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Working Paper

Financing incremental abatement costs under asymmetric information

Diskussionsbeiträge - Serie I, No. 294

Provided in Cooperation with:

Department of Economics, University of Konstanz

Suggested Citation: Schmidt, Carsten (1998) : Financing incremental abatement costs under asymmetric information, Diskussionsbeiträge - Serie I, No. 294, Universität Konstanz, Fakultät für Wirtschaftswissenschaften und Statistik, Konstanz

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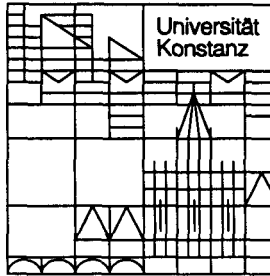
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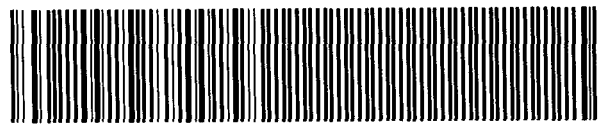


**Fakultät für
Wirtschaftswissenschaften
und Statistik**

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**Financing Incremental
Abatement Costs
under Asymmetric Information**

W 284 (294)



11. DEZ. 1998 Weltwirtschaft
Kiel

W 284 (294) *mi/b*

Diskussionsbeiträge

**Financing Incremental Abatement Costs
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Serie I - Nr. 294

875610

November 1998

Financing Incremental Abatement Costs under Asymmetric Information

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Abstract:

The paper analyzes international environmental agreements that incorporate transfers from a group of industrialized countries to developing countries in a situation of asymmetric information. The framework of the analysis is a static model of transboundary pollution in which information on abatement costs is public, but information on abatement benefits is private. The properties of cooperative solutions for separating and pooling equilibria are analyzed. It is shown under which circumstances it is not optimal for the donors to compensate recipients for their net incremental abatement costs, but where instead it is profitable for both parties to apply the gross incremental cost concept. The paper discusses the implications of the results for projects to protect global environmental resources within the concept of „joint implementation“.

JEL-classification: D61, D62, H77, Q20, Q28

Keywords: international environmental agreements, asymmetric information, incremental abatement costs, side payments, joint implementation

*Paper presented at the annual meeting of the Swiss Association of Statistics and Economics, 26.03.1998 in Stein am Rhein. I would like to thank Bernd Genser, Andreas Haufler and Sebastian Killinger for helpful discussions and comments. Jörg Schmidt helped to weed out the greatest linguistic boobs. All remaining shortcomings remain in my sole responsibility.

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1 Introduction

International environmental agreements increasingly make use of international transfers. Recent examples are the Framework Convention on Climate Change (Rio, 1992), the Montreal Protocol on the protection of the ozone layer (1986) or the biodiversity convention. Compensation payments are of particular importance when the countries involved in a transboundary pollution problem are considerably heterogeneous and when some parties seek to improve the international cost-effectiveness of related abatement activities. Whenever marginal abatement costs differ strongly across countries, a cost-effective cooperative solution implies an uneven distribution of abatement obligations. If the asymmetries are sufficiently strong, the gains from cooperation will be even negative for certain countries with relatively low marginal abatement costs. These countries will voluntarily cooperate only if they are conceded additional compensations. Prominent examples in this context are transfers granted by the *Global Environment Facility* (GEF) and the *Montreal Protocol Multilateral Fund* (MPMF) for activities of developing countries to protect global environmental resources. In both cases, the available funds are provided by industrialized countries who believe that the same environmental effect could be achieved by domestic measures only at higher costs. Another example for the practical relevance of international compensation schemes is the concept of *joint implementation* that has been elaborated in the course of the Rio process and that has recently been confirmed in the Kyoto Protocol. Although the precise modalities of the latter concept still have to be determined, any such project will at least implicitly make use of international compensations.

Bargaining on the size of international compensation payments is a difficult task already under perfect information. The problem is even aggravated in the presence of imperfect information on abatement costs and benefits. In the course of international negotiations there often exist strong incentives to misrepresent one's own damage and abatement costs and to give false information that support the own position. One reason for such behavior — which is the issue of the present paper — is that strategically over- or understating the own characteristics may allow to reap larger side payments. Up to now, many studies on international environmental agreements neglect the incentives for strategic behavior that are due to informational shortcomings.¹ Usually it is assumed that national governments have perfect

¹Barrett (1994), for example, analyzes international environmental agreements that are self-enforcing, but considers identical countries, assumes perfect information and rules out the possibility of side payments. Carraro and Siniscalco (1993) allow for international side payments, but assume perfect information and identical countries as well. See Mäler (1990) for a survey on international environmental problems under perfect and imperfect information.

information both on their own costs and benefits of environmental policy and those of all other countries. This assumption is quite heroic not only due to the markedly dynamic character of international environmental problems like global warming or the destruction of the ozone layer. Even under perfect foresight the fundamental problem remains that environmental preferences (i.e. information on marginal willingness to pay for the environment) are private information and therefore open to strategic manipulation.

The purpose of this paper is to investigate the role of asymmetric information for the transfer scheme that is adopted in an international environmental agreement including side payments. To this end, we compare compensations for net versus gross incremental abatement costs and analyze the respective incentives for truth-telling or false-reporting, the preferred transfer scheme and potential cooperative solutions. The notion of *incremental abatement costs* prescribes that recipient countries are compensated for their extra costs they incur due to participation in an environmental agreement. Under the net incremental cost rule, project-induced extra benefits that accrue to the host country of an environmental protection project are deducted from the payment that compensate this country for its gross incremental abatement costs. The extra benefits may be given in terms of an increased quality of the international environmental resource at stake, in terms of local environmental benefits or in terms of other, non-environmental side-benefits (e.g. technology transfer or capacity building in developing countries). The incremental cost concept is an operational guideline for institutions to promote cost-effectiveness in global environmental policy like the Global Environment Facility (see e.g. King 1993) and the Montreal Protocol Multilateral Fund as well as for *activities implemented jointly* [Art. 4 Par. 2a FCCC] and potentially for the *Clean Development Mechanism* of the Kyoto Protocol.²

The analysis illustrates that the application of the net incremental cost concept can be seen as the result of strongly unequal bargaining positions of the cooperating parties. It implies that the gains from environmental cooperation entirely go to the (industrialized) donors of transfers. Asymmetric information on the characteristics of the (developing) recipient countries, however, qualifies this result and secures cooperation gains also for those countries. Even if the donor coalition can dictate the terms of the agreement and is able to submit a differentiated „take it or leave it“-offer which corresponds to a separating equilibrium, the financing of net incremental costs is generally not optimal for the donors. The same holds when the transfer scheme has to be based on simple, undifferentiated rules which end up in a pooling

²See e.g. Bohm (1994) and Pearce (1994) for discussions of the concept of ‘joint implementation’. Asymmetric information in ‘joint implementation’ projects is also analyzed by Hagem (1996).

equilibrium. In cases where the countries are sufficiently asymmetric and knowledge on the imperfectly known variable is poor, it may be optimal both for recipients and donors to agree on a compensation of *full* incremental abatement costs.³ This result offers an explanation why the Framework Convention on Climate Change stipulates that recipients of international transfers granted in connection with joint implementation projects are compensated for their „agreed full incremental costs“ [Art. 4 Par. 3 FCCC].

