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Sustainable development and international distribution: Theory and application to rainforests as carbon sinks

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**Sustainable Development and International Distribution:
Theory and Application to Rainforests as Carbon Sinks**

by

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Abstract:

A situation is analysed in which two countries negotiate the financing of the incremental costs which accrue if one of them switches from a non-sustainable onto a sustainable development path. The other country's incentive to pay arises as it benefits from the developing country's environmental resources, but at an ever declining rate as long as development remains non-sustainable. The paper shows that such negotiations induce a redistribution of income in favour of the developing country which in general will exceed incremental costs. The paper also derives conditions under which the developing country has an incentive to get on a "less" sustainable path in the pre-agreement phase. In an application to the protection of tropical rainforests as carbon sinks it is shown that North to South redistribution of welfare would indeed be substantial. However, despite these transfer payments in excess of incremental costs the North would still gain enormously in efficiency terms from the use of the carbon sink option.

Keywords: Non-cooperative bargaining, environment, North-South cooperation, climate policy

JEL classification numbers: C72, F35, Q20

"States shall cooperate in a spirit of global partnership to conserve, protect and restore the health and integrity of the Earth's ecosystem. ... " [Rio-Declaration, Principle 7]

1. Introduction

In face of the environmental deterioration in LDCs a suggestion is that the North should contribute to the financing of the costs which are necessary to bring LDCs on a sustainable development track. Apart from altruistic motives or ethical responsibilities this request is justified by a claimed self-interest of the North in environmentally sane development in LDCs (e.g. Tham (1992) p. 33): The existence of environmental resources in the South or their services directly benefit the North, so it has a self-interest to protect them, or so the argument goes. The tropical rainforests and their importance for the global climate and for biodiversity are a point in case (Detwiler and Hall (1988), Simberloff (1986)).

There are interesting distributional implications to the proposal as well as to the self-serving motives behind it.

The argument implicitly suggests that some environmental resources have the property of "producing" non-marketable transfrontier services: A resource stock is located in an area under exclusive control of an LDC, but it provides a stream of environmental services some or all of which cannot be prevented from seeping abroad. This control problem obstructs trade in environmental services as the foreign beneficiaries prefer to consume these as a free lunch. Welfare is shifted away from the resource owner towards the free-riders compared to the standard trade in private goods case.

Non-sustainable development, however, changes the incentive structure and the international distribution of welfare. If development deteriorates the resource stock and consequently the international transmission of services then the free-riders have some incentive to pay if in exchange for their contribution the resource owner invests in sustainability. Assuming that the free-riders' benefits from a sustainable path exceed the costs it is suggestive that the developed North pays for the South's incremental costs of sustainable development. Welfare in the South would remain unaffected, but welfare in the North, though smaller than under riding a constant resource stock for free, would be larger than under non-sustainable development.

There is an important caveat to this argument. It addresses the normative question how much the South should obtain. But it does not address the positive question how much the North will pay and the South will receive.

This article addresses this latter question. Applying non-cooperative bargaining theory we explore the relative bargaining power of two countries negotiating transfer payments to achieve sustainable development. We determine and interpret the bargaining equilibrium and investigate the distributive effects.

As an important result we show that a resource owning country, being on a non-sustainable track, is able to obtain transfer payments systematically above the incremental costs of sustainable development. The analysis therefore implies that this type of international environmental cooperation will be more expensive to the North than the normative proposal suggests and that the South will gain in welfare terms.

We apply the bargaining model to the protection of the tropical rainforests for the purpose of climate policy. Using data on actual deforestation rates our simulations suggest that even for the overall very small actual deforestation rates equilibrium payments are substantially above incremental costs; and "tiny" cross-country differences in deforestation rates are associated with "huge" differences in bargaining power and consequently in the spread between transfers obtained and incremental costs incurred.

However, on the basis of numbers for the North's willingness to pay for carbon sequestration as they can be found in the literature and on the basis of land prices as approximations for incremental costs of protecting the forests the North still can buy into these carbon sinks at a fraction of what a domestic CO₂ policy would cost. Hence despite a hefty surcharge the "tree-option" is the efficient one.

An interesting proposition of the analytical model states that for small enough rates of decline of the stream of transfrontier services the resource owner benefits from an increase in that rate even if it also obtains environmental benefits from the resource. The simulations suggests that on the basis of their actual deforestation rates alone, and abstracting from domestic environmental benefits from the stock, virtually all examined countries hosting rain forests have an incentive to artificially boost the rate of destruction in a pre-agreement phase.

The model we use is reminiscent of the standard transboundary pollution problem (Marcusen (1975)). In contrast, however, goods are transferred abroad instead of bads. Also, the problem analysed here features a dynamic aspect of irreversible environmental degradation, which is essential in triggering international

cooperation when non-marketable environmental goods cross borders. In contrast, in the Marcusen model cooperation is possible in a static context.

Our model is also reminiscent of the common pool extraction problem (e.g. Kemp and Long (1980)) with one-directional dissipation. It differs, however, in that in the common pool problem the cross-border flows can be influenced by the recipient while in our model it is exclusively the party in possession of the source which can affect cross-border flows by switching on a sustainable track. Furthermore, in the common pool problem the stock remains constant if extractors remain inactive while in our problem the stock declines when parties are passive.

The two player bargaining game we employ is of the (1,1)-alternating-offer type with complete information. It differs from the standard infinite-horizon constant-size-of-the-pie game (Rubinstein (1982)) in the following respects:

1. During the bargaining process parties receive benefits in money terms from the resource's environmental services.
2. The pie is shrinking while bargaining takes place (Binmore (1987)).
3. The bargaining game is of the finite horizon type (Ståhl (1972)). The terminal bargaining round, T^* , however, is endogenous and can be readily interpreted. The finiteness of the bargaining process is due to an ever narrowing and eventually disappearing spread of benefits from environmental services over incremental costs of sustainable development as long as bargaining goes on.
4. The bargaining game features an eventual incentive to remain silent and not make serious offers anymore while the other party continues to negotiate seriously. In Ausubel and Deneckere (1992) a silence motive is derived under conditions of private information, and a silent party remains so during the entire game. In our perfect information game both parties make serious proposals initially but may become silent later on. Here silence is motivated by the fact that a party making a serious proposal and thus inducing sustainable development one period earlier must fully bear incremental costs for an additional period. These costs are to be compared with the rent the proposer can appropriate by securing a slightly larger resource stock. As this rent decreases during negotiations it eventually pays to remain silent and let the other party incur the additional costs.

The article is organised as follows. In Section 2 the model is developed. An equilibrium bargaining solution for the finite horizon discrete time bargaining model is derived in Section 3, and in Section 4 the endogenous bargaining horizon, T^* , is derived. As for the finite horizon discrete time bargaining model there are in general

four solutions, depending on an arbitrary first and last mover advantage we eliminate this arbitrariness in Section 5 by taking the discrete time model to the limit of continuous bargaining. Section 6 interprets the continuous time solution and derives some propositions. We then apply the bargaining solution to the problem of preserving tropical rainforests as carbon sinks in Section 7. Section 8 concludes the paper.

2. The Model

We consider two countries, one, the resource owner (R), on the territory of which an environmental resource is located, and one, the foreign beneficiary (B), which obtains windfall gains from the services the resource provides.

In period 0 when negotiations between R and B on the financing of sustainable development begin, B receives in money terms a value V_0 from the resource's services. We take it that V_0 is finite. As long as R is on a non-sustainable track B's service value declines over time. We take it that

$$V_t = a^t \cdot V_0 \quad \forall t = 0, 1, \dots, \tau \quad (1)$$

with $a < 1$. τ is the period in which the resource owner switches on a sustainable track.

Before that track is reached the money value of environmental services which R receives is given by

$$W_t = p^t \cdot g \cdot V_0 \quad \forall t = 0, 1, \dots, \tau \quad (2)$$

with $g \geq 0$ and $p \leq 1$. Note that while B's benefit from the resource is always positive but vanishing R neither need benefit from the resource ($g = 0$) nor need it suffer from a resource deteriorating development ($g > 0$ and $p = 1$).

We make the standard "small country" assumption in letting the international price for a unit of services be (and remain) constant. Hence, by assumption, there is a perfect substitute for R's services available to B. Assuming further that services are proportional to the resource stock this implies that the rates of decline also relate to the stock.¹

¹ In allowing different stocks (flows) and rates of decline in both countries the model also accommodates the case where R and B benefit from different properties of the resource, R, say, from biodiversity or a certain species and B, say, from climate services.

