Foreign transfers and tropical deforestation

Soest, Daan van; Lensink, Robert

Foreign Transfers and Tropical Deforestation: What Terms of Conditionality?

Daan van Soest and Robert Lensink

97C..

Foreign Transfers and Tropical Deforestation: What Terms of Conditionality?

Daan van Soest and Robert Lensink*

SOM Theme C: Coordination and growth in economies

Abstract

The international community considers the possibility to use aid as an instrument to improve natural resource conservation in developing countries. Basically, by making the amount of transfers dependent on the efforts of the recipient countries to improve conservation, appropriate incentives can be given. However, if the recipient countries feel that they can affect the financial compensation they receive per unit of forest land by adapting their land use decisions, forest conservation may not be improved by the introduction of conditional aid. In this paper, potential flaws of compensation functions are identified and solutions are suggested.

*Please send all correspondence to Robert Lensink, University of Groningen, Department of Economics, P.O. Box 800, 9700 AV Groningen, The Netherlands; e-mail: b.w.lensink@eco.rug.nl. The authors would like to thank Erwin Bulte, Nanne Brunia, Niels Hermes, Peter Kooreman and Howard White for their comments on an earlier version of this paper. Of course they are not responsible for any remaining errors.

1. Introduction

International concern about the global consequences of environmental degradation in developing countries has increased considerably over the last 20 years. Given the fact that the global marginal benefits of environmental protection very often exceed its domestic marginal benefits because environmental degradation has transboundary effects, a level of environmental protection develops which is suboptimally low from the point of view of the international community. This implies that if developed countries indeed want improved protection of the environment in less developed countries, they should be willing to compensate them financially. Therefore, the international community contemplates conditioning foreign aid donation or debt reduction on the efforts of developing countries' governments to combat environmental degradation (Jepma, 1995; Kahn and McDonald, 1994).

One of the principal resources to which these considerations apply are tropical rainforests. Deforestation occurs mainly because forested land is converted to agricultural use. Although most rainforests can be described as open-access resources, governments of tropical forested countries affect the rate of deforestation considerably. Partly, those governments stimulate deforestation directly as they develop land use plans in which part of the forests are designated to be converted to agricultural use. But they affect deforestation also indirectly by developing agricultural colonisation programs in rainforests and by increasing the profitability of agriculture by affecting the prices of natural resources and agricultural output. In this decision process, the flow of services provided by the rainforests (such as storage of greenhouse gasses and conservation of biodiversity) that have beneficial transboundary consequences are largely ignored precisely because no compensation takes place. The existence of these externalities gives a justification for financial transfers to induce developing countries to abstain from forest conversion so that forest conservation is improved relative to the extent of forest conservation that would result from weighing only the domestic marginal benefits and costs of deforestation.

There is a growing literature on how aid can improve rainforest conservation. Some papers focus on the effects of lump-sum donation of aid. This type of aid donation can be an effective instrument to combat deforestation as it reduces the necessity to exploit forests in order to earn foreign exchange (Barbier and Rauscher, 1994; Pearce and Warford, 1993, p. 17). As this is a rather passive way to use the instrument of foreign transfers, attention is now shifting to how aid can be used more actively by making the amount of transfers conditional on the efforts of tropical forested countries to improve forest conservation (Kolk, 1996, pp. 129 and 144).

However, introducing conditionality may induce strategic behaviour by the recipient countries: if they can affect the financial compensation they receive by adapting their land use decisions, forest conservation may not be improved by the introduction of conditional aid. This theme is explored in two recent papers. Stähler (1996) has drawn attention to the fact that the specification of the compensation function is of crucial importance. He starts off by proving that paying a fixed price per unit of forest conserved, long-run forest conservation is improved unambiguously. However, he argues that it is not very convincing to assume a fixed compensation per unit of forest land. It is likely that the smaller the forest area becomes, the more the international community is willing to pay to prevent the conversion of an additional unit of forest land. If tropical forested countries suspect that this mechanism exists, they will realise that they have "market power" in the sense that they are able to influence per-unit compensation through their behaviour with respect to deforestation. Stähler proves that introducing a non-fixed compensation price may have adverse effects in the sense that long-run size of the forest area turns out to be lower than if no compensation is introduced. Approximately the same line of reasoning is presented by Mohr (1996) with respect to the actual *rate* of deforestation. He constructs a bargaining game between North and South in which North tries to induce South to switch from an unsustainable development path to a sustainable one. In the negotiation phase, both parties try to maximise the present value of utility which depends on the ecological benefits rendered by rainforests and on the amount of money paid/received. Mohr finds that by increasing the instantaneous rate of deforestation, tropical forested countries can affect the amount of compensation paid per unit of forest land. Given the fact that tropical deforestation is to a large extent irreversible (Dudley, *et al*., 1995, p. 3; Kolk, 1996, p. 129), the slower deforestation takes place, the better.

The credibility problem about whether the donor community is indeed "hardnosed" in the sense that the per-unit compensation price is not increased when the forest area decreases, arises because of the fact that credibility only increases over time. It is likely that the evaluation of the recipient countries' performance takes place only once in a while, say on a yearly basis. If the donor countries do not increase per-unit compensation over several years while deforestation continuous, information is signalled that indeed they stick to their fixed per-unit compensation. However, during those years the recipient countries may have incentives to increase deforestation as long as they are not sure that the donor community is hardnosed.

