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Abstract: This paper demonstrates that partial cooperation with respect to the use of an international environmental resource can emerge when countries are able to opt to breach an agreement. Although the option of non-compliance restricts the set of coalitions on those which embrace merely two members, broader cooperation can emerge when these two countries compensate a third country for extra reduction efforts. The paper discusses also a reversible and a irreversible technology option and demonstrates that compensating a third country for the introduction of an irreversible technology may be even advantageous for the donors when this technology incurs higher costs than a reversible one (*JEL Classification*: Q 20).

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1. Introduction

During the last decade, the public concern has shifted the focus of environmental problems from local hot spots to international or even global pollution problems, and so did environmental economics. Expanding the pollution-concerned area did not merely create a new spatial problem. The new economic problem associated with the use of an international environmental resource is due to the lack of a central authority which is able enforce a specific environmental resource use by taxes, tradable permits or command and control. From an international perspective, regulation must be grounded on the voluntary participation of those countries which use and exploit the environmental resource. The sovereignty of countries demands that international environmental agreements must guarantee that every national participant is at least not worse off by sticking to the agreement than by breaching it.

Serious problems originate from the feature that restricting international pollution provides a public good. Hence, environmentalists fear that the strategy of free riding will turn out as a dominant one of all countries and will deteriorate environmental quality significantly or even endanger human living conditions. Economists discussing international pollution problems are not in that way pessimistic although they hardly claim that the full cooperative outcome will always emerge. Most of the respective literature concentrates on the possibility of stable coalitions as a subset of resource-using countries (see BARRETT, 1991, 1992, BAUER, 1992, CARRARO, SINISCALCO, 1992, HEAL, 1992). Stability demands that every sovereign member-country is always better off by remaining in the coalition than by leaving it and every outsider is always worse off by joining the coalition. Partial cooperation can emerge if the stable coalition contains more than one member.

However, these papers deal with the notion of sovereignty only in terms of voluntary participation. When countries have decided to sign an environmental treaty, they are supposed to behave compliant and to be able to stick credibly to the agreed-upon reduction efforts. This paper addresses the problem that countries need not to behave compliant because they are always able to repudiate the demands of other countries as interfering with their sovereign affairs. Accordingly, this paper assumes that the agreed-upon reduction plans must be self-enforcing and that all countries decide simultaneously whether they stick to the agreed-upon policy. Empirical evidence from international negotiations justifies to assume that the reduction policy will not be introduced in the very moment of the agreement but that a country decides about compliance with respect to the reductions one period later which will be revealed when the countries have moved simultaneously.

Given this tighter sovereignty constraint, it is obvious that - starting from the non-cooperative levels - cooperation can at best emerge between two countries but not among three because a third country will always prefer to ride free when two countries are already cooperating. Hence, the following two chapters start by dealing with cooperation between two countries. Section 2 discusses self-enforcing cooperation when the reduction technology is reversible, i.e. when both countries are able to return to the non-cooperative Nash reduction levels when the other agent has showed up non-compliant behavior. Section 3 discusses self-enforcing cooperation when reduction efforts are irreversible, i.e. that introducing a certain degree of reduction measures means to carry the corresponding costs forever. It also compares both technology options. Section 4 considers how the cooperating countries can succeed in compensating a third country for reductions which surmount its non-cooperative level. Section 5 summarizes and concludes this paper.

Two features are striking when discussing international environmental problems in terms of this tighter sovereignty constraint. On the one hand, restricting cooperation on two countries does not mean that all other parties remain at their non-cooperative levels. Instead, the two countries are able to compensate outsiders for additional reductions although these compensations have to meet certain compliance constraints. The paper demonstrates that partial cooperation among three countries is possible. It shows that multilateral agreements can be self-enforcing even in the presence of contract breach options because the inner coalition of merely two members is able to initiate additional reduction efforts of a third party through compensations. On the other hand, it is surprising that choosing an irreversible technology can be a dominant strategy for compensating an outsider. Even if this technology carries higher costs than the reversible one, it can provide a commitment option which can be more favorable for the paying countries. This potential superiority contrasts the strict inferiority in the case of self-enforcing cooperation.

2. Self-Enforcing Cooperation in the Case of a Reversible Technology

Throughout the paper, I assume that three countries use a global environmental resource by releasing harmful emissions into the atmosphere. For the sake of simplicity, I assume that all three countries i, j and k face identical benefits B of total reduction efforts R and identical costs C of individual (reversible) reduction efforts which are given by

$$(1) \quad \forall l \in \{i,j,k\}: \quad \begin{aligned} B_l &= \alpha R, \\ C_l &= \frac{\beta}{2} R_l^2, \\ U_l &= B_l - C_l, \\ R &= \sum_{i,j,k} R_l . \end{aligned}$$

For reasons of better tractability, I assume that i and j exhibit the same annual discount factors. Country k, however, exhibits a "significantly lower" discount factor:[1]

$$\delta = \delta_i = \delta_j \rangle \delta_k , 0 \langle \delta, \delta_k \langle 1.$$