The framework of the analysis is a static signaling game on emission abatements. Two heterogeneous parties negotiate an international environmental agreement to reduce globally harmful emissions. To this end, countries with relatively high marginal abatement costs grant transfers to low-cost countries. It is assumed that the two groups of countries act like single agents and that the parties can credibly commit to their treaty obligations.⁴ Information is imperfect in the sense that national abatement costs are public knowledge, but information on abatement benefits is private.⁵ This assumption reflects the fact that the economic costs of environmental protection measures abroad are relatively well known in comparison to the environmental preferences of the populations of foreign countries. The signaling device are emission abatements in the non-cooperative Nash equilibrium. On the basis of this information, the parties negotiate agreements that either include differentiated transfers for each type the recipient may take (separating equilibria) or uniform transfers to compensate for net or for full incremental abatement costs (pooling equilibria).

The structure of the paper is as follows. In section 2 we describe the basic model that is formulated in terms of costs and benefits of emission abatements and derive the properties of the non-cooperative Nash equilibrium and the global optimum. Section 3 describes as a benchmark possible agreements under perfect information. In section 4 we introduce asymmetric information and derive the signaling incentives under the two alternative incremental cost concepts. Section 5 analyzes the terms of the agreement in the separating equilibrium and in section 6 we derive the properties

³A similar result is derived by Mohr (1996) in a dynamic model of complete information where industrialized and developing countries bargain over the protection of an international environmental resource (rain forests) and accompanying transfers.

⁴In the context of the negotiations that led to the erection of the GEF and the MPMF, the formation of subcoalitions, the presence of outsider countries and enforcement problems have been relatively insignificant in comparison to other issues (see e.g. DeSombre and Kauffman 1996 and Fairman 1996).

⁵See Chillemi (1997) for a similar model with multiple countries that also allows for international side payments. Bac (1996) analyzes a repeated game of two countries under imperfect information about environmental valuations. Steiner (1997a, 1997b) considers international environmental agreements including transfers in the presence of asymmetric information on abatement costs.

of the pooling equilibria where transfers compensate either for net or full incremental abatement costs. It is investigated which of the transfer schemes is favored by each of the two coalitions. Section 7 discusses possible extensions and implications of the results for „joint implementation“ projects to protect global environmental resources.

2 The model

Consider a world divided in two groups of countries who act like single agents. The parties negotiate on reductions of emissions of a flow pollutant that constitutes a pure public bad. The international environmental agreement stipulates transfers from the group of donor countries D to the group of recipient countries R . Abatement quantities q_D and q_R add up to global abatements Q , where subscripts refer to the two groups of countries ($Q = q_D + q_R$).⁶ Assuming a one-shot game and abstracting from general equilibrium effects, the decision problem for each coalition reduces to balancing benefits against costs of abatement efforts. The public good-character of pollution reduction implies that a coalition's benefits B_k depend on global abatement quantities, whereas abatement costs C_k depend only on a coalition's own contribution. Net abatement benefits π of coalition k are⁷

$$\pi_k = B_k(Q) - C_k(q_k) \quad k = D, R. \quad (1)$$

As the subsequent analysis requires a comparison of welfare levels and in order to be able to analyze different scenarios of heterogeneity, abatement costs and benefits have to be specified further. Therefore, we assume linearly increasing marginal costs of abatements: $C'_k = c_k q_k$, $c_k > 0$, where c_k is a group-specific exogenous parameter that determines the slope of the marginal cost function for coalition k . This functional specification seems to be a reasonable approximation e.g. for CO₂ emissions (cf. Nordhaus 1991, p. 929).⁸ With respect to abatement benefits, we assume that the marginal benefit from the reduction of one unit of pollution is constant: $B'_k = b_k$, $b_k > 0$, where b_k is an exogenous coalition-specific parameter. This specification is empirically justified at least for some pollutants and over a certain range of

⁶For simplicity, we disregard heterogeneities and diverging interests within each group of countries and neglect the aspect of free riding by third countries that do not belong to any of the two groups.

⁷Although restrictive, assuming additive separability of the underlying preferences is the usual approach in the related literature (see e.g. Barrett 1994, p. 880; Carraro and Siniscalco 1993, p. 311; Chander and Tulkens 1997, p. 381) and is maintained here as well.

⁸Assuming that marginal abatement costs increase at an even steeper rate, as some of the empirical literature suggests, does not change the qualitative results.

abatement quantities.⁹ Global warming, for example, is not linear but logarithmic in CO₂ concentrations so that marginal damages that rise in temperatures may well be constant in CO₂ emissions and concentrations. Assuming that the cost of the first unit of abatement in the absence of any environmental concern is (close to) zero and integrating marginal abatement benefits and costs, national net benefit function (1) is specified and given by

$$\pi_k = b_k Q - c_k/2 q_k^2. \quad (2)$$

Global net benefits of abatements Π are the sum of the two coalition's net benefits π_D and π_R :

$$\Pi = (b_D + b_R) Q - c_D/2 q_D^2 - c_R/2 q_R^2. \quad (3)$$

Balancing marginal abatement benefits against costs determines the optimal quantity q_k of coalition k . In the following, we compare the non-cooperative equilibrium with the central planner (or full cooperative) solution.

Let us first look at the properties of the non-cooperative equilibrium when the two coalitions exhibit Nash behavior.¹⁰ In this case there is an independent maximization of each coalition's net benefit function (2) by choosing abatement levels that are optimal from the perspective of each coalition. From a single coalition's perspective abatement quantities are optimal when marginal benefits are equalized with marginal costs for this group:

$$\partial \pi_k / \partial q_k = b_k - c_k q_k \stackrel{!}{=} 0 \quad \Leftrightarrow \quad q_k^N = b_k / c_k. \quad (4)$$

As we have assumed constant marginal abatement benefits, the best response functions are orthogonal to each other and non-cooperative abatements do not depend on abatement efforts in the rest of the world. The intersection of the reaction curves determines the non-cooperative Nash equilibrium N .¹¹ Substituting equilibrium quantities (4) into global net benefit function (3) gives global net benefits of abatements under Nash behavior, denoted by $\Pi^N \equiv \Pi(q_D^N, q_R^N)$.

⁹See e.g. Carraro and Siniscalco (1993), p. 323–325, or Nordhaus (1991b), who assesses constant marginal benefits of carbon emission reductions as a rough approximation for the US. The assumption is made for the sake of analytical convenience, here. Assuming (linearly) decreasing marginal abatement benefits does not change the qualitative results.

