to enforce qualitative and quantitative logging rules with a fair degree of rigor would probably find a waste tax unnecessary and not worth the trouble.

IV. Fiscal Approaches to Forest Management: The Implicit Assumptions

Traditional fiscal approaches toward improved forest management are based on a number of implicit or stated assumptions reviewed and criticized below.

The Tax As an Incentive to Conserve Timber

It is commonly argued that reducing the price received by loggers for each unit of timber felled will foster improved management. As we have shown formally, lowering the price of timber, through a stumpage tax (or any other instrument having the same impact, such as an export ban), has the opposite effect and encourages wasteful forest management. This results from two mutually reinforcing mechanisms: the tax reduces the value of future harvests and therefore the incentive to preserve immature stock for the future; and the decline in revenue per unit further increases the incentives to compensate through reduced logging costs, leading to increased damage to the forest. The tax on the quantity of timber sold has the same effects as an increase in the interest rate or an anticipated decline in future timber prices, namely to encourage the liquidation of the asset.

The choice of sound management instruments must acknowledge that today's harvesting cannot be dissociated from future harvests. The resources spent on minimizing collateral damage in the course of logging must be seen as an investment in future harvest. For the sake of simplification, we have not dwelled on the distinction between pre- and post-harvest logging costs. A more complex model would reflect the fact that maintaining forest productivity over the long term entails establishing durable infrastructure (roads) and protection measures against man-made and natural shocks such as fire. Taking the usually high fixed costs of sustainable management into account necessarily implies a substantial difference between the cost structure of a long-term-minded logger and of a "fly-by-night operator," to the detriment of the former. This point is invariably overlooked in calculations of the profitability of logging, where only direct logging costs are included. In sum, any tax set at a level designed to collect the profits from a fly-by-night operator directly discriminates against long-term-minded operators who comply with qualitative rules at a high cost.[41]

This is not to deny that high net timber prices encourage logging. High logging profits generate pressures on governments to grant forest leases in the first place. The imposition of a tax may play a role in reducing such pressures. However, this will only succeed in taking the least commercially attractive sites

[41]Paris and Ruzicka (1991) discuss these questions in detail. Considering the additional costs involved, Reid and Rice (1997) argue that sustainable natural forest management is unattractive in most countries of tropical Latin America and advocate subsidies.

out of production because they will no longer attract lessees, but will not improve the management of intramarginal forests that are leased out. At best, the positive effects of a timber tax are limited.[42]

The Tax As a Positive Environmental Incentive

The taxation orthodoxy unrealistically assumes that each additional tree felled results in additional environmental damage and the socially optimal level of logging is reached when the social or environmental cost resulting from the extraction of the marginal log equals the marginal net private value of the marginal log extracted. Following this logic, a tax will automatically reduce the environmental damage from logging by reducing the marginal benefit.

In reality, environmental damage resulting from logging is, at best, only weakly related to the volume of timber extracted. Within a given site, environmental damage is caused by excessive cutting intensities (in violation of quantitative rules as well as poor logging and road-building practices) and, in many cases, the abandonment of an area following harvest, allowing encroachment by slash-and-burn cultivators. As to off-site damage, we have mentioned several factors that explain the magnitude of impacts far better than the intensity of logging. As we have shown above, the imposition of a tax will have no positive impact on these factors and, by penalizing compliance with logging rules, can even have the opposite effect of encouraging outright forest liquidation. The impact of logging-related environmental damage, notably soil erosion and the destruction of immature stock, are borne first by the concessionaire in the form of reduced subsequent harvests. For a long-term-minded logger who complies with qualitative logging rules, the divergence between private and social profits is not significant. By minimizing the impact of logging on immature stock, the operator will also minimize the off-site impacts. Conversely, a fly-by-night operator will generate severe on- and off-site damage regardless of the volume harvested. The disturbance to forest biodiversity resulting from logging operations is an important exception here. Because biodiversity is a public good that does not enter the loggers' private profit maximization, special measures are required.

