Trade, Tropical Deforestation and Policy Interventions*

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Abstract. Trade interventions are increasingly advocated as a means for controlling timber-related tropical deforestation. This paper analyzes the impact on deforestation of such policy instruments in a dynamic framework. The forest is modelled as a potentially renewable resource, and timber is extracted for purposes of export and domestic consumption. Optimality conditions for a variety of model specifications are derived, and the impacts of changes in the terms of trade and market structure on long-run deforestation are analyzed. The results of this analysis suggest that trade interventions that seek to affect the terms of trade against the export of tropical timber products are in the long run a second-best policy option for influencing the deforestation process.

Key words. deforestation, trade interventions, forest stock, tropical timber, large country exporter.

1. Introduction

Concerns about tropical deforestation have led to an increased focus on the role of the timber trade in promoting forest depletion and degradation. Recent reports suggest a marked increased in tropical deforestation in the 1980s, with the overall rate doubling from 0.6% in 1980 to 1.2% in 1990 (Dembner, 1991). However, the deforestation rate varies across regions, with an estimated annual rate for Latin America of only 0.9% compared with 1.7% for Africa and 1.4% for Asia.

Despite concern over the state of tropical deforestation and its implications for global welfare, several recent studies have indicated that the tropical timber trade is not the major *direct* cause of the problem — perhaps less than 10% of total deforestation — whereas conversion of forests for agriculture is much more significant (Amelung and Diehl, 1992; Barbier *et al.*, 1993; Binkley and Vincent, 1991; Hyde *et al.*, 1991). Nevertheless, it is clear that current levels of timber extraction in tropical forests — both open and closed — exceed the rate of reforestation (WRI, 1992). Less than one million hectares, out of an estimated total global area of 828 million hectares of productive tropical forest in 1985, was under sustained-yield management for timber production (Poore *et al.*, 1989). Moreover, timber extraction has a major *indirect* role in promoting tropical deforestation by opening up previously unexploited forest, which then allows other economic uses of the

Environmental and Resource Economics **4**: 75—90, 1994.
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forests such as agricultural conversion to take place (Amelung and Diehl, 1992; Barbier *et al.*, 1991). For example, in many African producer countries, around half of the area that is initially logged is subsequently deforested, while there is little, if any, deforestation of previously unlogged forested land (Barbier *et al.*, 1993).

Some of the environmental values lost through timber exploitation and depletion, such as watershed protection, non-timber forest products, recreational values, etc., may affect only populations in the countries producing the timber. Concerned domestic policymakers in tropical forest countries should therefore determine whether the benefits of incorporating these environmental values into decisions affecting timber exploitation balance the costs of reduced timber production and trade, as well as the cost of implementing such policies. The socially 'optimal' level of timber exploitation and trade is one where the additional domestic environmental costs of logging the forests are 'internalized' in production decisions, where feasible. Designing policies to control excessive forest degradation is clearly complex and requires careful attention to harvesting incentives. As recent reviews suggest, many domestic policies do not even begin to approximate the appropriate incentives required to achieve a socially optimal level of timber harvesting. More often than not, pricing, investment and institutional policies for forestry actually work to *create* the conditions for short-term harvesting by private concessionaires, and in some instances, even *subsidize* private harvesting at inefficient levels.[1] Over the long term, incentive distortions that understate stumpage values and fail to reflect increasing scarcity as old growth forests are depleted can undermine the transition of the forestry sector from dependence on old growth to secondary forests and the coordination of processing capacity with timber stocks (Binkley and Vincent, 1991).

Increasingly the world's tropical forests, including their remaining timber reserves, are also considered to provide important 'global' values, such as a major 'store' of carbon and as a depository of a large share of the world's biological diversity (Pearce, 1990; Reid and Miller, 1989). Similarly, even some 'regional' environmental functions of tropical forests, such as protection of major watersheds, may have transboundary 'spillover' effects into more than one country. But precisely because such transboundary and global environmental benefits accrue to individuals outside of the countries exploiting forests for timber, it is unlikely that such countries will have the incentive to incur the additional costs of incorporating the more 'global' environmental values in forest management decisions. Not surprisingly, sanctions and other interventions in the timber trade are one means by which other countries may seek to coerce timber producing countries into reducing forest exploitation and the subsequent loss of environmental values. In addition, trade measures are increasingly being explored as part of multilateral negotiations and agreements to control excessive forest depletion, to encourage 'sustainable' timber management and to raise compensatory financing for timber producing countries that lose substantial revenues and incur additional costs in changing their forest policy.