¹⁰By treating the two groups as single agents it is implicitly assumed that the (perfectly homogeneous) members of each group coordinate their environmental policies even in the non-cooperative Nash equilibrium.

¹¹The equilibrium is unique and stable because reaction curves (4) are linear with a slope of 0.

National abatement levels that are *globally* optimal are derived by maximizing the sum of net benefits (3) with respect to q_D and q_R .¹²

$$q_k^* = \frac{b_D + b_R}{c_k}. \quad (5)$$

Comparing the globally efficient allocation (5) with the non-cooperative allocation of abatements (4) illustrates the two basic sources of inefficiency. Not only aggregate abatements are too low ($Q^N < Q^*$), but also the distribution of abatement efforts across countries generally is not cost-efficient. Since marginal abatement costs are not equalized, the same global environmental standard could be achieved at lower overall costs. Only in the special case of $b_D = b_R$ do the two ratios $q_D^*/q_R^* = c_R/c_D$ and $q_D^N/q_R^N = (b_D c_R)/(b_R c_D)$ coincide. In this special case, marginal abatement costs are equalized and cost-effectiveness is reached even in the non-cooperative equilibrium.

In the following we assume that both marginal abatement benefits and costs are higher for coalition D ($b_D > b_R \wedge c_D > c_R$). Moreover, we define the group of recipient countries R to be worse off in the full cooperative solution (i.e. under global efficiency) in comparison to non-cooperation: $\pi_R^* < \pi_R^N \Leftrightarrow b_D^2 c_D > 2 b_R^2 c_R$. This type of asymmetry between the two groups of countries implies that marginal abatement costs are higher for countries D under non-cooperation and requires positive side payments from D to R in order to make countries R voluntarily cooperate. The above scenario stylizes the general division of countries into rich, industrialized donors and poor, developing countries that have to be bribed to cooperate on the protection of global environmental resources.

3 Agreements under perfect information

Consider negotiations on an international environmental agreement prescribing emission reductions and including a transfer from donor countries D to recipients R . The side payments serve to induce the cooperation of those countries which have a relatively little interest in pollution control but are able to reduce emissions at smaller marginal costs. Starting-point for negotiations is the non-cooperative Nash equilibrium. The agreement has to be individually rational for both parties, i.e. it has to guarantee at least the same utility as in the non-cooperative equilibrium.¹³ We take that the enforcement of the agreement is assured once it has been signed.¹⁴ Further-

¹²It has to be emphasized that uniqueness of globally efficient abatements is no more given once one leaves behind the simplifying assumptions made here. Chander and Tulkens (1997), p. 381–382, derive the conditions for uniqueness in a general setting.

¹³It is assumed that if a coalition is indifferent towards cooperation, it will cooperate.

¹⁴In the context of ‘joint implementation’ projects, allowing for binding commitments seems to be not too problematic because related projects can be delegated to private agents (companies or

more, it is assumed that the parties agree to maximize their collective gains from environmental cooperation during the negotiations. The optimization problem for the agreement then is

$$\max \Pi(q_D^C, q_R^C) \quad \text{s.t.} \quad (6)$$

$$\pi_D(q_D^C, q_R^C) - T \geq \pi_D(q_D^N, q_R^N) \quad (7)$$

$$\pi_R(q_D^C, q_R^C) + T \geq \pi_R(q_D^N, q_R^N), \quad (8)$$

where transfer T is defined in terms of transferable utility. Constraints (7) and (8) secure individual rationality of signing the agreement for both groups of countries. Writing the conditions together and rearranging shows that there always exists a positive transfer so that both constraints are fulfilled.¹⁵ The first order conditions of the optimization problem (6)–(8) yield the agreement

$$q_D^C = q_D^*, \quad q_R^C = q_R^*, \quad \pi_D^C - \pi_D^N \geq T \geq \pi_R^N - \pi_R^C. \quad (9)$$

It follows that under the above assumptions the agreement prescribes globally efficient emission abatements and results in maximal aggregate gains from cooperation. This outcome simply replicates the usual Samuelson condition for the efficient provision of a pure public good and corresponds to the Coasian bargaining solution. The structure of the game, however, does not suffice to identify a unique cooperative solution with respect to the amount of transfers T . The latter determine how the aggregate gains are distributed between donor and recipient countries which depends basically on the relative bargaining strengths of the negotiating parties.

For illustrative purposes, let us consider two extreme scenarios with respect to the distribution of aggregate gains from international environmental cooperation: The first scenario is that the gains are shared in equal amounts between the two coalitions. Transfers T in (9) then are unambiguously determined by

$$\pi_D^C - T - \pi_D^N \stackrel{!}{=} \pi_R^C + T - \pi_R^N \Leftrightarrow T = 1/2 \left[(\pi_D^C - \pi_D^N) - (\pi_R^C - \pi_R^N) \right]. \quad (10)$$

The other benchmark is that the gains go entirely to one party, for example the donor countries, and the recipients' welfare remains unchanged. This cooperative solution emerges if one party (in our example the donor coalition) is able to dictate the terms of the agreement and submits a „take it or leave it“-offer, whereas the other party

non-governmental agencies) and are monitored by an international institution that administers the financial funds.

¹⁵By definition, aggregate net benefits are higher under cooperation than in the non-cooperative Nash equilibrium: $\Pi^C > \Pi^N \Leftrightarrow \pi_D^C + \pi_R^C > \pi_D^N + \pi_R^N \Leftrightarrow \pi_D^C - \pi_D^N > \pi_R^N - \pi_R^C$. Hence, without additional restrictions on T , constraint $\pi_D^C - \pi_D^N \geq T \geq \pi_R^N - \pi_R^C$ is always fulfilled.

can only accept or reject it.¹⁶ In this case, individual rationality constraint (8) is binding and the transfer is given by

$$T = \pi_R^N - \pi_R^C = [C_R(q_R^C) - C_R(q_R^N)] - [B_R(Q^C) - B_R(Q^N)] \equiv T^n. \quad (11)$$

This transfer implies the financing of *net* incremental abatement costs incurred by the recipient. The first term in square brackets represents the *gross* incremental abatement costs due to R 's cooperation

$$T^g \equiv C_R(q_R^C) - C_R(q_R^N), \quad (12)$$

the second term stands for its incremental benefits. R 's gains from reduced pollution thus are in total subtracted from the side payments it receives as a compensation for higher abatement costs under cooperation. The above transfer schemes suggest that countries R may have an incentive to understate their true environmental preferences in cases where they possess private information on their benefits from a cleaner environment. If such a signaling strategy is successful it will reduce the deduction for the incremental benefits from environmental cooperation. In the following, we discuss R 's incentives (not) to reveal its true type under the two transfer schemes (11) and (12): compensations for net and for gross incremental abatement costs.