The literature offers a bounty of definitions for the concept of sustainable development (for a survey see Pezzey (1989)). There is therefore a large degree of freedom in formalizing sustainability. Fortunately, however, competing definitions seem to differ with respect to necessary rather than sufficient conditions for sustainability: There appears to exist agreement that development is sustainable if the value of the environmental resource stock is non-decreasing. We follow this sufficiency condition in defining sustainability (narrowly) as a constant sequence of period gains from the resource's services. If R switches on a sustainable track in τ

$$V_t = a^\tau \cdot V_0 \quad (3)$$

and

$$W_t = p^\tau \cdot g \cdot V_0 \quad (4)$$

$\forall t = \tau, \tau + 1, \dots$

We assume that sustainability causes total incremental costs S per period. We take it that S is constant over time. Total incremental costs are therefore independent of the remaining resource stock. Although intuitively one might expect S to depend on the remaining stock the functional relationship is not necessarily monotone.² We therefore presume independence implying increasing costs per unit of environmental services as time goes on. This is given, for example, if incremental costs depend on a given acreage whereas the quantity of the resource per acre is declining over time.

Declining environmental services during the bargaining process for B in combination with fixed incremental costs implies a finite time horizon, T^* , for negotiations as for small enough environmental services it does not pay anymore to incur incremental costs. Given the endogenously determined T^* the bargaining solution can be determined recursively.³

2 To sustain a large stock it may suffice to patrol the area (to prevent trespass) needing the fewer patrolmen the smaller the resource. A small stock may require additional nursing, becoming more intensive the smaller the stock. For example, the cumulative costs over the first 24 years of reintroducing 10 pairs of bobcats in the Black Forest in Germany have been estimated to exceed 6 million DM due to the intensive care considered to be necessary (Thor and Pegel (1992)).

3 Note that for a finite T^* to exist it is sufficient that the rate of decline of total period services for the free-rider eventually exceeds the rate of decline of total incremental costs per period.

We take it that $(1+g)V_0 > S$. This ensures that sustainable development pareto-dominates non-sustainable development if agreed on early enough. We also presume for simplicity $S > gV_0$, ensuring that R lacks an incentive to switch to sustainable development unilaterally, i.e. without obtaining transfer payments from B.

Time preferences of players are represented by the constant one period discount factors h , $0 < h < 1$, for R and k , $0 < k < 1$, for B.

The model is closed by defining the bargaining rules. We make the standard presumption of a (1, 1) alternating offer game, where the parties (R and B) take turns in making offers and where a counter offer can only be made after one period has elapsed. The game ends when one party accepts the other party's proposal or when $T+1$ is reached, whatever comes sooner. A proposal in period t is a duple (x_t, S) suggesting an eternal transfer payment per period, x_t , from t onwards from B to R, in exchange for R incurring incremental costs, S , in each future period. We take it that an agreement (acceptance of a proposal) is binding forever.⁴

3. Discrete Time Bargaining

Suppose a finite period T^* exists after which R and B cannot or will not bargain seriously anymore. Which party can make the final transfer proposal x_{T^*} in the final bargaining period T^* depends on who can make the first proposal in $t=0$ and on T^* being odd or even. Suppose B makes the proposal in $t=0$ and suppose T^* is even. Then, by assumption, B makes the proposal in T^* .

In infinite-horizon constant-size-of-the-pie games under complete information rational parties agree already in $t=0$ to avoid the time costs of waiting. In our shrinking-pie game this incentive is reinforced by the incentive of at least one party (B) to stop the resource decline, ceteris paribus the sooner the better. Hence under perfect information R and B will already agree in $t=0$ on (x_0, S) , where (x_0, S) is subgame perfect. Hence $\tau=0$. Given T^* , and given B making the final proposal (in T^*), x_0 can be determined recursively by the following algorithm.

If negotiations are still going on in T^* , an agreement on (x_{T^*}, S) in T^* will induce a period T^* present value to B, $Z_{T^*}^B$, of future net benefits from the resource of

⁴ Due to country sovereignty this assumption is not innocuous. It is, however, in the tradition of noncooperative bargaining theory. Stähler (1993) has recently extended bargaining theory incorporating an enforcement problem after an agreement has been reached.

$$Z_{T^*}^B \equiv (a^{T^*} \cdot V_0 - x_{T^*}) / (1-k)$$

Given $Z_{T^*}^B (V_{T^*}, x_{T^*})$, in order to win an agreement from B in T^*-1 , R must offer at least x_{T^*-1} such that

$$a^{T^*-1} \cdot V_0 + k \cdot Z_{T^*-1}^B (V_{T^*}, x_{T^*}) = Z_{T^*-1}^B \equiv (a^{T^*-1} \cdot V_0 - x_{T^*-1}) / (1-k)$$

making B indifferent between accepting x_{T^*-1} in T^*-1 and an agreement in T^* . R has no incentive to offer more, so x_{T^*-1} is the optimal offer of R given x_{T^*} . An agreement (x_{T^*-1}, S) would give R a present value of future net gains from the resource of

$$Z_{T^*-1}^R \equiv (g \cdot \rho^{T^*-1} \cdot V_0 - S + x_{T^*-1}) / (1-h)$$

where $x_{T^*-1} = x_{T^*-1} (V_{T^*-1}, x_{T^*})$.

Given $Z_{T^*-1}^R (S, V_{T^*-1}, W_{T^*-1}, x_{T^*})$ the optimal offer of

B in T^*-2 , x_{T^*-2} , satisfies

$$g \cdot \rho^{T^*-2} \cdot V_0 + h \cdot Z_{T^*-1}^R (S, V_{T^*-1}, W_{T^*-1}, x_{T^*}) = Z_{T^*-2}^R \equiv g \cdot \rho^{T^*-2} \cdot V_0 - S + x_{T^*-2}$$

from which we obtain the present value $Z_{T^*-2}^B (S, V_{T^*-2}, W_{T^*-2}, x_{T^*})$.

The first offer x_0 , $x_0 = x_{T^*-t}$ for $t = T^*$, can thus be recursively derived. If B also makes the proposal in $t = 0$

$$\begin{aligned} x_0 = & S \cdot (1-h) \cdot \sum_{j=0}^{(T^*/2)-1} (h \cdot k)^j \\ & + V_0 \cdot [(1-a)/a] \cdot \sum_{j=0}^{T^*/2} (h \cdot k)^j \cdot a^{2j} \\ & - g \cdot V_0 \cdot [(1-p)/k \cdot p^2] \cdot \sum_{j=1}^{T^*/2} (h \cdot k)^j \cdot p^{2j} \\ & + h^{T^*/2} \cdot k \cdot x_{T^*} \end{aligned} \quad (5)$$

For the bargaining horizon T^* , corresponding first period offers can be similarly derived for each of the three remaining perturbations of who moves first and last.

Whichever party's turn it is to make the final proposal in T^* , it compares the other party's discounted cumulative gains from the agreement (x_{T^*}, S) with the discounted cumulative gains from the remaining non-sustainable path. If B can make the final offer it is optimal to set x_{T^*} such that

$$(g \cdot V_0 \cdot \rho^{T^*} - S + x_{T^*}) / (1-h) = g \cdot V_0 \cdot \rho^{T^*} / (1-p \cdot h)$$

from which we obtain B's final offer

$$x_{T^*}^B = S - g \cdot V_0 \cdot \rho^{T^*} \cdot \frac{h \cdot (1-p)}{1-h \cdot p} \quad (6)$$

If R can make the offer in T^* , x_{T^*} is such that

$$(a^{T^*} \cdot V_0 - x_{T^*}) / (1-k) = a^{T^*} \cdot V_0 / (1-k \cdot a)$$

from which we obtain

$$x_{T^*}^R = a^{T^*} \cdot V_0 \cdot \frac{k \cdot (1-a)}{1-k \cdot a} \quad (7)$$

Given an exogenous T^* , $0 < T^* < \infty$, the four possible initial offers, one of which is (5), given (6), represent the relative bargaining power arising from the four possible but arbitrary allocations of the first and last mover advantage. In the next section T^* is endogenously determined for the bargaining game and it is shown that T^* is determined by either of three regimes. These have the property that only in one of them the last moving party is arbitrary while in the other two the arbitrary choice of the first mover has no impact on who enjoys the last-mover advantage.

4. The Bargaining Horizon

The effective bargaining horizon, T^* , can be found by considering three periods, T , T_B and T_R , which are critical for the negotiations. The first period, T , relates to the time after which both parties prefer the remaining non-sustainable track over sustainability. After T , an agreement is not feasible anymore. The other two periods, T_B and T_R refer to the time after which B respectively R remain silent to await the other party's offers.

The shrinking size of the pie during negotiations in the face of constant period costs of sustainability, S , sets a finite feasible bargaining horizon for the game, beyond which R and B cannot bargain anymore.

