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Msc in Economic Science

Coalition formation in International Environmental Agreements.
A Literature review.

Thesis:

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Abstract:
The following paper is an attempt to highlight the scientific progress that was made in the coalition formation literature during the past two decades. Firstly, it presents a comparative description of three baseline papers (Carraro & Siniscalco 1993, Barrett 1994, Diamantoudi & Sartzetakis 2006) that emphasized the majority of an international environmental agreement's characteristics. Secondly, it gives special importance to two papers that, at first sight, adopt a rather unorthodox point of view (Heugues (2009) and Marrouch & Chaudhuri(2011)) and finally examines the most important details of some promising scientific fields such as uncertainty and asymmetry introduction.

<u>Contents:</u>

1. Introduction

Global environmental issues, such as the management of the shared environmental resources and the transboundary pollution, apart from the necessary adaptive measures, calls for the cooperation of all countries involved, through the coordination of their national environmental policies. This coordination, as far as the transboundary pollution is concerned, is related to the participation of the countries in the international environmental agreements (IEAs). It is well known that countries can raise their returns under cooperation. Unfortunately, the option of free riding is always a motive not to participate in such an agreement gaining, this way, all the benefits (emission reduction) and skipping all the costs.

The Montreal Protocol on Substances that Deplete the Ozone Layer and the Kyoto protocol, as part of the United Nation Framework Climate Change Convention (UNFCCC) are the two main examples used in order to present a successful and a problematic attempt. Up to now theoretical analysis is not capable to answer the two main questions that come up:

- Which characteristics make such an agreement attractive to the candidate participants?
- How can we use these characteristics in order to make every country involved, to participate, securing on the other hand the stability of this agreement?

The majority of the IEA studies employs some concepts from game theory to explore the formation of a coalition that reduces pollution. A part of this literature takes into account that we are dealing with a cooperative game (Chander & Tulkens 1995, 1997) whereas another part, the popular one, uses noncooperative game theory (Carraro & Siniscalco 1993, Barrett 1994, Diamantoudi & Sartzetakis 2006).

Chander & Tulkens show that a stable IEA formed by all countries is a possible scenario. On the other hand, the noncooperative approaches either examine the simultaneous or the leader-follower games. Carraro & Siniscalco's model reexamined by De Cara & Rotillon(2001), Finus & Rundshagen (2001) and Rubio & Casino (2001) concludes that when we have quadratic benefit and damage functions the stable IEA will involve a maximum of two countries. Barrett's model is clearly more optimistic. He suggests that a stable IEA may include a large number of countries and that even the full cooperative case is possible. On the other hand, Diamantoudi & Sartzetakis use a more accurate model with a different choice variable and find that the size of the stable coalition is very small and, unfortunately, they show that the usage of the model parameters in order to improve the quality of a coalition is not a solution. Finally, Heugues tries to improve the model introducing a totally different assumption: the strategies of the candidate participants are not substitutes but complements. This assumption is based in theoretical and numerical research in trade theory and gives very interesting results ($s \leq N*75\%$), accompanied by some puzzling properties (the higher the environmental awareness the weaker the coalition!).

The literature review that follows, first of all describes three strategic substitutability models (Carraro & Siniscalco, Barrett and Diamantoudi & Sartzetakis) and compares their main results to the ones obtained by the papers that adopt strategic complementarity (Heugues and Marrouch & Chaudhuri). Finally, it describes briefly the most important papers that are related to the asymmetric countries hypothesis and to the uncertainty hypothesis highlighting the research fields that could help us develop the formation of IEAs.

2. The Literature review

The Models:

We consider N identical players (countries) that interact, generating non negative emissions of a specific global pollutant as a result of production and consumption activities. The aggregated emission levels affect negatively each one of them. Each author presents a different model to describe this interaction.

Carraro & Siniscalco (1993) use a welfare function of the following form: $P_i(x) = B_i(x_i) - D_i(x_i, x_{-i})$ where $B_i(x_i)$ is the benefit function ,$D_i(x_i, x_{-i})$ is the damage function, x_i are country i's emissions, $x=(x_{1...}x_n)=(x_i, x_{-i})$ are the global emissions and x_{-i}=x-x_i. It is also assumed that $B_i(x_i)$ is negatively sloped. On the other hand the damage function properties differ from country to country because they are based on subjective criteria.

Barrett (1994a) uses a totally different approach. First of all, in comparison with Carraro & Siniscalco, he introduces an abatement model and secondly he examines three types of specific functional forms: linear marginal abatement benefits and costs $\left(B_i(Q) = \frac{\widehat{b}}{N}(\widehat{a}Q - \frac{Q^2}{2}), C_i(q_i) = \frac{\widehat{c}q_i^{\,2}}{2} \right)$, constant marginal benefits and linear marginal costs $\left(B_i(Q) = \omega Q, C_i(q_i) = \frac{cq_i^{\,2}}{2} \right)$, constant marginal benefits and logarithmic marginal costs $\left(B_i(Q) = \omega Q, C_i(q_i) = \chi\sigma[(1-q_i/x)\ln(1-q_i/x) + q_i/x] \right)$ and finally linear marginal benefits and constant marginal costs $\left(B_i(Q) = \frac{\widehat{b}}{N}(\widehat{a}Q - \frac{Q^2}{2}), C_i(q_i) = dq_i \right)$ where $B_i(Q)$ is the benefit function, $C_i(q_i)$ is the cost function Q is the aggregated abatement effort and q_i is country i's abatement effort($\widehat{a}$, $\widehat{b}$, $\widehat{c}$ >0). It is interesting to see that in the Carraro & Siniscalco emission model a damage function is used to denote welfare losses whereas in the Barrett model a cost function takes its place. The reason that lies behind this result is intuitively simple. An emission level model pays attention to the pollution phenomenon (a damage factor) contrary to an abatement effort model which highlights the anti-pollution policy (a cost factor).

Similarly, Diamantoudi & Sartzetakis (2006) present an emission model with quadratic benefit and damage functions $\left[B(e_i) = b\left(ae_i - \frac{1}{2}e_i^{\,2} \right), D(E) = \frac{1}{2}cE^2 \right]$ where $B(e_i)$ is the benefit function, $D(E)$ is the damage function, e_i are country i's emissions, E are the global emissions (a,b,c>0). The usage of a damage function (in stead of a cost function) is to be expected.

Pure Cooperative Case vs Non Cooperative Case:

The pure cooperative case is the first scenario examined by the literature.

The countries use their aggregated benefits from the production-consumption procedure in order to face the damage caused by the aggregated emissions. In terms of an IEA, we have the grand coalition (every country is a signatory). The non cooperative case is exactly the opposite. Every country uses only its own benefits to face the damage caused by the aggregated emissions.