Forests As a Gift of Nature

Tax-based approaches somehow embody the notion that forests are a gift of nature and that the cash flows generated in harvesting them represent pure profit. Although this may be applicable to other natural resources, such as oil, the techniques involved in natural forest harvesting make it impossible to dissociate harvesting activities today from those aimed at generating future

[42]The timber tax works only to the extent that it makes certain forests no longer worth logging. This will have positive environmental impacts if and only if the other factors behind forest degradation (notably, conversion to subsistence agriculture or pastures by landless poor and extraction of fuelwood) are absent. If the areas put out of production because of the tax are large enough, it may lead to a rise in the price of timber. In this sense, its impact is different from an export ban, which would lead to a reduction in domestic timber prices.

harvests. To view forests as God-given resources ignores the cost involved in ensuring their long-term productivity and invites inappropriate policy responses. This applies regardless of whether the logging takes place in a virgin forest or *n*-th growth forest.

A Pristine Forest or an Over-Logged Forest

Contrary to underlying assumptions made by tax advocates, the policymaker's choice is rarely between a pristine forest and an over-logged forest. Except in sparsely populated or isolated areas, an open access, pristine forest must be protected against encroachment by loggers, farmers, and hunters. Unless the necessary funds for protection activities are available, the real choice is actually between a managed forest and a forest degraded through encroachment, illegal logging, and/or gradual conversion to low-value and unsustainable slash-and-burn agriculture. The first priority is to stop the continued process of degradation and restore productivity, where possible, through intensive management.[43] Thus, timber and environmental externalities can be considered as joint products, with the former subsidizing the latter. In some cases, activities such as ecotourism, biodiversity prospection, or sale of non-timber products can cover protection costs, at least partially.

Increasing taxation, combined with the provision of subsidies for the establishment of plantations, has the perverse effect of encouraging the outright conversion of still viable (but degraded) natural forests into monocrop plantations.

Logging As a Form of Pollution

Intentionally or inadvertently, taxation-based approaches to tropical forest management build on the superficial similarity that logging has with industrial pollution. If a pollution tax is now firmly established as an appropriate instrument to deal with industrial pollution, we have seen that the same is generally not true for tropical logging. The majority of industrial pollution taxes is appropriately levied on the concentration or (better still) volume of the pollutants, and not on the volume of activities giving rise to the emissions. Environmental economists would be rightly concerned if, say, sulfur dioxide (SO_2) emissions by coal-powered power plants were to be dealt with by taxing the electricity produced instead of the SO_2 emissions themselves (or their precursors, such as the sulphur content of coal). The mirror image of industrial applications in the context of tropical logging would be taxes on logging damage, not on logging per se. By not distinguishing between a legitimate activity and its possible (although not inevitable) environmental side effects, some analysts have ended up favoring an exceedingly blunt and inefficient tax alternative.

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[43]This is not to suggest that the world's few remaining virgin forests do not deserve special treatment. In many cases, such forests should not be available for any kind of commercial logging activities, or only at a very high price, in view of their exceptional environmental, cultural, and social value.

V. Alternatives to Fiscal Approaches: Implementing D and F

To a large extent, distortions between the lessor and the lessee's interests are the predictable results of a divorce between ownership and management of forest resources. Many of the environmental services provided by forests (including, notably, biodiversity conservation) are public goods, the provision of which may be in conflict with the logger's private interests). This argues against the privatization solution, at least in environmentally sensitive areas. The real challenge, therefore, is to devise instruments that provide maximum security of tenure to private lessees and credible means to enforce regulations to the lessor. This also implies confining the government to regulation, oversight, and enforcement functions while entrusting the private sector with the actual tasks of managing and protecting forests areas.

Paris, Ruzicka, and Speechly (1991) outline a proposal for a forest guarantee bond that meets these requirements and draw lessons from initial implementation experience.[44] The objective is to provide maximum security of tenure to forest lessors while simultaneously providing the government owner with a ready means to penalize violators of forestry laws. It also attempts to confine the government to regulatory and enforcement functions while entrusting the private sector with management.[45] In short, the scheme aims to create a situation where the managers of the resources (or the agents) benefit from good stewardship and suffer the consequences of bad management in the form of capital loss.