However well-intentioned they may be, both domestic and international environmental regulations and policies that attempt to 'correct' forest management decisions may have high economic, and even 'second order' environmental, costs associated with them (Barbier *et al.*, 1993). There is increasing concern that the potential trade impacts of environmental policies that affect forest and forest-based industries may increase inefficiencies and reduce international competitiveness. Moreover, the trade impacts of domestic environmental regulations may affect industries in other countries and lead to substantial distortions in the international timber trade. The overall effect on the profitability and efficiency of forest industries may be to encourage forest management practices that are far from 'sustainable'. Careful analysis of both domestic and international environmental policies affecting forest sector production and trade is therefore necessary to determine what the full economic and environmental effects of such policies might be.

The following model has been developed to facilitate analysis of the impact of policy interventions, market structure and transfers on a timber-exporting tropical forest country. The main focus of the analysis is on how these impacts relate to the country's decisions to produce timber, or processed goods that are based on timber extraction, and thus the rate of tropical deforestation. The model is similar to the one developed by Rauscher (1990), but it differs in two important respects. First, timber products can either be exported or consumed domestically, and the export earnings are used to import domestic consumption goods from abroad. This facilitates analysis of the *trade diversion* effect to domestic consumption of a policy intervention in the international timber market. Second, it is assumed that the tropical forest has positive *stock externalities* in the form of watershed protection, genetic diversity, microclimatic functions, etc. which directly affect the overall welfare of the country. The analytical results derived from the model are clearly affected by this assumption that the forest stock has some direct social value in addition to its use as a timber resource.

The model is simplified in some important respects. Domestic capital accumulation and any tropical reafforestation efforts are not modelled, and no other production or trade sectors are included, as this would complicate the analysis without providing deeper insights into the role of timber trade policy interventions in tropical deforestation. Initially, it is assumed that the country is a price taker in the international timber market and that trade is balanced. Later in the analysis we relax these assumptions to allow for market power and foreign asset accumulation (or debt).

2. The Basic Model

For the basic model, the following variables, parameters and functions are defined:

$N(t)$	tropical forest stock
$q(t)$	tropical timber logs extracted or commodities produced (log-equivalents)[2]
$x(t)$	tropical timber logs/products exported (log-equivalents)
$q(t) - x(t)$	domestic consumption of logs/products
$c(t)$	consumption of imported goods
$g(N(t))$	regeneration function of tropical forests
a	deforestation rate, per unit of (log-equivalent) timber extracted
p	terms of trade, p_x/p_c
δ	social rate of discount

Notation is simplified by omitting the argument of time-dependent variables, by representing a derivitive of a function by a prime, by employing numbered subscripts to indicate partial derivitives of a function, and by denoting the time derivitive and growth rates of a variable by a dot and hat, respectively.

The tropical forest country is assumed to maximize the present value of future welfare, W

$$\max_{q,\, x,\, c} W = \int_0^\infty U(q - x, c, N)\, e^{-\delta t}\, \mathrm{d}t \tag{1}$$

subject to

$$px = c, \tag{2}$$

$$\dot{N} = g(N) - aq, \tag{3}$$

$$N(0) = N_0 \text{ and } \lim_{t \to \infty} N(t) \geqslant 0, \tag{4}$$

$$N^{\max} > N^{\min} > 0,\, g(N^{\min}) = g(N^{\max}) = 0, \text{and } g''(N) < 0. \tag{5}$$

The control variables of the model are q, x and c. The additively separable utility function, U, is assumed to have the standard properties with respect to its partial derivitives, $U_i > 0$, $U_{ii} < 0$ ($i = 1, 2, 3$). Equation (2) is the initial trade balance assumption. Equations (3) to (5) are the standard renewable resource constraint, which suggest that any deforestation due to timber extraction net of regeneration will lead to a decline in the tropical forest stock.