This paper aims to analyse how the conditionality scheme should be designed so that strategic behaviour by the tropical forested countries can be precluded. In order to give stronger signals, it may be advantageous to let the compensation function depend on the current rate of deforestation as the recipient countries are then confronted directly with the consequences of their land use decisions. Combining the focal point of both Stähler's and Mohr's analyses, this paper addresses the strategic behaviour that may lead to adverse results either in the short run or in the long run. In order to do this, a model will be presented in section 2 which can be used to derive both the long-run forest size and the depletion path towards it that are optimal from the point of view of a tropical forested country, given the compensation scheme in place. Section 3 analyses the general long-run environmental consequences of introducing a compensation function. In section 4 the compensation function is specified explicitly and used to explore the environmental consequences for the short run as well as for the long run. Based on the results obtained in the fourth section, in the fifth section a specification is proposed that combines the most desired results. Finally, in the sixth section conclusions will be drawn.

2. The model

The main cause of deforestation in rainforest areas is conversion to agricultural land. Although forestry activities can inflict substantial damage upon the forests, they rarely result in actual deforestation. The forestry technique most often applied is selective logging, in which only a few trees of high commercial value are logged and extracted. Ehui, Hertel and Preckel (1990) have constructed a model that captures these facts. In this land allocation model, it is assumed that the government of a country endowed with rainforests maximises the net present value of forest exploitation, choosing the optimal rate of deforestation in each period. In order to be able to derive a compensation scheme that is credible and improves forest conservation both in the long and short run, we have modified their model by simplifying it somewhat, by taking into account that conversion timber can be sold, by specifying all equations explicitly and by adding a conditional transfer function. Our model is as follows:

$$W = \max_D \int_0^\infty R(t)e^{-rt}\,dt \qquad (1)$$

$$s.t.\ \dot{F}(t) = -D(t) \qquad (2)$$

$$R(t) = P(t)q(t) + P_A(t)Z(t)[F_0 - F(t)] + S(t) \qquad (3)$$

$$P(t) = \bar{P} - 2q(t) \qquad (4)$$

$$q(t) = (F(t) + (1-()D(t) \qquad (5)$$

$$Z(t) = \bar{Z} + "D(t) - \$[F_0 - F(t)] \quad (6)$$

$$S(t) = S(D(t), F(t)) \quad (7)$$

In this model, net present value *W* is maximised by choosing the optimal rate of deforestation (*D*) in each period (equation 1); revenues[1] in each period (denoted by *R(t)*) are discounted at rate *r*. Depletion of the forest stock is represented by equation (2), the equation of motion: the size of the forest stock (*F*) falls over time at the rate of deforestation.

Equation (3) shows that revenues are derived from forestry activities, agricultural production and foreign transfers. Forestry revenues in each period are equal to the quantity of timber supplied (*q*) in that period multiplied with the prevailing price in that period. Timber is produced using both selective logging techniques (which does inflict some damage upon the forests but does not cause a permanent reduction in biomass) in the entire forest *F* and clearfelling on land that is to be converted to agriculture *D*, extracting the commercially valuable stems. We normalise the forestry product price *P* to reflect the revenues per unit of land. For mathematical simplicity, we assume the timber demand function to be linear; see equation (4).[2] Under selective logging, only a fraction of the timber can be extracted, which is reflected by parameter γ. Therefore, the timber revenues earned per unit of land selectively logged are γP, with $\gamma<1$. If land is to be converted, the remaining timber stock is harvested yielding a revenue of $(1-\gamma)P$ per unit of land.

The second term in equation (3) represents agricultural revenues which results from multiplying the monetary yield per unit of land with the entire area of land under cultivation (F_0-$F(t)$, F_0 being the initial size of the rainforest area): all

[1]We assume all production to be costless: including costs would only complicate the mathematics without changing the results. Hence, the terms revenues and net revenues can be used interchangeably.

[2]The use of a downward sloping timber demand function is based on a survey of the literature presented by Barbier *et al*. (1994, p. 43). They show that indeed the tropical timber demand function is downward sloping at a country level. It can be easily be shown that our main results are not affected by this assumption: dropping it (and hence assuming the price to be exogenous) even yields the extreme case of our analysis.

deforested land is converted to agricultural land which is assumed to become productive instantaneously. The monetary yield consists of the price of agricultural products (which is assumed to be fixed at $\bar{P}_A$)[3], multiplied by the average per-unit land productivity *Z*. As is reflected in equation (6), land productivity is not fixed. Deforestation contributes to average soil productivity as burning of the forest cover increases average soil productivity because of the release of nutrients (Hecht, 1985). However, the proximity of forest cover increases average soil productivity because it prevents erosion and accelerates soil formation by shedding organic material onto the fallow land (Ehui *et al*., 1990); cumulative deforestation has a negative effect on average soil productivity.[4]

The third source of revenue is a foreign transfer. In Stähler's (1996) model, the compensation function depends only on the forest stock (*F*) in each period. However, given the potential flaw that rewarding forest conservation can induce strategic behaviour, a useful extension may be to include the possibility of punishment on deforestation (*D*) as well.

