Modesty Pays: Sometimes!

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Summary

Standard non-cooperative game theoretical models of international environmental agreements (IEAs) draw a pessimistic picture of the prospective of successful cooperation: only small coalitions are stable that achieve only little. However, there also exist IEAs with higher participation and more success. In order to explain this phenomenon, this paper departs from the standard assumption of joint welfare maximization of coalition members, implying ambitious abatement targets and strong free-riding. Instead, it considers that countries agree on modest emission reduction targets. This may sufficiently raise participation so that the success of treaties improves in terms of global emission reduction and global welfare. Thus, modesty may pay, though the first best optimum cannot be achieved.

Keywords: International environmental agreements, Internal&external stability, Modest emission reduction

JEL Classification: C72, H41, Q20

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1. Introduction

Standard non-cooperative game theoretical analyses of international environmental agreements (IEAs) draw a rather pessimistic picture of the prospective of successful cooperation between countries.[1] A large amount of the literature came to this conclusion in a *two-stage game* by applying the concept of *internal and external stability*.[2] In the first stage, countries decide whether they become a member of an IEA or remain a non-signatory. In the second stage, they decide on their emission level. Given the choices of the second stage, an IEA is called stable if no signatory has an incentive to leave the agreement and no non-signatory has an incentive to join the coalition. For the second stage, it is assumed that signatories choose emission levels that maximize the aggregate welfare to the coalition. Non-signatories play as singletons and choose their emissions that are optimal under autarky.

The equilibrium coalition depends on a number of assumptions.[3] The "standard model" assumes that countries′ welfare function comprise benefits (also sometimes called revenues) from individual emissions and damage costs from global emissions[4], signatories and non-signatories choose their emissions simultaneously (Nash-Cournot assumption) and there are no transfers. For a large set of specific welfare functions, it turns out that the equilibrium number of signatories is small and therefore stable coalitions improve only marginally upon the non-cooperative status quo (e.g., Bauer 1992, Botteon/Carraro 1997, Carraro/Siniscalco 1991 and Hoel 1992). The reason is that the free-rider incentive increases sharply with the

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[1] More positive results are derived from cooperative game theory. See for instance Chander/ Tulkens (1995 and 1997).

[2] Similar conclusions have been derived for repeated games by applying the concept of renegotiation-proof strategies. See for instance Barrett (1994a, b and 1999) and Finus/ Rundshagen (1998a).

[3] For an extensive overview see Finus (2001) and (2003b).

number of signatories and hence internal stability is already violated for small coalitions. Clearly, the standard model helps explaining the problems of international cooperation in the presence of environmental spillovers, but cannot explain IEAs with high participation like the Montreal Protocol or the Framework Convention on Climate Change. This requires a modification of the standard assumptions. Important modifications in the literature include the following items: 1) sequential choice of emissions, 2) transfers, 3) commitment, 4) reputation effects, 5) issue linkage and 6) minimum participation clause.

1) A *sequential choice* of emission levels implies that signatories, acting as Stackelberg leaders, considering the optimal choice of non-signatories, acting as Stackelberg followers (Barrett 1994b and 1997a). Consequently, signatories can better take into account possible leakage effects caused by non-signatories (as long as countries have no dominant strategy). Therefore, the equilibrium number of signatories under the Stackelberg assumption is at least as high (and usually higher) as under the Nash-Cournot assumption and coalition formation is more successful. However, the Stackelberg assumption is not innocuous for three reasons. First, as it is well known from industrial economics, there is the open question how players can credibly commit to be a Stackelberg leader. Second, it is difficult to justify why signatories should have a strategic advantage over non-signatories, which is particular true in a model with symmetric countries as assumed for instance in Barrett (1994b). Third, this assumption implies for internal stability that a signatory looses its strategic advantage when it leaves the treaty and becomes a non-signatory.

2) In the context of asymmetric welfare functions, *transfers* can help to increase participation in and success of IEAs (Botteon/Carraro 1997, Carraro/Siniscalco 1993 and Barrett 1997b). However, also the assumption of transfers in these models is not innocuous since it neglects

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[4] An alternative specification of this model with the same qualitative results assumes countries′ strategies to be abatement from some base emission level and welfare comprises benefits from

free-rider problems between donors and recipients (Finus 2002), free-rider problems within the group of donors (Barrett 1994a), as well as other incentive problems described in Mäler (1990). That these problems are important in reality is evident by recalling that only some "modern" IEAs like the Montreal Protocol and the Convention of Biological Diversity have provisions for transfers but that the backlog of payments under these protocols is large (Finus 2003b).

3) In Botteon/Carraro (1997), Carraro/Siniscalco (1993), Jeppesen/Andersen (1998) and Petrakis/Xepapadeas (1996) it is shown that if some countries are *committed* to cooperation irrespective of their free-rider incentive and compensate non-signatories for participation, cooperation will be more successful. Apart from the fact this result follows (almost) trivially from the assumption, it is evident that commitment is not compatible with the notion of self-enforcing IEAs of non-cooperative game theory as pointed out by Carraro/Siniscalco (1993).

4) Jeppesen/Andersen (1998) and Hoel/Schneider (1997) assume that non-signatories receive disutility from being outsiders (loss of reputation) where disutility increases with the number of countries signing an IEA. They find that the higher the disutility of being an outsider, the larger the equilibrium coalition will be. Again, it seems that this result is almost implied by assumption, though I would not deny that *reputation effects* may play some role in actual international treaty making. However, given the withdrawal of the US from the Kyoto Protocol, doubts remain whether reputation effects are strong enough to overcome the incentives of countries to pursue their self-interests.

5) Barrett (1997b), Botteon/Carraro (1998), Carraro/Siniscalco (1997) and Katsoulacos (1997) have demonstrated that if the public good agreement IEA is linked to a club agreement, like a trade agreement or a research and development agreement, participation in IEAs can be

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global abatement and costs from individual abatement.

raised.[5] *Issue linkage* implies that countries can only enjoy the benefits from the club good agreement if they also join an IEA. However, most reported instances of issue linkage (e.g., Ragland 1995) do not include multilateral agreements involving many countries but only bilateral agreements. This might be due to at least two reasons. First, package deals involving many countries will be associated with high transaction costs. Second, in reality, it will be difficult to exclude countries from trade agreements or defense pacts just because they did not sign an IEA.

6) Carraro/Marchiori/Oreffice (2003) demonstrate that the implementation of a *minimum participation clause* can help to increase the success of IEAs. Such a clause implies that a treaty only enters into force if a certain number of signatories have ratified it. It seems that this extension of the base model is very fruitful since it helps to explain the frequent application of minimum participation clauses in almost all IEAs in the past.

Taken together, I acknowledge that extensions of the "standard model" capture interesting aspects of international environmental treaty making, though not all of them appear to be convincing either on empirical or theoretical grounds.[6] In particular, it seems that an obvious extension has not received sufficient attention yet, namely a modification of the assumption of joint welfare maximization. This is surprising since casual empirical evidence suggests that coalition members neither choose their individual emission reductions cost-efficiently nor the sum of individual emission reductions is optimal for the coalition. On the one hand, abatement obligations of many IEAs are specified as (cost-inefficient) uniform emission reduction

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[5] Similar positive results have been obtained in the context of repeated games. See for instance Cesar/de Zeeuw (1996), Folmer/van Mouche/Ragland (1993), Folmer/van Mouche (1994) and Ragland (1995).

[6] An other recent modification that I do not mention since it is not directly related to my model involves the possibility to form multiple coalitions. See for instance Carraro/Marchiori (2003), Finus (2003a) and Finus/Rundshagen (2003).

quotas despite countries face different marginal abatement costs.[7] On the other hand, in many IEAs and in particular in framework conventions, the global abatement level is below optimal levels.[8] Both observations have been partly rationalized in models that assume that countries bargain either on the level of an efficient uniform tax rate or on an inefficient uniform emission reduction quota *and* agree on the smallest proposal (least common denominator rule). In Endres (1996 and 1997), it is shown that the bargaining outcome under the quota regime may be superior from an ecological and economic point of view in a two-country model. Later papers have confirmed the superiority of the quota over the tax regime in a repeated game framework. An inefficient though more symmetric allocation of emission reduction under the quota regime is compensated by higher stability (Endres/Finus 2002 and Finus/Rundshagen 1998b) and higher participation (Finus/Rundshagen 1998a). Also moderate abatement targets, as implied by the least common denominator rule, are compensated under both regimes by a higher participation (Finus/Rundshagen 1998a). The tradeoff between the level of emission reduction and participation in favor of participation has also been stressed in a later paper by Barrett (2003).