3. Optimality Conditions

The Hamiltonian of the above optimal control problem is

$$H = U(q - x, px, N) + \lambda[g(N) - aq], \tag{6}$$

where λ is the costate variable or the shadow price of the tropical forest. Assuming an interior solution, the maximum principle yields the following conditions

$$U_1 = \lambda a, \tag{7}$$

$$U_1 = pU_2, \tag{8}$$

$$\dot{\lambda} = (\delta - g')\lambda - U_3, \tag{9}$$

where $U_1 = \partial U/\partial(q - x)$, $U_2 = \partial U/\partial c$ and $U_3 = \partial U/\partial N$. Equation (7) indicates that, along the optimal trajectory, the marginal value of extracting one unit of timber (in terms of domestic consumption), U_1, must equal its marginal depletion cost, λa. Since extraction costs are zero in the model, the latter costs are *user costs*, the future stream of timber income foregone from extracting a unit today. Equation (8) indicates that, if international terms of trade are given, the relative marginal value of domestic timber to imported good consumption must be equated with the terms of trade, p. Finally, equation (9) yields a standard renewable resource dynamic condition for denoting the change in the value of the tropical forest stock when that stock also has direct value, as represented by U_3. As this condition is important for the analytical results of our model, we state its interpretation formally as

PROPOSITION 1. *The rate of change in the shadow price of the tropical forest, $\dot{\lambda}$, equals the difference between the opportunity cost of holding on to a unit of the forest, $(\delta - g')\lambda$, and the marginal social value of that unit, U_3.*

Since the Hamiltonian is concave in (q, x, c, N), the above conditions are also sufficient for an optimum. By combining equations (7) and (9) one obtains

$$\frac{\dot{q} - \dot{x}}{q - x} = 1/\eta_1(\delta - g' - aU_3/U_1), \tag{10}$$

where η_1 is the elasticity of marginal utility, U_1. Utilizing (10) and conditions (3), (4), (5), (7) and (8), one can solve for an optimal saddle path and the long run equilibrium. As the system is in equilibrium when the user costs, the felling rate, domestic and imported consumption and the forest stock are constant, the equilibrium can be characterized by the following system of equations

$$U_1 - pU_2 = 0, \tag{11}$$

$$(\delta - g')U_1 - aU_3 = 0 \text{ for } \dot{q} = \dot{x} = 0, \tag{12}$$

$$g(N^*) - aq^* = 0, \text{for } \dot{N} = 0, \tag{13}$$

where the equilibrium values of N and q are denoted by asterisks. Total differentiation of the system of equations (11)—(13) with respect to (q, x, N) can lead to characterization of the equilibrium state and trajectories leading to that state. It can be demonstrated that the determinant D of the Hessian matrix of above system must be negative in order for there to be a unique equilibrium in (q, N) space; i.e., the requirement for the curve $\dot{q} = 0$ to be positively sloped and to cut the curve $\dot{N} = 0$ from below is that $D < 0$ (see Appendix). This implies that the equilibrium is a saddle point, and the saddle path is positively sloped. Using these results, the optimal solution is represented graphically in Figure 1. The solution suggests

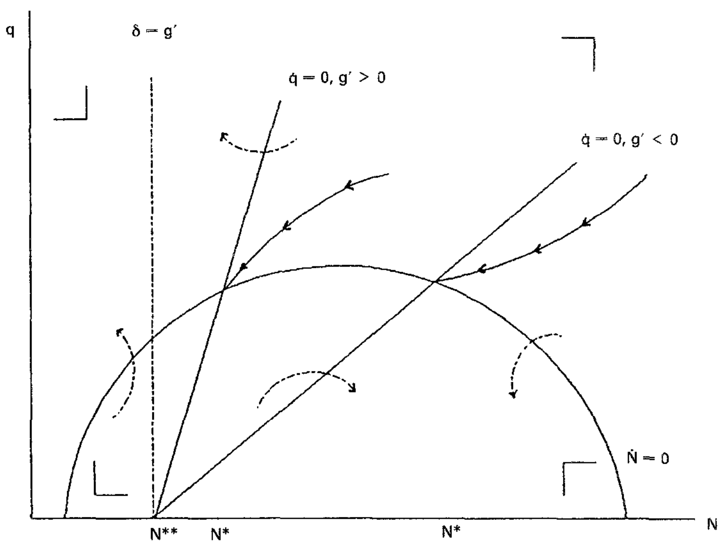

Fig. 1. The long run equilibrium of the tropical forest economy.

