Self-Enforcing Environmental Agreements: A Literature Survey on Non-Cooperative Games

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September 2014

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Table of Contents

Abstract

The purpose of this study is to present the main theoretical contributions in the emergence of self-enforcing international environmental agreements. We consider models that use as a policy instrument emission level or abatement efforts. We start our analysis with the simple static case assuming identical countries. As we relax our assumptions and we consider asymmetric countries and time dimension larger stable coalition closer to Pareto optimal state consists an equilibrium. We also investigate policies that assist in the enhancement of coalition such as transfers trade sanctions and issue linkage. The results are dubious and the usefulness of these policies depend on the assumptions of each model.

1. Introduction

Environmental pollution is considered a negative externality, a public good with negative sign, a ‘’public bad’’ as mentioned in the economic literature. The assumptions of the pollution in models is non-rivalry in consumption and non-excludable.

Traditional welfare economic approach assumes a central authority that enforces the appropriate environmental policies. These policies enforce domestic firms to internalize their proportion of damage that commit to the ambient environment. From the aspect of transboundary environmental problems the pollutants are countries. However, countries cannot be enforced to cooperate in the same way due to their sovereignty (Endres 2004, Finus 2000).

Since each country is free to enter an agreement and leave anytime the most appropriate methodology to address this issue is through game theoretic models. Welfare optimality is achieved if all countries cooperate in managing shared-environmental resources like the climate and ozone layer. In order to sustain full cooperation they have incentives to develop institutions to perform this task. These institutions do exist taking the form of International Environmental Agreements (IEAs). IEAs have to be self-enforcing in the sense that the terms of the agreement have to be such that will motivate countries to cooperate.

Countries that serve joint interest by tuning abatement efforts with purpose to contribute to the increase of global environmental quality, play cooperation. On the other hand, those that enjoy the benefits of the abatement efforts of others holding their emission levels in line with their individual interests –they free-ride on the others or they play defection.

The basic framework is Static prisoner’s dilemma, a one-shot game that the players are identical and know with certainty the payoffs at each strategic combination. The non-cooperative Nash equilibrium of this game is defection by all countries. Under this scenario, welfare and environmental quality are suboptimal.

If we account for asymmetric countries, time dimension and risky payoffs, then the equilibrium under certain circumstances can achieve the grand coalition.

In the dynamic version, we assume infinite planning horizon and low discount rate. The rest of the assumptions remain the same with the static case. The equilibrium of this game is cooperation since the individual benefits of this strategy yield higher benefits than defection. For sufficiently low discount rate if one party defects, though it gain more than cooperation payoff for one round, the other party punish the deviator by playing defection all the rounds after the incident. The punishment strategy is called trigger strategy and as Folk Theorem suggests, for sufficiently low discount rate guarantees the outcome of cooperation. However, for this result to be robust it is necessary that the agreement is renegotiation proof. An agreement that is not renegotiation proof makes the trigger strategy an irrational choice for the punisher since it is still in its best interest to cooperate with the party that defects.

In the traditional prisoner's dilemma, if we assume risky payoffs, depending on the risk attitude of the countries, a variety of results emerge. If we assume risk-neutral states then nothing changes compares to the initial model. However, if we assume that countries have risk-averse behavior and their purpose is to maximize a risk welfare function with elements of mean and standard deviation then the equilibrium changes. We assume that as the degree of cooperation increases so does the certainty. In this case, risk aversion makes cooperation preferable to defection.

A sustainable cooperation apart from profitable needs also to be stable. Profitability condition is satisfied if a country benefits more within an agreement than free-riding. Stability exists in an agreements when no member has incentive to defect (internal stability) and a non-member no incentive to enter the coalition (external stability). Internal stability can be achieved through re-optimization, expanded tit-for-tat strategy and ratification. External stability is feasible through transfers, issue linkage and sanctions.

Finally the main choice instruments on emission reduction are tax rate and quotas. Though, within a national framework the former is more efficient, in international economics the effectiveness of each instruments depends on the structure of the agreement and the assumptions that have been made.

In section 2 we present the main environmental issues and international agreements. In section 3 we define free-riding incentives. In section 4 we study the emergence of coalition in a non-cooperative environment. In section 5 and 6 we present the significance of cost-sharing and issue linkage with trade sanctions respectively in the stability and expansion of coalition.

2. International Environmental Problems and Agreements

2.1 International Environmental Problems

This subsection briefly presents the main environmental problems that call for international coordination and considered either causes or effects of climate change. A common characteristic of these issues is that their nature is transboundary or even global. Framework Convention on Climate Change defines climate change as the change which is attributed directly or indirectly to human activity that alters the composition of the global atmosphere and which is in addition to natural climate variability observed over comparable time periods. The major international environmental problems are Global warming, depletion of ozone layer, acid rain and biodiversity loss.