4 Signaling incentives

We scrutinize a scenario with asymmetric information on environmental preferences (i.e. abatement benefits) and perfect information on abatement costs. The analysis focuses on the incentives of recipient countries to strategically disguise their true type in order to induce higher side payments. For simplicity it is therefore assumed that only the abatement benefits of the recipients are imperfectly known, whereas those of the donors are common knowledge. Information is asymmetric on marginal abatement benefits, expressed by the benefit parameter b_R , which may take two alternative values: $\theta = \{b_R^-, b_R^+\}$. In other words, countries R may have either high (b_R^+) or low (b_R^-) marginal abatement benefits, the true type being known only by themselves.

The signaling device that allows for a strategic reporting of R 's marginal abatement benefits is the emission reduction in the non-cooperative Nash equilibrium. As abatement quantities q_k , cost parameters c_k and the characteristics of the Nash game are common knowledge, donor countries can infer from equ. (4) the marginal abatement benefits of the recipients. However, they can only observe the type that

¹⁶The corresponding optimization problem for the donors then is to maximize $[\pi_D(q_D^C, q_R^C) - T]$, resulting in globally efficient abatement quantities as in (9).

is *signaled* by R via q_R^N . By abating emissions by less than optimal Nash quantities, future recipients that are of the high type b_R^+ can signal to have low marginal abatement benefits and vice versa for type b_R^- . The donors know of this possibility but cannot detect the fraud. Instead, the parties have to agree on a solution that makes ‘truth-telling’ (i.e. non-cooperative abatement quantities that correspond to R ’s true type) rewarding for countries R .

Before investigating the properties of such an agreement in the presence of asymmetric information it has to be established if and under what conditions R has an incentive not to reveal its true type. Signaling false abatement benefits can be costly for R because of two reasons. Firstly, in the non-cooperative Nash equilibrium it has to choose abatements that do not correspond to its true optimal quantities. Secondly, also cooperative abatement quantities are not calculated on the basis of R ’s true environmental preferences but on the basis of the given signal. When deciding on the optimal signal, countries R therefore have to weigh the costs in terms of a suboptimally chosen environmental standard against the gains in terms of the amount by which the transfer can be increased.

4.1 Financing of net incremental abatement costs

Given a transfer that corresponds to the financing of net incremental abatement costs as in (11), we can define the potential net gain of misrepresenting the own type (indicated by \tilde{b}_R) as ‘information rent’ I^n :

$$I^n(\tilde{b}_R) = [\pi_R^N(\tilde{b}_R) - \pi_R^N(b_R)] + [T^n(\tilde{b}_R) - T^n(b_R)] + [\pi_R^C(\tilde{b}_R) - \pi_R^C(b_R)] \quad (13)$$

The first term in square brackets is the welfare loss incurred by the strategically chosen abatement quantity in the Nash equilibrium which does not correspond to the true optimal quantity. The second term is the change in the transfer induced by the wrongly given signal. It is positive (negative) in case R with type $\theta = b_R^+$ ($\theta = b_R^-$) signals to be of the low-type (high-type). The third term represents the change in welfare due to cooperative abatements (9) that do not correspond to the quantities calculated on the basis of R ’s true type. The sign of the third term generally is ambiguous, but positive when the countries are sufficiently asymmetric.¹⁷ Understating, for example, decreases both cooperative abatement costs and benefits, the net effect depending on parameter values. As there are only two types θ , the question whether ‘false-reporting’ pays off is answered by checking for each of the two types if I^n is positive.¹⁸ It turns out that for the low-type ($\theta = b_R^-$) overstating

¹⁷Appendix A.1 derives a sufficient condition for the third term to be negative.

¹⁸If (13) were a continuous function, the optimal value of \tilde{b}_R would be determined by setting the first derivation of I^n equal to zero.

never pays off, whereas for the high-type ($\theta = b_R^+$) understating always pays off, given that $b_D > b_R$ (see Appendix A.2). Hence, whenever the marginal abatement benefits of the donor countries are relatively higher, the recipients will signal to be of the low type, whatever their true marginal abatement benefits are ($\tilde{b}_R = b_R^- \forall \theta$).

4.2 Financing of gross incremental abatement costs

Given a transfer that corresponds to the financing of gross incremental abatement costs as in (12), we can define the potential net gain of misrepresenting the own type (indicated by \tilde{b}_R) as ‘information rent’ I^g :

$$I^g(\tilde{b}_R) = [\pi_R^N(\tilde{b}_R) - \pi_R^N(b_R)] + [T^g(\tilde{b}_R) - T^g(b_R)] + [\pi_R^C(\tilde{b}_R) - \pi_R^C(b_R)] \quad (14)$$

The signaling incentives under this rule are as follows: The first term of (14) is unambiguously negative, the second term is positive (negative) for $\tilde{b}_R = b_R^+ > \theta$ ($\tilde{b}_R = b_R^- < \theta$), and the third term is positive when countries are sufficiently asymmetric (see Appendix A.1) — the net effect being ambiguous. It turns out that for the high-type ($\theta = b_B^+$) understating never pays off, whereas for the low-type ($\theta = b_B^-$) overstating always pays off, given the financing of gross incremental abatement costs (see Appendix A.3). The intuition for the incentive of low-type countries to signal high marginal abatement benefits is that by such a strategy, recipient countries can induce higher cooperative abatement quantities. As they are entirely compensated for the corresponding incremental costs, the extra gain may overcompensate the loss going along with suboptimally large non-cooperative abatement quantities which work as the signal towards the donors. Interestingly, strategic signaling in this case leads to higher non-cooperative emission reductions and therefore counteracts to some extent the inefficiency of non-cooperative behavior.

A comparison of the signaling incentives under the two alternative transfer schemes yields that under the financing of net incremental costs, overstating never pays off and R always signals low environmental preferences, whereas under the financing of gross incremental costs, understating never pays off and R always signals high environmental preferences (Table 1). Given these signaling incentives, the

Table 1: Signaling incentives

	$\theta = b_R^+$	$\theta = b_R^-$
T^n	$\tilde{b}_R = b_B^- < \theta$	$\tilde{b}_R = b_B^- = \theta$
T^g	$\tilde{b}_R = b_B^+ = \theta$	$\tilde{b}_R = b_B^+ > \theta$

question arises as to how the negotiating parties can ensure that the recipients

of transfers reveal their true type. It is known from the theory of environmental regulation under imperfect information that this can be achieved by differentiated (separating) agreements. In the next section we therefore discuss the properties of an agreement that corresponds to a separating equilibrium.