The equilibrium size of the forest area is found by solving the current value Hamiltonian of the model:

$$H(D,F,\ ) = \lfloor Pq + (1-()D] + \bar{P}_A Z[F_0 - F] + S(D,F) \qquad D \tag{8}$$

Upon applying the Pontryagin's maximum principle and assuming an interior, the following first order conditions are obtained:

$$(t) \quad (1-()P(t) + "\bar{P}_A[F_0 - F(t)] - 2(1-()q(t) \quad S_D \tag{9}$$

---

[3]The assumption of a fixed price for agricultural produce facilitates the mathematics without changing the results.

[4]Of course, it is a crude simplification to use *average* agricultural productivity, especially when *marginal* deforestation decisions will subsequently be analysed. However, this approach is mathematically simple while the final conclusions will not be altered qualitatively if soil productivity is modelled in a more sophisticated way.

$$(t) \quad r \ (t) - (P(t) - \$\bar{P}_A[F_0 - F(t)] - S_F + \bar{P}_A Z(t) \qquad q(t) \tag{10}$$

The interpretation of equation (9) is that in each period the costs of deforesting an extra unit of forested land now rather than in the future (λ)[5] are equal to the (net) benefits of currently deforesting that extra unit. These benefits consist of four parts. The first term on the RHS reflects the direct revenues of deforestation in terms of timber sold. The second term represents the increased agricultural revenues arising from the positive effect of current deforestation on agricultural productivity. The third term is the fall in price at which the entire timber supply is sold as a result of the extra timber extracted from the deforested unit of land. The last term on the RHS is the loss in revenue caused by the conditionality of transfers on the rate of deforestation ($S_D<0$). Equation (10) is nothing but an extended version of the Hotelling rule (Hotelling, 1931): it is an intertemporal non-arbitrage condition which dictates that for an optimal solution, no gain in profits can be achieved by reallocating deforestation from one period to another. This implies that the shadow price of the forest stock should increase at rate *r*, reduced with the marginal cost of deforestation and increased with the marginal benefits that accrue to the decision maker. The marginal costs of deforestation are equal to the loss in revenue which can be earned by logging a unit of forest land selectively (γP), the loss in revenue caused by reduced average soil productivity as a result of reduced protection of the soils ($\beta\bar{P}_A(F_0\text{-}F)$) and the change in transfers resulting from conditionality on changes in forest size (S_F). The benefits of reducing the forest area with one extra unit are the revenues earned by having an extra unit of land under cultivation ($\bar{P}_A Z$) and the resulting price increase ($\gamma\theta q$), which benefits the tropical forested country as the price at which its entire timber supply can be sold, increases.

[5]The variable λ is the co-state variable associated with the equation of motion. It reflects the marginal value of the state variable (F) at each moment t (see for example Kamien and Schwartz, 1981, p. 152). Hence, this variable is akin to the Lagrange multiplier in a static optimisation problem, and can be interpreted as the shadow price of an extra unit of forested land.

3. The derivation of the long-run size of the forests and the depletion path towards it

On the basis of the equation of motion (2) and the first order conditions (9) and (10), the model can be solved. The equilibrium size of the rainforest area can be found by setting the time derivatives (F and λ) equal to zero. The resulting equilibrium forest size (F^*) is presented in equation (11):

$$F \quad F_0 \quad \left(\frac{\bar{P}_A \bar{Z} - [(-r(1-()][P(F_0)-2(F_0] + rS_D \quad S_F}{\bar{P}_A[2\$-r"] + 2(2((-r(1-()))} \right. \qquad (11)$$

The numerator of the second term on the RHS of equation (11) represents whether or not deforesting the *first* unit of land is desirable: in the initial situation, the present value of the stream of the marginal revenues of deforestation are compared with the present value of the stream of marginal revenues derived from forest conservation. This can be seen by rewriting the numerator as:

$$1 \quad)(P(F_0) - 2(F_0) + \frac{1}{r}\bar{P}_A \bar{Z} \geq^{?} \frac{(}{r}(P(F_0) - 2(F_0) \quad S_D \quad \frac{S_F}{r} \qquad (12)$$

On the LHS of (12), the present value of the marginal revenues of deforestation consists of the one-shot revenues of excessive logging (taking into account the effect on the price resulting from the downward sloping demand function) and the present value of the future revenues arising from the conversion to agricultural land. On the RHS, the present value of the marginal costs of deforestation are given. The first term reflects the benefits of selective logging that would be lost (consisting of the sales price and the effect of *not* deforesting a unit of land on the sales price). The second and third term arise because of the effects in terms of the foreign aid function. If the scheme depends only on *current* deforestation, there are one-shot losses in terms of the reduction in foreign transfers. If the scheme depends on *cumulative* deforestation, deforesting a unit of land does not only have financial consequences now but also in the future. If the present value of the marginal revenues stream of deforestation (LHS) exceeds the present value of marginal revenues generated by forest conservation (RHS), at least some deforestation is desirable: the equilibrium size of the rainforest area (F^*) is less than the initial size (F_0).[6] The denominator is likely to be positive and acts as a multiplier to determine optimal cumulative deforestation.