The forest guarantee bond has the following main features: its value is established through competitive public bidding in an impartial and transparent market-based manner. In effect, would-be lessors are asked what amount they are willing to deposit as a guarantee of their compliance with applicable rules, with the highest bidder obtaining the lease. In the context of our model, the bond scheme amounts to determining the initial payment D through an auction. The bidder willing to post the highest deposit, in guarantee of compliance, is awarded the lease. At the end of the lease, the forest is leased out to another party and the resulting new value of D, again the outcome of an open auction, reflects the increase or decline in value of the forest stand over the previous lease period as well as external circumstances, such as expected timber prices, interest rates, and others. This provides a ready means of determining the terminal payment F to be returned to the previous lessee. This is similar to a normal transaction whereby the temporary owner is able to capitalize the increased value of an asset upon sale. One lessee's up-front deposit becomes the previous one's terminal payment. It is not the purpose of this paper to describe the technicality of the bond principle. How it relates to the model developed in Section II, however, is straightforward. Since F must correspond

[44] Richardson (1992) makes a proposal along similar lines.

[45] This is especially useful when there are legal provisions preventing private ownership of forests. In many developing countries, the constitution stipulates that forests are state property. In some cases, this is accompanied by limitations on the maximum length of leases to a private party.

to the value of the discounted benefits the current logger should receive in order to maintain a sustainable logging path, this amount is also equal to the market value of the remaining stock and would therefore be the amount paid under an auction by the next logger, provided the auction is fair. In fact, the amount paid will also reflect the efficiency of the logger because his cost function would have an impact on the market value of the lease for him. Once again, this is at the basis of the Faustmann solution.

The bond encourages responsible long-term management by the lessee because non-depleting behavior is rewarded by the return of the bond with accrued interest (in addition to which the lessee could, at any time, sell his rights appreciated by improvements). Conversely, it provides for the prompt punishment of the lessee (partial or complete forfeiture of the bond) and compensation for the government in case of violation of the terms of the agreement. This is in contrast to the traditional system in which the government's options are limited to the cancellation of the violator's license. It is also in contrast to bidding based on the estimated volume of standing timber (that is, stumpage sales) in conditions of poor enforcement of management rules. Since compliance with forestry rules entails higher costs, operators intending to violate those rules could easily outbid compliance-minded competitors. The bond also provides a clear, market-based, indication of the expected profitability of forest management given the conditions imposed by the government.[46] Forests commanding very low bonds (or no bids) because of insufficient prospects for profits, in view of the risks and responsibilities involved, should be regarded as unsuitable for private management. The government should accordingly consider whether to subsidize their protection. Low bond values may reflect low expected profitability, given the conditions imposed, expected future prices and interest rates, and indeed the credibility of the lessor and associated risks of unjustified or illegal bond seizure.[47] Finally, unlike the timber-royalty system, the scheme obviates the necessity for continuous field-level monitoring or evaluation of timber extraction rates because no charges are collected on site.

A closely related alternative to this system would be to replace the up-front payment D by a requirement for the lessee to insure himself against the risk of being found in violation of logging rules, such as a third-party insurance common among car-rental companies. The party willing to insure against that risk, for a fee, would then contract a contingent liability reflecting the damage caused to the forest in case of violation of logging rules by the lessee, and would compensate the lessor. The system would naturally discriminate against parties with a poor past or expected performance record, because insurers would refuse to cover them. The scheme is highly complementary with eco-labeling schemes for timber because the monitoring mechanisms required to assess compliance with the terms of the lease are identical to those required to award an eco-label.

[46]Incidentally, the bond scheme, unlike outright privatization, leaves to the government the right to attach conditions to the lease (such as the obligation to respect environmental standards).

[47]Paris, Ruzicka, and Speechly (1994) discuss the determinants of guarantee bond values.