The main issue linked with climate change is the issue of global warming or greenhouse gases effect. Greenhouse gases (GHGs), which are carbon dioxide (CO_2), methane (CH_4) nitrous oxide (N_2O) and water vapor, are in the atmosphere and play significant role in the existence of life. GHGs allow sunlight to enter and prevent heat from leaving the atmosphere. Through this mechanism greenhouse effect, which is a natural phenomenon, regulate the temperature of the Earth near the surface. Human activities such as burning fossil fuels, deforestation, raising of livestock and the decay of waste fills have increased the concentrations of these substances in the atmosphere. The result is permanent increase in the average temperature of the Earth that has led to the change of the climate.

Another major environmental issue is the depletion of ozone layer. Ozone layer lies in the stratosphere of the Earth, it is a shield that protect life from sun's ultraviolet (UV) rays. Substances like chlorofluorocarbons (CFCs) which are emitted by human activity transmit through the atmosphere to the stratosphere and deplete ozone allowing thus UV rays to attain the surface. Overexposure to UV radiation can cause skin cancer, cataracts and immune suppression.

The burning of fossil fuels and generally production process is responsible for another transboundary environmental issue which is acid rain. Sulfur oxide (SO_2) and nitrogen oxide (NO) are transformed through chemical processes in the atmosphere and return on Earth's surface through wet depositions. The increased acidity of this type of rainfall is catastrophic for the soil and the water where it ends up.

Biodiversity refers to the number of the variety of species on Earth. Biodiversity loss is an issue attributed to human activity and climate change. Biodiversity loss is both a cause and effect of climate change. It contributes to climate change because the lack of variety of systems affects negatively the capability of Earth’s to absorb CO_2 emissions. Human intervention and more specifically deforestation, extensive agriculture and livestock growing have decreased the number of species. On the other hand, climate change threatens biodiversity. The capability of ecosystem to adapt to climate change depends on the variety of species. Due to biodiversity loss, climate change makes harder the survival of many species (Perring, 2010).

2.2 Major International Environmental Agreements

The first major step toward international coordination on environmental issues started with Montreal protocol, which was signed on 16 September 1987 and was put in force on 1 January 1989. The purpose of the agreement is to reduce the production and consumption of the ozone depleting substances (ODS). The initial agreement was signed by 46 countries. The protocol entails an adjustment provision that allows the parties to adopt new scientific information and exploit new technologies. Since its inception, the protocol has been amended four times with purpose to include more ODS and to create a financial mechanism which will induce developing countries to comply with the agreement. In 2009, universal participation was achieved making Montreal protocol the first multilateral agreement with global participation. The main achievement of the treaty is that the 98% of consumption of ODS has been phased out and by 2040 it is projected to phase out all ODSs. Scientists predict that between 2060 and 2075 the ozone layer over the Antarctic will revert to its pre 80’s level. Apart from ozone layer issue, the ODS involved in the agreement are also greenhouse gases (GHG) contributing thus to the resolution of the problem of climate change.

Kyoto protocol is the agreement mainly addressed to that issue attributed to 150 years of industrial activity. The agreement commit its parties to reduce the emissions of GHG. It was adopted in Kyoto, Japan on 11 December of 1997 and entered into force in February 2005. During the first commitment phase from 2008 to 2012, 37 industrialized countries and European Union committed on reducing their GHG emissions to an average of 5% below 1990 levels. The purpose of the first commitment was the reduction of emissions of the six main greenhouse gases (Carbon dioxide, Methane, Nitrous oxide, Hydrofluorocarbons, Perfluorocarbons and Sulphur hexafluoride). During the second phase from 2013 to 2020 it has been dealt to increase the reduction rate to 18%. Under the Protocol, countries must meet their targets through national measures.

However, the Protocol also offer three market based instruments. International Emission Permits represent a fraction of an allowed emission level. Each party depending on whether it want to emit more or less, buys and sells these permits in an organized market. Under the Clean Development mechanism, a signatory with restriction in its emission output has the option to invest in environmentally clean projects in developing world and gain in return higher CO_2 emission level in credit form. Under Joint Implementation, one signatory takes on an emission reduction project in another country and gets in exchange the respective Emission Reduction Units (ERU) where 1 ERU is equivalent to one ton CO_2 emission reduced. Kyoto Protocol has also established the necessary systems that monitor and support the trading of permits. Finally, under Kyoto protocol it has been created the adaptation fund. The main goal of the fund is to invest on technologies that protect the signatories from the adverse effects of climate change.