According to Carraro & Siniscalco, it is obvious that the critical decision for the countries is whether to act cooperatively (coalition formation case) or not. As it is well known the collective well being can be increased if all countries cooperate. This is a very important motive for every candidate participant. On the other hand, candidate countries will earn higher payoffs by free riding. The authors briefly say that according to the literature, profitable and stable coalitions do exist. Unfortunately the coalitions presented by the literature, attract a minority of candidate countries, a fact that makes them relatively useless.

Barrett presents specific functional forms which allow him to question the literature results. The comparison is very interesting. π_i denotes country i's payoff function $\left(\pi_i = B_i(Q) - c_i(q_i)\right)$ and Π denotes the joint welfare $\left(\Pi = \Sigma_i \pi_i\right)$. Optimizing Π: $Q_c = \frac{\hat{a}N}{n+\hat{\gamma}} > 0$, $q_c = \frac{\hat{a}}{n+\hat{\gamma}} > 0$ where $\hat{\gamma} \equiv \frac{\hat{c}}{\hat{b}}$. On the other hand optimizing the unilateral welfare function (non cooperative case) we get: $Q_{nc} = \frac{\hat{a}}{1+\hat{\gamma}}, q_{nc} = \frac{\hat{a}}{n(1+\hat{\gamma})}$.

Diamantoudi & Sartzetakis follow the same procedure as Barrett, but using different functional forms: $\Pi = \sum B_i(e_i) - \sum D(E)$ optimizing: $e_c = \frac{a}{1+\gamma N^2} > 0$, $E_c = \frac{Na}{1+\gamma N^2} > 0$ and optimizing $\pi_i = B(e_i) - D(E)$ we get: $E_{nc} = \frac{Na}{1+\gamma N} > 0$, $e_{nc} = \frac{a}{1+\gamma N} > 0$.

As it is expected the abatement effort is larger under cooperation ($Q_c > Q_{nc}$) and the emission level is larger under non cooperation ($e_c < e_{nc}$).

Partially cooperative case (coalition formation):

Some countries form a coalition acting as a group and others act non-cooperatively. Barrett assumes that a percentage A of the total countries acts cooperatively. Consequently we have AN signatory countries. The rest (1-A)N countries act non-cooperatively (non signatory countries). He also assumes that the non-signatories behave non-cooperatively after having observed the choice of signatories[1]. The best reply functions are given by $Q_n(A,Q_s) = \frac{(1-A)(\hat{a}-Q_s)}{1+\hat{\gamma}-A}$ where Q_n(>0) is the non signatory countries' abatement effort and $Q_s(A,Q_n) = \frac{A^2 N(\hat{a}-Q_n)}{A^2 N+\hat{\gamma}}$ where Q_s(>0) is the signatory countries' abatement effort.

Diamantoudi & Sartzetakis adopt exactly the same assumptions with a small difference in the definition of the signatory and non-signatory countries(S countries act cooperatively (signatories) whereas N-S countries act non-cooperatively (non signatories)). The best reply functions of the non-signatories are given by $e_{ns} = \frac{a-\gamma s e_s}{\gamma(\mathrm{N}-s)+1}$, $E_{ns} = \frac{(a-\gamma s e_s)(\mathrm{N}-s)}{\gamma(\mathrm{N}-s)+1}$ whereas the signatories are solving $\max_{e_s} s\left[B(e_s)-D(se_s+(n-s)e_{ns}(e_s))\right]$ and take $e_S = a\left(1-\frac{\gamma sN}{\Psi}\right) \underset{?}{>} 0$ and $E_S = sa\left(1-\frac{\gamma sN}{\Psi}\right)$ (where $\Psi = X^2+\gamma s^2$ and $X = 1+\gamma(\mathrm{N}-s)$). A problem that comes up is that for some γ, e_s and e_{ns} could be non positive. More precisely: e_s>0 iif $\gamma < \frac{4}{N(N-4)}$ and n>4 and e_{ns}>0 iif $\gamma > \frac{4}{N(N-4)}$ and n>4. Barrett overlooked this very important property because he is dealing with an abatement effort model (Q_n>0, Q_s>0). The stability-profitability conditions will give the precise number of participants both in the Barrett (abatement) model and in the Diamantoudi & Sartzetakis (emission) model. It should be noted that the stability-profitability definitions and conditions have no difference from the ones adopted by Carraro & Siniscalco.

[1] Every paper in the IEA literature describes the coalition formation game either as a simultaneous or as a leader-follower game, where the type of the game is exogenously assumed. An interesting alternative is presented in the Appendix.

Profitability Definition:

A coalition is profitable if the payoffs of a participant are larger than the ones of a non participant (every candidate country has a motive to enter).

Stability Definition:

A coalition is stable if every participant has a motive to stay, whereas, none of the rest of the countries has a motive to enter.

This definition corresponds to that of cartel stability presented in the oligopoly literature {D'Aspremont & Gabszewicz (1986)}.The participation rate is again computed by the conditions used by D' Aspremont (internal stability: $w_s(s^*) \geq w_{ns}(s^*-1)$ and external stability: $w_s(s^*+1) \leq w_{ns}(s^*)$). Where s* is the coalition size, w_s is the signatory's payoff and w_{ns} is the non signatory's payoff. The next step is simply to use the conditions and the best reply functions to compute some candidate coalition sizes.

It is very interesting to add that Barrett is using the payoffs' difference in order to detect under what circumstances an IEA performs optimally. The results are concentrated below:

	Unilateral abatement	$\Pi_c - \Pi_{nc}$
(c small, b large) γ small	large	small
(c large, b small) γ large	small	small
(c ≈ b ≈ small) γ≈1	large	small
(c ≈ b ≈ large) γ≈1	large	large

It is easy to see that, the most encouraging case is the last one. The table presented above will help us understand better the performance of an IEA under specific parameterization e.g. when N=10, α=100, b=1 and c=0.25 Barrett finds that A=0.4 (the stability conditions give a four country coalition). Generally it is easy to observe that $\frac{\partial A}{\partial \gamma} < 0$. Securing that γ is small, a large coalition accompanied by a small payoff difference will come up (large coalition with small impact). The impact is equally small when γ is large. On the other hand when c and b are both large (the more interesting case presented in the table above) the simulations give small coalitions. Generally when the problem is characterized by linear marginal benefits and costs, small γ will lead to a large coalition with large q_i^s, but small $\Pi_c - \Pi_{nc}$. When c and b are both large (γ~1), $\Pi_c - \Pi_{nc}$ is large but the participation is clearly smaller. It is critical to add that according to the author when N is small the stability conditions secure the coalition more efficiently.