VI. Conclusions: Some Guiding Principles for Forest Policy

Environmentally and economically sound logging implies respecting a number of concrete ecological and geophysical constraints that are weakly (if at all) related to either the volume or market value of the timber harvested. The concept of marginal environmental cost of logging has, therefore, little meaning, and taxes (other than a waste tax, which is difficult to assess) play little role in bringing marginal private and social cost into balance. The successful collection of (misnamed) environmental taxes on timber extracted is completely consistent with reduced timber extraction rates *and* accelerated environmental degradation. Stabilizing the total volume of logs extracted by forest concession holders (Indonesia, for example, is attempting to keep the annual output of industrial logs at 25 million cubic meters), even if achieved, may be a hollow victory because, given the other incentives in place, it will be accompanied by the continued degradation of the standing forest. An equally hollow victory would be a further increase of forest taxes, especially if channeled to a fund such as Indonesia's reforestation fund. From a practical standpoint, the enforcement of sound forestry practices cannot dispense with on-site monitoring, reinforced, in many cases, by public oversight of forest authorities' performance. This monitoring must focus on the ecological state of the remaining forest, rather than on the flow of timber extracted, and this paper has shown that taxes on the flow of timber can neither substitute nor complement monitoring. The challenge, therefore, is to devise an incentive structure that encourages voluntary compliance with the ecological constraints necessary for continued forest health and long-term productivity, while minimizing the cost of indispensable on-site monitoring and enforcement. This has immediate relevance in regions such as Central Africa, where large areas of old-growth forests (1.8 million square kilometers) are indiscriminately awarded for exploitation to private operators, with important negative environmental consequences, and continued relevance in the "old logging countries" such as Indonesia with still large areas of unconverted, over-logged forests.[48]

In line with the rationale underlying the Faustmann solution, this paper has proposed a bond instrument structured around the expected value of future harvests. The mechanism allows the logger to capitalize on his investment in future harvests, while reducing the need for costly monitoring. The bond proposed here should not be introduced *in addition to* existing timber taxes, nor be accompanied by increased taxes (as advocated by some, in Indonesia, for instance), but *instead of* them. The paper has also demonstrated that tax-based solutions hinge crucially on the regulators' ability to enforce logging rules strictly. We effectively argue that the *ceteris paribus* assumption, which would require all other variables to remain unchanged following the imposition of a levy, is simply untenable. Only strict regulation could force loggers to abandon efforts to shield their profits through cheaper—and environmentally harmful—techniques. Regulatory

[48]In Indonesia, some 150 forest concessions, covering 9.5 million hectares have been assigned, following their expiry, to the control of five state forest enterprises for "rehabilitation." See Barr (2001) for more detailed analysis of the Indonesia situation. See also Karsenty (2000) for a discussion of economic instruments in the Congo basin.

enforcement is actually a precondition for the tax to be levied as envisaged ex-ante. The tax serves no management purpose. Fiscal approaches to forest management assume the existence of a formidable capacity for field supervision, instead of substituting for it. Based on this analysis, we derive some guiding principles for sound forest policy. These principles are compatible with the proposed bond instrument, but are discussed below on the basis of their own merit.

Maximize the Opportunity Cost of Damaging Immature Stock

The focus of forest regulation should be the value of immature stock managed by the lessee, rather than the reduction of profit on timber harvested. In terms of our model, this requires that the terminal payment must be a fair reflection of the value of the forest at the end of the lease. Creating a market in immature stock by allowing rights to leases that have not yet expired to be traded (as with the bond) would reinforce this by allowing the lessor to realize the value of his investment in infrastructure and immature stock at any time during the lease. Proposals to increase transferability of forest leases and to increase the lease period to 35 years, as recommended by the World Bank in Indonesia, are sound but they are undermined by the increased taxation also recommended.

Maximize the Security of Tenure

Gestation periods, often in excess of 30 years, combined with uncertainty about future timber prices, fluctuations in interest rates, and a host of other factors,[49] make investments in the maintenance of forests and the necessary management of forest infrastructure rather risky. In addition to exogenous factors, the credibility of the lessor fundamentally affects the lessee's choice of technology and management approach. Even where a terminal payment is formally included in the lease, lessees will have strong incentives to liquidate the forest if the government is believed to be prone to canceling the concession arbitrarily or without compensation (as amply evidenced throughout the forest concession history in the tropics). The fact that the credibility of the lessor can never be taken for granted poses special challenges in the design of regulatory instruments.