The Convention on Biological Diversity (CBD) entered into force on 29 December 1993. It has received 168 signatories and the main purpose is to promote the conservation of biological diversity, to assure the sustainable use of resources and secure the equitable sharing of the benefits arising out of the utilization of genetic resources. The implementation occurs through measures in national levels and thorough transfers in international level. The transfers have either monetary form or non-monetary such as technology diffusion.

3. Free-riding incentives and Game Theory

Free-riding arises from the fact that environmental protection is a benefit that enjoy all countries while the costs incurred to protect it root from the efforts of each country individually, a fact known as the “Tragedy of Commons”. The appropriate methodology to model this behavior of countries is through applications Game Theory. This section presents the main articles that involve this behavior in their models.

Xepapadeas (1997) models this behavior in a static prisoner’s dilemma. Assuming a world with two identical countries, each one has to decide between cooperation (C) and defection (D) in a one shot game. Matrix 1 depicts the payoffs, which represent the welfare, of both countries for each combination of their decisions.

Country 2

		D	C
Country 1	D	(0,0)	(5,-1)
	C	(-1,5)	(3,3)

Matrix 1 The suboptimal result of defection is the equilibrium of this game

Source: Cesar 1994

The Nash equilibrium of this game is defection for both countries. The specific equilibrium is suboptimal in the sense that both countries can increase the combined welfare by moving to cooperation. Cooperation is Pareto optimal equilibrium since no further increase in one’s welfare can be done without affecting negatively the welfare of the other agent. However, the latter is not a sustainable outcome since each time one country plays cooperation the other one will find it more profitable to defect.

If we consider a dynamic version of this game the outcome of the equilibrium changes. Assume an infinitely repeated game, then applying the folk theorem (Friedman 1989) one can show that cooperation is a sustainable outcome. Assume a sufficiently low discount rate, As long as country 1 cooperates country 2 cooperates as well. If one of the agents play defection in one round then the other country applies the trigger strategy which is defection for all the rounds that follow. Each player maximizes a present value payoff function

$PV_i = \sum_{t=0}^{\infty} a^t \pi_{it}.$

Using the entries of the example it can be shown that for a discount factor of 0.90 results in cooperation since this strategy yields an outcome of 30. On the other hand if one country defects in one round it will receive the outcome of 5 for one round and 0 therefore.

There are two cases that make cooperation unsustainable in this dynamic version of the game. The first case refers to a version of a game that in the state of cooperation one country gains and the other loses compared to the non-cooperative outcome despite the increase of the total welfare. In this case the country that loses will always plays defection. Matrix 2 depicts that case.

Country 2

		D	C
Country 1	D	(0,0)	(5,-3)
	C	(-1,2)	(4,-1)

Matrix 2 Country 2 will always play defection

Source: Cesar 1994

The second case refers to the lack of renegotiation-proof trigger strategies. It is against the interest of the punishing country to proceed to defection since that would incur losses to that country as well. Defector recognizes that the punisher is unable to commit to trigger strategy and the result is defection for the Nash equilibrium subgames.

Carraro and Siniscalco (1993) analyze profitability and stability assuming identical countries that bargain non-cooperatively. They also presume a minimum participation rate for the coalition formation. When the conditions of profitability and the concepts of internal and external stability, which are analyzed in detail in the following section, are satisfied then the coalition is stable. Under the condition of stability no defector finds it optimal to ratify the agreement and no signatory has incentive to free ride.

Furthermore, Carraro and Siniscalco (1993) observe that the behavioral pattern of free-riding depends on the slope of players' reaction function. The slope of the reaction function determines the degree to which free-riding spillovers affect the existence and the size of the coalition. Two extreme cases are observed in the relevant literature. The first case refers to orthogonal free-riding. When player's reaction function in the emission game are orthogonal then free-riders can only benefit from emission reduction attributed to coalition formation, whereas defectors cannot damage the coalition. When player's reaction function are non-orthogonal then there is carbon leakage that leads to decreasing returns of cooperation. As one may notice while orthogonal free-riding may lead to a stable coalition, the assumption of non-orthogonal free-riding yields the non-cooperative Nash equilibrium.

4. Coalition Formation

In this section we present the emergence of agreements in a non-cooperative environment using game theoretic models. A general principle in the study of bargaining process is depending on the instrument under scrutiny, to define the equilibrium abatement or emission level for the non-cooperative and the full-cooperative case. The next step is to suggest policies that will move countries from a non-cooperative suboptimal state to the Pareto optimal cooperative state.