5 Transfers in the separating equilibrium

In this section we look at the separating equilibrium which ensures that revealing the true type is rational for the recipients of compensation payments. This is possible if the parties agree on differentiated (separating) agreements, depending on the type of the recipients. In our simplified framework two different agreements will be offered, one for each type. Maintaining the assumption that the parties maximize joint net benefits of cooperative abatements, the optimization problem being solved for each of the two possible types θ is:

$$\max \Pi \left(q_D^C(\theta), q_R^C(\theta) \right) \quad \theta = \{b_R^-, b_R^+\} \quad \text{s.t.} \quad (15)$$

$$\pi_D^C(\theta) - T(\theta) \geq \pi_D^N(\theta) \quad (16)$$

$$\pi_R^C(\theta) + T(\theta) \geq \pi_R^N(\theta) \quad (17)$$

$$\pi_R^N(b_R^-) + \pi_R^C(b_R^-) + T(b_R^-) \geq \pi_R^N(b_R^+) + \pi_R^C(b_R^+) + T(b_R^+) \quad (18)$$

$$\pi_R^N(b_R^+) + \pi_R^C(b_R^+) + T(b_R^+) \geq \pi_R^N(b_R^-) + \pi_R^C(b_R^-) + T(b_R^-) \quad (19)$$

The additional incentive compatibility constraints (18) and (19) ensure that coalition R is at least as well off under truth-telling as under false-reporting. Condition (18) secures that revealing its true type is incentive compatible for the low-type (indicated by π_R^-), while constraint (19) does the same for the type with high marginal abatement benefits (indicated by π_R^+). Given that the transfers do not restrict the maximization of Π^C , the resulting agreement prescribes for both types globally efficient abatements as in (9). The requirements on the size of the transfers, however, are more restrictive than under perfect information because they must be high enough to make the recipients at least indifferent between revealing and misrepresenting their true type.

The undifferentiated application of the net or gross incremental cost concept does not guarantee that the true type is revealed. For example, consider compensations for net incremental abatement costs that would be optimal for the donors under perfect information. From section (4.1) we know that, under this rule, R has always an incentive to signal low environmental preferences, irrespective of its true type. To make revealing the true type incentive compatible also in case that $\theta = b_R^+$, transfers to high-type R must be greater than the net incremental abatement costs.

The separating equilibrium that is optimal for the donors thus is

$$q_D^C = q_D^*(b_R^-), \quad q_R^C = q_R^*(b_R^-), \quad T(b_R^-) = T^n(b_R^-) \quad \text{for } \theta = b_R^-; \quad \text{and} \quad (20)$$

$$q_D^C = q_D^*(b_R^+), \quad q_R^C = q_R^*(b_R^+), \quad T(b_R^+) = T^n(b_R^-) + [\pi_R^N(b_R^-) - \pi_R^N(b_R^+)] \quad (21)$$

$$+ [\pi_R^C(b_R^-) - \pi_R^C(b_R^+)] \quad \text{for } \theta = b_R^+.$$

When countries R are of the low type, transfers compensate for the net incremental abatement costs of R and the cooperation gains go entirely to the donors (i.e. individual rationality constraint (17) is binding). In the case where countries R are of the high type, part of the gains go to R even if D is able to dictate the terms of the IEA. The transfer chosen in (21) makes R just indifferent between revealing its true type and understating its environmental preferences (i.e. incentive compatibility constraint (19) is binding). Hence, it exceeds the net incremental abatement costs of the high-type (see Appendix A.4). In a more general setting where information on θ is characterized by a continuous probability distribution function, offered transfers will generally exceed net incremental costs (except for the type with the lowest value of b_R). By inducing countries R to reveal their true (high) type, the donors circumvent the inefficiency losses from suboptimal abatement quantities otherwise chosen by R in order to exploit their informational advantage. Generally, there exists no undifferentiated (pooling) agreement that would make the donors better off than under an agreement which discriminates between types.¹⁹ However, it may be often not possible to negotiate complex differentiated agreements. In the next section we therefore investigate which uniform transfer scheme would be preferable if based either on the net or the gross incremental cost concept.

6 Transfers in the pooling equilibrium

Real world negotiations on international environmental policy often lead to simple, uniform solutions. For example, the policy instruments chosen for the internalization of transboundary externalities in most cases are not market-based but of the command-and-control type (e.g. an agreement on equal percentage emission reductions by all signatories). This may be true all the more under imperfect information, as agreeing on differentiated terms for each possible type on which information is imperfect will generally be connected with high negotiation costs. Environmental negotiations are more likely to lead to uniform cooperative solutions that apply to all possible types (i.e. pooling equilibria). Such solutions may not only be associated with lower negotiation and implementation costs. They also may work as a ‘focal

¹⁹This is shown e.g. by Ellis (1992) in the context of environmental regulation of polluting firms that have private information on their abatement costs.

point' during negotiations when agreement on one of multiple possible equilibria is difficult. Furthermore, they may reflect the bargaining positions when a uniform solution is in the interest of certain parties. In the context of our model, pooling equilibria that compensate either for net or gross incremental abatement costs are of particular interest. In the following, we describe at first the properties of these cooperative solutions and then analyze which of the two uniform transfer schemes emerges if it is endogenously chosen during negotiations.

Assume that the parties agree to maximize aggregate gains from environmental cooperation, but that in contrast to (15)–(19) the agreement does not differentiate between the possible types of R and that transfers compensate for net incremental costs as in (11). We know from section 4.1 that under the financing of net incremental costs recipient countries will always signal to have low marginal abatement benefits, irrespective of their true type ($\tilde{b}_R = b_R^- \forall \theta$). To make cooperation for countries R individually rational also when they are of the low-type, the uniform agreement has to be calculated for b_R^- .²⁰

$$q_D^C = q_D^*(b_R^-), \quad q_R^C = q_R^*(b_R^-), \quad T^n = b_D^2/2c_R - b_R^{-2}/c_D, \quad \theta = b_R^-, b_R^+. \quad (22)$$

Alternatively, the transfer scheme may be given by (12). With compensations for gross incremental costs recipient countries will always signal high marginal abatement benefits, irrespective of their true type ($\tilde{b}_R = b_R^+ \forall \theta$). The pooling equilibrium under this rule therefore is

$$q_D^C = q_D^*(b_R^+), \quad q_R^C = q_R^*(b_R^+), \quad T^g = b_D^2/2c_R + b_D b_R^+/c_R, \quad \theta = b_R^-, b_R^+. \quad (23)$$

Given the signaling incentives and the cooperative outcomes for the two types of pooling equilibria, which transfer scheme would be favored by each of the two parties when side payments in an international environmental agreement are to be based on either of the two incremental cost concepts? The answer will be given in two steps: at first we derive which of the two concepts is preferred by each coalition given the signaling incentives summarized in Table 1; then it has to be checked whether the optimal (and possibly unanimous) choice of the transfer scheme is in fact implemented, i.e. if it is time-consistent. The first part of the answer is given by comparing both the donors' and the recipients' welfare under the net with that under the gross incremental cost concept. The comparison is done separately for each of the two types that R 's marginal abatement benefits may take in order to determine which concept would have been optimal *ex post*, after the game has been

²⁰Note that agreements (22) and (23) will not lead to globally efficient abatement quantities if they are calculated for the wrong type. Cooperative abatements calculated for the low-type in (22) are inefficiently low if R in reality is of the high-type, abatements according to (23) are too high in the reverse case.

played. On the basis of this information it is then possible to deduce the optimal transfer scheme *ex ante*. Moreover, we check whether the interests of the two parties regarding the preferred incremental cost concept are in harmony or in conflict with each other.