Provide Means to Penalize Breaches of Rules While Economizing on Monitoring

As the owner of the forest, the government and the public bear the ultimate consequences of the lessee's violation of logging rules. Leases must therefore provide the means to penalize such behavior. Levying a theoretically attractive waste tax would require intensive on-site monitoring and is therefore highly impractical. Taxes levied on volume harvested play no useful role, except possibly to finance enforcement efforts when the funds are earmarked. The only way to provide the

[49]Deacon (1994, 1995) suggests that an unstable macroeconomic environment has been an important cause of deforestation in many countries.

necessary safeguard is to provide for the payment of a guarantee deposit at the beginning of the lease. This amounts to making the terminal payment reflect the value of the forest at the end of the lease, conditional on compliance. The forest guarantee bond discussed in this paper combines all these features. In addition, delinking monitoring from tax collection activities helps to avoid the inherent conflicts of interest involved. It also reduces the scope for corruption. If adequate periodical checks are made to curtail abuses, public involvement in monitoring loggers can further contribute to the rigorous enforcement of regulations while public disclosure of violations can provide a powerful reinforcement.

REFERENCES

Anant, T. C. A., and S. Sharma, 1985, "Dynamic Optimization with a Nonconvex Technology: Determination of Critical Stocks," *Mathematical Biosciences*, Vol. 75, pp. 187–204.

Asian Development Bank, 2000, *Cambodia: Forest Concession Reform*, a consultant draft report (Manila: Asian Development Bank).

Barr, Christopher, 2001, "Will HPH Reform Lead to Sustainable Forest Management? Questioning the Assumptions of the 'Sustainable Logging' Problem in Indonesia," in *Which Way Forward? People, Forests, and Policymaking in Indonesia,* ed. by C. J. Pierce Colfer and I. A. Pradnja Resosudarmo (Washington: Resources for the Future).

Bellman, Richard E., 1957, *Dynamic Programming* (Princeton: Princeton University Press).

Borhan Mohhamad, Bin Johari, and Eswar S. Quash, 1987, "Studies of Logging Damage Due to Different Methods and Intensities of Harvesting in Hill Dipterocarp Forests of Peninsular Malaysia," *Malaysian Forester*, Vol. 50, No. 1–2.

Bruenig, Eberhard F., 1996, *Conservation and Management of Tropical Rainforest: An Integrated Approach to Sustainability* (Wallingford, U.K.: CAB International).

Cassels, Dan, 1992, "Forested Watershed Controls in N.E. Australia As an Interim Model for Other Humid Tropical Forest Environments," *Tropical Forest Update*, Vol. 2, No. 2.

Clark, Colin W., 1990, *Mathematical Bioeconomics: The Optimal Management of Renewable Resources* (New York: John Wiley and Sons).

Contreras-Hermosilla, Arnoldo, 1997, "The 'Cut and Run' Course of Corruption in the Forestry Sector," *Journal of Forestry*, Vol. 95, No. 12.

Cropper, Maureen, 1988, "A Note on the Extinction of Renewable Resources," *Journal of Environmental Economics and Management*, Vol. 15, pp. 64–70.

Deacon, Robert T., 1994, "Deforestation and the Rule of Law in a Cross Section of Countries," *Land Economics*, Vol. 70, No. 4, pp. 414–30.

———, 1995, "Assessing the Relationship Between Government Policy and Deforestation," *Journal of Environmental Economics and Management*, Vol. 28, No. 1, pp. 1–18.

Environmental Intelligence Agency, 1996, *Corporate Power, Corruption, and the Destruction of the World's Forests* (London: Environmental Intelligence Agency).

Faustmann, Martin, 1849, "On the Determination of the Value which Forest Land and Immature Stands Possess for Forestry," English edition ed. by Michael Gane as "Martin Faustmann and the Evolution of the Discounted Cash Flow," Oxford Institute Paper No. 42 (1968).

Godoy, Ricardo, and K. S. Bawa, 1993, "The Economic Value and Sustainable Harvest of Plants and Animals from the Tropical Rainforest," *Economic Botany*, Vol. 47, pp. 215–19.

Hyde, William F., and Roger A. Sedjo, 1992, "Managing Tropical Forests: Reflections on the Rent Distribution Discussions," *Land Economics*, Vol. 68, No. 3, pp. 343–50.