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[7] The list of examples is long and includes the Helsinki Protocol, which suggested a 30 percent reduction of sulfur emissions from 1980 levels by 1993. Moreover, the "Protocol Concerning the Control of Emissions of Nitrogen Oxides or Their Transboundary Fluxes" signed in Sofia in 1988 called on countries to *uniformly* freeze their emissions at 1987 levels by 1995 and the "Protocol Concerning the Control of Emissions of Volatile Organic Compounds or Their Fluxes" signed in Geneva in 1991 required parties to reduce 1988 emissions by 30 percent by 1999.

[8] For framework conventions, like the Vienna Convention preceding the Montreal Protocol on CFC-reductions, the Framework Convention on Climate Change (FCCC) preceding the Kyoto Protocol on greenhouse gases reduction or the Convention Long Range Transboundary Pollution (LRTAP) preceding the Helsinki and Oslo Protocols on sulfur reductions, this is evident because they are only declarations of intentions without abatement obligations. However, this conclusion is also supported by empirical studies on the Montreal Protocol (Murdoch/Sandler 1997b), the Helsinki Protocol (Murdoch/Sandler 1997a), the Oslo Protocol (Finus/Tjøtta 2003), or the Kyoto Protocol (Böhringer/Vogt 2002).

In this paper, I exclusively focus on the effect of moderate emission reduction on the success of coalition formation like in Barrett (2003). Hence, I also stick to the simple assumption of symmetric countries and ignore transfers. Unlike this and the other papers mentioned above, however, I analyze the effect of moderate emission reduction on participation, global emissions and global welfare not in a repeated but in a two-stage stage game, defining stability of an IEA in terms of internal&external stability. Moreover, unlike Barrett (2003), I do not restrict attention to the grand coalition in the case of moderate emission reduction and, unlike the other papers mentioned above, the "degree of moderation" is chosen endogenously.

In what follows, I first lay out the standard model assuming joint welfare maximization in section 2. I call this "the classical case" with "ambitious emission reduction". Subsequently, I analyze what changes if countries agree on "moderate emission reduction". I call this "the non-classical case". Section 4 analyzes equilibrium conditions under which countries will agree on a moderate and not on an ambitious reduction scheme. Section 5 summarizes the main findings and points to future research questions.

2. The Classical Case

Let there be N symmetric countries and consider the following welfare function of country $i \in I$:

[1] $$\pi_i = B(x_i) - d\sum_{i=1}^{N} x_i$$

where I assume as in Hoel/Schneider (1997) a strictly convex benefit function from individual emissions, x_i, ($B'(x_i) > 0$, $B''(x_i) < 0$), a linear damage cost function from global emissions, $\sum x_i$, with constant marginal damages d>0, and $x_i \in (0, x_i^{max}]$. Let n denote the number of signatories and $i \in I^S$, then a signatory derives its optimal emission level from

[2] $$\max_{x_i}\left[B(x_i) - d\cdot(n\cdot x_i + (N-n)\cdot x_i^N\right]$$

which leads to the first order condition of a signatory:

[3] $B^{'}(x_i) = d \cdot n$.

A non-signatory $i \in I^{NS}$ (which is equivalent to $i \notin I^S$ because $I^S \cup I^{NS} = I$ and $I^S \cap I^{NS} = \varnothing$) simply maximizes [1] which leads to:

[4] $B^{'}(x_i) = d$.

Since $n \geq 1$ and d>0, it suffices for an interior equilibrium to require that x_i^{max} is sufficiently large and that $B^{'}(x_i = 0) \geq d \cdot n$. Due to constant marginal damages, countries have a dominant strategy and hence there exists a unique emission vector for any $n \in [1, N]$. *S*ignatories choose $x_i^S(n)$, which decreases in the number of participants ($\partial x_i^S(n) / \partial n < 0$), and *n*on-signatories choose x_i^N, irrespective of n. Thus, global emissions, $x^T = n \cdot x_i^S(n) + (N-n) \cdot x_i^N$, decrease in the number of signatories, $\partial x^T / \partial n < 0$. Therefore, a non-signatory′s welfare, $\pi_i^N = B(x_i^N) - d \cdot x^T$, increases with the number of participants ($\partial \pi_i^N / \partial n > 0$) because damages decrease with n. However, also a signatory′ s welfare, $\pi_i^S = B(x_i^S(n)) - d \cdot x^T$, increases with n ($\partial \pi_i^S / \partial n > 0$) because in the case of dominant strategies $\max_{x_i}\left[(n^1 + n^2) \cdot \pi_i^S(n^1 + n^2)\right] > \max_{x_i}\left[n^1 \cdot \pi_i^S(n^1)\right] + n^2 \cdot \max_{x_i}\left[\pi_i^N\right]$ where n^1 is the number of signatories before and $n^1 + n^2$ after n^2 non-signatories have joined the agreement, and, due to symmetry, $\pi_i^S(n^1) < \pi_i^N(n^1)$, and, hence, $\pi_i^S(n^1 + n^2) > \pi_i^S(n^1)$ must be true (though $\pi_i^S(n^1 + n^2) < \pi_i^N(n^1)$ is possible).

The equilibrium number of signatories follows from the condition of internal and external stability:

[5] internal stability: $\pi_i^S(n) \geq \pi_i^N(n-1) \; \forall \, i \in I^S$ and

[6] external stability: $\pi_i^N(n) > \pi_i^S(n+1)\ \forall\, i \notin I^S$.

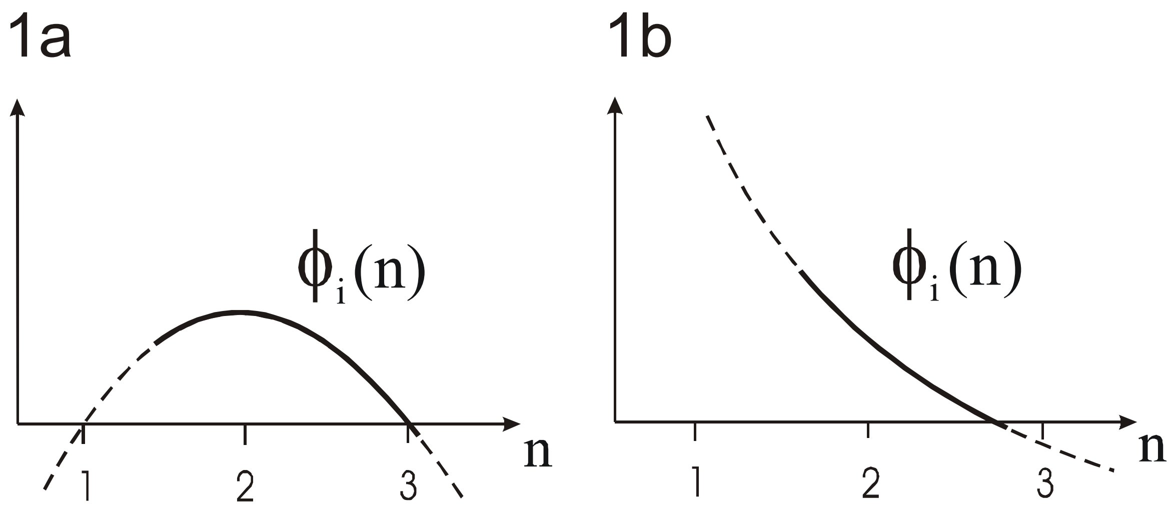
That is, no signatory should be better off by leaving the agreement with n members to become a non-signatory so that there are only n-1 signatories left. By the same token, no non-signatory should have an incentive to join the coalition of n members to become a signatory in a coalition of n+1 members. For the further analysis, it is helpful to define as in Hoel/Schneider (1997) the function $\Phi_i(n) = \pi_i^S(n) - \pi_i^N(n-1)$, noting that internal stability implies $\Phi_i(n) \geq 0$ $\forall\, i \in I^S$ and external stability $\Phi_i(n) < 0\ \ \forall\, i \notin I^S$. Figure 1 a and b show $\Phi_i(n)$ for two examples:

[7] $\pi_i = b\left(a \cdot x_i - \frac{1}{2} x_i^2\right) - d\sum_{1=1}^{N} x_i$ and

[8] $\pi_i = b\ln(x_i) - d\sum_{1=1}^{N} x_i$.