We start with the case that R has high-type marginal abatement benefits ($\theta = b_R^+$). Bearing in mind the signaling incentives of R and taking into account that the chosen rule influences abatement quantities and welfare in the non-cooperative Nash equilibrium (via the signaling behavior of R), the net concept is superior for D if

$$\pi_D^N(b_R^-) + \pi_D^C(b_R^-) - T^n(b_R^-) > \pi_D^N(b_R^+) + \pi_D^C(b_R^+) - T^g(b_R^+) . \quad (24)$$

By inserting the respective equilibrium abatements it can be shown that the donors do not always favor the net incremental cost concept.²¹ Given that the donor coalition has to choose between either of the two incremental cost concepts irrespective of the recipients' possible types, it faces a trade-off: on the one hand, transfers according to the gross-rule may eliminate strategic signaling incentives; on the other hand, this implies that part of the aggregate cooperation gains are shifted from D to R . In case that (i) the donors' marginal abatement benefits are sufficiently higher than those of the recipients (i.e. when the countries are very asymmetric) and (ii) the difference between the low and the high value of R 's type is substantial (i.e. when the knowledge on R 's marginal abatement benefits is poor), the donors will be better off by compensating the recipients for their *gross* incremental abatement costs of cooperation (see Appendix A.5). The reason for this outcome is that under the above parameter constellations, D 's losses due to a misrepresentation of R 's type are particularly high so that the gains of making countries R reveal their true (high) type more than compensate the distributional disadvantage of the gross concept. Recipient (high-type) countries prefer compensations for gross incremental costs if

$$\pi_R^N(b_R^+) + \pi_R^C(b_R^+) + T^g(b_R^+) > \pi_R^N(b_R^-) + \pi_R^C(b_R^-) + T^n(b_R^-) . \quad (25)$$

It turns out that condition (25) always holds (see Appendix A.5). Hence, in case the recipients possess in reality high-type marginal abatement benefits (the donors do not know this *ex ante*), both coalitions are better off under the gross incremental cost concept when knowledge on the recipients' true type is poor, and the two groups of countries are considerably asymmetric. This is a plausible scenario e.g. for 'joint implementation' projects.

²¹As stated in section 3, donor countries will of course always favor the net rule given that they know R 's true type. Here, however, the question is which rule turns out to be superior when D learns R 's true type only after the game has been played.

Presume now that R in reality possesses low-type marginal abatement benefits ($\theta = b_R^-$). Although R 's type is different, the signals under the two alternative transfer schemes are the same. Hence, the condition for the net incremental cost concept to be superior for the donors is identical to (24) and depends on the parameter constellations described above. Recipient countries prefer compensations for gross incremental costs when condition

$$\pi_R^N(b_R^+) + \pi_R^C(b_R^+) + T^g(b_R^+) > \pi_R^N(b_R^-) + \pi_R^C(b_R^-) + T^n(b_R^-) \quad (26)$$

holds. This is the case when the difference between D 's and R 's marginal abatement benefits is sufficiently larger than the difference between b_R^+ and b_R^- (see Appendix A.5). In contrast to the preferences of the donors, a larger difference between the low and the high value of marginal abatement costs works, *ceteris paribus*, against the recipients' preference of the gross concept. The reason is that not revealing but overstating their true environmental preferences is costly for the recipients in terms of suboptimally high non-cooperative and cooperative abatement quantities. These losses increase with the difference between b_R^+ and b_R^- . Nevertheless, there exist parameter constellations under which the gross incremental cost concept is superior both for the donors and the recipients. Equal interests are possible if the difference between the values of b_R^+ and b_R^- is sufficiently large, but the difference between D 's and R 's (high-type) marginal abatement benefits is even larger. A sufficient condition for the gross incremental cost concept to be unanimously preferred is that $b_D/b_R^+ > 2 + (c_R/c_D)$ (see Appendix A.5). The result that the gross rule may be preferred by both countries although it does *not* lead to a revelation of the true (low) type can be explained by the fact that overstating environmental preferences does not harm, but foster global welfare in the non-cooperative Nash equilibrium, resulting in higher emission reductions than according to R 's true type.

Which rule is preferred by the donors at the stage where they do not know R 's true type depends on the prior probabilities on R 's type. Ex ante, D favors the net incremental cost concept if²²

$$p \left[\pi_D^N(b_R^-) + \pi_D^C(b_R^-) - T^n(b_R^-) - \pi_D^N(b_R^+) - \pi_D^C(b_R^+) + T^g(b_R^+) \right] > \\ (1-p) \left[\pi_D^N(b_R^-) + \pi_D^C(b_R^-) - T^n(b_R^-) - \pi_D^N(b_R^+) - \pi_D^C(b_R^+) + T^g(b_R^+) \right], \quad (27)$$

p standing for D 's belief on the probability that $\theta = b_R^-$ ($0 < p < 1$). Since the terms in square brackets on both sides of the inequality are identical, a given profitability of the gross (net) incremental cost concept due to benefit and cost parameter values unambiguously increases with the probability that R is of the high (low) type. The results for the different cases are summarized in Table 2. Although the

²²Inequality (27) mirrors condition (24) being relevant for both types θ , where both cases are weighted by their probabilities.

Table 2: The preferred incremental cost concept

	$\theta = b_R^+$	$\theta = b_R^-$
D	$T^g \succ T^n$ for $b_D(b_R^+ - 2b_R^-)c_D > b_R^{+2}c_R$	$T^g \succ T^n$ for $b_D(b_R^+ - 2b_R^-)c_D > b_R^{+2}c_R$
R	$T^g \succ T^n$	$T^g \succ T^n$ for $b_D/b_R^+ > b_R^+/b_R^-$

Remark: $T^g \succ T^n$ stands for a party's preference for the gross compared with the net concept. The above conditions are only sufficient (see Appendix A.5).

countries' preferences for either of the two alternative transfer schemes depend on parameter values and on the beliefs of the donors about the type of the recipients, we can make the following statements: There exist scenarios where both parties favor *ex ante* the same rule and this may be financing the recipients' gross incremental abatement costs. The two basic reasons for the latter result are that this transfer scheme (i) avoids the inefficiencies due to strategically understating the true environmental preferences and (ii) counteracts the inefficiencies due to too low non-cooperative abatement efforts when signaling behavior leads to overstating the true environmental preferences.

