Can Social Externalities Solve the Small Coalitions Puzzle in International Environmental Agreements?

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Abstract

A puzzle in the literature on the formation of coalitions supporting International Environmental Agreements (IEAs) is that if an IEA leads to substantial gains, then it will not be supported by many countries. The non-cooperative game theoretic literature highlights the "small coalitions" puzzle by which only a small number of countries are willing to sign an environmental convention. In these models, a global coalition comprising all countries and generating significant benefits is not sustainable. Moreover they indicate that greater the number of countries in the coalition, higher the incentive of signatories to not respect their engagement. The present paper resolves this puzzle by introducing social externalities, in order to explain why some treaties can be sustained by nearly all countries, while others can be supported only by a handful.

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1. Introduction

When nations confront the global effects of environmental problems such as pollution emissions, they recognize that the welfare of a country depends not only on its own policy, but also on those of other countries. The formulation of environmental policy on an isolated national basis is therefore perceived to be inefficient. The recognition of "environment" as a global rather than a purely national issue has led to the signing of a number of "International Environmental Agreements" (or IEA) such as those to reduce ozone depletion, climate change and marine pollution.

The first theoretical contributions characterized environmental games between nations as a "prisoner's dilemma" leading them inevitably to be labelled as a "tragedy of the commons" problem. They implied that international agreements may not be effective as there were incentives for countries to "free-ride" given that the reduction of pollution emissions constituted a public good. However, IEAs continued to be signed. Over the past two decades, of the 194 members of the United Nations General Assembly, 184 have ratified the Montrel Protocol, 158 the Basel convention, 164 the Convention on International Trade in Endangered species and 146 the Kyoto Protocol. Thus, the main IEAs are supported by a majority of nations.

Presently, an extensive game-theoretic literature attempts to examine the strategic foundations of such international coalitions. Two main streams have emerged in this field since the last 15 years. The first argues that the formation of an IEA resembles the voluntary provision of a public good and formalizes the behaviour of countries as a cooperative game. It shows that an IEA ratified by all countries is stable (Chandler and Tulkens 1995). The second models IEAs as coalitions in a non-cooperative game (Heal 1992; Carraro and Siniscalco 1993; Barrett 1994; Péreau and Tazdaït 2001). A coalition is stable, when none of its members have an incentive to withdraw and when none of the non-members have an incentive to join the coalition (d'Aspremont *et al.* 1983). However, the predicted size of a stable IEA according to the second set of models is just between 2 to 4 countries, thereby contradicting reality. This result, which has been confirmed by a number of authors, is often referred to as the puzzle of "small coalitions".

A number of explanations have been put forward to resolve this puzzle. Lange and Vogt (2003) look at the implications of equity preferences for international cooperation in the reduction of some global pollutants. The existence of equity-interested countries increases the coalition size and leads to efficiency gains. Along this vein, Hoel and Schneider (1997) propose a model similar to that of Carraro and Siniscalco (1993), but with one major difference: non-environmental costs are incurred by non-signatories. Naturally, if this additional cost is high enough, it may reverse the original incentives, thus inducing the country to stay in the coalition. Repeated interaction between countries (Barrett 1999) and the interests of "issue linkage" as between environmental investment and trade or technology cooperation (Cesar and De Zeeuw 1996), have also been proposed to justify large coalitions.

The present article proposes yet another explanation: positive social externalities of a non-environmental nature that can be enjoyed if a country adheres to an IEA. In contrast to the "issue linkage" approach, there is no explicit negotiation linking adherence to a coalition to transfers on other issues1. Instead, all countries supporting an IEA benefit from a unilateral

[1] In the literature on "issue linkage", an IEA is explicitly linked to downstream tradeoffs on other specific issues such as trade policy, R&D, international debt and development assistance etc. once the coalition is formed so that the equilibrium is determined by the structure of tradeoffs between the different issues. In contrast, our paper does not consider any tradeoffs. A unilateral spillover is simply credited to all members of a coalition.

positive externality in the form of a spillover. International treaties permit us to enter into a dialogue of exchange and cooperation, creating a means of articulating reciprocal exchanges on other issues (social or political) and yielding positive social externalities. This assumption is also widely accepted by sociologists, who propose that cooperation has as much a social as an economic function, serving to build "social capital" between the partners concerned (Granovetter 1985). For example, the preservation of the environment can serve to "test" political relations, becoming a means to demonstrate a willingness to breach diplomatic gaps. For instance, the ratification of the Kyoto protocol by Russia was clearly interpreted as a good will gesture towards Europe, which in turn made efforts to facilitate the entry of Russia into the Word Trade Organization. This plainly illustrates the notion of a "social externality" that goes beyond reciprocity. The ratification served to strengthen the position of Russia in the international arena at a time when the reforms being implemented by the Kremlin to reinforce the centralization of power were being highly criticized by the Western powers.