Figure 1: Function $\Phi_i(n)$ for Two Examples

a) Welfare Function [7] b) Welfare Function [8]



Function [7] implies that $\Phi_i(n)$ is strictly concave and [8] that $\Phi_i(n)$ is strictly convex.[9] For [7], the equilibrium number of signatories is $n^* = 3$ and for [8], it is $n^* = 2$. That is, n^* is the largest integer equal or smaller than $\Phi_i(n) = 0$.

For the further analysis it is important to note that [1] implies $\Phi_i(n = 2)$ >0 and that a sufficient condition that $\Phi_i(n)$ is strictly decreasing for $n \geq 2$ is $B'''(x_i) \geq 0$ as shown in Hoel/Schneider (1997) in their appendix. I assume for the remainder $B'''(x_i) \geq 0$ and thus $n^* \in [2, N]$. Since π_i^S and π_i^N increase in n as mentioned above and because n=1 corresponds to the "classical Nash equilibrium" and n=N to the "classical social optimum", global welfare in n^* will be higher than in the Nash equilibrium and lower (equal if $n^* = N$) than in the social optimum. By the same token, global emission in n^* will be lower than in the Nash equilibrium and higher (equal if $n^* = N$) than in the social optimum since x_i^S decreases in n and x_i^{NS} remains constant as mentioned above.

3. The Non-Classical Case

A simple way of capturing the idea of moderate emission reduction is to assume that signatories do not perform [2] but

[9] $$\max_{x_i}\left[B(x_i) - \alpha \cdot d \cdot (n \cdot x_i + (N - n) \cdot x_i^N\right]$$

with $\alpha \leq 1$, and hence a signatory′ s first order condition is

[10] $$B'(x_i) = \alpha \cdot d \cdot n .$$

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[9] A sufficient condition for $B'(x_i) > 0$, $x_i \in (0, x_i^{max}]$ for welfare function [7] is $x_i^{max} = a$. In order to ensure $x_i \geq 0$ we need $b \geq dn/a$ since $x_i^N > x_i^S = (ba - dn)/b$. For welfare function [8], we

Therefore, comparing [10] with [3], $x_i^S(n) \leq x_i^S(\alpha,n)$ if $\alpha \leq 1$ as I assume henceforth. The advantage of this approach is that moderate emission reduction is not only assumed for a particular n, e.g., n^*, but consistently for all n. For non-signatories nothing changes. It seems sensible to require $x_i^S(\alpha,n) \leq x_i^N$ as an upper bound for $x_i^S(\alpha,n)$, implying that α cannot be too small.

In order to study the effect of moderate emission reductions on n^*, I insert $x_i^S(\alpha,n)$, $x_i^S(\alpha,n-1)$ and x_i^N in welfare function [1] and compute $\Phi_i(n) = \pi_i^S(n) - \pi_i^N(n-1)$ that I denote $\Phi_i(\alpha,n) = \pi_i^S(\alpha,n) - \pi_i^N(\alpha,n-1)$. This gives:

$$[11] \quad \Phi_i(\alpha,n) = \left[B(x_i^S(\alpha,n)) - d\cdot(n\cdot x_i^S(\alpha,n) + (N-n)\cdot x_i^N)\right] - \left[B(x_i^N) - d\cdot((n-1)\cdot x_i^S(\alpha,n-1) + (N-n+1)\cdot x_i^N)\right].$$

Clearly, $\pi_i^S(\alpha,n) \leq \pi_i^S(n)$ for a given n because $x_i^S(n)$ (and not $x_i^S(\alpha,n)$) maximizes a signatory´s welfare function. Also $\pi_i^N(\alpha,n-1) \leq \pi_i^N(n-1)$ since $x_i^S(n-1) \leq x_i^S(\alpha,n-1)$ implies higher environmental damages for free-riders. Hence, it is not immediately evident whether $\Phi_i(\alpha,n)$ lies above or below $\Phi_i(n)$. Therefore, we differentiate the components of [11] with respect to α, holding n constant, which gives after some manipulation (see Appendix 1):

$$[12] \quad \frac{\partial \pi_i^S(\alpha,n)}{\partial \alpha} = (\alpha-1)\cdot\frac{d^2n^2}{B''(x_i^S(\alpha,n)} \quad \text{and} \quad \frac{\partial \pi_i^N(\alpha,n-1)}{\partial \alpha} = -\frac{d^2(n-1)^2}{B''(x_i^S(\alpha,n-1)}$$

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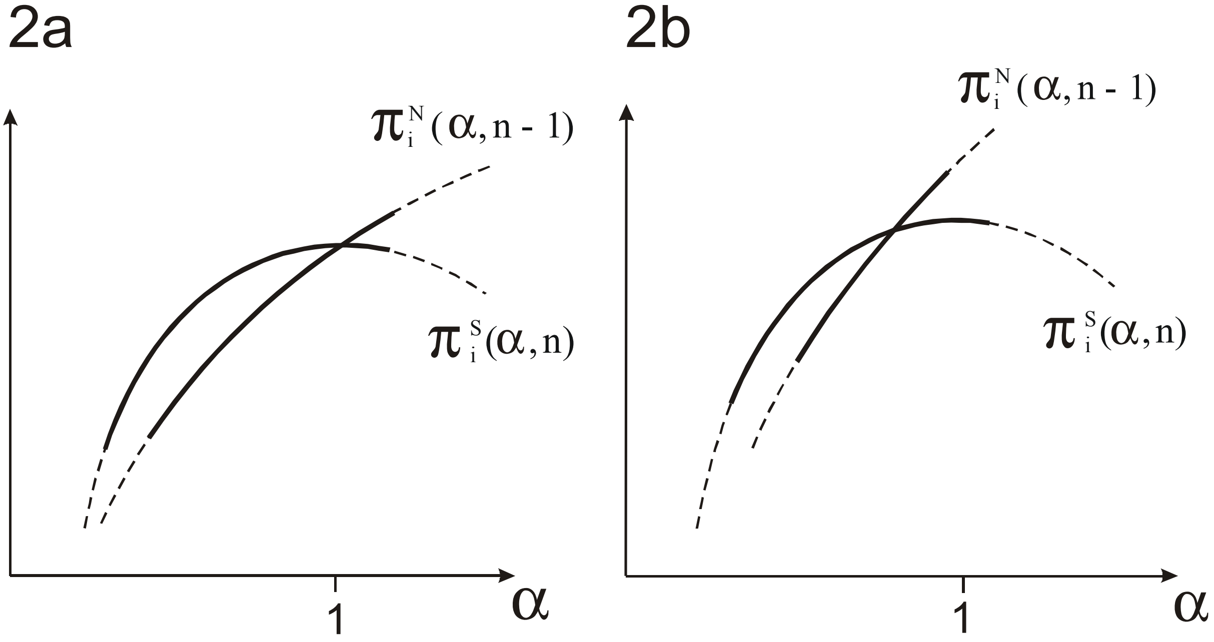
require $b \geq dn$ for $x_i \geq 0$ since $x_i^N > x_i^S = (b-dn)/dn$ and $x_i^{max} \geq (b-d)/d$ because $x_i^N = (b-d)/d$.