In order to be able to derive the depletion path, the transfer function needs to be specified explicitly. The general specification of the transfer function used in the rest of the paper is:

$$S(t) = aF(t) - \frac{b}{2}F(t)^2 - cD(t) - \frac{d}{2}D(t)^2 \qquad (13)$$

On the basis of this compensation function and redoing the maths as described above the following long-run equilibrium size of the rainforest can be found:

$$F_0 \quad \frac{\bar{P}_A\bar{Z} - ((-r(1-())(P(F_0) - 2(F_0) + bF_0 \quad rc \quad a}{\bar{P}_A[2\$ - r"] + 2(2((-r(1-()) \quad b} \qquad (14)$$

The depletion path towards the long-run equilibrium can be calculated by taking the time derivative of the co-state variable λ (equation 9), inserting the result together with the equation of motion (2) into equation (10) and solving the resulting second order differential equation (Apostol, 1967, pp. 322-328):

$$(F_0 \quad F\ )\ EXP\left(-\left[\sqrt{\frac{1}{4}r^2 + \frac{b + \bar{P}_A(2\$ - r") + 2(2((-r(1 \quad))}{d + 22(1-()^2}} \quad \frac{1}{2}r\ t\right]\right) \quad F \qquad (15)$$

In the remainder of this section we consider the effects of changes in the parameters of the compensation functions on the long-run equilibrium forest size, as well as the forest size during the adjustment period.

---

[6]Ehui and Hertel (1989) have applied the original Ehui, Hertel and Preckel (1990) model to estimate the optimal size of the rainforest area of Côte d'Ivoire. For reasonable parameter values they find that some deforestation is desirable. As we have extended the model by taking into account that conversion timber can also be sold, it is even more likely that at least some deforestation is desirable from the point of view of tropical forested countries' governments. Hence, in the rest of the paper we assume that the equilibrium size of the rainforest area (F^*) is less than its initial size (F_0).

4. The consequences of the choice of the compensation function

We start the analysis by considering the long-run effects of conditioning transfers on the remaining stock of the forest area. In general, rewarding forest conservation gives an incentive to achieve a higher size of the forest area in the long run and in the short run, as can be seen by calculating the first derivatives of F^* and $F(t)$ with respect to a:

$$\frac{F}{a} = \frac{1}{(2\$-r")\bar{P}_A + 22(((-r(1-()) + b} > 0 \qquad (16)$$

$$1 \quad EXP \quad \sqrt{\frac{1}{4}r^2 + \frac{b+\bar{P}_A(2\$-r")+2(2((-r(1-\;))}{d+22(1-()^2}} \quad \frac{1}{2}r \quad t \qquad \frac{F}{a} > 0 \qquad (17)$$

Equation (16) shows that if a tropical forested country receives a certain amount of money for each unit of land it still has, forest conservation is improved in the long run: the equilibrium forest size is increased. The donation of a fixed amount of money per unit of forest land also affects the instantaneous *rate* of deforestation positively: equation (17) shows that increasing a results in an increase in forest cover in each period. This result arises exclusively from the fact that increasing a decreases the optimal quantity of cumulative deforestation (F_0-F^*), which implies that the area deforested in each period should also be lower. Hence, if the compensation function is linear in F (*i.e.*, $S = aF$), per-unit compensation is fixed and forest conservation is improved both in the long run and in the short run.

However, as Stähler (1996) convincingly argues, such a linear compensation scheme is not credible as it is likely that the international community's marginal utility of forest conservation is decreasing if the forest size is increased. In other words, tropical forested countries are likely to expect that b is positive, reflecting decreasing marginal utility associated with increased forest conservation. The long- and short-run consequences are as follows:

$$\frac{\partial F^*}{\partial b} = -F^* \frac{\partial F^*}{\partial a} < 0 \qquad (18)$$

$$F \quad \frac{F(t)}{a} - \frac{\frac{1}{2}t\,(F(t) - F^*)\,(d + 22(1 \quad)^2)\,^{1}}{\sqrt{\frac{1}{4}r^2 + \frac{b + \bar{P}_A(2\$ - r") + 2(\quad (\quad r(1 \quad))}{d + 22(1- \quad)^2}}} < 0 \qquad (19)$$

Equation (18) replicates the result Stähler obtained: the more the international community's marginal willingness to pay for forest conservation is decreasing in forest size, the smaller becomes the long-run equilibrium forest size. Furthermore, forest depletion occurs faster because of two reasons. First, the higher *b*, the lower the equilibrium forest size and hence the larger cumulative deforestation, which implies that the area deforested in each period should also go up; this is reflected by the first term in equation (19). Second, the path becomes also steeper as parameter *b* also affects the magnitude of the exponential term: the importance of this effect is represented by the second term on the RHS of equation (19).

Hence, it is interesting to see that, although our model differs from that of Stähler (1996), it yields the same results with respect to the long-run forest size. A fixed per-unit compensation scheme (*b* is zero) would increase the long-run equilibrium size unambiguously: the first derivative with respect to *a* is positive. This corresponds to the analysis in section 3. However, the fact that from the international community's point of view there are decreasing marginal benefits associated with forest conservation has a strong impact on the equilibrium size: the more the international community is willing to pay for resource conservation if the forest size decreases (that is, the higher *b*), the lower the long-run equilibrium forest size. This is the Stähler result. Furthermore, as can be seen in equation (19), the instantaneous rates of deforestation will increase, not only because of the effect on the long-run equilibrium size but also because there is an additional incentive. By increasing the current rate of deforestation, the size of the forests is reduced quickly and hence the international community's willingness to pay increases rapidly so that the present value of the revenues is increased. The incentive to increase the rate of deforestation under the prospect that it will induce a higher return is one of the main results of Mohr's (1996) analysis.