4.1 A general model

The approach we present here is similar to Barrett (1991, 1992) Carraro and Siniscalco (1991, 1993) and Petrakis and Xepapadeas (1996). Consider a group of $i = 1 \dots n$ countries each one of them generating an emission level e_i to the ambient environment. The concentration of the pollutant described by damage function $D(e_i) = E = \sum_i e_i$ affects all countries. We assume that $D(0) = 0, D'(e_i) \geq 0$ *and* $D''(e_i) \geq 0$. Each one of them is affected by $m_i E$ where $m_i \geq 0$ is the marginal damage to each country i by environmental destruction. Adopting Hoel (1992) we assume that $m_1 \geq \cdots \geq m_n, M = \sum_i m_i \geq 0$. Countries with higher marginal damage suffer more by pollution while countries with $m_i = 0$ are not affected by the environmental destruction.

The benefit function of each country $B_i(e_i)$, $B_i(0) = 0$, increasing $B_i{}'(e_i) \geq 0$ and convex $B_i{}''(e_i) \leq 0$ in its argument. The welfare function is defined as:

$$W(e_i, e_{-i}) = B_i(e_i) - m_i E$$

Where , e_{-i} refers to the emission level of all countries apart from i.

The non-cooperative solution comes from the maximization of each country's welfare function.

$$max_{e_i} W(e_i, e_{-i}) = B_i(e_i) - m_i E$$

The first order conditions provide the Nash equilibrium level for each country.

$$e_i^{nc}: B_i{}'(e_i^{nc}) - m_i = 0$$

The next step is to calculate the emission level for the full cooperative case that corresponds to the Pareto optimal solution. This case refers to the maximization of the collective welfare of countries.

$$max_{(e_1 \ldots e_i) \geq 0} \sum_{i=1} W(e_i, e_{-i}) = \sum_{i=1}^{n} [B_i(e_i) - m_i E]$$

The first order conditions provide the first best emission level of each country.

$$e_i^c: B_i{}'(e_i^c) - M = 0$$

Let us assume that the benefit function is of the form:

$B_i(e_i) = b\left(ae_i - \frac{1}{2}e_i^2\right)$, where a and b are parameters. (4.1.1)

Then the first order conditions for the cooperative and the non-cooperative case yield the individual emission level $e_i^{nc} = a - m_i/b$ (4.1.2) and $e_i^c = a - nm_i/b$ (4.1.3) for each state respectively. The respective total emission level for the non-cooperative case would be $E^{nc} = na - nm_i/b$ and for the cooperative case $E^{nc} = na - n^2 m_i/b$ and n refers to the number of all countries. A comparison between the two states reveals that $e_i^c < e_i^{nc}$ and $E^c < E^{nc}$.

Hoel (1992) considers a two stage leadership-follower model in which coalition decides upon an emission level that corresponds to the median value of the signatories. Each participating country reduces its emission level by the same rate. Under the assumption of different marginal damage from the environmental pollution he finds that countries are better off in terms of welfare under the non-cooperative outcome. Hoel supports that when emission level decreases through a fixed rate for all countries participating in the coalition, pollution is in higher levels compared to individual optimization case. The reason is the lower participation rate in the agreement.

4.2 Profitability and Stability of Coalition

The purpose of an agreement is to make countries emit less compared to the non-cooperative case. Carraro and Siniscalco (1993) argue that an agreement is feasible only if the conditions of profitability and stability are satisfied.

Profitability is a necessary condition for the formation of a coalition. A coalition is profitable if all countries profit more under an agreement rather than being singletons. That is $W(e_i^c, e_{-i}^c) > W(e_i^{nc}, e_{-i}^{nc})$. Substituting (4.1.2) and (4.1.3) relations in the welfare function we get:

$$W(e_i^c, e_{-i}^c) = \frac{b}{2}\left[a^2 - \frac{n^2 m^2}{b^2}\right] - mn\left[a - \frac{nm}{b}\right] \quad (4.2.1)$$

And

$$W(e_i^{nc}, e_{-i}^{nc}) = \frac{b}{2}\left[a^2 - \frac{m^2}{b^2}\right] - mn\left[a - \frac{m}{b}\right] \quad (4.2.2)$$

From the relation $W(e_i^c, e_{-i}^c) > W(e_i^{nc}, e_{-i}^{nc})$ we get $W(e_i^c, e_{-i}^c) - W(e_i^{nc}, e_{-i}^{nc}) > 0$. Thus subtracting (4.2.1) from (4.2.2) we extract the condition of profitability:

$$W(e_i^c, e_{-i}^c) - W(e_i^{nc}, e_{-i}^{nc}) = \frac{m^2}{2b}[n-1]^2 > 0$$

That implies that a coalition is profitable if the number of its members is larger than 1. Another observation is that countries that suffer more, with higher marginal damage parameter gain more with participation, whilst countries that are not affected by environmental destruction, that is $m = 0$ are indifferent between cooperation or defection. Generally if:

$$m_i < \frac{B_i(e_i^c) - B_i(e_i^{nc})}{E^c - E^{nc}} \quad (4.2.3)$$

Then these countries have incentives to cooperate, while for countries that the reverse inequality holds are better off if they do not cooperate.