Unfortunately, the optimistic results presented above change radically when the correct assumptions are adopted. The comparison presented by Diamantoudi & Sartzetakis shows that the abatement and the emission model are equivalent and give exactly the same results when the restrictions and the assumptions that describe them are the same. The critical assumption that Diamantoudi & Sartzetakis add, and was absent from Barrett's model, assures that abatement effort cannot exceed the emission levels ($q_s \leq a$, $q_{ns} \leq a$) or, for simplicity's sake, emissions are positive ($e_s \geq 0$, $e_{ns} \geq 0$).

	welfare
In terms of emission	$w(e_i) = b\left(ae_i - \frac{1}{2}e_i^2\right) - \frac{c}{2}\left(\sum_{i \in N} e_i\right)^2$
In terms of abatement	$w(e_i) = \frac{\bar{b}}{N}\left(\bar{a}Q - \frac{1}{2}Q_i^2\right) - \frac{\bar{c}}{2}q_i^2$

where $\bar{c} = b$, $\bar{b} = Nc$, $\bar{a} = Na$ and $\bar{\gamma} = \frac{\bar{c}}{\bar{b}} = \frac{1}{\gamma N}$

As a consequence the results presented by Barrett reduce to the ones presented by Diamantoudi & Sartzetakis. They find that when N>4 the stability and profitability conditions give a stable coalition with two, three or four participants e.g. when N=10, α=10, b=6, c=0,39999, the two D' Aspremont conditions lead to a stable coalition with three participants.

Unfortunately the coalition size is never bigger than three even if we use different functional forms, as Barrett did. More precisely a benefit function with constant marginal benefits e.g. (Bi(Q) = ωQ) combined with the usual cost function gives a coalition with two participants, when N=2 and three participants for every other N. On the other hand, when we have constant marginal benefits and logarithmic marginal costs, the coalition has two participants irrespectively of N. Finally, for linear marginal benefits and constant marginal costs a coalition of two or more participants does not exist.

The last case examined by Barrett is the repeated game case. For a payoff function such as $\pi_i = \frac{\hat{b}}{N}(\hat{a}Q - \frac{Q^2}{2}) - dq_i - \frac{(a\hat{b} - dN)^2}{2\hat{b}N}$, the full cooperative outcome can be sustained as a self-enforcing IEA for a common discount rate close to zero if the number of countries N does not exceed N_{min} (N_{min} is increasing in a and b, and decreasing in d). Unfortunately, giving the game a dynamic character we do not succeed to come up with the full cooperative outcome.

Concluding, Barrett uses two frameworks to examine the IEA formation procedure. The first refers to the determination of an endogenous solution, whereas the second presents the IEA formation as a repeated game solution. As far as the first one is concerned, he shows that a coalition may not exist, or it may be unable to have more than two or three signatories. The participation can only increase when the difference in non cooperative payoffs and full cooperative payoffs are very small. The second approach gives similar results. Diamantoudi & Sartzetakis reexamine Barrett's model showing that under specific and subjectively true assumptions his model has no difference from the one presented by them. They find that a profitable and stable IEA has no more than four participants and as result even a very small difference between non cooperative and full cooperative payoffs cannot increase the participation rate.

Expanding Coalitions:

As it was formerly stated Carraro & Siniscalco observed that the coalition formation models, presented by the literature, predicted a small participation rate. Instead of presenting a new IEA formation model they tried to overcome this problem and help the enlargement of the coalition proposing the usage of self financed welfare transfers (i.e. coalition's gains are partly used to fund its enlargement).

First of all, they suppose that no countries can commit to the cooperative strategy. Using the D’ Aspremont conditions it is easy to show that, under the no commitment hypothesis, no self-financed transfer from the cooperating countries to the non-cooperating countries can successfully enlarge the original coalition. The relaxation of this hypothesis gives four alternative commitment forms:

1. Only the signatories commit to cooperation (stable coalition commitment).
2. Every signatory, even the new ones, must commit.
3. The number of committed countries is such that appropriate transfers can induce all other countries to cooperate (full-cooperation minimum commitment).
4. A subset of non-cooperating countries commits to transfer welfare in order to induce the remaining non-signatories to cooperate, and to guarantee the stability of the resulting coalition (external commitment).

Before the examination of these four alternatives, the authors add three basic restrictions that describe the alternative commitment forms:

i. Transfers must be self financed.
ii. The move to a larger coalition must be Pareto-improving.
iii. Committed countries choose the transfer in order to maximize the number of signatories (given the above two constraints).

<u>First case (stable coalition commitment):</u>

Commencing with a j-coalition, the members' commitment, combined with the appropriate transfers (smaller than the gains from the new, bigger, coalition and larger than the loss suffered by the entering countries) will persuade other r countries to participate (r and gain attained from expanding the coalition are positively related, whereas r and the free riding motive are negatively related).

The authors provide a specific example in Carraro & Siniscalco (1991).

Linear-quadratic benefit and damage functions emphasize the important role of the slope of the reaction functions. Orthogonal reaction functions give a small coalition of three or four countries irrespective of N.

Second case (sequential commitment):

There are many similarities between the stable coalition commitment and the sequential commitment. The coalition again uses a part of its gains to attract candidate participants. The difference between the two commitment forms is that every new member takes part in the funding process. The relation between r (the countries that can be induced to join the initial coalition), the gain from moving to a wider coalition and the free riding motive from the first case, is re-observed here.

It is obvious that sequential commitment is more demanding because of the additional stability condition: “Full cooperation cannot always be achieved because there may exist values of r for which the gain from further broadening the coalition is lower than the loss incurred by the entering country, i.e. the transfer would not be sufficient to induce one more country to join the coalition.”

The authors show that sequential commitment leads to full cooperation when the activities of the players are described by orthogonal reaction functions.

Third case(full cooperation minimum commitment):

Suppose that some countries commit. Then, in this case, there is a critical number of committing countries which is enough to persuade the rest of them to cooperate. Again the induction tool is the self financed transfers. Using the proper simulations the authors show that full cooperation is a feasible scenario if about 60 percent of the countries commit.

Fourth case(external commitment):

The greater the coalition the more the countries (either signatories or non signatories) gain. As a result some non signatory countries (in spite of not being members of the coalition) might have a motive to support coalition's enlargement and stability.

The usage of this tool, when the reaction functions are orthogonal, can persuade 70 percent of the countries to sign the agreement. Unfortunately, the simulation results presented by the two authors are far more pessimistic under the assumption of negatively sloped reaction functions. Even sequential commitment cannot make any difference.