The introduction of a social externality can reverse an initial lack of incentives, inducing a country to become a signatory to an IEA. Consequently, larger coalitions, including the global coalition may be supported, while ensuring at the same time that total welfare increases with the number of signatories.

2. Model

In this section, we start with the standard model presented in Barrett (1994), with constant marginal benefits and linear marginal costs and then we examine how the results change on introducing a positive social externality for signatories of an IEA. Consider a world with $i = 1, 2..., N$ identical countries, each of which emits a pollutant that damages a shared environmental resource. Each country can choose its abatement level q_i. Country *i*'s current abatement benefits, $B_i(Q)$ depends not only on its own reduction efforts but also on those of other countries as shown below.

$$B_i(Q) = \omega.(q_1 + ... + q_i + ... + q_n) \text{, where } Q = \sum_i q_i . \tag{1}$$

The positive and constant marginal benefit of abatement is ω.

However, each country's abatement costs are assumed to depend only on its own abatement level. For country *i*, let the convex abatement cost function, $C(q_i)$ be given by:

$$C_i(q_i) = c.q_i^2 / 2 . \tag{2}$$

The positive parameter *c* represents the slope of each country's marginal abatement cost curve.

Now suppose that the *N* countries play the following two-stage game. In the first stage, countries choose whether or not to participate in an IEA. Suppose *k* number of countries sign the IEA in the first stage. This can be observed and is common knowledge to all at the end of the first stage. In the second stage, the signatories of the IEA behave cooperatively by maximizing the coalition's aggregate welfare and implementing a coalition abatement effort, q^c. The non-signatories behave non-cooperatively by maximizing their individual welfare and applying the abatement effort, q^{nc}. In other words the non-signatories evoke the usual Cournot conjecture that every country chooses its abatement level taking as given the abatement levels of all other countries.

For simplicity, let the first *k* countries sign the IEA and the next *k+1* to *N* countries remain as non-signatories. Signatories of an IEA benefit from a social externality that increases with the size of the coalition, with $s > 0$ being the social externality parameter.

Each country i signing an IEA gets a payoff π_i^c or π^c. Every non-signatory country i gets a payoff of π_i^{nc} or π^{nc}. These are defined below.

$$\pi_i^c = \pi^c\left(k\right) = B(k.q^c + q_{k+1}^{nc} + q_{k+2}^{nc} + ... + q_N^{nc}) - C(q^c) + s.k\,; \tag{3}$$

$$\pi_i^{nc} = \pi^{nc}\left(k\right) = B(k.q^c + q_{k+1}^{nc} + q_{k+2}^{nc} + ... + q_i^{nc} + ... + q_N^{nc}) - C(q_i^{nc})\,. \tag{4}$$

Resolving by backward induction, we start with the second stage game and maximize $\pi^c(k)$ and $\pi^{nc}(k)$ with respect to q^c and q_i^{nc} respectively to get the equilibrium abatement values of signatories and non-signatories as shown:

$$q^c(k) = \frac{k.\omega}{c}, \qquad q^{nc}(k) = \frac{\omega}{c}. \tag{5}$$

Then the first stage equilibrium or the number of countries which will sign the IEA is found by identifying the coalition that satisfies both the conditions of internal and external stability.

Definition An IEA consisting of k^* signatories is self-enforcing if and only if it is both internally and externally stable, i.e.:

$$\pi^{nc}(k^*-1) \le \pi^c\left(k^*\right) \quad \textit{and} \quad \pi^{nc}(k^*) \le \pi^c\left(k^*+1\right) \tag{6}$$

Given the above definition we show in the following proposition that the size of an IEA coalition at equilibrium will depend on the relative values of the net benefit of the IEA (which is a function ω and c), and the social externality s.

Proposition: *For $N \ge 2$, the largest possible stable coalition is with k^* member countries, where $k^* = 2 + \tilde{s}/2 + \sqrt{1+2\tilde{s}+\tilde{s}^2/4}$ and $\tilde{s} = \frac{2.c}{\omega^2}.s$.*

Proof: Substituting the values of the benefits and costs from equations (1)-(5) in equation (6), the internal and external stability conditions can be written as follows:

$$F_{\text{int}}(k) = k^2 - k\left(4 + s.\frac{2c}{\omega^2}\right) + 3 \le 0\,; \textit{(internal stability condition).} \tag{7}$$

$$F_{ext}(k') = k'^2 - k'\left(2 + s.\frac{2c}{\omega^2}\right) - s.\frac{2c}{\omega^2} \ge 0\,; \textit{(external stability condition).} \tag{8}$$