Let us identify as Environmentally Conscious Countries (ENCC) those that represented by inequality (4.2.3). On the other hand let us identify as Less Environmentally Conscious

Countries (LENCC) those that marginally suffer less from the pollutant and the opposite inequality of the relation (4.2.3) represents them. Furthermore, we index ENCC with $j \in J$ and LENCC with $k \ni K$. Both J and K subsets are partitions of $N = \{1 \ldots n\}$, that is $J \cup K = N,\ J \cap K = \emptyset$. Suppose that ENCC form a coalition emitting at the full-cooperative level and LENCC play individually emitting at the Nash-Equilibrium level.

Profitability is a necessary condition for the formation of coalition, however sufficiency requires an agreement to be stable. Stability of the coalition refers to the internal stability, which is the state at which no country within the coalition has incentive to defect and external stability that refers to a situation that no country off the coalition has incentive to enter. The concept of stability as defined here it was originally introduced by D' Aspermont et al.'s (1983).

Following Carraro and Siniscalco (1993), the coalition of ENCC is internally stable if there is no incentive to defect,:

$$W_j\left(e_j^c, e_{-j}^c, e_1^{nc}, \ldots, e_k^{nc}\right) > W_j\left(e_j^{fr}, e_{-j}^c, e_1^{nc}, \ldots, e_k^{nc}\right)$$

And externally stable if there is no incentive to broaden the coalition:

$$W_j\left(e_j^c, e_{-j}^c, e_1^{nc}, \ldots, e_k^{nc}\right) > W_j\left(e_{j+1}^c, e_{-j}^c, e_1^{nc}, \ldots, e_{k-1}^{nc}\right)$$

This applies to all the countries that belong to subset J.

Using this framework we investigate the internal stability concept by analyzing the free-riding incentives that emerge in the case of grand coalition. Assume that $e_i^{fr} = e_i^{nc}$ is the emission level of the free-rider, then the total emission level takes the form of $E^{fr} = e_i^{fr} + \sum_{j \neq i}^{J} e_j^c$, that refers to the total emission level under full cooperation minus one defector plus the emission level of one free rider. That is

$$e_i^{fr} = e_i^{nc} = a - m_i/b \quad (4.2.4)$$

$$\sum_{j \neq i}^{J} e_j^c = (n-1)[a - (n-1)\, m_i/b] \quad (4.2.5)$$

Making the necessary algebraic manipulations,

$$E^{fr} = na - [(n-1)^2 - 1]\frac{m_i}{b} \ (4.2.6)$$

Substituting this value to:

$$W^{fr}\left(e_i^{fr}, e_j^c\right) = \frac{b}{2}\left[a^2 - \frac{m_i^2}{b^2}\right] - m_i\left[na - \frac{m_i[(n-1)^2-1]}{b}\right] \ (4.2.7)$$

Free-riding incentives are eliminated as long as $W\left(e_i^c, e_j^c\right) - W^{fr}\left(e_i^{fr}, e_j^c\right) > 0$

From (4.2.4) and (4.2.7) relations and after the necessary manipulations

$$W(e_i^c, e_{-i}^c) - W^{fr}\left(e_i^{fr}, e_j^c\right) = \frac{m_i^2}{2b}[1-n][n-3] > 0 \ (2.11)$$

That is a country has incentives to free-ride when the number of coalition members $n > 3$

Diamantoudi and Sartzertakis (2006) and Barrett (1994) investigate the maximum number of countries that can form a stable coalition under these assumption.

Barrett (1994) develops a Stackelberg model where coalition members act as a leader maximizing their collective welfare, while non-signatory maximize their welfare individually disregarding the fact that their decision may affect other countries. The choice instrument applied in his game is abatement efforts. The mechanism of the model involves rewarding in the form of the increase of abatement efforts of the coalition when a country joins them and punishing in the form of the decrease of their efforts when a member defects. The punishments and the rewards are in line with the maximizing behavior of the coalition making them thus credible actions. A significant finding of his investigation confirmed also by Diamantoudi and Sartzetakis (2006) is that the size of the coalition depending on the functional specification is no more than two or three countries. Furthermore, Barrett (1994) finds that when the ratio between the abatement cost and the slope of the global benefit function is small, agreement is signed by many countries with little effect on global net benefit compared to non-cooperative outcome. On the other hand, when this ratio is large, few countries sign the treaty but the benefits are large compared to the Nash equilibrium. However, Barrett underlies that many international agreements like the framework of climate change contain a minimum number of members' clause. When both abatement cost and marginal benefit are large self-enforcing agreements is sustained by many countries and the benefits increase substantially compared to the non-cooperative outcome.