Concluding, the main contribution of the paper is the examination of the basic characteristics of IEAs. It presents analytically the tools that could make them more attractive and finally pays attention to the problems that come up when the countries try to act cooperatively against the transboundary pollution problem. More precisely, according to the paper, there is a great variety of possible self enforcing agreements. It is feasible to make a profitable and stable partially cooperative agreement and even enlarge it, using the proper self-financed welfare transfers. A vital assumption for this model to be credible is the presence of a form of commitment. This special characteristic can even lead to the full cooperation case.

3. Strategic Complementarity Hypothesis

Melanie Heugues (2009) instead of following the literature on IEAs introduces a totally different assumption. It is well known that transboundary pollution problems imply a negative externality. According to the paper there is both a positive and a negative externality.

The payoff-welfare functions used by Carraro & Siniscalco, Barrett, Diamantoudi & Sartzetakis and generally the mainstream literature, assume that countries strategies are substitutable. This special characteristic is the one that makes free riding option so attractive and the stability conditions so important. An increasing number of empirical and theoretical international trade studies suggests that the interactions could be complementary i.e. if a country increases its abatement effort (decreases its emission level), the marginal cost of the others may fall. The reason that lies behind this result is intuitively simple. Knowledge spillovers, technological transfers, economies of scale and industrial specialization are the positive externalities that can switch the nature of the interaction.

The results she presents are equally interesting. Under circumstances, the coalition has much more than four participants with an equally important environmental impact. Unfortunately the percentage of the participants is never higher than 75% of N ($\forall$ N≥2).

The Model:

We assume that there exist N identical countries, $N = \{1, ..., n\}$. They interact, generating non negative emissions of a green house gas as a result of their economic activities. The aggregated emission levels affect negatively each one of them. She presents a model similar to the one presented by Diamantoudi & Sartzetakis. The payoff function is expressed as a net benefit function (f(x,y)=B(x)-D(x,y)) where $B(x) = b(x-1)^{1/2}$, $D(x, y) = c(x + y)^{1/2}$, x is the emission level of the country we are examining, z are the global emissions and $y = z - x$ (again $b, c > 0$). As it was formerly described, Barrett overlooks the fact that emissions are positive whereas Diamantoudi & Sartzetakis pay great attention to this property. On the other hand, M. Heugues not only supposes positive emissions but also that $x \geq x_{min}$ ("...a country cannot reduce its economic activities under some level..."). Simplifying: x_{min}=1.

A very important property, which secures the strategic complementarity, is the concavity of the damage function.

$$f(x, y) = B(x) - D(x + y) \Rightarrow \frac{\partial f(x, y)}{\partial x} = \frac{\partial B(x)}{\partial x} - \frac{\partial D(x + y)}{\partial x} \Rightarrow \frac{\partial^2 f(x, y)}{\partial x \partial y} = -\frac{\partial^2 D(x + y)}{\partial x \partial y}$$

$\frac{\partial^2 f(x, y)}{\partial x \partial y}$ is positive (strategic complementarity) iif $\frac{\partial^2 D(x + y)}{\partial x \partial y} < 0$ (concave damage function).

Pure Cooperative Case vs Non Cooperative Case (The Heugues Model):

Following the pattern we adopted earlier, we first examine the pure cooperative and the pure non-cooperative case and then the coalition formation scenario.

The behavior of each country is described by the unilateral welfare function (f(x,y)) whereas the behavior of the grand coalition (pure cooperative case) is described by $F(x) = NB(x) - ND(Nx)$. Optimizing $F(x)$ we get $x_c = \frac{z_c}{N} = \frac{N\gamma^2}{N\gamma^2 - 1}$, $z_c = \frac{N^2\gamma^2}{N\gamma^2 - 1}$, $\gamma = \frac{c}{b}$ and optimizing f(x,y) we take the best reply function: $x(y) = \frac{\gamma^2 + y}{\gamma^2 - 1}$. It is useful to add that using the identical countries assumption (y=(n-1)x) we can transform $x(y)$ into $x_{nc} = \frac{\gamma^2}{\gamma^2 - N}$ and z_c into $z_{nc} = \frac{N\gamma^2}{\gamma^2 - N}$. It is easy to see that the positivity condition is satisfied when γ>1 and the $\mathrm{x} \geq \mathrm{x}_{\min} = 1$ condition is satisfied when γ^2>N.

Partially cooperative case (coalition formation) (The Heugues Model):

The coalition formation procedure is presented as a two stage game. The countries firstly choose whether to enter the coalition or not and secondly, they optimize their behavior respectively. In the existing literature the coalition formation game is usually modeled as a leader-follower game. In this case the players act simultaneously.

Again s countries act cooperatively and N-s act non cooperatively.

The best reply functions for the signatories are given by optimizing $\max_{x_s} s\left(b(x_s - 1)^{\frac{1}{2}} - c(sx_s + (N-s)x_{ns})^{\frac{1}{2}} \right) \Rightarrow x_s(x_{ns}) = \frac{\gamma^2 s^2 + (N-s)x_{ns}}{s(\gamma^2 s - 1)}$ whereas the best reply functions for the non signatories are given by optimizing

$$\max_{x_i} b(x_i-1)^{\frac{1}{2}} - c(sx_s + (N-s-1)x_{ns} + x_i)^{\frac{1}{2}} \Rightarrow x_{ns}(x_s) = \frac{\gamma^2 + sx_s}{\gamma^2 - N + s}.$$ Using $x_s(x_{ns})$, $x_{ns}(x_s)$ together we get: $x_s = 1 + \frac{N}{s^2(\gamma^2 - N + s) - s}$, $x_{ns} = 1 + \frac{Ns}{s(\gamma^2 - N + s) - 1}$,

$$f_s = \frac{bN^{\frac{1}{2}}(1 - s\gamma^2)}{\left(s^2(\gamma^2 - N + s) - s\right)^{\frac{1}{2}}} \text{ and } f_{ns} = \frac{b\left(Ns\right)^{\frac{1}{2}}(1 - \gamma^2)}{\left(s(\gamma^2 - N + s) - 1\right)^{\frac{1}{2}}}.$$

Comparing $f_s(s)$, $f_{ns}(s)$, it is easy to see that $f_{ns}(s) > f_s(s)$ $\forall$ s (it is always more profitable to be a non signatory). In addition, the paper establishes another important result: $x_{ns} < x_{nc}$. This inequality corresponds to the complementarity hypothesis that characterizes the model (besides the non cooperating behavior adopted by n-s countries ($x_{ns} > x_s$) the coalition formation led them to reduce their emission level ($x_{nc} > x_{ns}$)).