When do these undesired results occur? For this specification, the long-run forest size (F^*) will turn out to be smaller than the equilibrium forest size arising without compensation (F_A^*) if the first derivative of the compensation function with respect to the forest size evaluated in the optimal forest size in the absence of a compensation scheme, is negative. In mathematical terms: if $S_F(F_A^*) < 0$, the long-run equilibrium size is reduced (see equation 11) and hence the depletion path is also steeper than in the absence of a compensation scheme. The results can also be illustrated graphically. In figures 1 and 2, using an arbitrary set of parameters, a comparison is made between three cases: 1) the situation without transfers conditioned to the forest stock; 2) the case were transfers are only linearly, and positively, related to the resource stock and 3) the case where a transfer function is used in which both *a* and *b* have positive values.

<insert figures 1 and 2>

The difference between figure 1 and 2 is the value of *b*, which is higher in figure 2. The figures confirm what has been said above: using aid to save the forest area may be very successful when transfers are linearly related to the remaining stock of forest. However, when *b* has a positive value, implying higher transfers when the resource stock declines the end result may be only marginally better than the result without transfers (figure 1), or even worse (figure 2).

One point of critique on the way in which this analysis is presented is that the specification used is continuous while in practice revision of the amount of transfers is likely to take place only once in a while (for example on a yearly basis). If tropical forested countries think that in the future the compensation price will be increased as forest size declines over time, they have an incentive to increase the current rate of deforestation above the rate that would occur if the compensation is not introduced, and also in the long-run cumulative deforestation may be increased. Only if per-unit compensation is not changed for at least several years (or maybe as long as a decade), recipient countries will become convinced that transfers depend linearly on the size of the forest area. This strengthens the case for announcing an explicit function that is actively adjusted every time a revision takes place. A function that is quite credible is one that punishes deforestation: periodically the amount of transfers is reduced on the basis of the (negative) change in forest cover.[7]

This analysis suggests that compensation functions would be more effective if tropical forested countries are confronted directly with the consequences of their behaviour. Hence, it may be useful to let the amount of transfers depend on the *rate* of deforestation. Calculating the first derivatives with respect to c and d reveals that introduction of such a scheme improves both long-run and short-run forest conservation unambiguously. In this scheme, the tropical forested country is punished for converting its forests to agricultural land: parameter c makes clear that the international community does not appreciate a reduction in the forest size, while a positive d reflects that the costs of deforestation are considered to be larger the faster deforestation takes place (the second derivative is negative). Hence, the total amount actually paid is reduced depending on the rate of deforestation.

Concerning the short- and long-run effects of introducing a positive c, the comparative statics results are as follows:

$$\frac{\partial F^*}{\partial c} = r\,\frac{\partial F^*}{\partial a} \tag{20}$$

$$\frac{\partial F(t)}{\partial c} = r\,\frac{\partial F(t)}{\partial a} > 0 \tag{21}$$

Hence, increasing c implies that the long-run equilibrium size is increased while short-run rates of deforestation are reduced solely because total cumulative deforestation is reduced. As can also be seen in equations (11) and (14) that rewarding forest

[7]Of course, there are important problems associated with measuring deforestation, but those problems are not smaller when measuring remaining forest area.

conservation will have a larger positive impact on the long-run equilibrium forest size than conditioning on the *rate* of deforestation: increasing parameter *c* with one unit results in an increase in long-run forest size that is only 100*r*% of an increase in *a* by one unit. The reason is that deforesting a unit at a certain moment only has a one period impact in case of conditioning on the flow indicator while the negative effect lasts forever if conditioning is based on the stock variable. Equation (22) shows that the depletion path is improved solely because cumulative deforestation is reduced.

Concerning introduction of a mechanism to show that the international community has an increasing adversity with respect to deforestation, a compensation function could be introduced with a positive *d*. The first derivatives of the forest size in each period and in the long run with respect to parameter *d* are as follows:

$$\frac{\partial F^*}{\partial d} = 0 \qquad (22)$$

$$\frac{1}{4} r^2 - \frac{\frac{1}{2} t\, (F(t) - F^*)}{\frac{b + \bar{P}_A(2\$ - r") + 2(2((-r(1-()))}{d + 22(1-()^2}} \quad \frac{b + \bar{P}_A(2\$ - r") + 22((-r(1 \quad))}{[d + 22(1-()]^2} > 0 \qquad (23)$$

From these comparative statics it is clear that *d* does not affect F^*: punishing non-linearly on the rate of deforestation will have no effect on long-run forest conservation (anyway, it does not have an *adverse* effect) while it affects the path directly by changing the value of the exponential term. The reasoning is that the marginal reduction of transfers increases with the rate of deforestation so that the recipient country has an incentive to flatten the depletion path over time.