Since $B''(x_i^S(\alpha,n) < 0$, $\partial\pi_i^S(\alpha,n)/\partial\alpha > 0$ for $\alpha < 1$ and $\partial\pi_i^S(\alpha,n)/\partial\alpha \leq 0$ for $\alpha \geq 1$. $\partial\pi_i^N(\alpha,n-1)/\partial\alpha > 0$ because $B''(x_i^S(\alpha,n-1) < 0$. This is shown in Figure 2 where $\pi_i^S(\alpha,n)$ and $\pi_i^N(\alpha,n-1)$ are drawn as a function of α.[10]

Figure 2: Welfare of Signatories and Free-riders as a Function of α



a) $n = n^*$

b) $n > n^*$

Figure 2a assumes $n = n^*$ and hence $\pi_i^S(\alpha,n) = \pi_i^N(\alpha,n-1)$ for $\alpha = 1$ whereas Figure 2b assumes $n > n^*$ and hence $\pi_i^S(\alpha,n) < \pi_i^N(\alpha,n-1)$ for $\alpha = 1$.[11] In any case, in order to establish $\Phi_i(\alpha,n) > \Phi_i(n)$, we require that $\pi_i^N(\alpha,n-1)$ decreases faster than $\pi_i^S(\alpha,n)$ if we lower α from $\alpha = 1$ as shown in Figure 2. More formally, we need that for $\alpha < 1$ $\partial\pi_i^S(\alpha,n)/\partial\alpha <$ $\partial\pi_i^N(\alpha,n-1)/\partial\alpha$ holds. Using [12], this implies:

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[10] It can be shown along the procedure described in Appendix 1 that $\partial^2\pi_i^N(\alpha,n-1)/\partial\alpha^2 < 0$ and $\partial^2\pi_i^S(\alpha,n)/\partial\alpha^2 < 0$ for $\alpha \leq 1$. That is, both functions are strictly concave.

$$[13] \quad (1-\alpha)\frac{n^2}{(n-1)^2} < \frac{B^{''}(x_i^S(\alpha,n)}{B^{''}(x_i^S(\alpha,n-1)} \ .$$

First, note that the right hand sight term is larger or equal to 1 and hence a conservative assumption is 1. Second, note that $n^2/(n-1)^2$ decreases in n. Since we know that in the classical case $n^* \geq 2$, a conservative assumption is $n = 2$ in [13]. Thus, [13] is satisfied in any case for $\alpha \geq \alpha^L = 3/4$. Consequently, $\Phi_i(\alpha,n)$ lies above $\Phi_i(n)$ for any $1 > \alpha \geq 3/4$ and any $n \geq 2$. In fact, if we let $1 > \alpha^1 > \alpha^2 > ... > 3/4$, then $\Phi_i(n) < \Phi_i(\alpha^1,n) < \Phi_i(\alpha^2,n) < ... < \Phi_i(3/4,n)$.[12] Consequently, we can conclude that $n^* < n^*(\alpha^1) \leq n^*(\alpha^2) \leq ... \leq n^*(3/4)$. However, as long as we have no information on the functional form of $\Phi_i(\alpha,n)$, we cannot establish a complete sequence of strict inequality signs because we cannot rule out functions as for instance drawn in Figure 3 at a general level.

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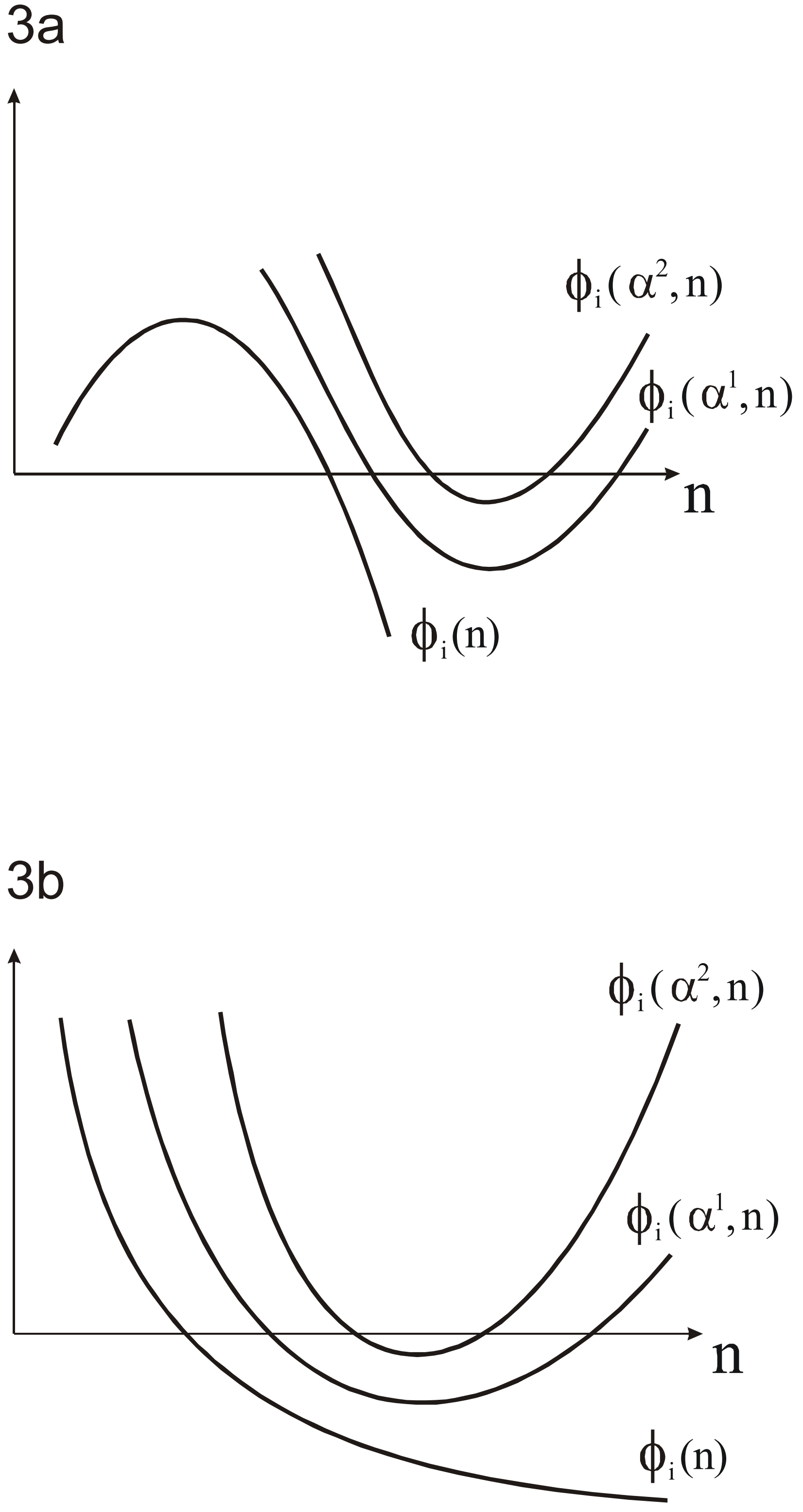
[11] Without loss of generality, we ignore integer constraints in the following analysis.

[12] Of course, if we know as in the case of welfare function [7] that $n^* = 3$ in the classical case, then stronger conclusions are possible because then $\Phi_i(\alpha,n)$ lies above $\Phi_i(n)$ for any $n \geq n^*$ and $\alpha \geq \alpha^L = 5/9$.

Figure 3: Possible Functional Forms of $\Phi_i(\alpha, n)$



Clearly, a sufficient condition for $n^* < n^*(\alpha^1) < n^*(\alpha^2) < \ldots < n^*(3/4)$ is that $\Phi_i(\alpha, n)$ is either a strictly concave or a strictly decreasing function as this is true for instance for welfare functions [7] and [8], respectively (see Appendix 2). Moreover, in order to establish a strict sequence for any α without the lower bound $\alpha^L = 3/4$, we need $\partial\alpha^L / \partial n < 0$. Thus, from [13] either g/k=1 or $\partial(g/k)/\partial n \geq 0$ must hold because simple manipulation of [13] gives:

$$[14] \qquad \alpha > 1 - \frac{g}{k}, \; g := \frac{B''(x_i^S(\alpha, n)}{B''(x_i^S(\alpha, n-1)}, \; k := \frac{n^2}{(n-1)^2} \; .$$

As shown in Appendix 3, this holds for welfare function [7] and [8]. Summarizing our findings leads to the following proposition:

Proposition 1

Let n^* denote the equilibrium number of signatories in the classical case and $n^*(\alpha)$ in the non-classical case with moderate emission reductions, and let $1 > \alpha^1 > \alpha^2 > \ldots$, then

a) $n^* < n^*(\alpha^1) \leq n^*(\alpha^2) \leq \ldots$ for $1 > \alpha \geq 3/4$.

b) $n^* < n^*(\alpha^1) < n^*(\alpha^2) < \ldots$ for $1 > \alpha \geq 3/4$ and if $\Phi_i(\alpha, n)$ is either a strictly concave or a strictly decreasing function.

c) $n^* < n^*(\alpha^1) < n^*(\alpha^2) < \ldots$ if $\Phi_i(\alpha, n)$ is either a strictly concave or a strictly decreasing function and if g/k=1 or $\partial(g/k)/\partial n \geq 0$, which is satisfied for instance for welfare function [7] and [8].