To determine the feasible bargaining horizon T , note that it must satisfy

$$Z_T^R \equiv (g \cdot p^T \cdot V_0 - S + x_T) / (1 - h) \geq g \cdot p^T \cdot V_0 / (1 - h \cdot p) \quad (8)$$

and

$$Z_T^B \equiv (a^T \cdot V_0 - x_T) / (1 - k) \geq a^T \cdot V_0 / (1 - k \cdot a) \quad (9)$$

Conditions (8) and (9) imply that each party must be at least as well off when development becomes sustainable in T as under the remaining non-sustainable path.

Replacing T^* by T in (6) and (7) and upon substituting (6) for x_T in (8) and (7) for x_T in (9) it follows immediately that (8) is fulfilled if B makes the final offer and (9) is fulfilled if R offers last. Hence if R offers last T is restricted by (8), and if B offers last the restriction on T is (9).

Both, substituting (6) for x_T in (9) and rearranging, and substituting (7) for x_T in (8) and rearranging leads to the same condition

$$\frac{a^T \cdot V_0}{S} \geq \frac{1 - k \cdot a}{k \cdot (1 - a)} - \frac{g \cdot p^T \cdot V_0}{S} \cdot \frac{1 - p}{1 - a} \cdot \frac{h}{k} \cdot \frac{1 - k \cdot a}{1 - h \cdot p} \quad (10)$$

T is defined as the largest integer satisfying (10). As the first term on the RHS is positive the bargaining horizon is necessarily finite as $a < 1$ and $V_0 < \infty$. Condition (10) ensures that the party which can make the final offer prefers the agreement (x_T, S) to the remaining non-cooperative and non-sustainable path. Note that (10) holds whichever party moves last. If for $T=0$ (10) is violated then a bargaining equilibrium does not exist. After T , R and B prefer the non-sustainable situation over the sustainable one. Hence existence of a bargaining equilibrium requires $T \geq 0$.

Next consider T_B and T_R . These critical periods take account of the incentive to remain silent when the resource stock is small.

It is necessary for the algorithm described in Section 3 to lead to a subgame perfect x_0 that for $t = 0, 1, 2, \dots$, each party whenever it is up to it to make a proposal does not prefer to remain silent (or make a non-serious offer) in order to accept the

serious proposal to be obtained in the subsequent period. Let T_R and T_B , respectively, be the period in which R and B make their last (serious) offer.

To determine T_R consider any period t in which R makes an offer. To be serious R's offer must leave B with at least $a^t \cdot V_0$ in t and $a^{t+1} \cdot V_0 - x_{t+1}$ thereafter. This implies a gain to R of at most $g \cdot p^t \cdot V_0 - S$ in t and

$x_{t+1} - S + a^t \cdot V_0 \cdot (1-a) + g \cdot p^t \cdot V_0$ thereafter. The cumulative present value of this offer is

$$g \cdot p^t \cdot V_0 - S + \frac{h}{1-h} \cdot [(x_{t+1} - S) + a^t \cdot V_0 \cdot (1-a) + g \cdot p^t \cdot V_0]$$

If R abstains from making a serious offer and accepts the serious offer obtained in $t+1$ R's cumulative present value is

$$g \cdot p^t \cdot V_0 + \frac{h}{1-h} \cdot [(x_{t+1} - S) + g \cdot p^{t+1} \cdot V_0]$$

It follows therefore for R that making a serious offer in t dominates being silent only if

$$\frac{a^t \cdot V_0}{S} \geq \frac{1-h}{h \cdot (1-a)} - \frac{g \cdot p^t \cdot V_0}{S} \cdot \frac{(1-p)}{(1-a)} \quad (11)$$

T_R is given by the largest integer of t fulfilling (11).

Rearranging (11) to yield

$$\frac{h}{1-h} \cdot a^t \cdot V_0 \cdot (1-a) + \frac{h}{1-h} \cdot g \cdot p^t \cdot V_0 \cdot (1-p) \geq S$$

alleviates interpretation. The first term on the LHS is the present value of rents R can appropriate from B in terms of bargaining concessions by securing a larger eternal flow of environmental services for B through a serious offer in t . The second term is the corresponding gain R receives directly from a larger resource stock. It pays to bargain seriously only if the sum of these gains are not exceeded by the additional costs of environmental protection, S , of achieving sustainability one period earlier, as these costs are borne by the party being responsible for this acceleration.

By an isomorphic argument it follows that B bargains seriously in any period t in which it can make an offer if

$$\frac{a^t \cdot V_0}{S} \geq \frac{1-k}{k \cdot (1-a)} - \frac{g \cdot p^t \cdot V_0}{S} \cdot \frac{1-p}{1-a} \quad (12)$$

T_B is given by the largest integer of t satisfying (12).

It follows from (11) and (12) that R's and B's incentive to make serious offers vanishes in finite time.⁵ Furthermore, once a party turns silent it remains so forever, and if it makes a serious offer in any period it does so at all earlier times.

We can now determine the effective bargaining horizon, T^* , which is either T , T_R , T_B or 0. Obviously we need not bother with T_R if $T < T_R$ nor with T_B if $T < T_B$. But consider the case in which either is smaller than T . But suppose both $T_R \geq 0$ and $T_B \geq 0$. Then, once a party turns silent it is optimal for the other party to make and maintain forever the minimal win offer, which is given by (6) for B's offer and by (7) for R's offer, if we replace T^* by t . As that offer is declining over time the silent party accepts the offer of the other party at the first possible instance after it ceases to make serious proposals itself.

The silence motive in this complete information game therefore imposes a restriction on the effective bargaining horizon T^* (as opposed to the feasible one, T). Restrictions (10)-(12) together require the effective bargaining horizon, T^* , to satisfy

$$\frac{a^{T^*} \cdot V_0}{S} \geq \max \left[\begin{array}{l} \frac{1-k \cdot a}{k \cdot (1-a)} - \frac{g \cdot p^{T^*} \cdot V_0}{S} \cdot \frac{1-p}{1-a} \cdot \frac{h}{k} \cdot \frac{1-k \cdot a}{1-h \cdot p}, \\ \frac{1-h}{h \cdot (1-a)} - \frac{g \cdot p^{T^*} \cdot V_0}{S} \cdot \frac{1-p}{1-a}, \\ \frac{1-k}{k \cdot (1-a)} - \frac{g \cdot p^{T^*} \cdot V_0}{S} \cdot \frac{1-p}{1-a} \end{array} \right] \geq \frac{a^{T^*+1} \cdot V_0}{S} \quad (1)$$

provided $T \geq 0$, $T_R \geq 0$ and $T_B \geq 0$. Hence from (10) - (13) $T^* = \min(T, T_R, T_B)$ if neither T , T_R or T_B is negative. Condition (13) represents three possible regimes determining the effective bargaining horizon.

Note that (6) and (7) in conjunction with (13) in general imply an arbitrary last mover advantage in the regime in which neither party turns silent in T^* . This is because the arbitrary last (due to the arbitrary first) mover makes the minimal offer (6) or (7) to appropriate for itself more than the discounted cumulative benefits of the

5 The party which is more impatient (in terms of h and k) turns silent earlier.

remaining non-sustainable track. The arbitrary last mover advantage arises as $x_{T^*}^R \neq x_{T^*}^B$ if the LHS exceeds the RHS of (13) in that regime.

Note that in the other two regimes, although $x_{T^*}^R \neq x_{T^*}^B$, the last mover advantage is not arbitrarily determined by the selection of the first mover. This is because in both these cases the final move is always made by the non-silent party irrespective of which one moves first. Hence in these regimes there exist only two possible initial offers depending on who moves first.

Also note that as all offers in $t = 0, 1, 2, \dots, T^*$ are serious the algorithm described in Section 3 implies that x_0 is subgame perfect.

Now consider the case $T \geq 1$ and either $T_B < 0$ or $T_R < 0$. In this case one party never starts bargaining seriously. It is straightforward that then the other party offers in $t=0$ or $t=1$ and thereafter (up to $\min(T, T_B)$ respectively $\min(T, T_R)$) the minimum offer (6), respectively (7), where T^* is replaced by t . Apparently the best a party can do which is silent from the beginning is to accept the minimum offer of the other party instantaneously.

Finally consider the case $T \geq 0$, $T_R < 0$ and $T_B < 0$. It can be easily checked that this case is feasible. It implies that when negotiations begin both parties want the agreement ($T \geq 0$) but both would also want to remain silent, given the other party spoke out ($T_R, T_B < 0$).