Assume for the moment that country i and country j cooperate and that any contract between them is enforceable. The optimal reduction level for both countries is given by

$$(2) \quad \forall l \in \{i,j\}: \quad R_l^* = \frac{2\alpha}{\beta}.$$

In order to simplify the modelling of the bargaining procedure, I assume that the bargaining gains will be divided according to the symmetric Nash bargaining solution. This approach can be even justified by a strategic bargaining approach (see RUBINSTEIN, 1982, BINMORE, OSBORNE, RUBINSTEIN, 1990) which eliminates first- and last-mover advantages appropriately (see STÄHLER, 1993) because the strategic bargaining approach can produce the equal split in the case of identical discount factors, too. If compliance can be guaranteed, both countries realize (2) and bargaining gains according to

$$(3) \quad \forall l \in \{i,j\}: \quad U_l^* - U_l' = \frac{\alpha^2}{2\beta}$$

The following figure shows the optimal reduction levels:

<Figure 1 about here>

The dotted curves which start at the origin of the non-cooperative outcome are the utility reservation curves. They and all iso-utility curves have the slope

$$(4) \quad l \neq m \in \{i,j\}: \quad \frac{dR_l}{dR_m} = \frac{\beta R_m - \alpha}{\alpha}$$

When non-compliance is an option for one country, the other country is able to punish the non-compliant country by sticking to the non-cooperative reduction level. I assume that both countries face an infinite repetition of the reduction game and I restrict their

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1 I will explain the notion of a significantly lower discount factor soon when I discuss why i and j cooperate.

threat options on infinite punishments.[2] The non-compliance option restricts the set of credible obligations. Consider e.g. country j which knows that only contracts which satisfy

$$(5) \qquad \frac{1}{1-\delta}\left[\alpha\left(R_i + R_j\right) - \frac{\beta}{2}R_i^2\right] - \left[\frac{\alpha^2}{2\beta} + \alpha R_j\right] - \frac{\delta}{1-\delta}\frac{3\alpha^2}{2\beta} \geq 0$$

will not be broken by country i. The first term represents the discounted value of infinite cooperation, the second term the instantaneous gain from breaching the contract while the other country sticks to it and the third term represents the discounted value of the disagreement outcome starting one period later.[3] Comparing (5) and (2) indicates that compliance problems do arise if δ does not reach at least 0.5.[4] If $\delta < 0.5$, (5) and a corresponding condition for j give i and j respective minimum reduction efforts from which they must not fall short:

$$(6a) \qquad \hat{R}_i = \frac{\alpha}{\beta} + \frac{1}{\delta}\left\{\frac{\alpha}{2\beta} + \frac{\beta}{2\alpha}R_j^2 - R_j\right\} = \frac{\alpha}{\beta} + \frac{1}{\delta}\frac{\beta}{2\alpha}\left[R_j - \frac{\alpha}{\beta}\right]^2$$

$$\hat{R}_j = \frac{\alpha}{\beta} + \frac{1}{\delta}\left\{\frac{\alpha}{2\beta} + \frac{\beta}{2\alpha}R_i^2 - R_i\right\} = \frac{\alpha}{\beta} + \frac{1}{\delta}\frac{\beta}{2\alpha}\left[R_i - \frac{\alpha}{\beta}\right]^2$$

with $\dfrac{d\hat{R}_i}{dR_j} = \dfrac{1}{\delta}\dfrac{\beta R_j - \alpha}{\alpha}$ $\qquad \dfrac{d\hat{R}_j}{dR_i} = \dfrac{1}{\delta}\dfrac{\beta R_i - \alpha}{\alpha}$

(6a) observes that the compliance constraint curves are steeper than the utility reservation curve.[5] The figure displays these curves by the broken lines. Any contract must lie in the area between these curves to be self-enforcing. If δ falls short from 0.5, the compliance constraints rule the cooperative outcome out as the figure does it.

D and E are the compliance-constrained reduction levels on which i and j agree upon in a symmetric Nash bargaining solution. The symmetry with respect to costs benefits and the identical discount factors guarantee that only point C, the intersection of the compliance constraints, is the perfect equilibrium because the same discount rates demand an equal split and the same costs and benefits demand the same efforts. Then, the symmetry ensures that both countries agree upon the highest reduction efforts

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2 However, a weakly renegotiation-proof strategy according to FARRELL, MASKIN (1989) and VAN DAMME (1989) would produce the same constraints. This result holds for the reversible and the irreversible technology option. The proof is available upon request.

3 The country decides on whether to behave compliant or not in the previous period whereas the costs and benefits arise in the following period. (5) gives the compliance problem in terms of the period of potential cooperation. A rebasing on the period of the agreement merely demands to multiply (5) by δ and does not change it.

4 This case is not a too unrealistic one because several years can elapse between repetitions.

5 For $\delta \to 1$, the compliance constraint curves and the utility reservation curves converge.

which just fulfil the compliance constraints when the constraints are binding. Thus, the reduction levels are

$$\text{(6b)} \quad \forall l \in \{i,j\}: \quad R_l = \begin{cases} \frac{2\alpha}{\beta} & \text{if } \delta > 0.5 \\ [1+2\delta]\frac{\alpha}{\beta} & \text{if } \delta \leq 0.5 \end{cases}$$

The figure can also explain the notion of a sufficiently low discount factor of k. Consider a substitution of i by k. Then, j represents both i and j in separate self-enforcing contractual relations with k. The compliance constraint for j which the impatience of k defines is given by the dotted and broken line. If the discount factor ensures such a steep curve as in the figure, i and j are always better off by a mutual agreement than by contracting with k. In the figure, the utility level at C which j receives gives the highest obtainable utility level in a contract with k. This highest obtainable utility level represents an extremely asymmetric contract with k and j would have to concede a lot in order to reach the symmetric bargaining solution. Thus, a significantly low discount factor leaves only i and j as contract partners because their cooperation is a dominant strategy for both in this model. From this point of view, the impatient country k benefits from its low discount factor because its impatience is rewarded by the free-rider-ticket. Hence, impatience does not necessarily conflict with a good performance for the respective country which receives the benefits of reductions free of charge.