The different mechanism that sustains the IEA, alters the behavior of the countries-players and as a result changes the participation level as well. Using again the D' Aspremont conditions there exists a unique stable IEA whose size only depends on *n* and γ:

(i) For any γ and *n* = 2, both countries are always better off in cooperating;
(ii) For n ≥ 3, if $\gamma^2 \to n$ (the most favourable condition), the stable coalition *s** gets together between 50% and 75% of the countries concerned with the environmental problem; the larger is *n*, the most s* tends toward 50% of the countries.
(iii) For n ≥ 3, if $\gamma^2 \to 4n$ (the perception of damages is very strong with respect to the perception of benefits), the stable coalition brings together only two or three countries.

With respect to the results presented above the larger the environmental awareness ($\gamma^2 \to 4n$) the smaller the participation. Unfortunately the detailed examination of the D' Aspremont conditions, apart from the unique and stable IEA presented above, gives an awkward result:

$$L(s) = f_s(s) - f_{ns}(s-1) \Rightarrow L(s) = \frac{bN^{\frac{1}{2}}(1-s\gamma^2)}{\left(s^2(\gamma^2 - N + s) - s\right)^{\frac{1}{2}}} - \frac{bN^{\frac{1}{2}}(s-1)^{\frac{1}{2}}(1-\gamma^2)}{\left((s-1)(\gamma^2 - N + s - 1) - 1\right)^{\frac{1}{2}}}$$

It is obvious that in the pure non cooperative case (s=1) the denominator equals to zero and L(s) is not defined. This detail weakens the model and makes its results useless.

If we ignore this technical problem of the model all our attention is attracted by the result that presents a negative relation between environmental awareness and the number of signatory countries. This proposition apart from seeming puzzling, it is also exactly opposite to the results presented by the literature (Barrett, Diamantoudi & Sartzetakis etc). Burger & Kolstad (2010) using experimental evidence prove it right. The most interesting part is that they ignore totally the research made by M. Heugues, a detail that shows clearly that in spite of the technical drawbacks of her model the research into strategic complementarity is very promising.

The model that they use is even simpler than the ones presented above. Each country either abates $(q_i = 0)$ or pollutes $(q_i = 1)$. $\Pi_i = q_i - \gamma Q$, where $Q = \Sigma_i q_i$ and $0 < \gamma < 1$, where γ is the ratio of the marginal damage from a unit of pollution to the marginal cost of abating a unit of pollution. $\left(\gamma_{Barrett} = \gamma_{Burger\&Kolstad} = \frac{1}{n\gamma_{Sartzetakis\&Diamantoudi}}\right)$. The simplicity of the model allows us to observe the standard literature result: Coalition size decreases as MPCR (Marginal per capita return to abatement or equally: $\gamma_{Barrett}$) increases. The experimental format used by the authors helps them to test this theoretical prediction (details are available in the actual paper). Firstly they pay attention to a standard noncooperative game with no possibility of coalition formation and secondly they examine the same game except with coalition formation available. In this model if a majority votes to cooperate the coalition’s entire endowment becomes public investment (abatement). On the contrary, if a minority votes to cooperate every player acts unilaterally (private investment = no abatement). It is very important to highlight the fact that according to theory when $\gamma_{Barrett}$=0.3 the coalition has four participants and when $\gamma_{Barrett}$ is doubled ($\gamma_{Barrett}$=0.6) the signatories reduce to two.

Surprisingly, the experiment gives exactly the opposite results agreeing this way with the M. Heugues proposition. Doubling $\gamma_{Barrett}$ from 0.3 to 0.6 increases coalition size by a statistically significant amount (statistical robustness is proved analytically by the authors). It is important to add that the authors admit their weakness to explain this difference between theoretic prediction and experimental evidence. Obviously, It would be very interesting to re-interpret the complementarity case using more suitable functional forms or generally a different point of view. The paper of Marrouch & Chaudhuri (2011) is trying to reinterpret the strategic complementarity hypothesis introducing adaptation.

According to the literature, the countries around the world are using two different economic tools to face the problems generated by climate change. On the one hand, countries try to act cooperatively formulating coalitions in order to reduce more effectively the damages caused by the aggregated emissions and on the other hand, they are undertaking adaptive measures. We consider again a model similar to the one presented by Diamantoudi & Sartzetakis with N countries and emission as choice variable. Each country's net benefits are given by $w(E, a_i)$ where:

$$w(E, a_i) \equiv B(e_i) - D(E, a_i) - C(a_i) = e_i\left(\alpha - b\frac{e_i}{2}\right) - (\omega E - \gamma a_i - \theta a_i E) - \frac{c}{2}a_i^2$$

Where $\alpha > 0, b > 0, c > 0, \omega > 0, \gamma \geq 0, \theta \geq 0$

e_i is the emission level, E are the aggregated emissions and the adaptation level undertaken by country i is given by a_i. θ is the degree to which adaptation is able to reduce marginal damage from emissions (the different adaptive measures undertaken by regions i.e different theta differ significantly in their ability to reduce marginal damage from emissions) and γ is an index that shows how interactive adaptation measures can be.

As usual, in the pure (non) cooperative case, the countries simultaneously choose e_i and a_i maximizing the aggregated (unilateral) welfare:

$$e_c = \frac{n\theta\gamma + c(\alpha - n\omega)}{c\beta - n^2\theta^2}, \ a_c = \frac{\theta\gamma + n\theta(\alpha - n\omega)}{c\beta - n^2\theta^2}, e_{nc} = \frac{\gamma\theta + c(\alpha - \omega)}{c\beta - n\theta^2}, \ a_{nc} = \frac{\beta\gamma + n\theta(\alpha - \omega)}{c\beta - n\theta^2}$$

It is easy to observe that when the denominator of country i's best response function is positive $\left(c\beta > \theta^2\right)$ then the emission strategies of the countries are strategic complements $\left(\frac{\partial e_i}{\partial e_j} > 0\right)$[2]. This very interesting property was ignored by the existing literature because of the absence of the adaptation hypothesis (it is easy to see that for $\gamma = \theta = 0$ the model reduces to the one presented by Diamantoudi & Sartzetakis where $\frac{\partial e_i}{\partial e_j} < 0$). Similarly the authors derive the equilibrium values in the partially cooperative case denoted by e_s^*, a_s^*, e_{ns}^* and a_{ns}^* (each one of them is a function of the parameters s, θ, γ and ω). A very interesting question that comes up is the following: How different values of θ affect the stability function?

Case 1: No adaptation $\left(\gamma = \theta = 0\right)$

Exactly the case developed by Diamantoudi & Sartzetakis.

Case 2: Adaptation without interaction $(\theta = 0$ and $\gamma > 0)$

In this case we take into consideration that adaptation exists but it does not affect the emission levels. Apparently, the stable size of IEAs is no different from the one predicted in the literature (in fact the authors prove that for $\theta = 0$ and for all $\gamma \geq 0$, $s^* = 3$).