This case can be treated as a static 2×2 non-cooperative game. Obviously, remaining silent cannot be an optimal strategy if the other party remains silent too. The same can be said of an outcome in which both spoke out. However, if either spoke out and the other remained silent none had an incentive to defect. Hence an equilibrium requires either party to be silent and the other to make proposals. For reasons already given both parties then agree already on the first proposal made.⁶

There are two equilibria in this case irrespective of which party can move first. The first equilibrium involves B making a proposal (in $t=0$ or $t=1$), given by (6), where T^* is replaced by $t=0$ or $t=1$. The second involves R making a proposal, in either $t=0$ or $t=1$, given by (7), where T^* is replaced by $t=0$ or $t=1$.⁷

6 Also note that the party which plays the part of the proposer does so in the first possible instance. This is because from (11) and (12) the incentive to remain silent is weakest at the beginning of negotiations.

7 Note that in the case $T \geq 0$, $T_R < 0$, $T_B < 0$ an equilibrium selection cannot be undertaken on the basis of who moves first. This is because if the first mover is silent in $t=0$, which would correspond to her most preferred outcome, the game ends at the earliest in $t=1$. But in $t=1$ the other party is the first mover in a new game starting in $t=1$.

5. Continuous-Time Bargaining

In this section we eliminate the arbitrary first and possibly arbitrary last mover advantage. We thus reduce the four (or two) possible bargaining solutions corresponding to the four (or two) permutations of these advantages to a single solution. In infinite-horizon constant-size-of-the-pie games the first mover advantage can be eliminated by randomizing the identity of proposers in each period or by making the period length infinitesimal (Sutton (1986)). We apply the second method in eliminating the first mover advantage. We show that thereby an arbitrary last mover advantage is also eliminated.

Let the time delay between successive proposals be Δt and let $\Delta t = T^*/n$, where n is the number of proposals which can be made in the interval $[0, T^*]$. The continuous time bargaining equilibrium equivalent to (5) can be derived by letting $\Delta t \rightarrow 0$ and $n \rightarrow \infty$. It is

$$\begin{aligned}
 x_0 = & S \cdot \frac{1-h}{1-h \cdot k} \cdot \left[1 - e^{-(1-h \cdot k)T^*/2} \right] \\
 & + V_0 \cdot \frac{1-a}{1-h \cdot k \cdot a^2} \cdot \left[1 - e^{-(1-h \cdot k \cdot a^2) \cdot T^*/2} \right] \\
 & - g \cdot V_0 \cdot \frac{1-p}{1-h \cdot k \cdot p^2} \cdot \left[1 - e^{-(1-h \cdot k \cdot p^2) \cdot T^*/2} \right] \\
 & + e^{-(1-h \cdot k)T^*/2} \cdot x_{T^*}
 \end{aligned} \tag{5'}$$

The condition for the effective bargaining horizon (13) is replaced by

$$\frac{e^{-(1-a) \cdot T^*} \cdot V_0}{S} = \max \left[\begin{array}{l} \frac{1-k \cdot a}{k \cdot (1-a)} - \frac{g \cdot e^{-(1-p) \cdot T^*} \cdot V_0}{S} \cdot \frac{1-p}{1-a} \cdot \frac{h}{k} \cdot \frac{1-k \cdot a}{1-h \cdot p}, \\ \frac{1-h}{h \cdot (1-a)} - \frac{g \cdot e^{-(1-p) \cdot T^*} \cdot V_0}{S} \cdot \frac{1-p}{1-a}, \\ \frac{1-k}{k \cdot (1-a)} - \frac{g \cdot e^{-(1-p) \cdot T^*} \cdot V_0}{S} \cdot \frac{1-p}{1-a} \end{array} \right] \tag{13'}$$

provided $T \geq 0$, $T_R \geq 0$ and $T_B \geq 0$. Note that under continuous bargaining, T , T_R and T_B , respectively, are determined by the equality of the LHS and the first, second and third term on the RHS of (13') if T^* is replaced by T , T_R and T_B . For $T \geq 0$ and either $T_B < 0$ or $T_R < 0$ then the effective bargaining horizon is $T^* = 0$. The same holds if both T_B and T_R are negative but $T \geq 0$.

Let regime I, II and III respectively be that in which T^* is determined by the first, second or third term on the RHS of (13').

The final offers at the effective bargaining horizon T^* are now

$$x_{T^*}^B = S - g \cdot e^{-(1-p) \cdot T^*} \cdot V_0 \cdot \frac{h \cdot (1-p)}{1-h \cdot p} \quad (6')$$

and

$$x_{T^*}^R = e^{-(1-a) \cdot T^*} \cdot V_0 \cdot \frac{k \cdot (1-a)}{1-k \cdot a} \quad (7')$$

In the bargaining equilibrium defined by (5'), (6'), (7') and (13') the first-mover advantage is removed. We now show that a last-mover advantage, if arbitrary (as is the case in regime I), is also removed if bargaining is continuous.

Under continuous bargaining a choice of who moves first does not predetermine in regime I who can make an offer in T^* . This is because for $\Delta t \rightarrow 0$ there is an infinite number of possible offers and counter-offers in $[0, T^*]$ if $T^* > 0$. This creates an indeterminacy as to whether $x_{T^*}^R$ or $x_{T^*}^B$ will be the final offer in regime I.

It follows, however, from (6'), (7') and (13') that $x_{T^*}^R = x_{T^*}^B$ if T^* is determined under regime I. As both parties would make the same final offer, the bargaining equilibrium is not affected by the arbitrariness of the final mover under continuous bargaining.

Note that the continuity of bargaining does not affect the non-arbitrariness of the last mover advantage in regimes II and III. Consider, for example, regime II. In this case R turns silent in $\lim_{\Delta t \rightarrow 0} (T^* - \Delta t)$ to accept B's offer x_T^B in $\lim_{\Delta t \rightarrow 0} (T^* + \Delta t)$. Hence in regime II the final offer is given by (6'). By a similar argument the final offer in regime III is given by (7').

Having eliminated all first and all arbitrary last mover advantages the four (under regime I) or two (under regimes II and III) possible initial proposals converge. We therefore can take (5') as the initial proposal for any choice of first (and induced last) moving party.

We summarize Sections 3-5 by

Theorem 1: Under continuous time bargaining a bargaining equilibrium exists only if $T \geq 0$. If $T \geq 0$, $\tau=0$ and the equilibrium period transfer payment from B to R, x_0 , is

a) unique and given by $x_0 = x_{T^*}^B$, where $x_{T^*}^B$ is given by (6') with $T^*=0$, if $T_B \geq 0$ and $T_R < 0$

b) unique and given by $x_0 = x_{T^*}^R$, where $x_{T^*}^R$ is given by (7') with $T^*=0$, if $T_B < 0$ and $T_R \geq 0$

c) not unique with x_0 given as under either a) or b) if $T_B < 0$ and $T_R < 0$

d) unique and given by (5'), where T^* , $T \geq T^* \geq 0$, is given by (13') and

(i) $x_{T^*} = x_{T^*}^R = x_{T^*}^B$ if $T^* \equiv \min(T, T_R, T_B) = T$

(ii) $x_{T^*} = x_{T^*}^B$ if $T^* \equiv \min(T, T_R, T_B) = T_R$

(iii) $x_{T^*} = x_{T^*}^R$, otherwise,

in case $T_B \geq 0$ and $T_R \geq 0$.

The interesting case is d). In the next section we explore its properties.

6. Properties

We analyse the properties of the transfer payments from B to R induced by the bargaining equilibrium of case d) in Theorem 1. In most of the analysis we assume $a \in]-1, 1[$, i.e. we take it that the rate of decline of environmental services for B is in this sense moderate.

From (13') it immediately follows

Lemma 1: The bargaining horizon, T^* , is an increasing function of V_0/S .

Hence the more of the services can be sustained with 1 \$ the longer can R and B haggle without forsaking the chance for an eventual agreement.

Let $g=0 \vee p=1$. In this case only B suffers from the resource decline. This situation is extreme in shifting onto the side of B the relative loss of letting opportunities to agree fade away. The third term in (5') vanishes and (13') is given by

$$\frac{e^{-(1-a) \cdot T^*} \cdot V_0}{S} = \max \left[\frac{1-k \cdot a}{k \cdot (1-a)}, \frac{1-h}{h \cdot (1-a)} \right] \equiv \psi \quad (13'')$$

For $g=0 \vee p=1$ B will not turn silent as long as cooperation dominates non-cooperation. T^* is therefore determined either by regime I or II. From (i) or (ii) of Theorem 1 and (6') it follows therefore $x_{T^*}=S$.

From Lemma 1 there exists V_0^{\min} such that $T^*=0$. Upon using (5') it immediately follows

Lemma 2: Given $g=0 \vee p=1$, for $V_0 = V_0^{\min} \Leftrightarrow T^*=0, x_0=S$.