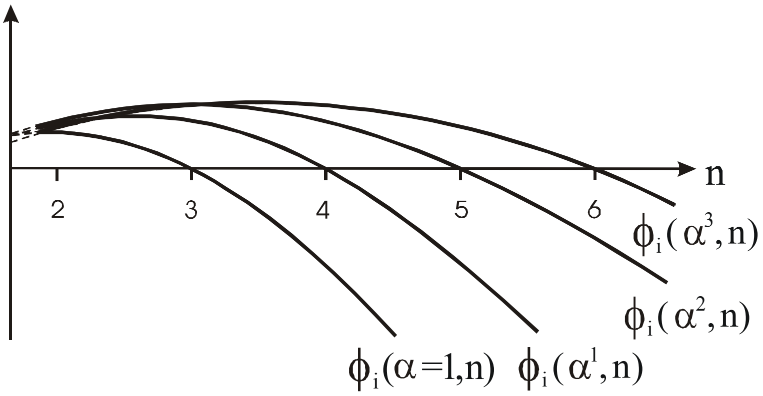
Proof: See the arguments developed above and Appendix 1 to 3. Q.E.D.

Proposition 1 is illustrated for welfare function [7] and [8] in Figure 4.

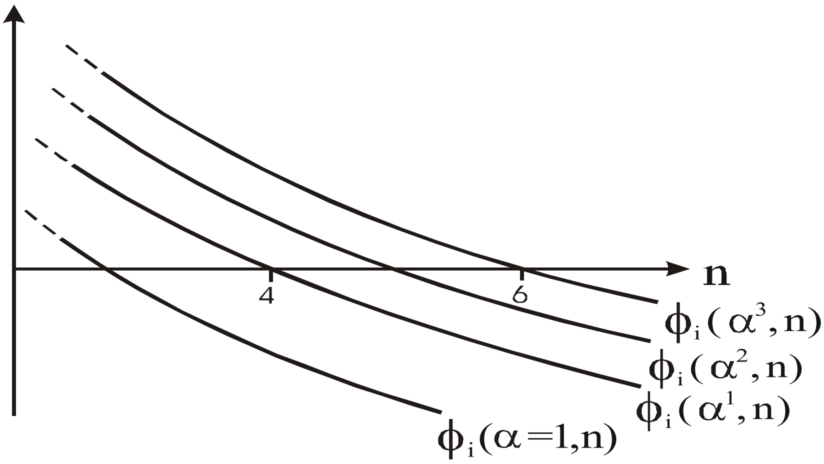
Figure 4: Functions $\Phi_i(n)$ and $\Phi_i(\alpha,n)$ for Two Examples

a) Welfare Function [7] b) Welfare Function [8]

4a



4b



For welfare function [8], with $\Phi_i(\alpha,n)$ strictly decreasing, $\Phi_i(\alpha,n)$ lies always above $\Phi_i(n)$ with $\Phi_i(n) < \Phi_i(\alpha^1,n) < \Phi_i(\alpha^2,n)$, $1 > \alpha^1 > \alpha^2 > \ldots$. For welfare function [7], with $\Phi_i(\alpha,n)$ strictly concave, $\Phi_i(n) < \Phi_i(\alpha^1,n) < \Phi_i(\alpha^2,n)$ is only true for $\alpha^L \geq 5/9$ at $n = n^* = 3$ but since $\partial(g/k)/\partial n \geq 0$, α^L decreases continuously if we move along the n-axis (e.g., $\alpha^L \geq 7/16$ at n=4).

In a next step, we analyze how moderate emission reductions affect global emissions. Clearly, at $n = n^*$, global emissions would be higher for moderate emission reductions since $x_i^S(n) \leq x_i^S(\alpha, n)$ (recalling that $x_i^N(n) = x_i^N(\alpha, n)$ because of dominant strategies). However, $\alpha < 1$, implies $n^* < n^*(\alpha)$ as shown above. Hence, in the non-classical equilibrium, there are less non-signatories that emit $x_i^N \geq x_i^S(\alpha, n)$, or as we may write now $x_i^N \geq x_i^S(n^*(\alpha))$ to indicate that n^* depends on α. Consequently, if the increase in the number of signatories is sufficiently large, this may compensate for moderate emission reductions and hence global emissions may be lower in the non-classical than in the classical equilibrium. Whether this is actually true, is difficult to conclude at a general level, but can be established for specific functions. For instance, for our two examples we find:

Proposition 2

For welfare function [7] and [8] (where $n^* < n^*(\alpha^1) < n^*(\alpha^2) < \ldots$, $1 > \alpha^1 > \alpha^2 > \ldots$, holds), global emissions decrease when lowering α until the maximum participation is reached.

Proof: A sufficient condition that global emissions decrease if we lower α is $x_i^S(n^*) \geq x_i^S(n^*(\alpha^1)) \geq x_i^S(n^*(\alpha^2)) \geq \ldots$, $1 > \alpha^1 > \alpha^2 > \ldots$, which I prove in Appendix 4 for welfare function [7] and [8]. Q.E.D.

From Proposition 2, it follows that from an ecological point of view, we should lower α until the maximum participation is reached, but not below this value.[13]

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[13] Depending on the number of countries N and the specific welfare function, maximum participation may either imply full participation (if N is not too big) or only partial cooperation if we consider that α cannot become too small because of the constraint $x_i^S(\alpha, n) \leq x_i^N$.

Another pending question is how moderate emission reduction affects global welfare. The global effect comprises the effect on former non-signatories in the classical case that are also non-signatories in the non-classical case (group 1), former non-signatories that are now signatories (group 2) and former signatories that are still signatories (group 3). For group 1, it is evident that this depends solely on global emissions since they choose x_i^N in both cases. That is, these countries will be better off (worse off) in the non-classical case if global emission decrease (increase) because their environmental damages decrease (increase). For group 2 and 3, conclusions are more difficult since not only damages but also benefits are affected. Nevertheless, as Proposition 3 demonstrates, clear-cut results can be derived at the aggregate level under rather mild conditions.

Proposition 3

Suppose global emissions decrease and the number of signatories increases when lowering α (as this is true for instance for welfare function [7] and [8]), then global welfare increases when lowering α until the maximum participation is reached.

Proof: Consider two equilibria $n^*(\alpha^1) < n^*(\alpha^2)$ with $\alpha^1 > \alpha^2$ and global emissions $x^T(n^*(\alpha^1)) > x^T(n^*(\alpha^2))$. Let individual emissions of signatories be $x_i^S(n^*(\alpha^1)) \leq x_i^N$ and $x_i^S(n^*(\alpha^2)) < x_i^N$. Suppose first that we hold global emission constant when moving from $n^*(\alpha^1)$ to $n^*(\alpha^2)$. Consequently, signatories have to choose $x_i^{S\#}(n^*(\alpha^2))$ where $x_i^S(n^*(\alpha^1)) < x_i^{S\#}(n^*(\alpha^2)) < x_i^N$. Thus, former non-signatories in $n^*(\alpha^1)$ that are now signatories in $n^*(\alpha^2)$ reduce emissions and former signatories that are still signatories increase emissions. Thus, due to non-constant marginal benefits, aggregate benefits of these two groups of countries will have increased and hence also aggregate welfare increases of these two groups (since damages remain constant). Suppose now that we lower $x_i^{S\#}(n^*(\alpha^2))$ to the level $x_i^S(n^*(\alpha^2))$. Since $\pi_i^S = B(x_i^S) - d \cdot (n \cdot x_i^S + (N-n) \cdot x_i^N)$ is a strictly concave function in x_i^S, and $x_i^S(n^*(\alpha^2))$ is above the level that maximizes π_i^S, aggregate welfare of these two groups will increase further. Clearly, because $x^T(n^*(\alpha^1)) > x^T(n^*(\alpha^2))$, non-signatories′ welfare will also increase. Q.E.D.

Thus, moderate emission reduction, associated with higher participation and lower global emissions, increases global welfare because of two reasons. First, lower global emissions imply lower individual and aggregate environmental damages. Second, aggregate benefits increase because the emission reduction burden is shouldered by more countries.