Again, these results can also be illustrated graphically; see figure 3. As can be derived from this figure, letting transfers depend negatively on *D* and D^2 results in improved long-run forest conservation (compared with the situation without any compensations) while it also reduces short-run deforestation compared with a compensation scheme which simply penalises *D*.

<insert figure 3 about here>

5. Derivation of the preferred specification

On the basis of the comparative statics analysis in section 4, two main conclusions can be drawn. First, long-run forest conservation can be improved either by rewarding forest conservation using a fixed per-unit compensation price or by reducing transfers for every unit of land converted. Second, it was argued that the international community's marginal willingness to pay is decreasing with forest size which implies that strategic behaviour of recipient countries may effectively undermine the success of the compensation policy. This can occur when some donor countries examine periodically the success of the previously announced fixed compensation price, and reconsider this compensation price when the effect of the compensation policy falls short of expectations. Recipient countries expecting this behaviour may then decide to anticipate by deliberately increasing the rate of deforestation, and ultimately receive a higher compensation price per unit of forest land. In practice it is quite likely that this occurs so that the success of a policy of monetary compensations for preserving a forest stock primarily depends on the signals which are given by the donor community. Donors should try to avoid signalling their *implicit* willingness to increase the compensation price when the forest stock declines. A possibility to do this is to make clear that a reduction in the forest size is not appreciated by *explicitly* stating that the tropical forested country will be "punished" when the rate of deforestation is positive: it may be sensible for the international community to signal its increasing dislike of deforestation by giving parameter *d* a positive value.

On the basis of the above considerations we propose an explicit compensation function in which developing countries are linearly rewarded for having a positive *stock* of forest, while the amount of donations are, at an increasing rate, negatively related to the *rate* of deforestation. This means that the preferred donation ($\hat{S}$) function becomes:

$$\hat{S}(t) = aF(t) - \frac{d}{2}D(t)^2 \qquad (24)$$

If the donor community signals that the amount of transfers will be reduced quadratically when the rate of deforestation is positive (and of course sticks to its announcement when revision takes place), the tropical forested country will have no incentive to act strategically by increasing the rate of deforestation. In terms of forest conservation, this compensation scheme improves forest conservation in the long run as well as during the adjustment path. This is shown in figure 4, which compares the preferred transfer policy with a policy of only rewarding on the basis of the stock of forest and the policy of no conditionality.

<insert figure 4 about here>

The policy of rewarding on the basis of the forest stock is the preferred policy when forest conservation in long run is aimed at, while a policy of "punishing" quadratically on the rate of deforestation is very effective during the adjustment period. A combination of the two serves both objectives.

6. Conclusions

In this paper an analysis is presented of the consequences of making aid dependent on forest conservation in order to reduce the attractiveness of deforestation from the point of view of tropical forested countries. It is shown that giving a fixed per-unit compensation increases forest conservation unambiguously both in the short and in the long run. However, it is likely that the international community's marginal willingness to pay decreases with forest size. If recipient countries expect that indeed the international community is willing to pay more per unit of forest land the smaller the forest area becomes, they may have an extra incentive to deforest rather than that it becomes less attractive. Even if the international community does not intend to increase per-unit compensation as deforestation continues, it is difficult to convey that signal to the recipient countries: the only way those countries can become convinced that they cannot increase per-unit compensation by increasing the rate of forest conversion is when after several years the compensation price remains fixed while deforestation continues. This implies that until that time tropical forested countries will have deforested at a higher pace than in the absence of a compensation scheme.

It is therefore preferable for the international community to explicitly state a compensation function that closely follows developments in the recipient countries. It is derived that if the compensation function reflects the international community's love for forest conservation but also its increasing (marginal) aversion of deforestation, forest conservation is improved in both the short and long run.

References

Apostol, T.M. (1967), *Calculus Volume I*, John Wiley and Sons, New York, Second Edition

Barbier, E.B., J.C. Burgess, J. Bishop and B. Aylward (1994), *The Economics of the Tropical Timber Trade*, Earthscan Publications, London

Barbier, E.B. and M. Rauscher (1994), "Trade, Tropical deforestation and Policy Interventions", *Environmental and Resource Economics*, **4**, pp. 75-90

Dudley, N., J-P. Jeanrenaud and F. Sullivan (1995), *Bad Harvest? The Timber Trade and the Degradation of the World's Forests*, Earthscan Publications, London

Ehui, S.K. and Th.W. Hertel (1989), "Deforestation and Agricultural Productivity in the Côte d'Ivoire", *American Journal of Agricultural Economics*, **71**(3), pp. 703-711

Ehui, S.K., Th.W. Hertel and P.V. Preckel (1990), "Forest Resource Depletion, Soil Dynamics, and Agricultural Development in the Tropics", *Journal of Economic and Environmental Management*, **18**(2), pp. 136-154

Hecht, S.B. (1985), "Environment, Development, and Politics: Capital Accumulation and the Livestock Sector in Eastern Amazonia", *World Development*, **13**, pp. 663-684

Heller, P.S. (1975), "A Model of Public Fiscal Behavior in Developing Countries: Aid, Investment and Taxation," *American Economic Review*, **65**, pp. 429-445