Hence if only B suffers from the resource decline and if the bargaining horizon gives R no opportunity to use the declining resource stock strategically then B's transfer payment is equal to the incremental costs of sustainable development. In this situation bargaining over sustainable development does not affect net income and welfare in the resource owning country while it increases welfare, compared to the non-sustainable track, in the country benefitting from the resource's existence.

The following proposition is important.

Proposition 1: Given $g=0 \vee p=1$, if $V_0 > V_0^{\min} \Leftrightarrow T^* > 0$, a sufficient condition for $x_0 > S$ is $a \in]-1, 1[$.

The proof of Proposition 1 is given in the Appendix.

Compared to the case $T^*=0$, if $T^* > 0$ bargaining power is shifted towards the resource owner as it is able to use the fading resource strategically to obtain transfer payments in excess of incremental costs. The resource owning country can secure for itself a net transfer income. Negotiating sustainability is therefore a vehicle to obtain an "export" income for the supply of international services the resource owner cannot obtain from market participation due to the fleeting nature of these services. Bargaining over sustainable development shifts welfare from the beneficiary of environmental services to the resource owning country. Note that Proposition 1 states that a sufficient condition for this welfare shifting and income creating effect is that the rate of decline of the resource is not extremely large.

Now consider the general case $g \geq 0, p \leq 1$.

From (5'), (6'), (7') and (13') x_0 is continuous and differentiable in g . From Proposition 1 it therefore follows

Corollary 1: If $T^* > 0$ if $g = 0$, then there exists $\varepsilon_1, \varepsilon_1 > 0$, such that $x_0 > S$ if $0 < g < \varepsilon_1$.

Hence if R possesses sufficient bargaining power to negotiate a net transfer income if it does not benefit from the resource directly (which is the case if $T^* > 0$), then it also obtains a transfer income above the necessary incremental costs if it directly but moderately benefits from the resource's existence. Note, however, that in the case $g > 0$ and $p < 1$, it is not necessary that $x_0 > S$ for R to gain in welfare terms. With $g > 0$ and $p < 1$, R can agree to pay for part of incremental costs and still be better off than without an agreement.

Let $\gamma \equiv S/V_0$. Hence $\gamma, \gamma < 1$, is the cost necessary to sustain one unit of the resource's services for B. Let $g \geq 0$ and $p \leq 1$. Dividing (5'), (6') and (7') by V_0 it follows that for a given γ and T^* the transfer payment per service unit, x_0/V_0 , is independent of V_0 . From Lemma 1 it therefore follows $d(x_0/V_0)/dV_0 = 0$ if γ is constant.

Consider n strategically independent negotiations between B and n resource owners $R_i, i = 1, \dots, n$.

It then follows immediately

Proposition 2:

If $a_i = a_j, g_i = g_j, p_i = p_j$ and $h_i = h_j$, then $x_0^i / V_0^i = x_0^j / V_0^j$ if $\gamma^i = \gamma^j$

$$\forall V_0^i \neq V_0^j, i, j = 1, \dots, n.$$

Proposition 2 states that the sheer size of the resource stock (or of its services) has no impact on the bargaining power if γ is constant. Other things being equal a large resource owning country is therefore unable to negotiate a larger transfer per resource (or service) unit compared to a small resource owner if the quantity of resources which can be sustained by 1 \$ is the same in both.

Let $x_0/V_0 \equiv \phi(\gamma)$. It follows

Corollary 2: Given $\gamma, x_0 - S = [\phi(\gamma) - \gamma] \cdot V_0$, with $\phi(\gamma) - \gamma < 1$. If $g = 0 \vee p = 1$ then $0 \leq \phi(\gamma) - \gamma < 1$.

Proof of Corollary 2 is given in the Appendix.

Net total period gains for R increase by less than the resource size if the feasible milage per \$, $1/\gamma$, remains constant. If $g > 0$ and $p < 1$ R and B can agree on transfer payment below necessary costs S . If $\phi(\gamma) - \gamma < 0$ this is the case. Then Corollary 2

states that the total contribution of R to the financing of sustainability is linear in V_0 with slope $|\phi(\gamma) - \gamma|$.

We have shown in Proposition 1 and Corollary 1 that a resource owning country can obtain net income and increase its welfare when negotiating sustainability. Critical to this income and welfare increasing opportunity is the resource owner being on a non-sustainable track initially. A natural question then is whether transfer payments are larger if R is initially on a track which is "less" sustainable. Put differently, does a resource owning country have an incentive to shift on an environmentally more destructive path in order to create a larger bargaining leverage in future negotiations?

We can make

Proposition 3: If $g = 0 \vee p = 1$ there exists $\epsilon_2, \epsilon_2 < 1$, such that $\epsilon_2 < a < 1$ is sufficient for $dx_0/da < 0$.

Proof of Proposition 3 is given in the Appendix.

Consider the general case $g \geq 0, p \leq 1$. Suppose R's own rate of decline of environmental services is linked to B's rate by a continuous, differentiable and finitely sloped function $p = \mu(a)$. By continuity and differentiability of x_0 in g it follows immediately from Proposition 3

Corollary 3: Given a continuous, differentiable, and finitely sloped function $p = \mu(a)$, for each $a \in]\epsilon_2, 1[$ there exists $\epsilon_3, \epsilon_3 > 0$, such that $dx_0/da < 0$ if $0 < g < \epsilon_3$.

Proposition 3 implies that at least for a small enough rate of decline a resource owner not affected by environmental deterioration indeed obtains better terms on x_0 if the other bargaining party's rate of decline increases. Corollary 3 implies that whenever this is true it is at least also true if R directly benefits from the resource's services a little bit. Given R's inability to earn regular export income from the sale of environmental services this creates a moral hazard effect on the side of resource owning countries: If you find yourself being on a sustainable track get off; and if you are off, at least if you are only slightly so, get further off.⁸ It should be mentioned, however, that the implicit assumption behind Proposition 3 and Corollary 3 is that switching between different non-sustainable development tracks is costless or sufficiently cheap.

8 In an earlier work (Mohr, 1990) this "burn-thy-forest" incentive has been heuristically derived in a constant-size-of-the pie, infinite-horizon bargaining game, where the rate of decline of foreign benefits is represented by an exogenous increase in the foreign beneficiary's rate of pure time preference.

From a bargaining theoretic perspective the underlying reason for these results is a simple one. If R is not or less affected by environmental deterioration it can exert additional pressure on B by allowing faster deterioration. Note, that in the bargaining game this haggling on the back of nature is not detrimental to it as parties agree already in $t=0$. Contrary to the accelerated destruction incentive, which appears to be rather robust, this latter property is an artefact of the bargaining game not possessing much empirical relevance.

It is interesting to investigate the international distribution in the case in which R and B are identical except for the resource ownership. To that end suppose now $g=1$, $a=p$ and $h=k$. A well-known result of non-cooperative bargaining theory states that in a constant-size-of-pie, infinite-horizon game identical parties split the pie evenly (e.g. Sutton, 1986). In our model this would imply $x_0 = S/2$. We can, however, make

Proposition 4: If R and B are identical except for the resource ownership, if $h=k < 1$ then $x_0 \geq S/2 \Leftrightarrow T^* \geq 0$.

Proof of Proposition 4 is given in the Appendix. The following corollary is also proved in the Appendix:

Corollary 4: If R and B are identical except for the resource ownership, then $\lim_{h \rightarrow 1} x_0 = S/2 \forall T^* \geq 0$

Proposition 4 and Corollary 4 imply that the difference in resource ownership alone fails to shift bargaining power and welfare from B to R only if the parties also fail to be impatient. With impatient parties the difference in resource ownership alone suffices to twist bargaining power and welfare in favour of the resource owning country compared to an equal sharing of incremental costs. Countries on the territory of which environmental resources are located, which supply the world with services to be consumed in equal quantities by all, do possess an owner advantage in negotiating sustainability.

In the next Section we apply the theory to the protection of tropical rainforests for the purpose of carbon sequestration.

7. Application

Huge quantities of carbon are contained in the world's tropical rainforests. In as much as the rainforests disappear carbon is released in the form of CO_2 into the atmosphere, thus contributing to the greenhouse effect. Protecting the rainforests, for the purpose of locking carbon in, can be treated in the framework developed.

The rainforests are a resource owned by nations on the territory of which they are located. As the resource holds back carbon it produces transboundary environmental services as the temperature increase which is said to adversely affect the North is thereby slowed down and the total increase is smaller. The resource owners cannot "hold back" these services, so the North would have the luck to get them for free were the rainforest owning countries on a sustainable development track which preserves the stock. However, the rainforests are on the decline and with them the climate services they provide. This sets the stage for international negotiations on sustaining them. In this section we apply the model to this problem. We explore whether in face of the surcharges to be paid carbon sequestration in the South is still efficient for the North. We also explore the distributive effects of this form of international climate cooperation.