3. Self-Enforcing Cooperation in the Case of an Irreversible Technology

This section addresses self-enforcing cooperation when the introduction of the reduction technology is irreversible: when a country has introduced specific reduction efforts which are based on an irreversible technology, it cannot go back and has to carry the corresponding costs in every following period. The dichotomous comparison of technologies will give a surprising clue with respect to the superiority of technologies when contracts which compensate a third country must be self-enforcing. The irreversible technology substitutes the cost function in (1) by

$$\text{(7)} \quad \forall l \in \{i,j,k\}, \forall t \geq 0: \qquad D_l(t) = \frac{\gamma}{2} R_l(t)^2, \;\; R_l(t+1) \geq R_l(t).$$

Some preliminaries are helpful in preparing the considerations below. First, non-compliance means that one country does not follow a specific dynamic plan and remains at the reduction level of the previous period whereas the other country has moved a step further. Correspondingly, punishment means that the other country remains at this level and will never introduce additional reduction measures. Thus, irreversibility constrains both the non-compliance and the punishment options.

Second, if a self-enforcing plan exists, this plan can never reach the optimal outcome because both countries' reductions should never exceed the cooperative level. Reaching the optimal outcome (or any other final stage) would change the infinitely repeated game into a finitely repeated one. According to the well-known Chain Store Paradox (SELTEN, 1978), finitely repeated games can be solved recursively and leave only the non-compliance option as a subgame-perfect strategy because no punishment is available when the last period is reached. When non-compliance option is a dominant strategy in the last period, it is also a dominant one in the next-to-last period, and so on. Hence, a self-enforcing plan can maximally approach the cooperative outcome but never reach it. Two additional comments may be useful to pronounce the logic of the technology choice in an agreement. First, irreversibility implies no specific problem in terms of an option value which can only arise if the future costs and benefits are associated with uncertainty. Second, the switch to an irreversible technology does not impose a credibility problem because remaining at the non-cooperative level of the reversible technology does not add to the compliance constraint.

The question arises whether such a self-enforcing reduction plan exists which meets the condition that every country expects at least the same utility from further reductions than from remaining at a level when the other country has gone one step further. This condition must hold for all periods.

(8) $$R(t) = \frac{2\alpha}{\gamma} - f(t)\frac{\alpha}{\gamma}, f(0) = 1, f' < 0, \lim_{\tau\to\infty} f(\tau) = \theta \geq 0$$

mirrors the dynamic contract and specifies the piecemeal approach. The cooperative efforts are $2\alpha/\gamma$ for each country. Starting from the non-cooperative level, the contract increases the reduction efforts step by step and approaches $(2-\theta)\alpha/\gamma$ in the course of time. The function f(t) describes the dynamics of the contract which must meet the compliance constraint. $V(\tau,I)$ and $V(\tau,O)$ denote the discounted value of the inside option and the outside option, respectively, when t has reached τ.[6] The benefits of the inside option originate from sticking to the agreement in all following periods whereas the benefits of the outside option originate from breaching the contract. Hence, $V(\tau,I)$ and $V(\tau,O)$ are given by

6 The symmetry of countries i and j enables me to omit the subscript.

(9)
$$V(\tau,I)=\sum_{t=\tau}^{\infty}\delta^t\left\{\frac{4\alpha^2}{\gamma}-f(t)\frac{2\alpha^2}{\gamma}-\frac{\gamma}{2}\left[\frac{2\alpha}{\gamma}-f(t)\frac{\alpha}{\gamma}\right]^2\right\}=$$
$$\sum_{t=\tau}^{\infty}\delta^t\left\{\frac{2\alpha^2}{\gamma}-f(t)^2\frac{\alpha^2}{2\gamma}\right\}$$
$$V(\tau,O)=\sum_{t=\tau}^{\infty}\delta^t\left\{\frac{4\alpha^2}{\gamma}-f(\tau-1)\frac{\alpha^2}{\gamma}-f(\tau)\frac{\alpha^2}{\gamma}-\frac{\gamma}{2}\left[\frac{2\alpha}{\gamma}-f(\tau-1)\frac{\alpha}{\gamma}\right]^2\right\}=$$
$$\sum_{t=\tau}^{\infty}\delta^t\left\{\frac{2\alpha^2}{\gamma}-\frac{\alpha^2}{\gamma}[f(\tau)-f(\tau-1)]-f(\tau-1)^2\frac{\alpha^2}{2\gamma}\right\}$$

$V(\tau,O)$ takes into account that the other country goes one step further but remains at this level in order to punish non-compliance. The compliance constraint is much more complex compared to the case of reversible investments because $V(\tau,I)$ must not fall short from $V(\tau,O)$ for every positive integer value of τ:

(10)
$$\forall\tau\geq 1: V(\tau,I)-V(\tau,O)\geq 0\Leftrightarrow$$
$$\sum_{t=\tau}^{\infty}\delta^t\left\{f(\tau-1)^2\frac{\alpha^2}{2\gamma}-f(t)^2\frac{\alpha^2}{2\gamma}-[f(\tau-1)-f(\tau)]\frac{\alpha^2}{\gamma}\right\}\geq 0$$

The appendix proves that a self-enforcing contract can at best induce a $\theta=1-\delta$ when $\tau\to\infty$. Hence, the upper limit of cooperation is given by

(11) $$R^{\infty}=(1+\delta)\frac{\alpha}{\gamma}.$$

No self-enforcing contract exists which attempts at realizing the cooperative level but the upper limit depends crucially on the impatience of both cooperating countries. For instance, both countries could agree upon the timing of reductions according to a dynamic function g^t:

(8') $$R(t)=\frac{2\alpha}{\gamma}-(1-\delta)\frac{\alpha}{\gamma}-g^t\delta\frac{\alpha}{\gamma}=\frac{\alpha}{\gamma}\left[1+\delta-\delta g^t\right].$$

Contract (8') is no optimal contract because it satisfies (10) only for $t\to\infty$. But this specification allows for calculating the discounted benefits of the inside and outside option explicitly:

(9') $$V(\tau,I)=\sum_{t=\tau}^{\infty}\delta^t\left\{\frac{2\alpha^2}{\gamma}\left[1+\delta-\delta g^t\right]-\frac{\alpha^2}{2\gamma}\left[1+\delta-\delta g^t\right]^2\right\}$$
$$V(\tau,O)=\sum_{t=\tau}^{\infty}\delta^t\left\{\frac{\alpha^2}{\gamma}\left[1+\delta-\delta g^{\tau}\right]+\frac{\alpha^2}{\gamma}\left[1+\delta-\delta g^{\tau-1}\right]-\frac{\alpha^2}{2\gamma}\left[1+\delta-\delta g^{\tau-1}\right]^2\right\}$$

Applying formula (10) and substituting for the benefit and cost parameters gives the compliance constraint

$$(10') \quad \frac{\delta-1}{1-\delta g}+\frac{1}{1-\delta}-\frac{\delta}{g(1-\delta)}\geq 0.$$

Hence, a g satisfying

$$(12) \quad g=1+\frac{\delta}{2}-\sqrt{\delta-\frac{\delta^2}{4}}$$

defines a self-enforcing dynamic contract. E.g.,

$$(13) \quad R(t)=\frac{\alpha}{\gamma}\left[1+0.5-0.5*0.5^t\right]$$

describes this contract for δ=0.5.

Until now, I have addressed reversible and irreversible technologies as non-competing options. The constant-growth-model helps to explain the choice of technologies when both technologies are available and differ in costs. The availability of both technologies is only given as an option if the country has not yet decided for the irreversible technology. I restrict the analysis of cost comparisons on discount factors which fall short from 0.5. For a δ surmounting 0.5, the cost advantage of the irreversible technology must apparently be very large to overcompensate for the benefits from choosing the reversible one because the reversible reaches the full cooperation already in the first period. Additionally, I assume that dynamic contracts are restricted to functions according to (8'). W(β) and W(γ) denote the discounted value of compliance-constrained cooperation by choosing a reversible and irreversible technology, respectively, for δ < 0.5:

$$(14) \quad W(\beta)=\sum_{t=0}^{\infty}\delta^t\left\{\frac{2\alpha^2}{\beta}(1+2\delta)-\frac{\alpha^2}{2\beta}(1+2\delta)^2\right\}=\frac{1+2\delta}{1-\delta}\frac{3-2\delta}{2}\frac{\alpha^2}{\beta}$$

$$W(\gamma)=\sum_{t=0}^{\infty}\delta^t\left\{\frac{2\alpha^2}{\gamma}\left[1+\delta-\delta g^t\right]-\frac{\alpha^2}{2\gamma}\left[1+\delta-\delta g^t\right]^2\right\}=$$

$$\left\{\frac{3+2\delta-\delta^2}{1-\delta}-\frac{2\delta-2\delta^2}{1-\delta g}-\frac{\delta^2}{1-\delta g^2}\right\}\frac{\alpha^2}{2\gamma}$$

Equalizing W(β) and W(γ) gives the relationship of the cost parameters β and γ which renders both countries indifferent between both technology options:

$$(15) \quad \frac{\gamma}{\beta}=\frac{1-\delta}{1+2\delta}\frac{1}{3-2\delta}\left\{\frac{3+2\delta-\delta^2}{1-\delta}-\frac{2\delta-2\delta^2}{1-\delta g}-\frac{\delta^2}{1-\delta g^2}\right\}$$

To shed some light on the empirical implications of equalizing both technology options, I observe that this ratio is always below 1 but increases with a decrease of δ:

$$\frac{\gamma}{\beta}(\delta=0.4)=0.7992,\frac{\gamma}{\beta}(\delta=0.3)=0.8497,\frac{\gamma}{\beta}(\delta=0.1)=0.8945$$

Thus, an irreversible technology must always show a cost advantage to be chosen by both cooperating countries. This cost advantage must be the lower, the lower the discount factor is. But in the case of identical costs, both countries will never bargain for irreversible reduction efforts. There is no scope for the introduction of irreversible reduction technologies in the cooperating countries unless they compensate for the piecemeal approach by significantly lower costs. But significantly lower costs would have already induced a voluntary switch to the irreversible technology. Common piecemeal reduction policy can never initiate a switch to an irreversible reduction technology.