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[2] max W(E,a_i) gives $e_i = \frac{(\alpha\text{-}\omega)c+\theta\gamma+\theta^2 \sum_{j^1 i}^{n} e_j}{c\beta\text{-}\theta^2}$

Case 3: Adaptation with interaction $(\theta > 0$ and $\gamma > 0)$

In this scenario adaptation not only exists, but also interacts with the size of IEAs. More specifically the stable size of IEAs is positively related to θ. Furthermore it is proved that for $\theta > 0{,}1$ the equilibrium level of global welfare is also increasing in θ. Finally the authors show that for positive θ, it is possible to have large coalitions that reduce joint emissions relative to non cooperation. Up to now, literature ignored the first result and proved the other two wrong.

Is Strategic Complementarity able to help us solve the problem?

We have presented two models that deal with strategic complementarity. M. Heugues substitutes the convex cost function with a concave one, considering pure strategic complementarity. The paper, apart from having a serious technical problem, gives us a rather interesting conclusion: environmental awareness and $s_{optimal}$ are negatively related. This result is in contrast with every model in the literature that assumes strategic substitutability. On the other hand, the really puzzling result is the experimental evidence presented by Burger & Kolstad (another "strategic substitutability" model) that proves Heugues' proposition true.

The second paper we present (Marrouch & Chaudhuri) uses adaptation in order to make the model more flexible. The strategies according to Marrouch & Chaudhuri are mixed (depending on the parameters they are either complements or substitutes). This is the first model that presents this potential.

Compared to the mainstream literature both papers give optimistic results. According to M. Heugues s_{max}=75%N when environmental awareness is relatively small and on the other hand Marrouch & Chaudhuri prove that s_{max}=N when adaptation is interactive. It is easy to see that adding strategic complementarity hypothesis in the model is a very useful (and intuitively logical) amendment that develops the quality of the research that is related to coalition formation games bringing it closer to reality.

Asymmetries across countries and uncertainty are useful extensions that could make our models even more realistic. The following pages contain a brief literature review as far as these extensions are concerned.

4. Introducing Asymmetries

McGinty's paper (2007) is the first paper in the literature that presents an analytical solution of the coalition formation game assuming asymmetric players (countries) and we will use it as a benchmark. He uses Barrett's abatement model adding in the formula a new variable called benefit share (α_i >0). The benefit function is now a little different:

$$B_i(Q,\alpha_i)=b\alpha_i\left(aQ-\frac{Q^2}{2}\right)$$

The cost function is no different from the one used by Barrett. The new net benefit function is:

$\pi_i\left(\alpha_i,c_i,q_i,Q\right)=b\alpha_i\left(aQ-\frac{Q^2}{2}\right)-\frac{c_i\left(q_i\right)^2}{2}$. In order to develop the stability and profitability conditions of the coalition, the author introduces transfers among the signatories as a system of tradable pollution permits. Signatories sell their surplus $\left(q_s(k)-q_r(k)\right)$ receiving P(k) for every pollution permit that they sell. As it is expected, the equilibrium price is equal to the marginal abatement cost.

All the income from this procedure is distributed optimally only when none of the participants has economic motives to withdraw from the coalition. For example, the mechanism proposed by the paper refers to the distribution of the surplus in proportion to their benefit-cost ratio. Surprisingly, the results under the more realistic assumption of asymmetry are more encouraging by the time the signatories abatement effort is higher when nations are different.

McGinty follows Barrett (1997) using either the proportion of the difference between the no and full cooperation outcomes or the proportion of the global payoff difference, in order to measure IEA's performance. He uses these proportions both in the seven and in the twenty nation simulation showing that asymmetry reduces the non cooperative and increases the grand coalition levels of abatement.

K. Calvin (2010) on the other hand, in spite of introducing asymmetries, pays great attention to the fact that the main drawbacks of our research are the assumptions of the models and the definition of the abatement level. We consider N heterogeneous (asymmetric) players and, as usually, a two stage game (stage zero followed by stage one). In stage zero, each player chooses whether to become a signatory (m_i=1) or a non signatory (m_i=0). Each country's decision is related to its cost and damage functions:

$$C_i(a_i) = \alpha_i a_i^2 , \ D_i(A) = \beta_i \left(\Gamma - \mathrm{A}\right)^2$$

Where a_i is the level of abatement of player i , Γ is the status quo global emission level, A is the global abatement level and α_i , β_i are constant parameters specific to player i. All this procedure takes place under complete and perfect information.

Using backward induction we begin from stage one. Each candidate country compares the cost of joining the coalition to the cost of free riding:

$$\alpha_\mathrm{N} \overline{a}_N^2 + \beta_\mathrm{N} \left(\Gamma - \sum_{i \in M_{N-1}} \overline{a_i} - \overline{a}_N \right)^2 \le \beta_\mathrm{N} \left(\Gamma - \sum_{i \in M_{N-1}} \overline{a_i} \right)^2$$

and becomes a signatory iif

$$\overline{a}_N \le \frac{2\beta_\mathrm{N} \left(\Gamma - \sum_{i \in M_{N-1}} \overline{a_i} \right)}{\beta_\mathrm{N} + \alpha_\mathrm{N}}$$

The inequalities above refer to player N. The expressions for the rest N-1 players are similar. We similarly continue to stage zero maximizing the participation rate. Finally we solve a system NxN computing the abatement effort for each one of the N players. It is interesting to add that “...In a numerical implementation of the model, we find that the United States’ Kyoto specified abatement level exceeds its maximum acceptable amount. Thus, the US’ decision not to ratify Kyoto is not surprising...”.

Contrary to McGinty and Calvin, Peters & Schuler (2007) present a different asymmetry model. Instead of assuming N different countries the authors divide them into two groups: low and high marginal abatement cost countries: c for the n countries that have low marginal abatement costs and C=cd for the N countries that have high marginal abatement costs (d>1). Similarly, $p = \Lambda(1-0.5\Lambda) - ac$ is the net benefit function for the low cost countries and $P = \Lambda(1-0.5\Lambda) - AC$ is the net benefit function for the high cost countries. (Λ are the aggregated emissions, a is the low cost countries abatement effort and A the high cost countries abatement effort). The smaller feasible coalition has $s + S \geq 2$ where s (n-s) are the low cost coalitioners (singletons) and S (N-S) are the high cost coalitioners (singletons). In the beginning the authors prove that coalitions with high cost participants only, are unstable $\left(s^* = 0, S^* \geq 2\right)$. On the contrary, if $c \geq 0.8$ there always exists a unique, stable, pure low cost coalition $\left(s^* \geq 2, S^* = 0\right)$. In fact, the pure low cost coalition is equivalent to the coalition formation presented by the literature under homogeneity. Finally it is proved that in order to form a mixed coalition the cooperation of all the low cost countries is a prerequisite. "...Intuitively speaking, whether an IEA with both types is stable or not, depends on the number of low cost countries n and on the difference in marginal abatement cost d...".