Diamantoudi and Sartzetakis (2006), consider a model in which non-signatories behave strategically in contrast with Carraro and Siniscalco (1993) and Barrett (1994) where individuals act as price takers. They consider as a choice instrument emission level and they investigate the concept of stability and the maximum number of signatories in a self-enforcing IEA.

In their model they consider a benefit function of the form (4.1.1) and a quadratic cost function of the form $D(E) = \frac{1}{2}c(E)^2$. Using the adjustment mechanism introduced by Barrett (1994) and the concept of stability they derive the number of countries participating in the self-enforcing IEA. They confirm the finding of Barrett (1994) that for small ratio of damage to benefit the number of signatories ranges from 2 to 4. A significant find of their analysis is that the strategic behavior of the non-signatories alters the relationship between the welfare and the number of coalition members. As the coalition grows in size, the welfare of the members' decreases. At the number of the countries in which coalition stabilizes their welfare is close to the minimum value of the specific function.

4.3 Further specifications of static model

Diamantoudi and Sartzetakis (2002) consider a leadership model with symmetric countries focusing on the structure of the coalition in equilibrium and disregarding the process with which the coalition was formed. They study the stability of coalition when countries are non-myopic, that is countries take into account the fact that if they defect so will do the other signatories collapsing thus the coalition. The main difference with similar studies (Carraro and Siniscalco 1993, Barrett 1994) is that the country that contemplates to defect does not consider only the gain from potential abatement reduction but also the loss in welfare from the collapse of the agreement that its behavior will yield. That is, a non-myopic country considers all the sequence of the events that will occur once it defects. In this framework Diamantoudi and Sartzetakis (2002) define the concepts of farsighted internal and external stability. No country has incentive to defect if the sequence of events that will follow will have as a result lower welfare level for that country. In the context of external stability, no singleton has incentive to join a coalition if the sequence of the events that will follow will yield lower welfare level than its current state. As Figure 1 depicts there exist a coalition of size s* in which $W(s-1) \leq W(s^*) \leq W(S+1)$ making it thus internally and externally stable. In a similar manner Diamantoudi and Sartzetakis investigate the case in which countries decide to cooperate or defect in groups achieving thus either the grand coalition or the non-cooperative outcome.

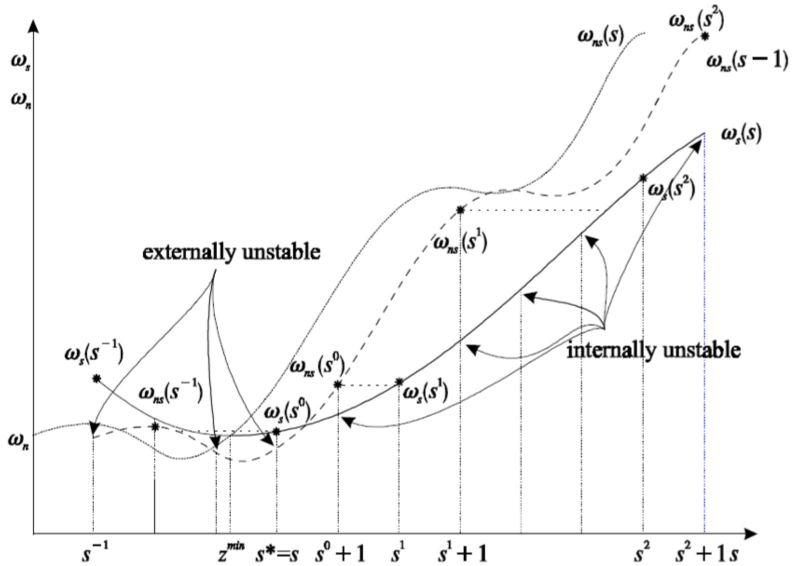

Figure 1
Source: Diamantoudi and Sartzetakis 2002

Their analysis conclude that when the actions of the countries are coordinated grand coalition is more certain case compared to the case that countries act individually.

Carraro (1998) examines the case in which more than one agreements can emerge in a non-cooperative environment of symmetric players. He finds that under orthogonal free-riding multiple agreements yield higher welfare compared to the single agreement case.

Under non-orthogonal free-riding and the possibility of single agreement the non-cooperative Nash equilibrium is the only outcome. For the case of multiple agreements free-riding externality generate two effects. On the one hand, leakage generates free-riding incentives to small coalition members disturbing the stability of these agreements. On the other hand when coalitions are large free-riding externalities generate increasing returns to coalition size and decreasing returns to free-riders reinforcing thus large coalitions. The result is two equilibria, one with large in size coalition and one with many small coalitions or singletons.