International Tropical Timber Organization, 1996, "Reduced Impacts, Increased Costs?" *Tropical Forest Update*, Vol. 6, No. 3.

———, 1997, "Sustainable Forest Management in Brazil," *Tropical Forest Update*, Vol. 7, No. 3.

Karsenty, Alain, 2000, *Economic Instruments for Tropical Forests: The Congo Basin Case* (London: International Institute for Environment and Development)(originally published in French).

Lewis, T. R., and Richard Schmalensee, 1977, "Nonconvexity and Optimal Exhaustion of Renewable Resources," *International Economic Review*, Vol. 18, pp. 535–52.

Mitra, Tapan, and Henry Y. Wan, 1986, "On the Faustmann Solution to the Forest Management Problem," *Journal of Economic Theory*, Vol. 40, pp. 229–49.

Munoz-Braz, Evaldo, and Marcus V. N. D'Oliveira, 1997, "Damage Produced to the Tropical Moist Forest by Planned Harvesting," *Commonwealth Forestry Review*, Vol. 74, No. 3, pp. 12–27.

Page, John M., Jr., Scott R. Pearson, and Hayne E. Leland, 1976, "Capturing Economic Rents from Ghanaian Timber," *Food Research Institute Studies*, Vol. 15, No. 1, pp. 25–51.

Paris, Remi, and Ivan Ruzicka, 1991, "Barking up the Wrong Tree: The Role of Rent Appropriation in Sustainable Tropical Forest Management," Occasional Paper No. 1 (Manila: ADB Environment Office).

———, 1993, "The Case Against Environmental Taxes for Sustainable Forestry," *Journal of Forestry*, Vol. 91, No. 4, pp. 22–26.

Paris, Remi, Ivan Ruzicka, and Hugh Speechly, 1991, "Performance Guarantee Bonds for Commercial Management of Natural Forests: Early Experience from the Philippines," *Commonwealth Forestry Review*, Vol. 73, No. 2, pp. 106–12.

Reid, John W., and Richard E. Rice, 1997, "Assessing Natural Forest Management as a Tool for Tropical Forest Conservation," *Ambio*, Vol. 26, No. 6, pp. 382–86.

Repetto, Robert, 1988, *The Forest for the Trees? Government Policies and the Misuse of Forest Resources* (Cambridge, Massachusetts: Cambridge University Press).

———, and Malcolm Gillis, eds., 1988, *Public Policies and the Misuse of Forest Resources* (Cambridge, Massachusetts: Cambridge University Press).

Richardson, Dennis S., 1992, "Sticks and Carrots in Forest Concession Management," *Commonwealth Forestry Review*, Vol. 71, No. 3, pp. 167–70.

SGS Forestry, 1996, *Congolese Forest Policy and Practice: Problems and Opportunities, a Consultant Report for the World Bank* (Oxford: SGS Forestry).

Skiba, A. K., 1978, "Optimal Growth with a Convex-Concave Production Function," *Econometrica*, Vol. 46, pp. 527–39.

Swallow, S. K., P. J. Parks, and D. N. Wear, 1990, "Policy-Relevant Nonconvexities in the Production of Multiple Forest Benefits," *Journal of Environmental Economics and Management*, Vol. 19, No. 3, pp. 264–80.

Vincent, Jeffrey R., 1993a, "Managing Tropical Forests: Comment," *Land Economics*, Vol. 69, No. 3, pp. 313–18.

———, 1993b, "Depletion and Degradation Are Not the Same," *Journal of Forestry*, Vol. 9, No. 4, pp. 24–25.

———, and Theodore Panayotou, 1994, "Tropical Timber Concession Policies," paper presented to the 50th Congress of the International Institute of Public Finance, Cambridge, Massachusetts, August, pp. 22–25.

Weidelt, Hans-Joachim, and Valeriano S. Banaag, 1982, *Aspects of Management and Silviculture of Philippine Dipterocarp Forests* (Eshborn: Shriftenreihe der GTZ).

World Bank, 1999a, *Environmental Implications of the Economic Crisis and Adjustment in East Asia*, Discussion Paper Series 01 (Washington: World Bank).

———, 1999b, *Five Years After Rio: Innovations in Environmental Policy* (Washington: World Bank).