The rainforest countries we study are listed in Table 1. The first column gives the total size of their rainforests and the second column gives the size as a percentage of the world stock. Table 1 contains all tropical rainforest countries with a stock of more than 2 % of the world total (including non-tropical forests).⁹ The third column gives the actual country specific annual deforestation rates in per cent $((1-a) \cdot 100)$.

The next two pairs of columns give bargaining equilibria of bilaterally negotiating sustainability of the rainforests between the North and each of the countries listed. We know from Proposition 2 that the total size of a country's rainforest stock does not affect the bargaining equilibrium. We can also infer from Corollary 2 that the equilibrium ratio, x_0/S , of international transfer payments (from the North to a specific forest owning country) x_0 relative to the necessary costs of preserving the rainforest, S , does depend only on the ratio, V_0/S , of the North's money value of the rainforest's services, V_0 , and incremental costs, S .

9 With the exception of Bangladesh and New Guinea for reasons given shortly.

Table 1: The Pure Effect of Differing Rates of Decline

	Stock of Closed Forests (000 hectares)	Stock of Closed Forests (Percent)	Deforestation rates in % ((1-a)·100)	x_0/S	T	x_0/S	T
Bolivia ¹	44,010	3.1	0.2	5.11	1094	1.79	405
Brazil ¹	357,480	24.9	0.5	10.67	596	3.61	338
Columbia ¹	46,400	3.2	1.8	24.87	214	10.31	157
Mexico ¹	46,250	3.2	1.8	24.87	214	10.31	157
Peru ¹	69,680	4.9	0.4	8.97	699	3.02	370
Venezuela ¹	31,870	2.2	0.4	8.97	699	3.02	370
Zaire ²	105,750	7.4	0.4	8.97	699	3.02	370
India ²	36,540	2.5	0.1	2.91	1541	1.16	128
Indonesia ²	113,895	7.9	1.1	18.65	323	6.91	219
Total	851,875	59.3					
World	1,436,492 ³	100					

¹Calculations of a are based on annual deforestation rates for the 1981-1985 period (Amelung/Diehl (1992); own calculations)

²Rates of decline as reported by the World Resources Institute (1990).

³Total Forest Area in Africa, Asia, Oceania and Central & South America. (World Resources Institute (1990))

⁴ $g=0$, $h=k=0.98$, $V_0=100$, $S=1$

⁵ $g=0$, $h=k=0.92$, $V_0=100$, $S=1$

Calculations of the equilibrium surcharge x_0/S for both bargaining situations are based on a fictitious ratio V_0/S of 100:1, common to all countries. This ratio allows for a ready interpretation of the bargaining equilibrium in terms of percentage surcharges on S or percentage gains relative to the North's fictitious willingness to pay, V_0 . As the size of the stock is irrelevant and as V_0/S is taken to be the same for all, countries are therefore taken in Table 1 to be identical except for the rate of decline of their rainforests. Table 1 gives therefore the pure effect of differing rates of decline on the bargaining solution.

The first column of bargaining solutions, given by the ratio x_0/S and the equilibrium bargaining horizon T (in years), is based on an annual discount rate $((1-h)·100=(1-k)·100)$ of 2%, common to the North and each of the countries listed. This discount rate is advocated by Cline (1992) to be appropriate when evaluating climate policy. The second set of bargaining solutions supposes a larger discount rate of 8% which is more in line with the current World Bank evaluation practices (Birdsall and Steer (1993)). All the other calculations reported in this section (Tables 2-5) are based on an 8% discount rate.

Table 2: Effects of "Conservative" Climate Policies

	S^1	V_0/S^2	V_0/S^3	V_0/S^4	V_0/S^5
Bolivia	63	2.87	5.58	9.73	11.65
Brazil	150	1.20	2.33	4.07	4.87
Columbia	193	0.93	1.81	3.16	3.78
Mexico	239	0.75	1.46	2.55	3.05
Peru	93	1.94	3.77	6.57	7.86
Venezuela	164	1.10	2.14	3.73	4.46
Zaire	236	0.76	1.48	2.59	3.09
India	519	0.35	0.67	1.17	1.41
Indonesia	445	0.40	0.79	1.37	1.64

¹The price per ha land, S , is calculated as follows: The Brazilian land price of 150 \$/ha (Schneider (1993)) is weighted by an index based on the ratio of the 1990 national value added in agriculture (World Bank (1992)) and the total national stock of cropland and permanent pastures (World Resource Institute (1990)).

²Nordhaus (1991): Low estimate: $V_0=180$ US\$/ha

³Penny a Gallon of Gas: $V_0=350$ US\$/ha

⁴Enacted Tax: Finland $V_0=610$ US\$/ha (Schneider (1993))

⁵Nordhaus (1991): Medium estimate: $V_0=730$ US\$/ha

In this section all calculations of transfer payments are based on the assumption that countries owning rainforests are themselves not affected by climate change. This assumption in turn implies that they do not benefit from their rainforests' climate services. This correspond to the case $g=0$ in the analytical model. From Theorem 1, case d), and (13") it then follows $T < T_B=T_R$ as we presume $h=k$. Hence in the application neither party turns silent before both lose their interest in reaching an agreement. The equilibrium effective bargaining horizon is therefore indeed $T^*=T$.

The assumption that some countries are completely insulated against the greenhouse effect is actually incorrect (e.g. Hasselmann (1991)). However, climate models suggest that this assumption is more innocuous the closer a country is to the equator (as changes in average temperatures would be concentrated at higher latitudes), the more humid a region is (as arid and semi-arid regions are more vulnerable to changes in humidity) and the less vulnerable a country is to sea level rises (e.g. Enquete (1989)). This suggests that the earth's tropical rainforest belt is less affected by climate change. For simplicity and lack of data on the costs of climate change in this region we represent this in the calculations by setting $g=0$ for all rainforest owning countries.¹⁰

Tables 2-5 depart from the assumption of a uniform and fictitious ratio of 100:1 for V_0/S . Instead, in Tables 2-5 incremental costs are taken to depend on the price of

¹⁰ Because of its vulnerability to a sea level rise we have excluded Bangladesh from the calculations.

land to be converted from forest to agricultural use (Schneider (1993)). In other words, it is presumed that to sustain a hectar of rainforests it must be bought thereby preventing conversion.

Table 3: Effects of Dutch and Swedish Enacted Carbon Tax

	V_0/S	x_0/S	$x_0/V_0^{1/2}$	T
Bolivia	71.79	1.43	0.02	236
Brazil	30.00	1.45	0.05	98
Columbia	23.32	2.80	0.12	76
Mexico	19.81	2.36	0.13	65
Peru	48.48	1.73	0.04	189
Venezuela	27.49	1.20	0.04	47
Zaire	19.09	-	--	-
India	8.67	-	--	-
Indonesia	8.67	1.23	0.11	12
Average ²	22.96	1.49	0.06	77

¹Enacted Tax: Netherlands and Sweden: $V_0=4500$ US\$/ha (Schneider (1993))

²Parameter values of all countries except Zaire and India are weighted by the relative size of the resource; $a=0.993$.

The first column in Table 2 gives the land price per hectar of rainforest for the countries listed. The equilibrium transfers from the North to these countries, reported in Table 3-5, are based on these prices. The land price in \$ for a hectar of Brazilian forest is that which is used in Schneider (1993).¹¹ For lack of similar data for the other countries we induce relative differences of incremental costs by weighting the price of 150 \$/ha with an index for the relative productivity of agricultural land in the other countries¹².

Tables 2-5 differ with respect to the value used for V_0 . We represent V_0 by the requested or revealed willingness to pay of the North as it can be inferred from cost-benefit analyses of climate policy, from existing greenhouse gas taxes, or from otherwise proposed or considered greenhouse policies. In that we follow again Schneider (1993) and examine the willingnesses to pay listed there.

11 Schneider lists several land prices which vary substantially across Brazilian provinces. He bases his own cost-benefit analysis of investing in the Brazilian carbon sink on the relatively high price of 150 \$/ha.

12 The land price for New Guinean forest thus induced is prohibitively high thus making negotiations on its preservation impossible. New Guinea is therefore excluded from the list of countries possessing 2% or more of the total stock of forests.