PROPOSITION 2. *The equilibrium forest stock, N^*, is determined by equating the social discount rate, δ, and the rate of return from holding on to the forest stock, $g'(N^*) + aU_3/U_1$. The equilibrium will occur to the left of the maximum sustainable yield (MSY) if $g'(N^*) > 0$, and it will occur to the right of the MSY if $g'(N^*) < 0$.*

Thus, as depicted in Figure 1, if the initial level of the forest stock is high (i.e. $N_0 > N^*$), then the economy will deforest some of this stock through timber extraction.

Moreover, equations (11)—(13) also imply

PROPOSITION 2a. *If U_3 were $= 0$, then the equilibrium forest stock, N^{**}, would occur at $\delta = g' > 0$.*

As shown in Figure 1, it must follow that $N^{**} < N^*$. That is, if the economy values only tropical timber then it will tolerate a lower level of tropical forest in the long run than if it also considers the other values provided by the forest.

4. Comparative Static Analysis: Trade Interventions vs. Transfers

Comparative static analysis of the long run equilibrium can be employed to indicate what impacts that reductions in the terms of trade for tropical timber and forest products, either through import bans, tariffs or other controls, may have on the tropical forest country's decision to deforest. As noted, the model already suggests that the tropical forest has positive *domestic* externalities in the form of watershed protection, genetic diversity, microclimatic functions, etc. which directly affect the overall welfare of the country. However, the *international* externalities, such as the role of the forests as a 'store' of biodiversity and carbon and their 'macro' climatic functions, are essentially ignored by domestic policymakers. Thus it can be assumed that intervention in the global timber market is motivated by the international community — notably tropical timber importers — attempting to force the country to 'internalize' the global values ascribed to its tropical forest that are lost through the depletion arising from timber production.

A ban on tropical timber imports or the imposition of import taxes that discriminate against trade in tropical timber reduces the terms of trade. In the model, a reduction in the terms of trade, p, has the following impacts on the long run equilibrium forest stock of the timber exporting country

$$\frac{\mathrm{d}N^*}{\mathrm{d}p} = \frac{[1 + \eta_2]U_2[-a(\delta - g')U_{11}]}{D}, \tag{14}$$

where η_2 is the elasticity of marginal utility, U_2, with respect to imported consumption goods. If the absolute value of η_2 is large, then marginal welfare in the economy is highly responsive to a change in imported consumption goods, c. We characterize this condition as 'import dependency'. The following proposition therefore results from (14)

	$\lvert\eta_2\rvert > 1$	$\lvert\eta_2\rvert < 1$
$g' > 0$	$\mathrm{d}q^*/\mathrm{d}p > 0$ $\mathrm{d}x^*/\mathrm{d}p$?	$\mathrm{d}q^*/\mathrm{d}p < 0$ $\mathrm{d}x^*/\mathrm{d}p$?
$g' < 0$	$\mathrm{d}q^*/\mathrm{d}p < 0$ $\mathrm{d}x^*/\mathrm{d}p < 0$	$\mathrm{d}q^*/\mathrm{d}p > 0$ $\mathrm{d}x^*/\mathrm{d}p > 0$

If trade interventions by importing countries do not always achieve the desired effect of encouraging timber exporting nations to reduce exploitation of their tropical forest stock, then an alternative policy may be the provision of an 'international transfer' of funds to encourage exporting countries to forego the income earned from forest exploitation. Essentially, the rest of the world is 'subsidizing' tropical forest countries to conserve rather than cut down their trees. For example, Agenda 21 of the UN Conference on Environment and Development has estimated that international financing of over US$1.5 billion annually will be required by tropical forest countries to reduce deforestation (ITTC, 1992).[3]

A large transfer of international funds to tropical forest countries to assist with sustainable forest management and forest conservation has the effect of 'freeing up' domestic financial resources for other purposes. In our model, an international transfer or subsidy can be represented by an increase in foreign exchange available for consumption of imported goods; i.e., it supplements timber export earnings. Thus (2) now becomes

$$px + s = c, \tag{2$'$}$$

where s is the amount of the international transfer, or subsidy. The comparative statics of equation (11) in the system (11) to (13) becomes

$$U_{11}\,\mathrm{d}q + [-U_{11} - p^2 U_{22}]\,\mathrm{d}x = pU_{22}\,\mathrm{d}s. \tag{17}$$