4. Equilibrium Analysis

Reviewing Proposition 1 to 3 together, it remains to draw some conclusions about possible equilibria. For the discussion, two cases may be distinguished. In the *first case*, we may assume that, initially, no coalition exists. Hence, in a first step, countries have to decide whether to remain in this situation or form a coalition. If they form a coalition, then, in a second step, they have the choice between the classical and non-classical case where in the latter case they can choose between various forms of a moderate emission reduction scheme through the choice of the level of α. The decision in the first step is easy to predict: countries will cooperate in any case since they either choose a moderate emission scheme if $\pi_i^S(n^*) < \pi_i^S(n^*(\alpha))$ for some α or the classical emission scheme if $\pi_i^S(n^*) > \pi_i^S(n^*(\alpha))$ for all α but we know from section 2 that $\pi_i^S(n^*) > \pi_i^S(n=1) = \pi_i^N(n=1)$ and $n^* \in [2, N]$. Hence, we can conclude that there will be some cooperation in equilibrium.

Proposition 4

Suppose that initially no coalition exists, then countries will cooperate in any case, implementing either an ambitious (classical case) or a moderate emission reduction scheme (non-classical case). Global welfare will be higher and global emissions lower than in the absence of cooperation.

Proof: See the arguments above. For global emissions this follows trivially from $x_i^S(n^*(\alpha)) < x_i^N$, $x_i^S(n^*) < x_i^N$, $n^*(\alpha) > 1$ and $n^* > 1$. For global welfare in the classical scheme, this has been shown in section 2 and if the non-classical case scheme is implemented, $\pi_i^N(n=1) = \pi_i^S(n=1) < \pi_i^S(n^*) < \pi_i^S(n^*(\alpha))$ holds by assumption and $\pi_i^N(n^*(\alpha)) > \pi_i^S(n^*(\alpha))$ must be true since $x_i^S(n^*(\alpha)) < x_i^N$ and therefore non-signatories have higher benefits but the same damages as signatories. Q.E.D.

The decision in the second step is more difficult to predict at a general level. First, we do not know whether a $\alpha < 1$ exists for which $\pi_i^S(n^*) < \pi_i^S(n^*(\alpha))$ is true. Second, suppose that such a α exists, which is not unlikely given the fact that moderate emission reduction imply more signatories (see Proposition 1a) and a more equal distribution of emission reduction burdens as argued in the proof of Proposition 3. Then, however, it is nevertheless possible that $x^T(n^*) < x^T(n^*(\alpha))$ and hence $\pi_i^N(n^*) > \pi_i^N(n^*(\alpha))$. This may even imply $\pi^T(n^*) > \pi^T(n^*(\alpha))$ where π^T denotes total welfare. Third, to make things even worth, even if a $\alpha^\#$ with $n^*(\alpha^\#)$ exists for which $\pi^T(n^*) < \pi^T(n^*(\alpha^\#))$ and $x^T(n^*) > x^T(n^*(\alpha^\#))$ is true, we do not know whether countries settle for this or some other globally inferior α^*. In contrast, under the assumption of Proposition 3, things are straightforward (see also footnote 13):

Proposition 5

Suppose that initially no coalition exists.

a) *If global welfare and the number of participants increase when lowering α, then countries will implement a moderate emission reduction scheme. This will be the scheme with highest (possible) participation and global welfare (given the contraint of stability).*

b) *If global emissions decrease and the number of participants increases when lowering α (as this is true for instance for welfare function [7] and [8]), then countries will implement a moderate emission reduction scheme. This will be the scheme with highest (possi-*

ble) participation and global welfare and lowest global emissions (given the contraint of stability).

Proof: a) We show that $\pi^T(n^*) < \pi^T(n^*(\alpha))$ is only possible if and only if $\pi_i^S(n^*) < \pi_i^S(n^*(\alpha))$ holds. A repeated application of this proof by letting $1 > \alpha^1 > \alpha^2 > ...$, replacing n^* by $n^*(\alpha^1)$ and $n^*(\alpha)$ by $n^*(\alpha^2)$, gives that $\pi^T(n^*(\alpha^1) < \pi^T(n^*(\alpha^2)) < ....$ is only possible if and only if $\pi_i^S(n^*(\alpha^1) < \pi_i^S(n^*(\alpha^2)) < ...$ holds. Suppose $\pi^T(n^*) < \pi^T(n^*(\alpha))$ and $\pi_i^S(n^*) > \pi_i^S(n^*(\alpha))$ would be true. This is only possible if $\pi_i^N(n^*) < \pi_i^N(n^*(\alpha))$, which requires $x^T(n^*) > x^T(n^*(\alpha))$. Consequently, environmental damages would drop and hence $\pi_i^S(n^*) > \pi_i^S(n^*(\alpha))$ is only possible if $x_i^S(n^*) > x_i^S(n^*(\alpha))$ was to hold. Moreover, since $\Phi_i(n^*) = \pi_i^S(n^*) - \pi_i^N(n^* - 1) = 0$ and $\Phi_i(n^*(\alpha)) = \pi_i^S(n^*(\alpha)) - \pi_i^N(n^*(\alpha) - 1) = 0$ by definition, this requires that $\pi_i^N(n^* - 1) > \pi_i^N(n^*(\alpha) - 1)$ and consequently that $x^T(n^* - 1) < x^T(n^*(\alpha) - 1)$ must hold. Thus, it remains to be shown that $x_i^S(n^*) > x_i^S(n^*(\alpha))$ and $x^T(n^* - 1) < x^T(n^*(\alpha) - 1)$ is not possible. From the first order conditions of n^* and $n^*(\alpha)$ signatories $B'(x_i^S(n^*)) = n^* \cdot d$ and $B'(x_i^S(n^*(\alpha))) = \alpha \cdot n^*(\alpha) \cdot d$, $x_i^S(n^*) > x_i^S(n^*(\alpha))$ requires $\alpha > n^* / n^*(\alpha)$ (and hence $n^* < n^*(\alpha)$ must be true because $\alpha < 1$). However, $n^* / n^*(\alpha) > (n^* - 1)/(n^*(\alpha) - 1)$ and hence from the first order conditions of $n^* - 1$ and $n^*(\alpha) - 1$ signatories $B'(x_i^S(n^* - 1)) = (n^* - 1) \cdot d$ and $B'(x_i^S(n^*(\alpha) - 1)) = \alpha \cdot (n^*(\alpha) - 1) \cdot d$, $x_i^S(n^* - 1) > x_i^S(n^*(\alpha) - 1)$ follows, which makes $x^T(n^* - 1) < x^T(n^*(\alpha) - 1)$ impossible. To see this note that the last inequality would imply:

$(n^* - 1) \cdot x_i^S(n^* - 1) + (N - n^* + 1) \cdot x_i^N < (n^*(\alpha) - 1) \cdot x_i^S(n^*(\alpha) - 1) + (N - n^*(\alpha) + 1) \cdot x_i^N$. Since $x_i^S(n^* - 1) > x_i^S(n^*(\alpha) - 1)$, we may substitute $x_i^S(n^* - 1)$ for $x_i^S(n^*(\alpha) - 1)$. Rearranging terms gives: $x_i^N < x_i^S(n^* - 1)$ which is false by assumption.

b) We show that $x^T(n^*) > x^T(n^*(\alpha))$ implies $\pi_i^S(n^*) < \pi_i^S(n^*(\alpha))$. Thus, we prove that $x^T(n^*) > x^T(n^*(\alpha))$ and $\pi_i^S(n^*) > \pi_i^S(n^*(\alpha))$ is not possible which is exactly what we have done under a) above. Since $x^T(n^*) > x^T(n^*(\alpha))$ implies $\pi_i^N(n^*) < \pi_i^N(n^*(\alpha))$ global welfare will be higher in $n^*(\alpha)$ than in n^*. Again, a repeated application of this proof by letting $1 > \alpha^1 > \alpha^2 > \ldots$ is obvious. Q.E.D.

In the *second case*, we may alternatively assume that a coalition already exists where signatories choose emissions as in the classical case. Then, the question arises whether signatories have an incentive to switch to a moderate emission reduction scheme and if so to which. However, even more important is the question whether some or all non-signatories have an incentive to join the coalition under a new scheme. A first partial answer to this question is provided in Proposition 6.

Proposition 6

Suppose that initially a coalition of n^* members exists (classical case). Then former non-signatories will join the coalition under a moderate emission reduction scheme so that $n^*(\alpha) > n^*$, $\alpha < 1$, if and only if global emissions decrease. The new equilibrium $n^*(\alpha)$ constitutes a Pareto-improvement.