As already pointed out it has to be checked, however, if opting for the gross rule is also optimal once the true type of the recipients is revealed, i.e. if it is time-consistent. From section 3 we know that this is of course not the case for the donors and that instead the net incremental cost concept is optimal for them, given knowledge on R 's true type. The recipients, anticipating D 's inclination for the net concept in case of truth-telling, will therefore not reveal but understate their environmental preferences in the non-cooperative game. If this time-consistency problem cannot be solved, the pooling equilibrium with the net rule and the potentially false representation of R 's type emerges although it may be inferior to the gross concept from the perspective of both parties.

One possible solution to the above time-consistency problem could be that the donor countries credibly commit themselves to the application of the gross incremental cost concept *before* the recipients decide on non-cooperative abatement quantities which are used for strategic signaling. This commitment could be a unilateral obligation, it could also be the outcome of environmental negotiations that

proceed in several steps and result in subsequently amended agreements.²³ Another solution both to the time-consistency problem and the question which incremental cost concept is in fact applied when the transfer scheme has to be based on simple, uniform rules lies in the relative bargaining strengths of the negotiating parties. Agreement on compensations for gross incremental abatement costs may simply be produced by the fact that the recipient countries — given they favor this rule — are able to push through their interests during negotiations. Paradoxically, the bargaining strength of the recipients is also to the benefit of the donors if it helps to overcome the time-consistency problem described above. In any case, the application of the gross incremental cost concept results in a more equitable distribution of the gains from environmental cooperation between (industrialized) donor and (developing) recipient countries.

7 Conclusions

This paper shows that in the presence of asymmetric information on environmental preferences it may no longer be optimal for donor countries to compensate recipients for their net incremental costs of cooperative emission abatements. This holds even if the donors are in the position to submit a „take it or leave it“ offer and where the terms of the agreement are differentiated for each type the recipients' characteristic may take (i.e. a separating equilibrium). The mark-up of transfers in this case serves to render revealing their true type incentive compatible for the recipients and can be regarded as 'information rent'. In cases where international transfers have to be based on simple, uniform rules (i.e. a pooling equilibrium), there exist scenarios in which donor as well as recipient countries will favor the application of the gross over the net incremental cost concept. Although the former transfer scheme shifts part of the cooperation gains from the donors to the recipients, it reduces the inefficiencies through strategic pre-negotiation behavior and may therefore be beneficial also for the donors.

The parameter constellations for which financing gross incremental abatement costs is favored by both parties are exactly those that one has in mind when international environmental negotiations between industrialized and developing countries take place: marginal abatement benefits and costs are both considerably higher for the industrialized donor countries and knowledge on the true environmental prefer-

²³Of course, potential donor countries could try to infer the other party's characteristics from the observation of pollution reduction efforts even before a future agreement is on the agenda. In that case, the precommitment on the gross incremental cost concept would neither be necessary nor optimal from the perspective of the donors.

ences in developing countries is poor (Table 2). Furthermore, agreement on the full incremental cost concept not only supports the conjecture that asymmetric information may compensate for the generally weak bargaining position of developing countries and that these countries are in a better bargaining position than often thought. Paradoxically, in case of a pooling offer, a strong bargaining position of the recipients can also be to the benefit of the donors because it helps to overcome the time inconsistency in the choice of the superior full incremental cost rule.

The present analysis has to be considered with care due to the restrictive assumptions and the specific nature of the model. There are a number of straightforward extensions that would enable to check the validity of the results also in a more general context. One is to consider a situation where negotiations do not lead to a maximization of joint gains from cooperation. Another simplification of the model is that only recipients dispose of private information but donors do not. It remains to be shown which agreement and transfer scheme emerges when both parties are able to pursue signaling strategies. Furthermore, also other signaling devices than non-cooperative emission abatements may be possible.

A model-extension that seems to be particularly relevant in the context of 'joint implementation' is to allow for local environmental and/or economic benefits in recipient countries. Such extra gains undoubtedly often exist in developing countries. It is often argued that these should be subtracted from the transfers that compensate for the incremental abatement costs a project generates. However, considering private information on local benefits entails that the recipients may have again an incentive to signal low environmental preferences. It is possible that the incentive would prevail even if global emissions are hardly (or, in case of pure emission trading, not at all) reduced by a single project, as long as global and local pollution are closely related to each other. Strategic signaling behavior would harm donor countries also in this case, given that the signal is set in terms of inefficiently low abatements of the global pollutant. Similar results are thus to be expected and the superiority of the gross-rule may still be valid. Furthermore, the above framework permits to relax the assumption of two homogeneous groups of countries and to regard the parties as two single countries that agree on a bilateral transaction under a multilateral framework treaty. A single project then has a negligible impact on global pollution and will only aim at redistributing international abatement efforts cost-effectively. This is the relevant scenario for the analysis of joint implementation projects and transactions within a possible future tradable permit system under the Framework Convention of Climate Change. In this respect, the present analysis is only a first step towards the analysis of cost-effective global environmental policy in the presence of imperfect information.

Appendix

A.1 Change of R 's cooperative net benefits by misrepresenting its type

The change of R 's cooperative net benefits in case of 'lying' is $\pi_R^C(\tilde{b}_R) - \pi_R^C(b_R)$. Inserting cooperative abatement quantities (9) and simplifying yields that the third term of (13) is positive if

$$\begin{aligned} & 2b_R\tilde{b}_Rc_R - 2b_R^2c_R + 2b_Db_Rc_D - 2b_D\tilde{b}_Rc_D + 2b_R\tilde{b}_Rc_D - b_R^2c_D - \tilde{b}_R^2c_D > 0 \\ \Leftrightarrow & 2b_Dc_D(b_R - \tilde{b}_R) - 2b_Rc_R(b_R - \tilde{b}_R) - c_D(b_R - \tilde{b}_R)^2 > 0 \\ \Leftrightarrow & 2(b_Dc_D - b_Rc_R) > (b_R - \tilde{b}_R)c_D \end{aligned}$$

Hence, only in cases in which the countries are fairly homogeneous and where the difference between b_R^+ and b_R^- is sufficiently large (for $c_D \approx c_R$, a sufficient condition for the above inequality to hold is $2(b_D - b_R) > b_R - \tilde{b}_R$), R loses in terms of cooperative net benefits when not revealing its true type. In all other cases the third term of (13) is positive, regardless of R 's true type.