Thus an increase in international transfers, s, has the following impact on the long-run equilibrium forest stock, N^*

$$\frac{\mathrm{d}N^*}{\mathrm{d}s} = \frac{pU_{22}[-a(\delta - g')U_{11}]}{D} > 0. \tag{18}$$

The following proposition therefore holds

PROPOSITION 4. *A direct international transfer, s, will increase the long run equilibrium forest stock, N^*, unambiguously.*

In comparing Propositions 3 and 4, it is clear that the comparative statics of the long run equilibrium clearly favour international transfers as the preferred method of inducing tropical timber exporting countries to conserve their tropical forests.

5. The Large Country Exporter

The above model has assumed that the timber exporting country is a price-taker in the international market; that is, as one of many tropical timber exporters, the country is unable to affect the world price of traded tropical timber products through changing its own level of production and export of timber products.

However, currently some tropical timber exporters, particularly the major South East Asian producers (e.g., Malaysia and Indonesia), dominate the international markets in certain tropical timber products. Other countries (e.g. Brazil, Zaire and Papua New Guinea) have the potential also to become large-scale producers and exporters (Barbier *et al.*, 1993). The ability of these large-country exporters to use their apparent market power to influence global prices for their timber products depends to a large extent on the availability of alternative supplies, e.g. from both other tropical and temperate forest regions, and on end-use substitution between tropical timber products from different sources, between tropical and temperate timber products and between timber and non-timber substitutes (e.g., aluminum, concrete, plastics, ceramics, etc.). Some analysts suggest that global supplies of timber are more than adequate even in the long run, and that the shift in production from 'old growth' to secondary forests could rule out the possibility of even large tropical timber producers of asserting any market power (Sedjo and Lyons, 1990). Others have indicated that, while there is always scope for greater substitutibility between tropical timber and other products in the long run, substitution for some tropical timber products in major importing markets may be more problematic in the short run (Buongiorno and Manarung, 1992; Vincent, Brooks and Gandapur, 1991). Finally, Rauscher (1990) has shown that, at least theoretically, the 'cartelization' of a group of tropical timber exporters could lead to significant market power and greater conservation of their tropical forests.

As the possibility of a large country exporter (or group of exporters) of tropical timber products influencing international prices cannot be definitely ruled out, it is worth exploring the potential impacts further.

In our model, if a large country exporter is able to influence prices then

$$x = x(p), \text{ with } x'(p) < 0 \text{ and } x''(p) > 0. \tag{19}$$

(11) now becomes

$$U_2 p(1 + 1/\varepsilon) = U_1, \text{ where } \varepsilon = x'(p)p/x. \tag{11$'$}$$

The Appendix indicates that the determinant D of the Hessian matrix of the modified simultaneous system (11)$'$, (12) and (13) is less than zero, which is again a necessary condition for a unique equilibrium. If this is the case then

$$\frac{dN^*}{d(1/\varepsilon)} = \frac{pU_2(-a(\delta - g')U_{11}x'(p)}{D} > 0. \tag{20}$$

PROPOSITION 5. *An increase in market power, $1/\varepsilon$, of the large country exporter(s) will increase the long run equilibrium forest stock, N^*, unambiguously.*

To the extent that large country exporters can increase their market power and influence international timber prices, then they can afford to conserve more of their tropical forests in the long run. Increased monopolistic power or cartelisation of tropical timber supply appears to have a resource-conserving effect.[4]

Will increased international transfers to a large country exporter also enhance forest conservation? The effects of an increased international subsidy, s, has the following impact on the long run equilibrium forest stock

$$\frac{dN^*}{ds} = \frac{p(1 + 1/\varepsilon)U_{22}[-a(\delta - g')U_{11}x'(p)]}{D} > 0. \tag{21}$$

Assuming $|\varepsilon| < 1$, an international transfer to a large country exporter will increase its forest stock in the long run. Thus Proposition 4 also holds for the large country exporter.