Most studies that investigate coalition formation in the context of International Environmental Agreements assume a minimum participation clause for the agreement to be formed. Carraro et al. (2009) endogenize the decision regarding the minimum participation rate for an agreement to be formed. They employ a three-stage coalition formation in which at the first stage countries decide on the size of the clause, at the second stage countries decide whether to cooperate or not and in the last stage they define the emission level based on a leadership model where signatories maximize their collective welfare and defectors play individually. They find that if the profitability condition is satisfied, players select a minimum clause of many members compared to the total amount of countries facing though higher free-riding incentives due to the small number of defectors in the last stage. These two contradicting arguments may result to the collapse of a coalition deal. They conclude that the size of the minimum participation clause that offsets the free-riding incentives depends on the concavity of the benefit function or equivalently the change of the collective benefit as the size of the cooperating countries increases.

Barrett (2000) investigates the coalition formation under the assumption that countries are asymmetric. Asymmetry roots from the differences in the abatement efforts of each country and the differences in the evaluation of environmental quality. He assumes two type of countries, type 1 which is the rich countries and type 2 which is the pour countries. Abatement efforts of rich countries are more effective than the respective efforts of poor countries, that is $b_2 > b_1$ where b_i is the marginal abatement efforts of country i. He also assumes that rich countries benefit more by higher environmental quality than poor countries, that is $a_2 > a_1$, where a_i refers to marginal benefit of each type of country.

If N is the number of all countries refer to $N_1 \ni N$ the number of poor countries and $N_2 \ni N$ the number of rich countries. Let us also assume that Z is the total amount of countries that abate with $z_1 \cup z_2$ being subsets of Z referring to the amount of each type of countries that abate. The payoff function of either type of country $i = 1,2$ if is not engaged in any abatement efforts is:

$$\Pi_i^p = a_i(b_1 z_1 + b_2 z_2)$$

Whereas if it abates the payoff function of country i is:

$$\Pi_i^A = -c + a_i(b_1 z_1 + b_2 z_2)$$

Where c refers to the abatement cost of the country type i engaged in abatement efforts

We normalize environmental benefit $a_2 = 1, a_1 \in [0,1]$. We assume also that $c>b_2$ and total payoff of all countries is increasing in z_1, z_2 , that is $a_1 N_1 + N_2 > c/b_1$.

Under these conditions the non-cooperative Nash equilibrium is pollution by all countries even if they know that they would be better off if everyone was playing abate.

The two-stage game entail the decision of whether a country will be a signatory or not in the first stage and whether they will abate or pollute in the second stage. Solving backward, Depending on the parameter values, which determine the degree of asymmetry, Barrett (2000) obtain that there may exist a self-enforcing agreement consisting of a subset of type 1 or type 2 countries or a combination of these two types. The latter result is feasible only under weak asymmetry and it is the only case in which if one signatory defects then everyone plays pollute. In the other two cases where IEA contains a subset of countries of the same type, incremental accession or defection does not affect the behavior of other countries. Though under asymmetric countries there exist multiple equilibria, under strong asymmetry the only feasible outcome is cooperation among a subset of countries of type 2, whereas the countries of type 1 are completely sidelined.

4.4 Dynamic models

Until now we have assumed identical and asymmetric countries in a static framework and environmental destruction of flow type. We also considered models that assume non-myopic agents. We proceed our analysis by presenting studies that consider for time horizon with pollutant of stock type.

The social welfare function for each country $i = 1 \dots n$ is

$$W_{it} = \int_0^\infty e^{-rt}[B_i(e_{it}) - D_i(E_t)]dt \quad (4.4.1)$$

Where r is the discount factor and t is for time. Accumulation of the stock pollutant is described by the differential equation:

$$\dot{E}_t = \sum_{i=1}^{n} e_{it} - \delta E_t \quad (4.4.2)$$

Maximizing 2.12 subject to 2.13 constraint we obtain the differential equations that lead us to steady state emission level. Where δ describes the absorption rate of the pollutant by "Mother Nature".

The current value Hamiltonian for the cooperative case is defined as

$$H = \sum_{i=1}^{n}[B_i(e_{it}) - D_i(E_t)] + \lambda_t\left[\sum_{i=1}^{n} e_{it} - \delta E_t\right] \quad (4.4.3)$$

λ_t refers to the cooperative valuation of global pollutant. According to the maximum principle and assuming that $e_{it} \geq 0$, the sufficient and necessary conditions are

$$B_i{}'(e_{it}) = \lambda_t \quad (4.4.4)$$

$$\dot{\lambda}_t = (r + b)\lambda + \sum_{i=1}^{n} D_i(E_t) \quad (4.4.5)$$

$$\dot{E}_t = \sum_{i=1}^{n} e_{it} - \delta E_t \quad (4.4.6)$$

And the transversality condition:

$$\lim_{t\to\infty} \exp(-rt)\lambda_{it}e_{it} = 0 \quad (4.4.7)$$

Solving 4.4.4 for e_{it} we obtain the cooperative emission level as a function of the shadow cost λ.

$$e_{it}^* = e_{it}^*(\lambda_t) \quad (4.4.8)$$

For the cooperative case, The modified Hamiltonian differentiation system that determines the evolution of the global pollutant and its shadow cost λ is obtained by substituting 4.4.8 to the equations 4.4.5,4.4.6 and 4.4.7.