Proof: Suppose that global emissions would remain constant or increase after additional countries have joined the coalition. Then damages of a former non-signatory, say j, that would become a signatory would remain constant or increase. Due to $x_j^S(n^*(\alpha)) < x_j^N$, its benefits would decrease and hence also its welfare. Consequently, accession would be irrational. Thus, $x^T(n^*) > x^T(n^*(\alpha))$ must be true if j joins so that $n^*(\alpha) > n^*$. Hence, former and current non-signatories, say k, benefit from the accession in any case because of lower damages, i.e., $\pi_k^N(n^*) < \pi_k^N(n^*(\alpha))$. Former signatories, say i, will also benefit because: a) $\pi_i^S(n^*) < \pi_j^N(n^*)$

holds due to symmetry, b) $\pi_j^S(n^*(\alpha)) > \pi_j^N(n^*)$ must hold for a former non-signatory that is now a signatory, otherwise accession would not be irrational, and c) $\pi_j^S(n^*(\alpha)) = \pi_i^S(n^*(\alpha))$ holds due to symmetry. Q.E.D.

From Proposition 6 we can conclude that whenever a non-signatory is prepared to join the coalition under a moderate emission reduction scheme, this is also in the interest of signatories and of other non-signatories. Moreover, it implies that if a coalition already exists, a moderate emission reduction scheme is only implemented if and only if it leads to an improvement in terms of global emissions and global welfare. This conclusion is stronger than under the assumption that no coalition exists initially since it holds not only for the assumption of Proposition 5 but generally.[14] That is, no moderate emission reduction scheme that is inferior to an ambitious reduction scheme will be implemented if initially a coalition exists, whereas this is possible if initially no coalition exists (though ruled out under the conditions of Propositon 5). Despite this clear-cut conclusion, also under the assumption that initially a coalition exists the question remains whether a moderate emission reduction scheme will be implemented and if so which one. Again, a general conclusion is difficult. However, under the assumptions listed in Proposition 5, it is evident that $\pi_i^S(n^*(\alpha))$ increases if we lower α (see the proof of Proposition 5). Hence, non-signatories will accede if α is chosen small enough so that $\pi_j^S(n^*(\alpha)) > \pi_j^N(n^*)$ holds (and provided N is large enough). For instance, for welfare function [7] where $n^* = 3$ it turns out that α must be smaller than 0.69 so that $\pi_j^S(n^*(\alpha)) > \pi_j^N(n^*)$ is true. However, since $n^*(0.69) \approx 4.8$ and because n^* must be an integer value, the threshold of α is actually 0.65 with $n^*(0.65) = 5$ as shown in Figure 5.

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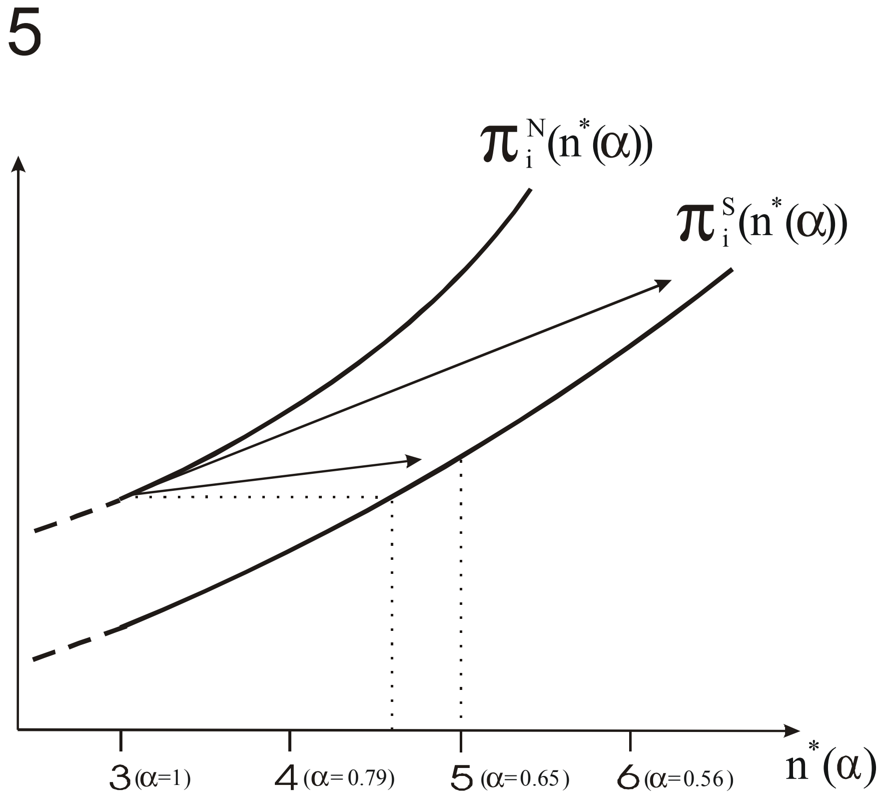
[14] From the proofs of Proposition 6 it is evident that the result also extents to a sequential coalition formation process where α is successively lowered and the number of signatories successively increased.

Figure 5: Incentive Switching to a Moderate Emission Reduction Scheme



Clearly, since $\pi_i^S(n^*(\alpha))$ continuously increases when lowering α, signatories will not offer $\alpha = 0.65$ but a lower α that guarantees maximum participation, provided N is larger than 5 (see footnote 13).[15] Hence, Proposition 5 also holds if initially a coalition of n^* members exists.

Taken together, we may conclude that countries will cooperate in any case. It is likely that they settle for a moderate emission reduction scheme (non-classical case) that is superior to an ambitious emission reduction scheme (classical case) in terms of global welfare and/or global emissions. Nevertheless, also moderate targets can only mitigate the free-rider problem but

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[15] Qualitative similar results can also be derived for welfare function [8].

cannot achieve the first best outcome. Even if moderate abatement targets would lead to full cooperation, emission levels would be above optimal levels (since $x_i^S(\alpha, n) > x_i^S(n)$, $n \in [2, N]$). Moreover, under the assumption that initially no coalition exists, it cannot be generally ruled that countries settle for a moderate emission reduction scheme that is inferior to the ambitious reduction scheme.

5 Summary and Conclusion

This paper started from the observation that the pessimistic prediction of non-cooperative game theoretical models do not always match with real world observations of IEAs. It has been argued that one important reason for this difference is the assumption of joint welfare maximization that implies the implementation of an ambitious emission reduction target among coalition members. Therefore, we analyzed the effect of moderate emission reduction targets. It has been shown that modesty may pay: a higher participation may compensate for lower abatement targets, so that global emissions may decrease in equilibrium. This has also a positive effect on global welfare since abatement burdens are carried by more countries. We argued that if initially a small coalition with an ambitious abatement scheme exists, then countries will only switch to a moderate abatement scheme if this leads to a Pareto-improvement. In contrast, if initially no coalition exists, then it is possible (though not very likely) that countries implement a moderate abatement scheme that is inferior to the ambitious abatement scheme. We derived conditions under which these "negative" cases can be ruled out.

Overall, the model helps to explain why participation in some IEAs is higher than predicted by theory. Moreover, it provides some rationale for modest emission reductions as frequently observed in reality: in a second best world with no enforcement authority and large free-rider incentives, a second best solution may achieve more than an ambitious first best solution.

The model assumed linear damage cost functions for simplicity, implying dominant strategies. However, departing from this assumption would not change the qualitative results. In fact, it would reinforce the positive effect of modest abatement targets. With non-dominant strategies, moderate emissions reductions have additionaly a similar effect as the Stackelberg assumption mentioned in the Introduction. Reduced abatement efforts of signatories are matched by an increase of abatement efforts of non-signatories. Consequently, larger coalitions are stable. Moreover, the positive welfare effect due to a more symmetric allocation of abatement burdens involves not only countries that are non-signatories under an ambitious scheme and that are signatories under a moderate scheme but also countries that are non-signatories under both regimes.

Also the assumption of symmetric countries eased the exposition but is not crucial. Since we modeled the degree of moderation by assuming that countries consider not the sum of marginal damages of coalition members but only a fraction α of it ($0 \le \alpha < 1$), cost-efficiency of emission reduction within a coalition of asymmetric players would still be ensured. Hence, there is no reason why the positive welfare effect of a moderate scheme may not carry over to asymmetric countries. Moreover, in a world of heterogeneous interests, one may expect that moderate abatement targets may be even more likely if countries can only agree on the lowest common denominator when negotiating abatement targets.