4. Transfers to a Third Country

This section will demonstrate that the need for significantly lower costs does not necessarily apply on the transfer policy of the two cooperating countries and that a technology switch can be favorable for the paying countries. It shows that compensating k for reductions which surmount its cooperative ones leaves more scope for the irreversible technology. The plan of this section is to compare an arbitrary compensation pricing rule for the case of policies which aim at irreversible reduction measures with a pricing rule which aims at reversible reduction measures and lets the donors skim the maximum bargaining gains. The section shows that the latter compensation rule is not unambiguously superior for identical costs.

The joint compensation policies of i and j do not depend on their joint reduction efforts. Both countries are able to agree upon a specific amount of compensations which they transfer to country k. This transfer does not raise compliance problems because a contract which specifies that the receiver has to introduce reduction measures only when both countries have paid can guarantee that both countries meet their agreed-upon monetary obligations. Hence, i and j face no mutual compliance problem with respect to compensation policies. If country k behaves non-compliant, it will never receive any transfers in the future.

Both countries can try to initiate either irreversible extra reductions or reversible extra reductions. Their benefits from transfers which induce extra reductions must be discounted by δ because a transfer given now implies a reduction one period later. Hence, the Lindahlian marginal utility which arises from extra reductions is $2\delta\alpha$ per unit. When both countries agree upon compensating for extra reductions which are based on an irreversible reduction technology, a mutual compliance problem arises. On the one hand, the discounted value of transfers which k receives must at least equalize the benefits of non-compliance. On the other hand, country k takes into account that i and j cannot commit credibly to pay compensations for already introduced reduction measures. Country k knows that it receives no transfers for an already realized degree of reductions.

$$\forall\tau \geq 0:$$

(16) $$\sum_{t=\tau}^{\infty}\delta_k^t X(t) - \frac{\delta_k^{\tau+1}}{1-\delta_k}\Delta[\upsilon(\tau)] \geq \delta_k^{\tau} X(\tau) \Leftrightarrow$$

$$\sum_{t=\tau}^{\infty}\delta_k^{t+1} X(t+1) - \frac{\delta_k^{t+1}}{1-\delta_k}\Delta[\upsilon(\tau)] \geq 0$$

displays the corresponding mutual compliance constraint. X, Δ and υ denote the transfers, the extra costs and the extra reduction measures, respectively, which the transfers induce. (16) demands that the transfers in one period should not only cover the discounted costs of the corresponding irreversible reduction measures but also that the discounted value of sticking to a dynamic compensation schedule must not fall short from the benefits of non-compliance.

Because δ_k differs from δ, determining the division of bargaining gains raises a determination problem. I circumvent this problem by assuming a specific compensation policy although this assumption is likely to conflict with the Nash bargaining solution but the mere interest in investigating the role of technology choices justifies this simplification. Except for the initial period 0, I assume that the cooperating countries are prepared to compensate the outsider for every *new* reduction measures on the basis of their Lindahlian utilities:

(17a) $$\forall t \geq 1: \quad X(t) = 2\delta\alpha[\upsilon(t) - \upsilon(t-1)]$$

The reservation concerning transfers given in period 0 originates from potential switching costs which k has to carry when the irreversible technology incurs higher costs than the reversible one. Then, country k has to be compensated for the lower non-cooperative benefits which are due to a lower voluntary reduction level:

(17b) $$X(0) = \begin{cases} 2\delta\alpha\upsilon(0) \text{ if } \gamma \leq \beta \\ \left[\frac{3\alpha^2}{\beta} - \frac{3\alpha^2}{\gamma}\right]\frac{\delta_k}{1-\delta_k} + 2\delta\alpha\upsilon(0) \text{ if } \gamma > \beta \end{cases}$$

(17b), however, does not influence the compliance constraint because the decision about compliance depends solely on the transfers in the following periods. The structure resembles the problem of cooperation in an inner coalition. By the means of a dynamic contract which is described by the function h(t), the appendix proves that compensation policies can at best approach but never reach

(18) $$\upsilon^{\infty} = (2\delta - 1)\frac{\alpha}{\gamma}$$

which demands a discount factor δ which surmounts 0.5. If $\delta < 0.5$, i and j will refrain from any compensation policy. (18) shows that the limit of extra reduction efforts depends solely on the impatience of the paying countries. This surprising feature is due to the logic of compensation policies. Compensations are given in advance and the receiver has to decide on whether to receive *further* transfers and to carry the corresponding costs *one period later*. Consider a certain period τ. The donors pay a certain amount $X(\tau)$ to induce extra reductions one period later, i.e. $\tau+1$. The receiver compares the discounted sum of future costs and the discounted sum of future transfers, both starting in $\tau+1$ because the payments of period τ have been received anyway. A low discount factor of the receiver merely decreases the potential switching costs for which the receiver has to be compensated.