Is the introduction of asymmetric countries able to help us solve the problem?

We have presented three models that deal with asymmetric countries. Two of them (McGinty and Calvin), assume that each country behaves differently from the others, whereas Peters & Schuler deviate the countries into two groups (high cost and low cost countries). McGinty introduces this difference in each country's benefit function, using a new variable (benefit share). Furthermore, he considers a pollution permits market whose gains are used by the countries in order to develop the stability conditions that define s. Contrary to the mainstream literature, Calvin describes a framework in which the cost of abatement is independent of the coalition membership. In fact, the choice of a country (sign or not the coalition) is only related to its costs and damages from entering the coalition or not. Finally, Peters & Schuler show that the stability and the profitability of a coalition are related to the nature of its signatories (a coalition without the "low cost" countries cannot be stable).

McGinty proves that asymmetry firstly, reduces the non cooperative and increases the grand coalition abatement efforts, even when the coalition's gains are large and secondly, increases the size of the coalition. Calvin on the other hand, refers only to its size: grand coalition is a feasible scenario. Finally, Peters & Schuler show that the coalition size is negatively related to n (the number of the low cost countries) and also that, the closer we are to the homogeneity hypothesis the greater is the coalition (this result is different from what McGinty observed but we should pay attention to the different frameworks developed by these papers).

It is clear that the asymmetry hypothesis brings these models closer to reality and surprisingly makes them more optimistic as they predict larger and more profitable coalitions.

5. Introducing Uncertainty

Apart from the very interesting Burger & Kolstad (2010) the two authors are presenting another model introducing uncertainty (Burger & Kolstad (2009)): "…there are two possible states of the world, high (H) and low (L), with probabilities π and (1-π), respectively. Let γ take on a value dependent on the state of the world: γ_H and γ_L, in expectation simply γ. We assume that the state of the world is revealed between the two stages of the game; thus, in the membership game, agents are unaware of the state of the world but in the contributions game they do know the state of the world…". Obviously there are, potentially, two coalition sizes. As a result, uncertainty can either increase or decrease the coalition size. It is useless to say that this is not a satisfactory scenario (low prediction ability). Additionally they are trying to check their theoretical results by using an experimental framework (it is described thoroughly in the actual paper). Firstly, they find (contrary to the literature(see Barrett)) that the coalition size and the return on the public good are positively related (this result is familiar from Burger & Kolstad (2010)). Secondly, they show that uncertainty has neither a positive nor a negative effect on the coalition size. In fact, their experiment shows that these two variables of the model are weakly related.

Instead of introducing uncertainty as nature's behaviour,Na & Shin (1998) assume that uncertainty is described better in an incomplete information context: the players are not initially informed about their marginal benefit of aggregate abatement. The uncertainty is resolved either before (ex ante) or after (ex post) the negotiations:

Ex ante negotiation:

In this case, country i is either a coalitioner or a non coalitioner. The authors, using the difference between the coalitioner's and the singleton's payoff prove that any country has a motive to join a coalition when the two other countries act as coalitioners (simplifying: N=3). The grand coalition (s*=3) is the only stable coalition structure.

Ex post negotiation:

The authors compare again the payoffs of the coalitioners and the singletons and prove that the grand coalition is never a stable outcome (under circumstances a coalition with two members exists and is stable but the grand coalition is never beneficial). It is easy to understand that when the differences between the three countries are small (unresolved uncertainty) and as a result they share similar characteristics, it is easier for them to form coalitions (someone could say that the intuition adopted by the authors here, has many similarities to the one presented by Arrow in his theorem).

According to them, coalitions are more likely to form between similar countries, and the sooner they are signed the stronger they get. An interesting alternative to the Na & Shin paper is the Finus & Pintasilgo (2010) analysis. The basic difference between the two models is the introduction of a third learning scenario. Apart from full and no learning scenarios the authors examine the partial learning case. The membership decision is based again on expected payoffs though, these payoffs differ from those under full uncertainty, given that more information is available. All three scenarios differ with respect to the first stage of the game. Under the full learning scenario each country's decision is based on known payoffs. On the other hand, according to the partial learning scenario each country's decision is based on realized parameter values and finally the no learning scenario is based on the expected parameter values.

In addition to the three learning choices, the authors are examining five different cases of uncertainty: uncertain distribution of benefits with or without transfers, uncertain level of benefits, uncertain distribution of costs, and uncertain level of costs. They confirm that in spite the fact that more information is useful for individual agents this could be untrue in the coalition case (many agents acting as one). If the candidate coalitioners learn that the gains from cooperation are going to be asymmetrically distributed this knowledge weakens the coalition. Secondly this research pays attention to the fact that apart from efficiency and cost effectiveness, strategic and distributional issues are equally important. Finally it is demonstrated that if diversity is accompanied by an appropriate transfer mechanism the enlargement of the coalition is favoured.

Jointly to the Burger & Kolstad and Na & Shin models, Breton & Sbragia (2010) are examining the case when the countries are not fully informed in the environmental damage caused by their production and consumption activities but they are trying to increase their knowledge using a Bayesian learning process. The revenue function is the familiar $R(q_{it})$. On the contrary, the authors examine three different damage functions:

1. $D(P_t) = dP_t + \rho\varepsilon_t$
2. $D(P_t) = \left(d + \rho\varepsilon_t\right) P_t$
3. $D(P_t) = d\left(P_t\right)^2 + \rho\varepsilon_t$

Where d (the uncertainty factor) is an environment damage parameter and ε_t is a random variable $\left(\varepsilon_t \in (0,1)\right)$.

<u>The endogenous learning process:</u>

Countries do not know the exact d so they estimate it. More specifically: $d \in \left\{d_H, d_L\right\}$ and π is the probability that $d = d_H$ and 1-π that d is worth d_L. Additionally we assume that an active learning process takes place: countries observe the global environmental damage and the pollution stock, updating their benefits for the next period (the author calculates the updating rule for the three different damage functions).

The first phenomenon investigated by her is the impact of uncertainty on the environment. According to the numerical illustration: “...Uncertainty can be environmental worsening, or environmental enhancing, depending on the pollution stock, on the common belief, and on the true value of the environmental damage parameter...”(this is exactly what Burger & Kolstad(2009) prove). The second question refers to the convenience in terms of emissions and welfare, of adopting the Bayesian learning process. The simulations help us to understand that countries that follow a Bayesian learning process have different equilibrium emissions than if they were using a mixed strategy depending only on the level of the pollution stock observed.