6. Foreign Assets and Debt

An initial assumption of the model was that the trade of the tropical timber exporting country is balanced. We now relax this assumption to analyse qualitatively the effects of foreign asset (or debt) accumulation. The inclusion of a foreign capital market results in an additional condition in the model

$$\dot{A} = px - c + rA, \tag{22}$$

where $A > 0$ implies accumulated foreign assets, $A < 0$ accumulated foreign debts, and r is the interest earned (or owed). In what follows, we assumed that $A > 0$.

The Hamiltonian (6) is modified to

$$H = U(q - x, c, N) + \lambda[g(N) - aq] + \mu[px - c + rA], \tag{23}$$

with μ as the costate variable representing the shadow value of foreign asset accumulation. Assuming an interior solution, the maximum principle yields the following conditions

$$U_1 = \lambda a, \tag{24}$$

$$\mu = U_2 = U_1/p, \tag{25}$$

$$\dot{\lambda} = (\delta - g')\lambda - U_3, \tag{26}$$

$$\dot{\mu} = (\delta - r)\mu. \tag{27}$$

Conditions (24) and (26) have the same interpretation as (7) and (9) before. Equation (25) is similar to (8), although now the relative marginal value of domestic timber to imported good consumption must be equated not only with the terms of trade, p, but with the implicit value of accumulated foreign assets, μ. Condition (27) governs the rate of appreciation in the value of foreign assets, which is determined by the opportunity cost of holding on to a unit of these assets, $(\delta - r)$.

Conditions (24)—(27) also imply that the growth rates of the variables U_1, U_2, λ and μ are equal along the optimal path, which lead to the following relationships

$$(r - g') = aU_3/U_1 > 0, \text{and} \tag{28}$$

$$\dot{N} = \frac{(r - g')(\delta - r)}{(aU_{33}/U_1) + g''}. \tag{29}$$

Equation (28) can be interpreted as an efficiency condition. It suggests that in order for foreign assets to be an optimal form of wealth for the timber exporting country, the rate of return on these assets, r, must equal the rate of return from 'holding on' to its tropical forests, $g' + aU_3/U_1$. Otherwise, there is no point in the country extracting and exporting timber as a means to accumulating foreign assets.

Condition (29) governs the growth (or depletion) path of the tropical forest along the optimal trajectory for the economy. If the opportunity cost of holding onto foreign assets is negative, i.e. $\delta - r < 0$, then the forest stock will be allowed to expand, i.e. $\dot{N} > 0$. Moreover, the social value of accumulating foreign assets is falling, i.e. $\dot{\mu} < 0$. Effectively, the interest rate r is so large (relative to the return on other assets in the economy as represented by δ) that the economy is better off becoming a net lender of its foreign assets and reducing its timber exploitation to hold on to more forests. However, if the opportunity costs of holding assets is positive, i.e. $\delta - r > 0$, then the country will continue to exploit its tropical forests for timber and $\dot{N} < 0$.

Moreover, due to Equations (25) and (27), U_1 grows at a rate $(\delta - r)$, and this implies that the right hand side of (28) goes to zero for small discount rates and to infinity for large values of this parameter. Therefore, the very long run solution is $N = N^{\max}$ in the first case, and $g' = r$ in the latter. If the discount rate is small, then the economy will save and consumption is increasing over time. The marginal utility of consumption is reduced such that the value of the tropical forest in terms of the consumption good rises. The opposite argument applies if δ is large. Then the marginal utility of consumption is increased along the optimal path, and the relative value of the forest resource declines until the pure arbitage condition $g' = r$ holds.[5]

Thus assuming in equilibrium that $\delta = r$ and that Condition (28) will also be valid in the long run, so long as $U_3/U_1 > 0$, then the following proposition holds

PROPOSITION 6. *With a foreign capital market and positive stock externalities ($U_3 > 0$), the forest resource will never be exhausted. Equilibrium forst stock N^* will be determined by $\delta = r = g' + aU_3/U_1$, which will always be greater than the equilibrium N^{**}, as determined by $\delta = g' > 0$ in Figure 1.*

The system of equations determining the equilibrium now correspond to (11)—(13) with r inserted for δ. But the second argument of the utility function is no longer px as before but $px + rA$. Unfortunately A is not determined. It can be computed from the starting values of A and N, which implies

$$A_0 + pN_0 = A + pN \quad \text{or} \quad A = A_0 + pN_0 - pN. \tag{30}$$

Using this in the comparative statics, it follows that the first-row third-column element of the first matrix in the Appendix has to be rp^2U_{22}. Thus the sign of the determinant of the Hessian matrix D remains negative as before. Thus we obtain