In order to compare both technology options, let l^t denote the specific dynamics of a dynamic compensation contract. The extra reduction level is given by

$$(19)\quad \upsilon(t) = \frac{\alpha}{\gamma} + (2\delta - 2)\frac{\alpha}{\gamma} - l^t(2\delta - 1)\frac{\alpha}{\gamma} = \left[1 - l^t\right]\left[2\delta - 1\right]\frac{\alpha}{\gamma}.$$

(19) and the specific compensation policy (17a) allow for calculating the LHS of the compliance constraint (16):

$$\sum_{t=\tau+1}^{\infty} \delta_k^t X(t) = 2\delta\alpha \sum_{t=\tau+1}^{\infty} \delta_k^t\left[\upsilon(t) - \upsilon(t-1)\right] = 2\delta\alpha \sum_{t=\tau+1}^{\infty} \delta_k^t l^t\left[l^{-1} - 1\right]\left[2\delta - 1\right]\frac{\alpha}{\gamma} =$$
$$2\delta\frac{\alpha^2}{\gamma}\left[l^{-1} - 1\right]\left[2\delta - 1\right]\frac{\delta_k^{\tau+1} l^{\tau+1}}{1 - \delta_k l}$$

(19) produces extra costs according to

$$(20)\quad \begin{aligned} \Delta\left[\upsilon(\tau)\right] &= \frac{\gamma}{2}\left\{\left[(1 - l^\tau)(2\delta - 1)\frac{\alpha}{\gamma}\right]^2 - \left[(1 - l^{\tau-1})(2\delta - 1)\frac{\alpha}{\gamma}\right]^2\right\} = \\ &\frac{\gamma}{2}(2\delta - 1)^2\frac{\alpha^2}{\gamma^2}\left\{2\left[l^{\tau-1} - l^\tau\right] + l^{2\tau} - l^{2(\tau-1)}\right\} \end{aligned}$$

and a compliance constraint according to

$$(21)\quad 2\delta\left[l^{-1} - 1\right]l - \frac{2\delta - 1}{2}\left\{2\left[l^{-1} - 1\right] + l^\tau - l^{\tau-2}\right\} \geq 0.$$

When τ grows infinitely, l^τ and $l^{\tau-2}$ vanish. Thus, the critical l from which the dynamic contract should not fall short from is given by

$$(22)\quad l = \frac{\delta - 0.5}{2\delta}.$$

If $\delta > 0.5$, the discounted net benefits which arise for i and j are the discounted sum of the instantaneous Lindahlian utilities minus the transfers. As i and j pay on the basis of the next periods' Lindahlian utility, the discounted net benefits of this policy are given by

(23)
$$\Theta = \sum_{t=1}^{\infty} \delta^t 2\alpha\upsilon(t-1) - SC = \sum_{t=1}^{\infty} \delta^t 2\alpha[1 - l^{t-1}][2\delta - 1]\frac{\alpha}{\gamma} - SC =$$
$$\frac{2\alpha^2}{\gamma}\delta^2[2\delta - 1]\frac{1-l}{(1-\delta)(1-\delta l)} - SC .$$

$$SC = \begin{cases} 0 \text{ if } \beta \geq \gamma \\ \left(\frac{3\alpha^2}{\beta} - \frac{3\alpha^2}{\gamma}\right)\frac{\delta_k}{1-\delta_k} \text{ if } \beta \langle \gamma \end{cases}$$

are the switching costs which i and j have to bear when they want to initiate extra reductions which are based on a cost-inferior irreversible technology. (23) is the result of an arbitrary compensation policy which does not necessarily skim the whole bargaining gains. Other contracts which are more favorable for i and j are conceivable, too. Unless the switching costs are dramatically high or the discount factor δ is very low, this dynamic contract provides i and j with positive net benefits. Their calculation is straightforward, e.g.

$$\Theta[\delta = 0.6] = 3.15 * 10^{-3}\frac{2\alpha^2}{\gamma} - SC,$$

$$\Theta[\delta = 0.8] = 1.8353\frac{2\alpha^2}{\gamma} - SC.$$

Compensation policies which are based on a reversible technology are time-invariant because the reductions in the past do not play any role for the present extra reductions. The extra costs of reductions are given by:

(24) $$\Phi(\omega) = \frac{\beta}{2}\left\{\left[\frac{\alpha}{\beta} + \omega\right]^2 - \left[\frac{\alpha}{\beta}\right]^2\right\} = \alpha\omega + \frac{\beta}{2}\omega^2.$$

ω denotes the extra reduction efforts which are based on a reversible technology and initiated by transfers. The compliance constraint is time-invariant, too, and - because the same arguments apply as in the case of the irreversible technology - does not depend on the discount factor of k:

(25)
$$\frac{1}{1-\delta_k}X(\omega) - \frac{\delta_k}{1-\delta_k}\left[\alpha\omega + \frac{\beta}{2}\omega^2\right] \geq X(\omega) \Leftrightarrow$$
$$X(\omega) \geq \alpha\omega + \frac{\beta}{2}\omega^2$$

Again, the compensations will never exceed $2\delta\alpha\omega$ because they are given in advance. I assume that i and j are able to skim the whole bargaining gains in the case of compensating for a reversible technology. They just meet the compliance constraint by their transfers to k and maximize the Lindahlian utility:

$$\text{(26)}\quad \max_{\omega}\left\{2\delta\alpha\omega-\left[\alpha\omega+\frac{\beta}{2}\omega^2\right]\right\}\Rightarrow\omega^*=\begin{cases}0 \text{ if } \delta\langle 0.5\\(2\delta-1)\frac{\alpha}{\beta} \text{ if} \delta\geq 0.5\end{cases}$$