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Appendix 1

In order to study the effect of α on $\Phi_i(\alpha,n) = \pi_i^S(\alpha,n) - \pi_i^N(\alpha,n-1)$ we note that

$$[A1] \quad \pi_i^S(\alpha,n) = B(x_i^S(\alpha,n)) - d\cdot(n\cdot x_i^S(\alpha,n) + (N-n)\cdot x_i^N) \text{ and}$$

$$\pi_i^N(\alpha,n-1) = B(x_i^N) - d\cdot((n-1)\cdot x_i^S(\alpha,n-1) + (N-n+1)\cdot x_i^N)$$

as described in the text in equation [11]. Differentiation of $\pi_i^S(\alpha,n)$ and $\pi_i^N(\alpha,n-1)$ with respect to α, holding n constant, gives:

$$[A2] \quad \text{a)} \quad \frac{\partial\pi_i^S(\alpha,n)}{\partial\alpha} = \frac{\partial B(x_i^S(\alpha,n))}{\partial x_i^S(x_i^S(\alpha,n))}\cdot\frac{\partial x_i^S(\alpha,n))}{\partial\alpha} - d\cdot n\cdot\frac{\partial x_i^S(\alpha,n))}{\partial\alpha} \text{ and}$$

$$\text{b)} \quad \frac{\partial\pi_i^N(\alpha,n-1)}{\partial\alpha} = -d\cdot(n-1)\cdot\frac{\partial x_i^s(\alpha,n-1))}{\partial\alpha} .$$

Denoting $\partial B / \partial x_i^S$ by B' the first order conditions of n signatories and of n-1 signatories read:

[A3] a) $B'(x_i^S(\alpha,n)) = \alpha \cdot d \cdot n$ and b) $B'(x_i^S(\alpha,n-1)) = \alpha \cdot d \cdot (n-1)$.

Differentiating [A3] a) and b) with respect to α and using the theorem of implicit functions gives:

[A4] a) $\dfrac{d \cdot n}{B''(x_i^S(\alpha,n))} = \dfrac{\partial x_i^S(\alpha,n))}{\partial \alpha}$ and b) $\dfrac{d \cdot (n-1)}{B''(x_i^S(\alpha,n-1))} = \dfrac{\partial x_i^S(\alpha,n-1))}{\partial \alpha}$.

Substitution of [A4] a) and [A3] a) into [A2] a) and of [A4] b) into [A2] b) gives [12] in the text.

Appendix 2

We claim in the text that $\Phi_i(\alpha,n)$ is strictly concave for welfare function [7] and strictly decreasing for welfare function [8] for any α and hence also for $\alpha = 1$, representing the classical case denoted by $\Phi_i(n)$ in the text. From the first order conditions of signatories we derive for [7]:

[A5] $x_i^S(\alpha,n) = \dfrac{b \cdot a - \alpha \cdot d \cdot n}{b}$, $x_i^S(\alpha,n-1) = \dfrac{b \cdot a - \alpha \cdot d \cdot (n-1)}{b}$, $x_i^N = \dfrac{b \cdot a - d}{b}$

Substitution in $\Phi_i(\alpha,n)$ as defined in equation [11] in the text gives:

[A6] $\Phi_i(\alpha,n) = \dfrac{d^2 \cdot (n^2 \cdot \alpha^2 + 1 - 4 \cdot n \cdot \alpha + 2 \cdot \alpha)}{2b}$, $\dfrac{\partial \Phi_i(\alpha,n)}{\partial n} = \dfrac{d^2 \cdot \alpha \cdot (n \cdot \alpha - 2)}{b}$,

$$\frac{\partial^2 \Phi_i(\alpha,n)}{\partial n^2} = -\frac{d^2 \alpha^2}{b} .$$

For welfare function [8] we find:

[A7] $x_i^S(\alpha,n) = \dfrac{b - \alpha \cdot d \cdot n}{\alpha \cdot d \cdot n}$, $x_i^S(\alpha,n-1) = \dfrac{b - \alpha \cdot d \cdot (n-1)}{d \cdot (n-1)}$, $x_i^N = \dfrac{b-d}{d}$

[A8] $\Phi_i(\alpha,n)=b\cdot\left(\ln\left(\frac{b}{\alpha\cdot d\cdot n}\right)-\ln\left(\frac{b}{d}\right)+1\right),\ \frac{\partial\Phi_i(\alpha,n)}{\partial n}=-\frac{b}{n},\ \frac{\partial^2\Phi_i(\alpha,n)}{\partial n^2}=-\frac{b}{n^2}$.

Appendix 3

[14] in the text requires $\alpha>1-g/k$ where $g:=B''(x_i^S(\alpha,n)/B''(x_i^S(\alpha,n-1)$ and $k:=n^2/(n-1)^2$. For welfare function [7], g=1 since $B''=-b$. Thus, $g/k=1/k$ and therefore $\partial(g/k)/\partial n=\left(2\cdot(n-1)\right)/n^2>0$. For welfare function [8], g=$k=n^2/(n-1)^2$ and hence [14] requires $\alpha>0$ which is satisfied in any case.

Appendix 4

A sufficient condition that global emissions decrease if we lower α is that individual emissions, x_i^S, decrease or remain constant when lowering α since $n^*(\alpha)$ increases. For welfare function [7], we set $\Phi_i(\alpha,n)=0$ in [A6] and solve for n which gives two solutions:

[A9] $n^*(\alpha)=\frac{2+(-)\sqrt{3-2\cdot\alpha}}{\alpha}$

where the first with "+" is the desired solution. Clearly, $\partial n^*(\alpha)/\partial\alpha<0$ and $n^*(\alpha)>3$ if $\alpha<1$. Because in the classical case we have $x_i^S(n^*=3)=(b\cdot a-d\cdot 3)/b$ and in the non-classical case $x_i^S(\alpha,n^*(\alpha))=(b\cdot a-d\cdot\alpha\cdot n^*(\alpha))/b$ (see [A5] above), we require that $\alpha\cdot n^*(\alpha)>3$ and that $\partial(\alpha\cdot n^*(\alpha))/\partial\alpha<0$ which is easily checked to be true. For welfare function [8], we find $n^*=e\approx 2.718$ and $n^*(\alpha)=e/\alpha$ and hence $x_i^S(n^*)=x_i^S(\alpha,n^*(\alpha))$=(b-$d\cdot e$)/($d\cdot e$).

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(lix) This paper was presented at the ENGIME Workshop on "Mapping Diversity", Leuven, May 16-17, 2002
(lx) This paper was presented at the EuroConference on "Auctions and Market Design: Theory, Evidence and Applications", organised by the Fondazione Eni Enrico Mattei, Milan, September 26-28, 2002
(lxi) This paper was presented at the Eighth Meeting of the Coalition Theory Network organised by the GREQAM, Aix-en-Provence, France, January 24-25, 2003
(lxii) This paper was presented at the ENGIME Workshop on "Communication across Cultures in Multicultural Cities", The Hague, November 7-8, 2002
(lxiii) This paper was presented at the ENGIME Workshop on "Social dynamics and conflicts in multicultural cities", Milan, March 20-21, 2003
(lxiv) This paper was presented at the International Conference on "Theoretical Topics in Ecological Economics", organised by the Abdus Salam International Centre for Theoretical Physics - ICTP, the Beijer International Institute of Ecological Economics, and Fondazione Eni Enrico Mattei – FEEM Trieste, February 10-21, 2003
(lxv) This paper was presented at the EuroConference on "Auctions and Market Design: Theory, Evidence and Applications" organised by Fondazione Eni Enrico Mattei and sponsored by the EU, Milan, September 25-27, 2003
(lxvi) This paper has been presented at the 4th BioEcon Workshop on "Economic Analysis of Policies for Biodiversity Conservation" organised on behalf of the BIOECON Network by Fondazione Eni Enrico Mattei, Venice International University (VIU) and University College London (UCL) , Venice, August 28-29, 2003
(lxvii) This paper has been presented at the international conference on "Tourism and Sustainable Economic Development – Macro and Micro Economic Issues" jointly organised by CRENoS (Università di Cagliari e Sassari, Italy) and Fondazione Eni Enrico Mattei, and supported by the World Bank, Sardinia, September 19-20, 2003
(lxviii) This paper was presented at the ENGIME Workshop on "Governance and Policies in Multicultural Cities", Rome, June 5-6, 2003
(lxix) This paper was presented at the Fourth EEP Plenary Workshop and EEP Conference "The Future of Climate Policy", Cagliari, Italy, 27-28 March 2003

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