Let $\tilde{s} = \frac{2.c}{\omega^2}.s$. The solutions k verifying inequality (7) lie within the interval $\left[\underline{k}\,;\overline{k}\right]$ with:

$$\underline{k} = \tilde{s}/2 + 2 - \sqrt{1+2\tilde{s}+\tilde{s}^2/4} \text{ and } \overline{k} = \tilde{s}/2 + 2 + \sqrt{1+2\tilde{s}+\tilde{s}^2/4}\,.$$

The solutions k' satisfying inequality (8) lie in the interval $\left(-\infty, \underline{k}'\right] \cup \left[\overline{k}', +\infty\right)$ with

$$\underline{k}' = \tilde{s}/2 + 1 - \sqrt{1+2\tilde{s}+\tilde{s}^2/4} = \underline{k} - 1 \text{ and } \overline{k}' = \tilde{s}/2 + 1 + \sqrt{1+2\tilde{s}+\tilde{s}^2/4} = \overline{k} - 1\,.$$

Consequently all values of k satisfying the condition $k \in \left[k^*-1; k^*\right]$ with $k^* = \overline{k} = \tilde{s}/2 + 2 + \sqrt{1+2\tilde{s}+\tilde{s}^2/4}$, verify the two inequalities. This is also illustrated in figure 1.

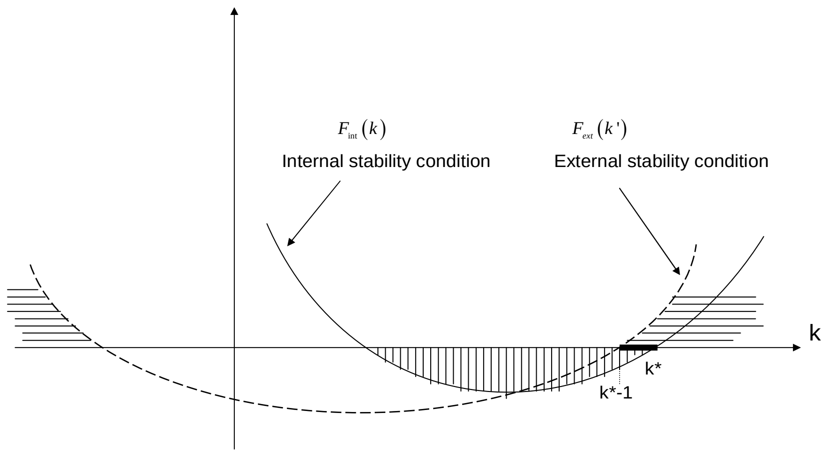

Figure1. Values of k that satisfy the criteria of self-enforcing IEA.

At equilibrium, global benefits are an increasing function of the number of signatories. Let the total net benefits of an IEA with k^* members be given by $\Pi(k^*) = \Pi^c(k^*) + \Pi^{nc}(k^*) = k^*.\pi^c(k^*) + (N-k^*).\pi^{nc}\left(k^*\right)$. This can be rewritten as:

$$\Pi(k^*) = \frac{\omega^2}{2c}\left[k^*.(k^*-1).(2N-k^*-1) + N.(2N-1) + \tilde{s}.\left(k^*\right)^2\right].$$

Then: $$\frac{\partial\Pi\left(k^*\right)}{\partial k} > 0 \text{ and } \frac{\partial^2\Pi\left(k^*\right)}{\partial k^2} > 0.$$

The global abatement under an IEA then emerges as:

$$Q\left(k^*\right) = k^{*2}\frac{\omega}{c} + \left(N-k^*\right)\frac{\omega}{c}, \text{ with } \frac{\partial Q\left(k^*\right)}{\partial k} > 0 \text{ and } \frac{\partial^2 Q\left(k^*\right)}{\partial k^2} > 0.$$

The above features clearly indicate the advantages of large coalitions; greater the number of signatories, higher the global benefits. Furthermore, the number of signatories at equilibrium, k^*, is positively correlated to $\tilde{s}$ (recall proposition).

It can also be noted that the difference between the total benefits under full cooperation, with all countries being signatories and total non-cooperation is an increasing function of $\tilde{s}$ as:

$$\frac{\Pi^c(N) - \Pi^{nc}(0)}{\Pi^{nc}(0)} = \frac{(N-1)^2 + N.\tilde{s}}{(2N-1)};$$

where $\Pi^{nc}\left(0\right) = \sum_{i=1}^{N}\pi_i^{nc}\left(0\right) = \frac{\omega^2}{2c}N(2N-1)$, and $\Pi^c\left(N\right) = \sum_{i=1}^{N}\pi_i^c\left(N\right) = \frac{\omega^2}{2c}N^3 + N^2.s$.

Therefore, the incentives to join an IEA, the size of an IEA at equilibrium and the global benefits under an IEA are all increasing functions of $\tilde{s} = \frac{2.c}{\omega^2}.s$. In other words, higher the value of the non-environmental spillover *s* with respect to the pure environmental benefit of an IEA (which is a function of ω and *c*) greater the incentives to join an IEA.