If $\delta < 0.5$, i and j will introduce no compensation policies. The discounted sum of net benefits according to these *best policies* is given by

$$\text{(27)}\quad \begin{aligned}&\Xi=\frac{1}{1-\delta}\left\{2\delta\frac{\alpha^2}{\beta}[2\delta-1]-\left[\frac{\alpha^2}{\beta}[2\delta-1]+\frac{\beta}{2}\frac{\alpha^2}{\beta^2}[2\delta-1]^2\right]\right\}=\\&\frac{\alpha^2}{\beta}\frac{2\delta-1}{1-\delta}\frac{2\delta-1}{2}\end{aligned}$$

Although compensation policies which encourage for reversible reduction measures achieve the maximum degree of reductions in the next period, they do not necessarily launch the best compensation policies for i and j. Assuming a discount factor of 0.8 produces discounted net benefits of

$$\Xi(\delta=0.8)=0.45\frac{2\alpha^2}{\beta}.$$

If the costs of both technology options coincide, i.e. $\beta=\gamma$, $\Xi(\delta=0.8)$ falls short from the discounted net benefits of the corresponding compensation policy based on irreversible reduction measures. As the support for reversible reduction measures was able to skim the maximum bargaining gains, the scope for compensating for irreversible reduction measures is likely to be larger. I refrain from discussing the technology preference of the *receiver* which may be opposite to the donors' one. Conflicts may arise on the technology choice unless I assume that the donors are Stackelberg leaders who can determine the technology.

The section has shown that the problem of technology choice is totally different for the cooperating countries and for the compensations given to a third country. If the cooperating countries in the inner coalition exhibit a discount factor which exceeds 0.5, they will introduce compensation policies. Discount factors which exceed 0.5 also guarantee that the full cooperative level in the inner coalition is reached. Unless the costs of the reversible technology surmount the costs of the irreversible technology significantly, this cooperation is based on reversible reduction measures. The full cooperation of the inner coalition is a necessary and sufficient condition for any compensation policies. The compensation policies do not depend on the impatience of the country which is to be compensated for extra reductions but on the impatience of the paying countries which face a time lag between compensations and realized extra reductions. Furthermore, the ambiguity with respect to the preferred technology for which compensations are paid can explain why impatient countries receive support for irreversible technologies which seemingly do not fit in with the demands of cost minimization. They can bear a strategic advantage for the donors which may even overcompensate for higher costs. This strategic advantage is the greater the lower the discount factor of the receiver is because a low discount factor induces low switching costs.

5. Summary and Conclusions

This paper has demonstrated that partial cooperation with respect to the use of an international environmental resource can emerge when countries are able to opt to breach an agreement and decide about compliance simultaneously. Although merely two countries join an inner coalition, broader cooperation can also emerge because these two countries are able to pay a third country for extra reduction efforts. Self-enforcing compensations to third countries enlarge the set of those countries whose reduction efforts exceed their non-cooperative level. When addressing environmental problems which affect more than three countries, either this inner coalition can compensate further countries or other subcoalitions can emerge. Thus, although an inner coalitions comprises only two countries, broader cooperation is not restricted to coalitions which consist of two-member-subcoalitions. The paper assumes identical benefits and costs and demonstrated the crucial role of the discount factors in such a setting. They decide on the countries which join a coalition and the impatience of the donors decides on the degree of extra reductions whereas the impatience of the receiving country plays no role except for the switching costs.

Exploring the implications of irreversible technologies, the paper demonstrated that irreversibility can provide commitment options which can render these technologies superior even if they incur higher costs than the reversible technology. This result can explain policies which compensate for the introduction of an obviously cost-inferior reduction technology which is very capital-intensive. This strategy is even more successful if both countries can mitigate non-compliance incentives by in-kind-transfers which substitute monetary compensations (see STÄHLER, 1992).

6. References

Barrett, S. (1991), *The Paradox of International Environmental Agreements*, mimeo, London Business School.

Barrett, S. (1992), *International Environmental Agreements as Games*, in: Conflicts and Cooperation in Managing Environmental Resources, ed. by R. Pethig, Springer: Berlin.

Bauer, A. (1992), *International Cooperation over Environmental Goods*, Münchener Wirtschaftswissenschaftliche Beiträge Nr. 92-17.

Binmore, K., Osborne, M., Rubinstein, A. (1990), *Noncooperative Models of Bargaining*, The Foerder Institute for Economic Research Working Paper No. 12-90, Tel-Aviv University.

Carraro, C., Siniscalco, D. (1992), *Strategies for the International Protection of the Environment*, Nota di Lavorno della Fondazione Eni Enrico Mattei 4.92.

Damme, E. van (1989), *Renegotiation-proof equilibria in repeated prisoner's dilemma*, Journal of Economic Theory, 47: 206-207.

Farrell, J., Maskin, E. (1989), *Renegotiation in Repeated Games*, Games and Economic Behavior, 1: 327-360.

Heal, G. (1992), *International Negotiations on Emission Control*, Structural Change and Economic Dynamics, 3: 223-240.

Rubinstein, A. (1982), *Perfect Equilibrium in a Bargaining Model*, Econometrica, 50: 97-109.

Selten, R. (1978), *The Chain Store Paradox*, Theory and Decision, 9: 127-159.

Stähler, F. (1992), *Pareto Improvements by In-Kind-Transfers*, Kiel Working Paper No. 541, The Kiel Institute of World Economics.