Hotelling, H. (1931), "The Economics of Exhaustible Resources", *Journal of Political Economy*, **39**, pp. 137-175

Jepma, C.J. (1995), *Tropical Deforestation: A Socio-Economic Approach*, Earthscan Publications, London

Kahn, J. and J. McDonald (1994), "International Debt and Deforestation", Chapter 4 in Brown, K. and D.W. Pearce (eds.), *The Causes of Tropical Deforestation; The Economic and Statistical Factors giving Rise to the Loss of the Tropical Forests*, UCL Press, London

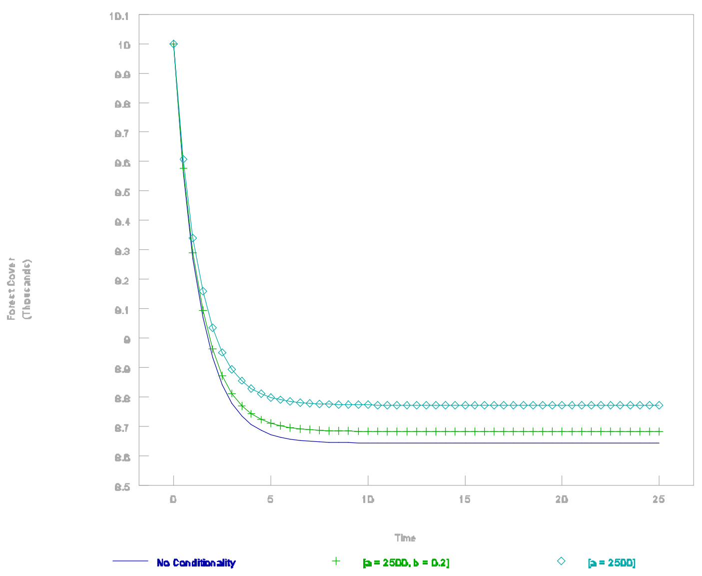
Kamien, M.I. and N.L. Schwartz (1981), *Dynamic Optimization: The Calculus of Variations and Optimal Control in Economics and Management*, North Holland, New York

Mohr, E. (1996), "Sustainable Development and International Distribution: Theory and Application to Rainforests", *Review of International Economics*, **4**(2), pp. 152-171

Rauscher, M. (1990), "The Optimal Use of Environmental Resources by an Indebted Country", *Journal of Institutional and Theoretical Economics*, **146**(3), pp. 500-517

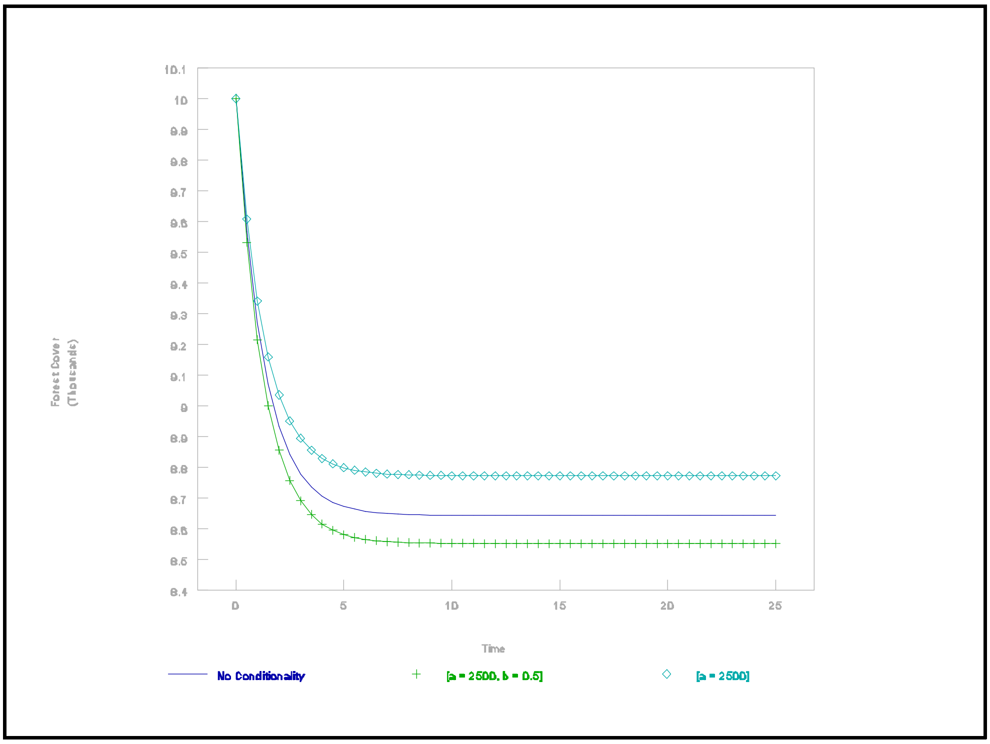
Stähler, F. (1996), "On International Compensations for Environmental Stocks", *Environmental and Resource Economics*, **8**, pp. 1-13

Figure 1: The consequences of conditioning using a fixed per-unit compensation function (a=2500) and a decreasing per-unit compensation function (a=2500, b=0.2), with S_F positive