A.2 Signalling incentives under financing of net incremental abatement costs

Inserting into (13) the equilibrium quantities for non-cooperative and cooperative abatement quantities (4) and (9) and simplifying yields

$$\begin{aligned} I^n(\tilde{b}_R) &= \tilde{B}_R(\tilde{Q}^N) + B_R(\tilde{Q}^N) - 2B_R(Q^N) + B_R(\tilde{Q}^C) - \tilde{B}_R(\tilde{Q}^C) \\ &\quad + 2C_R(q_R^N) - 2C_R(q_R^N) \\ &= \frac{1}{c_Dc_R} \left[b_R\tilde{b}_R(2c_D + c_R) - b_R^2c_D - \tilde{b}_R^2(c_D + c_R) + b_Dc_D(b_R - \tilde{b}_R) \right] \\ &= 1/c_R \left[b_D(b_R - \tilde{b}_R) - (b_R - \tilde{b}_R)^2 \right] + 1/c_D \left[b_R\tilde{b}_R - \tilde{b}_R^2 \right]. \end{aligned}$$

By inspecting the last line the sign of I^n for the two possible types can be determined: for $\theta = b_R^+$ ($\theta = b_R^-$), the second term in square brackets is positive (negative), while the first term in square brackets is positive for $b_D - b_R > -\tilde{b}_R$ (always negative for $\theta = b_R^-$). Hence, overstating never pays off, whereas a sufficient condition for understating to pay off is $b_D > b_R$.

A.3 Signalling incentives under financing of gross incremental abatement costs

The signaling incentives for each of the two types under compensations for gross incremental abatement costs are derived by inserting into (14) the equilibrium quan-

tities (4) and (9) for non-cooperative and cooperative abatements, respectively:

$$\begin{aligned}
I^g(\tilde{b}_R) &= [\pi_R^N(\tilde{b}_R) - \pi_R^N(b_R)] + [T^g(\tilde{b}_R) - T^g(b_R)] + [\pi_R^C(\tilde{b}_R) - \pi_R^C(b_R)] \\
&= 1/(c_D + c_R) \left[2b_R\tilde{b}_R c_D - \tilde{b}_R^2 c_D - b_R^2 c_D + b_R\tilde{b}_R c_R - b_R^2 c_R + b_D b_R c_D - b_D \tilde{b}_R c_D \right] \\
&= 1/(c_D + c_R) \left[b_D c_D - b_R c_R - (b_R - \tilde{b}_R) c_D \right].
\end{aligned}$$

Inspection of the last line yields that for $\theta = b_R^+$ the value of (14) is maximal when R reveals its true type (the third term in the square bracket becomes zero) and that for $\theta = b_R^-$ overstating always pays off (the third term in the square bracket is positive) under the gross rule.

A.4 Transfers to the high-type in the separating equilibrium

The transfer (21) granted in case R is of the high type is greater than it would be under financing R 's true net incremental costs if

$$T = T^n(b_R^-) + [\pi_R^N(b_R^-) - \pi_R^N(b_R^+)] + [\pi_R^C(b_R^-) - \pi_R^C(b_R^+)] > T^n(b_R^+).$$

Inserting the equilibrium quantities for non-cooperative and cooperative abatement quantities (4) and (9), using (11) and simplifying yields

$$\begin{aligned}
&2\tilde{b}_R c_R (b_R - \tilde{b}_R) + 2b_D c_D (b_R - \tilde{b}_R) - 2c_D (b_R - \tilde{b}_R)^2 > 0 \\
\Leftrightarrow &\tilde{b}_R (c_D + c_R) + c_D (b_D - b_R) > 0,
\end{aligned}$$

where $\tilde{b}_R = b_R^-$ and $\theta = b_R^+$. Hence, a sufficient condition for the transfer to be larger is that marginal abatement benefits of the donors are higher than those of the recipients ($b_D > b_R$) which has been assumed.

A.5 Preferred incremental cost concepts

Case 1 ($\theta = b_R^+$)

a) Donors: Inserting the relevant values of (4) and (9) in (24) and simplifying yields that donors prefer compensations for gross incremental abatement costs over the net incremental cost concept if

$$\begin{aligned}
&\pi_D^N(b_R^+) + \pi_D^C(b_R^+) - T^g(b_R^+) > \pi_D^N(b_R^-) + \pi_D^C(b_R^-) - T^n(b_R^-) \\
\Leftrightarrow &2b_D b_R^+ c_D - 4b_D b_R^- c_D - b_R^{+2} c_R - b_R^{-2} c_R > 0 \\
\Leftrightarrow &2b_D c_D (b_R^+ - 2b_R^-) > (b_R^{+2} + b_R^{-2}) c_R.
\end{aligned}$$

From the left hand side of the last line we see that for the gross concept to be favored $b_R^+ > 2b_R^-$ is necessary. A sufficient condition for the inequality to hold is $b_D (b_R^+ - 2b_R^-) c_D > b_R^{-2} c_R$ which is fulfilled when the countries are sufficiently

asymmetric.

b) Recipients: Inserting in (25) the relevant quantities of (4) and (9) and simplifying yields

$$\begin{aligned} & \pi_R^N(b_R^+) + \pi_R^C(b_R^+) + T^g(b_R^+) > \pi_R^N(b_R^-) + \pi_R^C(b_R^-) + T^n(b_R^-) \\ \Leftrightarrow & b_R^{+2} c_D + b_R^{-2} c_D - 2b_R^+ b_R^- c_D + b_R^{+2} c_R + b_R^{-2} c_R - b_R^+ b_R^- c_R + b_D b_R^- c_D > 0 \\ \Leftrightarrow & (c_D + c_R)(b_R^+ - b_R^-)^2 + b_R^+ b_R^- c_R + b_D b_R^- c_D > 0. \end{aligned}$$

Hence, high-type R always prefers the gross over the net incremental cost concept.

Case 2 ($\theta = b_R^-$)

a) Donors: As countries R irrespective of their true type signal the same marginal abatement benefits under the two alternative transfer schemes, the relevant condition for the gross rule to be superior for D is the same as in case 1 (see above).

b) Recipients: Low-type recipients have an incentive to overstate their environmental preferences under the gross rule. The condition for the gross rule to be preferred by R therefore is

$$\begin{aligned} & \pi_R^N(b_R^+) + \pi_R^C(b_R^+) + T^g(b_R^+) > \pi_R^N(b_R^-) + \pi_R^C(b_R^-) + T^n(b_R^-) \\ \Leftrightarrow & -b_R^{+2} c_D + 2b_R^+ b_R^- c_D - b_R^{-2} c_D + b_R^+ b_R^- c_R + b_D b_R^- c_D > 0 \\ \Leftrightarrow & b_R^-(2b_R^+ - b_R^-) c_D + (b_D b_R^- - b_R^{+2}) c_D + b_R^+ b_R^- c_R > 0. \end{aligned}$$

The second term in brackets is positive for $b_D/b_R^+ > b_R^+/b_R^-$. The latter is a sufficient condition for the gross concept to be preferred by recipients that are of the low type.

A sufficient condition for the gross incremental cost concept to be unanimously preferred in both cases can be derived by assuming that the above sufficient condition for low-type countries is fulfilled just with equality ($b_D/b_R^+ = b_R^+/b_R^-$) and inserting this into the condition under which D prefers the gross concept. Substituting for b_R^- and rearranging yields $b_D/b_R^+ > 2 + (c_R/c_D)$. For $c_D \approx c_R$, we have $b_D > 3b_R^+$ as a sufficient condition.

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