Table 4: Effects of Nordhaus' High Estimate

	V_0/S	x_0/S	$x_0/V_0^{1/2}$	T
Bolivia	105.30	1.86	0.02	428
Brazil	44.00	1.88	0.04	174
Columbia	34.20	3.87	0.11	98
Mexico	27.61	3.22	0.12	86
Peru	71.12	2.29	0.03	284
Venezuela	40.32	1.52	0.04	142
Zaire	27.99	1.22	0.04	51
India	12.72	-	-	-
Indonesia	14.84	1.46	0.10	46
Average ^{/2}	32.84	1.91	0.06	128

^{/1}Nordhaus (1991): High estimate: $V_0=6600$ US\$/ha

^{/2}Parameter values of all countries except India are weighted by the relative size of the resource; $a=0.993$.

Table 5: Effects of 1990 CBO Study

	V_0/S	x_0/S	$x_0/V_0^{1/2}$	T
Bolivia	159.54	2.54	0.02	636
Brazil	66.67	2.58	0.04	258
Columbia	51.81	5.60	0.11	121
Mexico	41.81	4.62	0.11	109
Peru	107.74	3.20	0.03	388
Venezuela	61.09	2.04	0.03	246
Zaire	42.41	1.58	0.04	155
India	19.28	-	-	-
Indonesia	22.48	1.75	0.09	70
Average ^{/2}	49.75	2.63	0.05	187

^{/1}Estimate of the Congressional Budget Office: $V_0=10,000$ US\$/ha (Schneider (1993))

^{/2} see ^{/2} in Table 4.

Values of V_0 are calculated presuming that presently 100 tons of carbon are sunk in an average hectare of rainforest throughout the world, which would eventually be released into the atmosphere if countries stay on a non-sustainable track.¹³

On the basis of 100 tons of carbon released if a hectare of rainforest is completely destroyed the inclinations to pay represented in Table 2 are 180 \$/ha, 350 \$/ha, 610 \$/ha and 730 \$/ha respectively. They represent the willingness to pay as it is implied by 1. the low cost estimate of Nordhaus (1991), 2. a tax of a penny a gallon of gas, 3. the enacted Finnish carbon tax and 4. the Nordhaus (1991) medium

¹³ This is the net release used in Schneider (1993). This quantity varies, however, depending on the quality of the natural biotope as well as on the past and present economic activity in it. Note that the assumption of homogeneity of rainforests is the more justified the larger the total forest area which is to be covered by a carbon sink policy.

estimate. The calculation of equilibrium payments in Table 3 is based on a willingness to pay of 4500 \$/ha as is implied by the enacted Dutch and Swedish carbon tax. Table 4 presumes a willingness to pay, as is implied by the Nordhaus (1991) high estimate, of 6600 \$/ha. Finally in Table 5 a US-CBO estimate of 10.000 \$/ha is taken to represent the North's willingness to pay.

Before the discussion of results four remarks are due. First, the calculation of V_0/S in the application is based on land prices and values for carbon sunk in trees. Under market conditions the former is a present value and an approximation of the present value of annual incremental costs of sustaining a hectar rainforest. If the willingness to pay of the North is the result of a cost-benefit analysis of climate policy, as ideally it should, then the value of 100 tons of carbon sunk in a hectar of land is also in present value terms. It is the discounted benefit of having a smaller greenhouse gas concentration in future years. Hence as both the data on S and V_0 are in present value terms, their ratio is also the ratio of the current value service flow and flow of incremental costs if the North and the South have the same discount rate. As we use identical discount factors in the application we can represent the ratio of flows V_0/S in the analytical model by the ratio of present values.

Secondly, in approximating incremental costs by weighted land prices per hectar we marginalize negotiations which in the analytical model are formulated in terms of a total stock. Hence, the data set we use in the application presumes a situation as if the North would negotiate with each country the preservation of single (representative) heclars separately. We know from Proposition 2 that this interpretation conforms with the analytical model. The implicit, but important, presumption, however, is that the North bargains with a country's government and cannot operate on the market for land as an ordinary (atomistic) market participant. We shall instantly see that governments owning rainforests have every incentive to prevent this.

Thirdly, using land prices as approximations of incremental costs, in combination with the presumption that a forest is always homogeneous, provides a straightforward interpretation of why the (total) incremental cost is invariant to the total stock and of how precisely the resource is supposed to decline: The area covered presently by the rainforests will always be so (hence total incremental costs are fixed), but as time goes on while development is non-sustainable more and more carbon will have evaporated into the atmosphere.

Fourth, the construction of the marginal cost data on the basis of Brazilian land prices suggests that the results are most reliable in the case of Brasil but less so for

the other countries. Results for countries other than Brazil may therefore be interpreted as a multi-parameter sensitivity analysis with a suggestion as to which countries might be roughly associable with the parameter constellations. Also, the use of land prices to represent incremental costs must be viewed as an upper bound on the necessary costs to protect carbon sinks.

The equilibrium transfer payments, needed to preserve tropical carbon sinks, which are reported in Tables 1-5 suggest:

1. (Table 1): In order to entice a substantial redistribution from North to South only very small rates of decline of the rainforests are needed. For the hypothetical benefit-cost relation, V_0/S , of 100:1 the 0.1% annual rate of decline of the Indian rainforest, for example, suffices to induce a net profit for India from sustaining its forest relative to costs of 191 (16)% in the 2 (8)% discount case. For other countries with more quickly disappearing rainforests this net profit is even much larger. As the South can win a bounty in bilateral negotiations, the government of a rainforest hosting country has every incentive to monopolize its domestic supply of carbon sinks to the North.

2. (Table 1): International redistribution is sensitive to the discount rates applied to climate policy. A smaller discount rate (2% instead of 8%) which is more favourable to a tougher climate policy (Cline (1992)), is also more favourable to redistribution from North to South.

3. (Table 1): International redistribution is highly sensitive to even tiny differences in the rates of decline. For example, in the 8% discount rate case an increase in the rate of decline from 0.1% to 0.2% (India to Bolivia) implies an increase of transfers by 63% of incremental costs, and an increase from 1.1% to 1.8% (Indonesia to Columbia) implies an increase of transfers by almost 3.5 times the necessary costs. As there is considerable uncertainty as to what the correct rates of decline are (Melillo et al. (1985)) carbon sink preservation creates a market with a strong willingness to pay for (remote) control and observation services.

4. (Table 1): Other things being the same and for the range of rates of decline listed in Table 1, virtually every country would benefit from a somewhat larger rate of decline. The North therefore faces a moral hazard problem on the side of rainforest owning countries. These have an incentive to boost destruction (or at least do nothing against a further acceleration unilaterally) in a pre-agreement phase.

5. (Table 1): It is particularly expensive to protect forests which are under the threat of quick extinction. Therefore, and counter to popular sentiments, if a carbon

sink policy is to be implemented on a limited budget such that not all rainforests can be sustained, it is rational to give up the most perishable ones and concentrate on the protection of those which need it least.

6. (Table 2): Up to and including a willingness to pay of 730 \$/ha, which corresponds to Nordhaus' (1991) medium estimate of warming damages, a carbon sink policy is infeasible in the countries listed, unless incremental costs are (substantially) smaller than those assumed. This follows because for the parametric specification listed in Table 2 a bargaining equilibrium does not exist. This is because the feasible bargaining horizon, T , is negative. The interpretation of this is that for these (low) unit valuations the quantity of carbon caught in the national stocks is already too small. The North is better off riding the remaining non-sustainable track for free. In view of international redistribution a conservative climate policy of the North is therefore bad news for the South. These results also provide an explanation for the failure to reach a substantial agreement on the protection of rainforests at the 1992 Rio Conference.

7. (Table 3): A carbon sink policy is feasible for a valuation of 4500 \$/ha such as is induced by the Dutch and Swedish enacted carbon tax. Note that even at this valuation, which is more than 6 times the Nordhaus medium estimate valuation, a sink policy remains infeasible for some rainforests (Zaire, India). The equilibrium transfer payments suggest that even at a benefit-cost ratio substantially below the fictitious 100:1 ratio (Table 1) the surcharges on incremental costs remain hefty (ranging between 20% (Venezuela) and 280% (Columbia)). The results also suggest that despite the redistribution thereby induced the Swedish and Dutch governments pursue on the margin an extremely inefficient climate policy. As the x_0/V_0 values show, replacing the Dutch and Swedish carbon tax by buying into carbon sinks (where it is feasible) would permit CO₂ emission abatement at costs which range between only 2% (Bolivia) and 13% (Mexico) of those which are actually borne at home.

8. (Table 3 and 4): The values (in years) for T suggest that even at relatively high valuations of 4500 and 6600 \$/ha time to strike an agreement on protection is quickly running out for some rainforests. This in view of 5. is less troublesome for those rainforests which would be relatively expensive to protect in terms of x_0/V_0 (e.g. Indonesian rainforest in the case of Table 3 (due to large incremental costs and a large rate of decline)). The possibility of forever foresaking an agreement within a few decades causes, however, concern in the case of rainforests which (e.g. in the case of Table 4) could be bought into at relatively little costs.