Is the introduction of Uncertainty able to help us solve the problem?

We have presented four models that are dealing with the introduction of uncertainty in the model. These models have two goals. Firstly, they are trying to answer if uncertainty is affecting the size of the coalition and secondly, they are trying to point out differences in the behavior of the coalitions under an uncertain environment.

According to Burger & Kolstad uncertainty has some times a positive and some times a negative effect on the size of the coalition. None of these is really significant. They believe that this effect is small enough to ignore it. Na & Shin are exploiting a model with asymmetries and uncertainty and prove that coalitions with similar participants are more trusted (they agree with Peters & Schuler in spite the fact that they use different models). Similarly they show that an uncertain environment could be beneficial for every coalition. Breton & Sbragia use a dynamic model and develop it by adding more complicated learning procedures. The conclusions are similar to the ones presented by Burger & Kolstad. Finally we described the Finus & Pintasilgo model where we came across familiar results. More precisely, they present the positive effect of uncertainty confirming Na & Shin and reconsider McGinty’s results proving that a proper transfer mechanism in a diversified environment is very helpful for coalition’s success.

Concluding, the majority of the papers presented above proves that uncertainty affects positively the size of the coalition. This is a rather optimistic result by the time the literature gave very small coalitions. The enrichment of these models with more special characteristics (more complicated games, more than one coalitions etc) could make them even more realistic.

6. Conclusions

We have described the assumptions and the results of four important papers in the IEA formation literature. Carraro & Siniscalco present a model without specific functional forms which focuses on the coalition expansion policies and especially on the self-financed welfare transfers. It is encouraging to find that "…such schemes of partial commitment and transfers can even lead to cooperation by all countries…".Barrett uses an abatement effort model with specific benefit and damage functions and shows that a coalition with N participants is possible when the difference in net benefits between the non cooperative and full cooperative outcomes is very small. It is critical to add that, in comparison with Carraro & Siniscalco, Barrett does not use self-financed welfare transfers as a coalition formation mechanism.

Diamantoudi & Sartzetakis reexamine the coalition formation game using an emission level model. According to this, the coalition has never more than four participants. The really interesting part of the paper is the direct comparison between their emission level model and the abatement effort model used by Barrett. They present a detailed solution to show the equivalence between the two models when the correct assumptions are used. The full cooperative scenario without welfare transfers cannot be a solution.

Heugues presents as interesting alternative. According to the paper "…the results provided under the assumption of weak strategic complementarity between countries are more optimistic than those observed until now in the literature…". In fact, under circumstances, the participation rate is 75%. This model in spite of the very optimistic results that gives us, seems useless because the functional forms used in it are unable to describe the behavior of the model for s=1(pure non cooperative case). The second paper that introduces strategic complementarity (Marrouch & Chaudhuri) proves that s_{max}=N when adaptation is interactive and gives a clear signal that despite the technical weaknesses of Heugues' model we should reexamine it thoroughly.

Surprisingly the literature that is related to the introduction of asymmetric countries in the model (McGinty, Calvin, Peters & Schuler etc) gives equally optimistic results. In fact the complexity of these models is the characteristic that enables us to observe properties of the IEAs that we ignored. The last part of the literature we examined was related to uncertainty. It is obviously more realistic a model in which the decisions of the countries are not fully related to observable data but to expected behaviors. Similarly to asymmetry models, the uncertainty models despite being more complicated give optimistic results compared to the models that examine IEAs under certainty (coalitions are bigger and more beneficial).

Up to now literature is unable to explain satisfactorily the form of the coalition formation game. Following Diamantoudi & Sartzetakis the next step is to reexamine the game, relaxing some basic restrictive assumptions: e.g the usage of spatial topology is a dimension that could make the model more realistic (the smaller the distance between two countries, the bigger the interaction). An interesting scenario would be the consideration of more than two coalitions (the candidate participants will have a variety of options). Alternatively, we could use as starting point the asymmetry and uncertainty models and examine even more complicated games (more stages, more complicated transfer mechanisms, more complicated and different between countries learning procedures etc). Finally it would be beneficial to pay attention to the continuously growing literature that is related to the political lobbies and their potential effect in each country's behaviour. Undoubtedly the political force of a lobby (for or against a coalition) can make a great difference in the policy followed by a country.

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8. Appendix

Endogenous timing in pollution control: Stackelberg versus Cournot-Nash equilibria. Heugues, M (2011):

According to the author every paper in the IEA literature describes the coalition formation game either as a simultaneous or as a leader-follower game, where the type of the game is exogenously assumed. The question that M. Heugues is trying to answer is: what if the type of the game is endogenously determined?

The model presented here is a simple two stage-two players game. In the first stage, both countries decide simultaneously the date they want to play in the second stage: “Early” or “Late”, whereas in the second stage they choose their individual emission level maximizing, as usual, their net benefit function: ($f_1(x,y)=B_1(x)-D_1(x+y)$, $f_2(x,y)=B_2(x)-D_2(x+y)$) where x is country 1's emission level and y is country 2's emission level. There are two possible outcomes:

- if both countries choose the same date (Early-Early or Late-Late) then the game is played simultaneously.

- If not the game is played sequentially.

Each country’s behavior is defined by the second derivative of its damage function. D_i is either strictly convex ($f_i''<0$, strategic substitutes) or strictly concave ($f_i''>0$, strategic complements).

Heugues proves that when both countries have a strictly convex damage function then we have a Cournot-Nash equilibrium (more precisely, both countries are choosing “Early”). This happens firstly, because both countries are motivated to act as leaders and secondly, because both have a strong incentive not to be followers.

On the contrary, when both countries have a strictly concave damage function, if country i chooses to play “Early” then country j chooses to play “Late” (i, j $\in[1,2]$, $i \neq j$). Unfortunately, the model cannot endogenously explain who is the leader and who is the follower. We can easily answer this question when the countries behave differently (country i has a concave damage function and country j has a convex damage function). In this case, the country whose payoff function presents strategic substitutability is the leader and the country whose payoff function presents strategic complementarity is the follower.

Concluding, when countries' strategies are substitutes each country is motivated to lead and as a result we have a simultaneous game and the equilibrium is a Cournot-Nash. On the other hand, when the strategies are complements a second mover advantage can appear and as a result we have a leader-follower game with a Stackelberg equilibrium. It is very interesting to compare these results to the models adopted by the papers above e.g Barrett(1994) and Diamantoudi & Sartzetakis (2006) present a leader-follower game in a strategic substitutability framework, whereas Heugues (2009) presents a simultaneous game in a strategic complementarity framework. All these cases are in direct comparison with the results presented here.