Stähler, F. (1993), *Strategic Bargaining for Self-Enforcing Contracts*, mimeo, The Kiel Institute of World Economics.

Appendix

Evaluation of the limit of self-enforcing reduction efforts

Rearranging (10) and eliminating the benefit and costs parameters leads to a rewritten compliance constraint:

$$f(\tau-1)^2 - f(\tau)^2 + \delta f(\tau)^2 - \frac{1-\delta}{\delta^\tau}\sum_{t=\tau+1}^{\infty}\delta^\tau f(\tau)^2 \geq 2[f(\tau-1)-f(\tau)] \Leftrightarrow$$

$$f(\tau-1)+f(\tau)+\frac{\delta f(\tau)^2 - \frac{1-\delta}{\delta^\tau}\sum_{t=\tau+1}^{\infty}\delta^\tau f(\tau)^2}{f(\tau-1)-f(\tau)} \equiv \Omega(\tau) \leq 2$$

I evaluate the limit by a linear approximation. I define $f(\tau+1)=a, f(\tau)=a+b, f(\tau-1)=a+2b, f(\tau+2)=a-b,...$ Inserting this linear approximation into the sum term of the compliance constraint gives

$$\frac{1-\delta}{\delta^\tau}\sum_{t=\tau+1}^{\infty}\delta^\tau f(t)^2 = (1-\delta)\sum_{n=1}^{\infty}\delta^n[a-(n-1)b]^2 =$$

$$\delta a^2 - \left\{2ab\sum_{n=1}^{\infty}2\delta^n(n-1) - a^2b^2\sum_{n=1}^{\infty}2\delta^n(n-1)^2\right\}(1-\delta) =$$

$$\delta a^2 - \left\{\frac{2\delta^2 ab}{(1-\delta)^2} - a^2b^2\sum_{n=1}^{\infty}2\delta^n(n-1)^2\right\}(1-\delta)$$

and leads to $\Omega(\tau) = 2a + 3b + 2\delta a + \delta b + \frac{2\delta^2 a}{1-\delta} - (1-\delta)a^2 b\sum_{n=1}^{\infty}\delta^n(n-1)^2$.

Due to $\lim_{n\to\infty}\{\delta^n[n-1]^2\} = 0$

(necessary condition for convergence) and

$$\lim_{n\to\infty}\left\{\frac{n^2\delta^{n+1}}{(n-1)^2\delta^n}\right\} = \delta\lim_{n\to\infty}\left\{\frac{n^2}{n^2-2n+1}\right\} = \delta\langle 1$$

(sufficient condition for convergence), the sum term in $\Omega(\tau)$ converges when $n\to\infty$. This allows for calculating the infinite limit of $\Omega(\tau)$ which is given for $b\to 0$ and must not exceed 2:

$$\lim_{\tau\to\infty}\Omega(\tau) = \lim_{b\to 0}\Omega(\tau) = \frac{2a}{1-\delta} \leq 2 \Leftrightarrow a \leq 1-\delta \Rightarrow \theta = 1-\delta$$

This shows that a self-enforcing dynamic contract can maximally approach 1-δ.

Evaluation of the limit of the dynamic self-enforcing compensation contract

Again, I evaluate the limit by a linear approximation. Let h(t) represent the dynamics of the contract:

$$\upsilon(t)=\frac{\alpha}{\gamma}-h(t)\frac{\alpha}{\gamma}, h(0)=1, h'\langle 0, 0\langle h(t)\leq 1, \lim_{\tau\to\infty} h(\tau)=\psi.$$

Using

$$\upsilon(t)-\upsilon(t-1)=\left[h(t-1)-h(t)\right]\frac{\alpha}{\gamma}$$

$$2\delta\frac{\alpha^2}{\gamma}\sum_{t=\tau+1}^{\infty}\delta_k^t\left[h(t-1)-h(t)\right]-\delta_k^{\tau+1}\frac{\frac{\alpha^2}{2\gamma}\left[h(\tau)^2-h(\tau-1)^2\right]+\frac{2\alpha^2}{\gamma}}{1-\delta_k}$$

gives the compliance constraint

$$2\delta\frac{\alpha^2}{\gamma}\sum_{t=\tau+1}^{\infty}\delta_k^t\left[h(t-1)-h(t)\right]\geq\delta_k^{\tau+1}\frac{\frac{\alpha^2}{2\gamma}\left[h(\tau)^2-h(\tau-1)^2\right]+\frac{2\alpha^2}{\gamma}\left[h(\tau-1)-h(\tau)\right]}{1-\delta_k}$$

The linear approximation $h(\tau)=c, h(\tau+1)=c-d, h(\tau-1)=c+d, \ldots$ changes the compliance constraint into

$$2\delta+c+\frac{d}{2}-2\geq 0.$$

The self-enforcement-condition is always met if this condition holds for a d→0 because a zero d represents the limit of strictly decreasing additional reductions:

$$2\delta+c-2\geq 0\Leftrightarrow c\geq 2-2\delta\Rightarrow\psi=\begin{cases}1 \text{ if } \delta\leq 0.5\\ 2-2\delta \text{ if } \delta\rangle 0.5\end{cases}$$

This shows that a self-enforcing compensation policy will be introduced if δ surmounts 0.5 and that h can at best approach 2-2δ.

Figure 1: Restricted Cooperation in the Case of a Reversible Technology