PROPOSITION 7. *The comparative static effects on the long run equilibrium forest stock, N^*, have the same signs in the borrowing-and-lending and the previous model of the timber exporting country. The magnitude of the effects may differ.*

7. Conclusion

This paper has examined several aspects of the links between the trade in tropical timber and deforestation from the perspective of an exporting country. The various versions of the model developed here have highlighted a number of important features of this linkage.

First, if the producer country values its tropical forests solely as a source of timber export earnings then it will aim for a smaller forest stock in the long run than if it also considers the other values provided by the forest. Understanding the full range of benefits accruing from their tropical forests, e.g. watershed protection, genetic diversity, tourism, microclimatic functions, etc., is important to determining the direct social value of forest conservation.

Second, if importing nations want the exporting countries to conserve more of their forests, trade interventions appear to be a second-best way of achieving this result. Under certain conditions, they may even prove to be counter-productive. In contrast, international transfers, which in our model simply reduce the dependency of the producer country on the exploitation of the forest for export earnings, are more effective in promoting conservation of the forest stock.

Third, increased market power by a large country exporter or group of exporters may actually lead to greater forest conservation. The greater the market power, the higher the returns per unit of output and the less need to exploit tropical forests more heavily. Nevertheless, even in the monopoly case, an international subsidy to reduce dependence on tropical timber exploitation will incite greater forest conservation.

Finally, the existence of a foreign capital market may further ensure that the tropical timber country may conserve its forest stock in the long run. If the rate of return on foreign assets is very high, the economy may switch into becoming a net lender and prefer even to increase its forest stock. However, even when interest rates are low and consequently the opportunity cost of holding on to foreign assets is high, the economy will not completely exhaust its forests.

Several recent reviews of global forest sector policies have discussed implications similar to those analyzed theoretically in our model (Barbier *et al.*, 1993; Binkley and Vincent, 1991; Hyde *et al.*, 1991). Generally, these studies have also concluded that trade intervention is a 'second best' option for controlling tropical deforestation. Nonetheless, the use of bans, tariffs and other trade measures to discourage 'unsustainable' tropical timber exploitation continue to be advocated. As our paper has attempted to show, sometimes the more simple solutions lead neither to a straightforward, nor to the desired, results.

Appendix

Comparative static solution of the simultaneous equation system (11), (12) and (13) can be represented by

$$\begin{vmatrix} U_{11} & -U_{11}-p^2U_{22} & 0 \\ (\delta-g')U_{11} & -(\delta-g')U_{11} & -g''U_1-aU_{33} \\ -a & 0 & g' \end{vmatrix} \begin{vmatrix} \mathrm{d}q \\ \mathrm{d}x \\ \mathrm{d}N \end{vmatrix}$$

$$= \begin{vmatrix} U_2+pxU_{22} & 0 \\ 0 & U_3 \\ 0 & q \end{vmatrix} \begin{vmatrix} \mathrm{d}p \\ \mathrm{d}a \\ \ \end{vmatrix}.$$

Solution can be derived through the application of Cramer's rule. However, the key issue is the sign of the determinant of the Hessian matrix of the above system. We therefore derive this result. Having signed the determinant, the comparative static results are fairly straightforward.

The determinant D of the Hessian matrix is

$$D = g'p^2U_{11}U_{22}(\delta-g') - a(U_{11}+p^2U_{22})(g''U_1+aU_{33}).$$

The right hand side is negative but the lefthand side is ambiguous as g' is unsigned. However, it can be shown that $D < 0$ is a requirement for the curve $\dot{q}$ to be positively sloped and to cut the curve $\dot{N}$ from below, which is a necessary (but not sufficient) condition for there to be a unique equilibrium in (q, N) space.