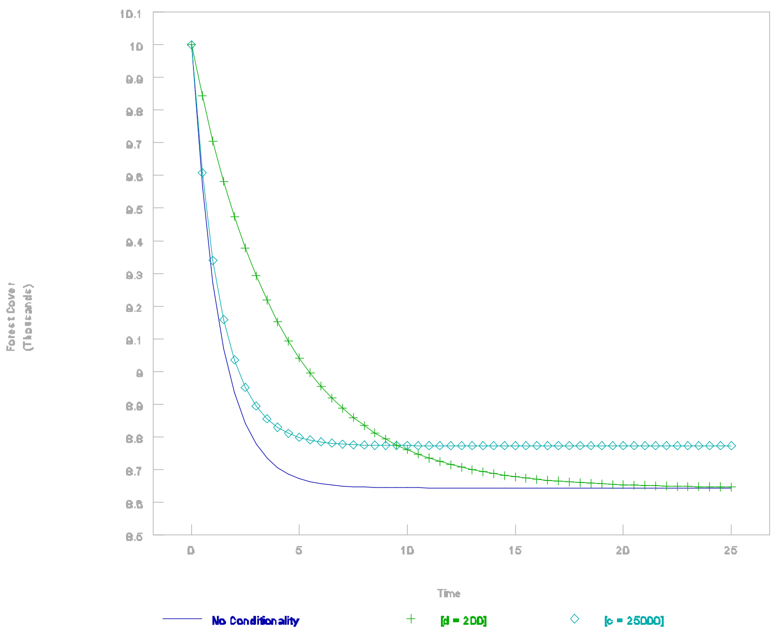
Parameter values: $\overline{P}$=40,000, θ=20, $\overline{P}_A$=100, γ=0.15, r=0.1, $\overline{Z}$=250, α=0.1, β=0.1, F_0=10,000.

Figure 2: The consequences of conditioning using a fixed per-unit compensation function (a=2500) and a decreasing per-unit compensation function (a=2500, b=0.5), with S_F negative



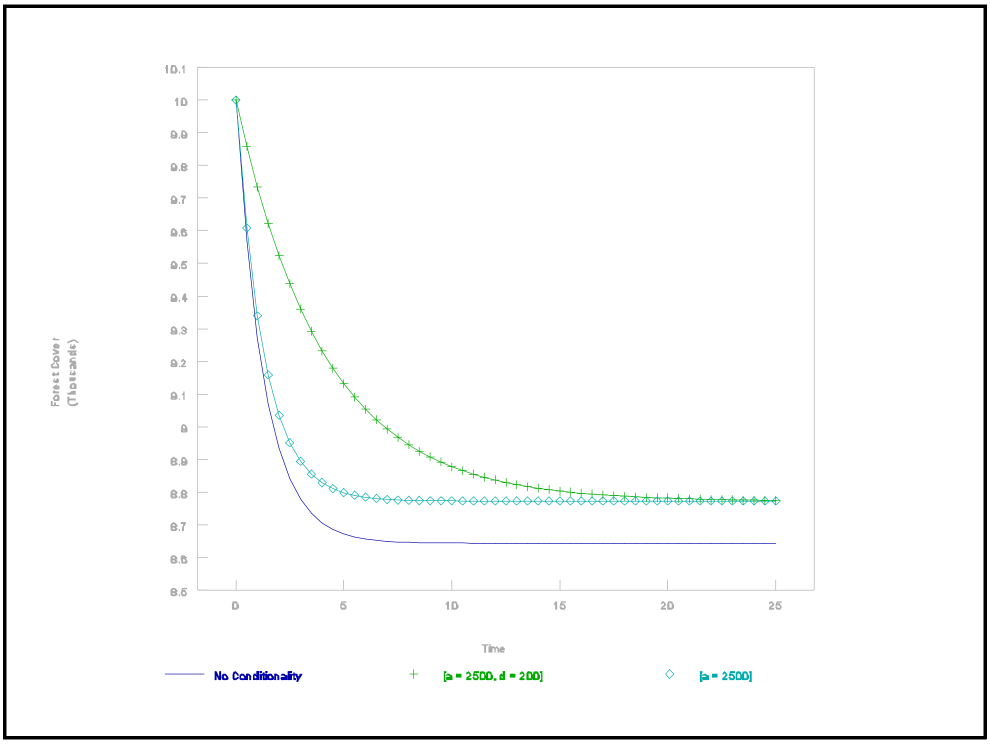
Parameter values: $\overline{P}$=40,000, θ=20, $\overline{P}_A$=100, γ=0.15, r=0.1, $\overline{Z}$=250, α=0.1, β=0.1, F_0=10,000.

Figure 3: The consequences of punishing linearly on current deforestation (c=25000) and quadratically on current deforestation (d=200)



Parameter values: $\overline{P}$=40,000, θ=20, $\overline{P}_A$=100, γ=0.15, r=0.1, $\overline{Z}$=250, α=0.1, β=0.1, F_0=10,000.

Figure 4: The consequences of conditioning using a fixed per-unit compensation function (a=2500) and using the preferred compensation function (a=2500, d=200)



Parameter values: $\bar{P}$=40,000, θ=20, $\bar{P}_A$=100, γ=0.15, r=0.1, $\bar{Z}$=250, α=0.1, β=0.1, F_0=10,000.