3. An illustration

We now present a series of simulations to prove that global coalitions are possible under certain parameter configurations. Table 1 gives the values of $\tilde{s}$ and the equilibrium coalition size k^* as a function of the parameters of the environmental benefit associated with an IEA, (c, ω), and the value of the non-environmental spillover *s*.

s / c/ω^2	**0**	**.1**	**.5**	**1**	**5**	**10**	**100**
.05	$\tilde{s}$=0 k^*=3	$\tilde{s}$=.01 k^*=3	$\tilde{s}$=.02 k^*=3	$\tilde{s}$=.1 k^*=3	$\tilde{s}$=.5 k^*=3	$\tilde{s}$=1 k^*=4	$\tilde{s}$=10 k^*=13
.25	$\tilde{s}$=0 k^*=3	$\tilde{s}$=.05 k^*=3	$\tilde{s}$=.25 k^*=3	$\tilde{s}$=.5 k^*=4	$\tilde{s}$=2.5 k^*=5	$\tilde{s}$=5 k^*=8	$\tilde{s}$=50 k^*=**53**
.5	$\tilde{s}$=0 k^*=3	$\tilde{s}$=.1 k^*=3	$\tilde{s}$=.5 k^*=3	$\tilde{s}$=1 k^*=5	$\tilde{s}$=5 k^*=8	$\tilde{s}$=10 k^*=13	$\tilde{s}$=100 k^*=**100**
5	$\tilde{s}$=0 k^*=3	$\tilde{s}$=1 k^*=4	$\tilde{s}$=5 k^*=8	$\tilde{s}$=10 k^*=23	$\tilde{s}$=50 k^*=**53**	$\tilde{s}$=100 k^*=**100**	$\tilde{s}$=1000 k^*=**100**
25	$\tilde{s}$=0 k^*=3	$\tilde{s}$=5 k^*=8	$\tilde{s}$=25 k^*=28	$\tilde{s}$=50 k^*=**100**	$\tilde{s}$=250 k^*=**100**	$\tilde{s}$=500 k^*=**100**	$\tilde{s}$=5000 k^*=**100**
50	$\tilde{s}$=0 k^*=3	$\tilde{s}$=10 k^*=13	$\tilde{s}$=50 k^*=**53**	$\tilde{s}$=100 k^*=**100**	$\tilde{s}$=500 k^*=**100**	$\tilde{s}$=1000 k^*=**100**	$\tilde{s}$=10000 k^*=**100**
100	$\tilde{s}$=0 k^*=3	$\tilde{s}$=20 k^*=23	$\tilde{s}$=100 k^*=**100**	$\tilde{s}$=200 k^*=**100**	$\tilde{s}$=1000 k^*=**100**	$\tilde{s}$=2000 k^*=**100**	$\tilde{s}$=20000 k^*=**100**

Table1: Number of signatories k^* and the value of $\tilde{s}$ (for N=100).

Table 1 reveals that an IEA can be supported by a small or a large number of signatories. Higher the value of $\tilde{s} = \frac{2.c}{\omega^2}.s$, greater the number of signatories. Evidently, $\tilde{s}$ is higher whenever the social externality *s* is greater. Furthermore, when the externality is zero, the standard result with $k^* = 3$ can be re-confirmed. Another interesting point of note is that the number of signatories increases with the ratio $\frac{c}{\omega}$; higher the costs of abatement or lower the benefits from abatement, greater the number of countries supporting the IEA. Finally, as long as the social externality *s* is positive, it is possible to verify that there exist values of c and ω that permit a global coalition with all countries being signatories. For example, for s = 0.5, c = 0.01 and ω = 0.01, we have a global coalition with all countries being signatories. The situation of full cooperation permits the augmentation of the abatement efforts while at the same time ensuring a maximum benefit for the signatories. This clearly contradicts the standard result enunciated in Barret (1994), according to which a global IEA coalition is not stable, whenever the potential gains from cooperation are much greater than from non-cooperation.

4. Conclusion

A problem that has been puzzling economists trying to model IEAs as a non-cooperative game is that large coalition IEAs are never stable, unless the gains from cooperation are trivial. This is however, in contradiction with reality, where major environmental conventions are supported by a majority of countries and the gains are assumed to be non-trivial. By introducing a social externality as a spillover benefit of becoming a member of the IEA, this paper shows that the incentive structure of an IEA can be changed and even a global coalition can be ensured. In fact, greater the externality enjoyed by the signatories, greater the abatement efforts, and also greater the global benefits. Even if we suppose that all countries are homogenous in terms of benefits and abatement costs, our model provides a possible resolution of the “small coalitions puzzle”.

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