9. (Table 3-5): Comparing x_0/V_0 values for individual countries across the range between 4500 \$/ha and the high CBO estimate of 10,000 \$/ha suggests that the relative efficiency gains from carbon sequestration are rather insensitive to variations in the willingness to pay. For example, the efficiency gain of investing into the Brazilian forest remains almost constant around the 96% level.

8. Conclusions

The paper analyses a bargaining situation in which two countries negotiate the financing of the costs which accrue if one of them switches from a non-sustainable on a sustainable development track. The other country's incentive to contribute to the financing of these costs arises from a problem of a fading free-rider position: It benefits free of charge from the other country's environmental resources, however, at a declining rate as long as development remains non-sustainable. This bargaining situation catches, so the paper argues, some of the key elements in North-South negotiations on certain international environmental problems such as, for example, the preservation of tropical rainforests or biodiversity.

The paper demonstrates that such negotiations will induce payments from North to South which are above the necessary incremental costs of sustainability. Such international environmental cooperation will therefore come about with a redistribution of income and wealth from North to South.

In an application of the analytical model to the preservation of tropical rainforests for the purpose of climate protection it is shown that for the observed rates of decline of rainforests this redistributive effect would be substantial. However, it is also shown that, despite these hefty surcharges to be borne by the North, investing into tropical rainforest preservation would nevertheless imply an enormous efficiency gain compared to emission related policies in the North.

The analysis brings to the fore some important strategic aspects of North-South cooperation to protect the environment. It is, however, not complete. A fuller investigation would have to address at least one further issue which has been excluded here.

The analytical model investigates bilateral negotiations between a beneficiary of environmental services and a single resource owning country. It does therefore abstract from the possibility of coalitions between several resource owners.

Coalition-building and in particular a cartel of resource owners is in fact suggestive from the model. The application shows how country specific conditions translate in bilateral negotiations into country specific surcharges on incremental costs. This implies a ranking of resource owning countries with which the beneficiary would like to bargain (given by the ordinal ordering of x_O/V_O values in Tables 3-5 with the lowest value country being the favourite). In bilateral negotiations the beneficiary would engage in price discrimination thus buying into the resource at different costs. If all resource owners with which bilateral negotiations are feasible would form a cartel then the beneficiary would have to pay a single surcharge to all members. In Table 3-5, for example, this cartel surcharge would be the x_O/S_O values in the bottom line, labeled "Average", where country specific parameters are weighted by the relative size of the resources (Table 1) and the bargaining equilibrium is calculated on the basis of the induced average values of parameters. Such a cartel amongst resource owners would be stable if cartel gains would suffice to compensate countries which individually could negotiate higher transfers. This also suggests that the total quantity of resources to be sustained can be used by the beneficiary of environmental services to strategically influence the cartel stability as that quantity determines which countries would be inside and which ones not. Thereby the North could also strategically influence the surcharge it must bear.

Hence beyond the issues discussed in the model there are a number of other strategic issues which wait to be addressed in the context of the international financing of sustainable development.

Appendix

Proof of Proposition 1: Given Lemma 2 the proof is established if $a \in]-1, 1[$ is sufficient for $d x_0/dV_0 > 0$ as from Lemma 1 $dT^*/dV_0 > 0$.

For $g = 0 \vee p = 1$ it follows from (5')

$$\frac{dx_0}{dV_0} = \frac{\partial x_0}{\partial V_0} + \frac{\partial x_0}{\partial T^*} \cdot \frac{\partial T^*}{\partial V_0}. \quad (A1)$$

From (5'), $\partial x_0 / \partial V_0 > 0$ if $T^* > 0$. Hence it is sufficient for $dx_0/dV_0 > 0$ that $\partial x_0 / \partial T^* \geq 0$. Using (13'') it follows from (5') that $\partial x_0 / \partial T^* \geq 0$ if

$$e^{[(1-a)-h \cdot k \cdot (1-a^2)]/2} \cdot T^* \geq \frac{h \cdot (1-k)}{(1-a) \cdot \psi} \quad (A2)$$

From (13'') we can replace the denominator on the RHS of (A2) by

$$\max \left[\frac{1-k \cdot a}{k}, \frac{1-h}{h} \right]$$

From this it follows that the RHS of (A2) is smaller than 1.

Therefore sufficient for $\partial x_0 / \partial T^* > 0$ is

$$(1-a) - h \cdot k \cdot (1-a^2)/2 \geq 0$$

for which it suffices that $(1-a)/(1-a^2) \geq 1/2$ as $h \cdot k \in]0, 1[$. This is fulfilled if $a \in]-1, 1[$.

Proof of Corollary 2: From the definitions of γ and $\phi(\gamma)$, $x_0 - S = [\phi(\gamma) - \gamma] \cdot V_0$. $\phi(\gamma) - \gamma < 1$ as $\phi(\gamma) < 1$, or else B would lose from the bargaining equilibrium compared to non-cooperation. $\phi(\gamma) - \gamma \geq 0$ if $g = 0 \vee p = 1$ follows from Lemma 2 and Proposition 1, from which $\phi(\gamma)/\gamma \geq 1$.

Proof of Proposition 3: From Theorem 1, (6') and (7')

$$\frac{dx_0}{da} = \frac{\partial x_0}{\partial a} + \frac{\partial x_0}{\partial T^*} \cdot \frac{\partial T^*}{\partial a} \quad (A3)$$

From the proof of Proposition 1 $\partial x_0 / \partial T^* > 0$ if $g = 0 \vee p = 1$. Let $\psi = \psi(a)$. From (13'')

$$\frac{\partial T^*}{\partial a} = [T - \psi'(a) / \psi(a)] / (1-a) \quad (\text{A4})$$

where

$$\psi'(a) / \psi(a) = \frac{1}{1-a} \cdot \begin{cases} \frac{1-k}{1-k \cdot a} \\ 1 \end{cases} \text{ if } \psi = \begin{cases} \frac{1-h}{h \cdot (1-a)} \\ \frac{1-k \cdot a}{k \cdot (1-a)} \end{cases} \quad (\text{A5})$$

From (13''')

$$T^* = -\ln [(S/V_0) \cdot \psi] / (1-a) \quad (\text{A6})$$

Substituting (A5) and (A6) in (A4) gives

$$\lim_{a \rightarrow 1} \frac{\partial T^*}{\partial a} = - \left(\lim_{a \rightarrow 1} \left(\frac{1}{1-a} \right)^2 \right) \cdot \left[\ln (\gamma \cdot \lim_{a \rightarrow 1} \psi(a)) + 1 \right]$$

As from (13''') $\lim_{a \rightarrow 1} \psi(a) = \infty$ it follows $\lim_{a \rightarrow 1} \partial T^* / \partial a = -\infty$.

Finally, from (5') $\lim_{a \rightarrow 1} \partial x_0 / \partial a$ is finite (and negative) if $g=0 \vee p=1$. Hence

from (A3) $\lim_{a \rightarrow 1} dx_0 / da = -\infty$.

Proof of Proposition 4: For $g = 1$, $a = p$, $h = k$, (5') simplifies to

$$x_0 = S \cdot \frac{1-h}{1-h^2} \cdot [1 - e^{-(1-h^2) \cdot T^*/2}] + e^{-(1-h^2) \cdot T^*/2} \cdot x_{T^*} \quad (\text{A7})$$

and the three regimes in (13') converge such that T^* is determined by

$$e^{-(1-a) \cdot T^*} \cdot (V_0 / S) = \frac{1}{2} \cdot \frac{1-h \cdot a}{h \cdot (1-a)} \quad (\text{A8})$$

As regimes disappear, $x_T^R = x_T^B$. Using this we can replace x_{T^*} in (A7) by (7'), letting $h=k$. Upon using (A8), (A7) simplifies to yield

$$x_0 = S \cdot \left[\frac{1-h}{1-h^2} e^{-(1-h^2) \cdot T^*/2} \cdot \left(\frac{1-h}{1-h^2} - \frac{1}{2} \right) \right] \quad (\text{A9})$$

For $h < 1$, $(1-h)/(1-h^2) > 1/2$ and hence $dx_0/dT^* > 0$ if $h < 1$. Also from (A9), $x_0 = S/2$ if $T^* = 0$. Hence $x_0 > S/2$ if $T^* > 0$.

Proof of Corollary 4: $\lim_{h \rightarrow 1} (1-h)/(1-h^2) = 1/2$. Hence from (A9)

$$\lim_{h \rightarrow 1} x_0 = S/2.$$

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