The implicit function rule applied to the above simultaneous equation system (11), (12) and (13) yields

$$U_{11}\,\mathrm{d}q = (U_{11}+p^2U_{22})\,\mathrm{d}x$$

$$(\delta-g')U_{11}\,\mathrm{d}q - (\delta-g')U_{11}\,\mathrm{d}x = (g''U_1+aU_{33})\,\mathrm{d}N$$

$$-a\,\mathrm{d}q = -g'\,\mathrm{d}N.$$

Substituting for dx yields

$$\left.\frac{dq}{dN}\right|_{\dot{q}=0} = \frac{(g''U_1 + aU_{33})(U_{11} + p^2U_{22})}{(\delta - g')p^2U_{22}U_{11}} > 0.$$

$$\left.\frac{dq}{dN}\right|_{\dot{N}=0} = \frac{g'}{a}.$$

It follows that

$$\left.\frac{dq}{dN}\right|_{\dot{N}=0} > \left.\frac{dq}{dN}\right|_{\dot{q}=0}$$

also implies that $a(U_{11} + p^2U_{22})(g''U_1 + aU_{33}) > g'p^2U_{11}U_{22}(\delta - g')$, and thus $D < 0$.

In the monopoly case, comparative static solution of the simultaneous equation system (11)′, (12) and (13) can be represented by

$$\begin{vmatrix} U_{11} & \phi & 0 \\ (\delta - g')U_{11} & -(\delta - g')U_{11}x' & -g''U_1 - aU_{33} \\ -a & 0 & g' \end{vmatrix} \begin{vmatrix} dq \\ dp \\ dN \end{vmatrix}$$

$$= \begin{vmatrix} U_2p & 0 \\ 0 & U_3 \\ 0 & q \end{vmatrix} \begin{vmatrix} d1/\varepsilon \\ da \\ \end{vmatrix}.$$

The determinant D of the Hessian matrix of the above system is

$$D = a[g''U_1 + aU_{33}]\phi - g'(\delta - g')U_{11}[U_{11}x'(p) + \phi],$$

where

$$\phi = -U_{11}x'(p) - p^2U_{22}(1 + 1/\varepsilon)^2 - U_2(1 + 1/\varepsilon) + U_2p(\varepsilon'(p)/\varepsilon^2) < 0.$$

It follows that the condition

$$\left.\frac{dq}{dN}\right|_{\dot{N}=0} > \left.\frac{dq}{dN}\right|_{\dot{q}=0}$$

also implies that $a(g''U_1 + aU_{33})\phi < g'(\delta - g')U_{11}[\phi + U_{11}x'(p)]$, and thus $D < 0$.

Notes

* We would like to thank Joanne Burgess for contributing to discussions that resulted in this paper, which were held at the Beijer Institute of Ecological Economics of the Royal Swedish Academy of Sciences. We acknowledge the financial support given by the Beijer Institute and the hospitality of its staff, and in particular we are grateful to Prof. Karl-Göran Mäler for inviting us to use the facilities at Beijer and to Charles Perrings, Director of the Biodiversity Programme. Additional support for Edward Barbier's participation in the research was also provided by the International Tropical Timber Organization, under contract no. PCM(XI)/4, "Economic Linkages Between the International Trade in Tropical Timber and the Sustainable Management of Tropical Forests". We are grateful to comments provided by two anonymous referees; however, the usual disclaimer applies.

[1] For example, see Barbier *et al.* (1991); Gillis (1990); Hyde *et al.* (1991); Pearce (1990); and Repetto (1990).

[2] Processed timber products are assumed to be converted to log-equivalents.

[3] The proposed international financing is for, specifically, sustaining the multiple roles and functions of all types of forests, forest lands and woodlands (US$860 million *per annum*); enhancement of the protection, sustainable management and conservation of all forests, the greening of degraded areas through forest rehabilitation, afforestation, reforestation and other rehabilitation measures (US$460 million p.a.); and promoting efficient utilization and assessment to recover the full valuation of the goods and services provided by forests, forest lands and woodlands (US$230 million p.a.).

[4] According to Solow (1974, p. 8), "the monopolist is the conservationist's friend". Usually this holds along an adjustment path towards a steady state, which is independent of market structure. In our model, in contrast, the long run equilibrium is also affected.

[5] Note that Equation (28) also implies that there is a relocation of assets at $t = 0$ such that (28) holds forever after. Thus, there is a jump in N corresponding to a jump in the opposite direction in A. The extraction rate is plus or minus infinity in this point of time. However, the long-run equilibrium remains unaffected.

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