For the non-cooperative outcome to distinct cases are observed in the literature. Open loop strategies involve the maximization for each country its individual welfare considering the initial stock of global pollutant, that is:

$$e_{it} = f_{it}(E_0)$$

For the case of Feedback strategies, each country uses Markov strategies and the emissions are a function of the current stock of global pollution. Assuming linear Markov strategies the expression of emission is of the form

$$e_{it} = f_{it}(E_0) = e_i - \delta E_t$$

Substituting each emission function in each country's individual Hamiltonian equation we obtain the current value Hamiltonian for each case.

The solution to each case can show that the global emission output is higher in open loop strategies compared to feedback Nash equilibrium and that the emission level in the latter case is higher compared to the case that open loop strategies are considered.

As in the static case, dynamic models are modeled in two stages. In the first stage countries decide whether to join or not in a coalition and in the second stage they define their infinite horizon emission output (Rubio Casino 2005). Dynamic models are solved through a differential equations infinite horizon game in either open loop or feedback strategies. Signatories maximize their collective welfare whereas defectors maximize their welfare individually. Rubio and Ulph (2007) consider a dynamic differential equations game where at each stage countries negotiate not only the emission output level but also the membership. As a result, the number of signatories varies with the stock of pollutants. As in the static case, the authors find an inverse relation between the size of the stable coalition and the welfare of the signatories.

Similar to the static case, the concepts of internal and external stability are taken under consideration and are related to the concept of renegotiation-proof that must characterize a committed trigger strategy in a repeated framework.

Breton et al (2010) assume a set of identical countries competing over the optimal emission level in a Leadership dynamic framework. In the first stage countries negotiate membership but they are free to leave or join the coalition in the following stages.Their main finding is that depending on the amount of the initial stock of pollutant coalition is not always a feasible outcome. For low levels of initial stock of pollutant equilibrium varies from defection by all countries to partial participation to an agreement. Furthermore they find that the participation rate increases the more sophisticated the agents are assumed. In that case agents are not characterized by bounded rationality but they consider the evolution of the stock pollutant as a result of their actions. Finally, as in the static case, they confirm the negative relation between the number of signatories and their welfare in IEA. Bahn et al (2009) extend the model of Breton (2010) for asymmetrical countries. They calibrate their model using parameters from the MERGE model, which divides the world into 9 subgroups of countries. As in the static case they find that countries that incur little environmental damage have more incentives to defect compared to these countries that suffer more by environmental destruction.

5. Cost-sharing.

As we analyzed in the previous section a coalition is formed either by a group of countries which find welfare improving to cooperate to face an environmental problem or through a two stage game in which in the first stage countries decide whether they will join the agreement. In most cases, emerges an equilibrium that consists of a stable IEA and a number of free-riding countries. Signatories find it welfare improving to offer incentives to defectors to join the agreement through transfers. However, these transfers cannot be higher than the gains that will emerge from the expansion of the coalition to the existing members. Cost sharing refers to the allocation of gains from cooperation in a Pareto improving way. The asymmetry with which benefits and costs are allocated among countries make necessary a cost-sharing rule of transfers.

The amendment of Montreal protocol in 1990 involved transfers from developed to developing countries with purpose to motivate the latter group to join the agreement. This resulted to a significant increase of the participants that ratified the agreement. The establishment of Kyoto Protocol and the United Nations Framework Convention on Climate Change have considered for such allocative mechanism, the Global Environment Facility (GEF). Since 1991 GEF has distributed 12.5 billion which have been invested in 3690 projects for 165 developing countries. This section reviews some of the most significant studies that investigate the role of transfers in the formation of self-enforced environmental agreements.

Carraro and Siniscalco (1993) find that in the context of two-stage game with symmetric countries if signatories of the agreement are able to commit to the agreement then transfers are able to induce free-riders to join the agreement and increase total welfare

Following Chander and Tulkens (1995) the objective function if each country in terms of emission abatement and environmental damage is defined as

$$J_i(e_i e_{-i}) = c_i(e_i) - D_i(E), \qquad E = \sum_{i=1}^{n} e_i \ (5.1)$$

We define as $c_i(e_i)$ the abatement cost function with ${c_i}'(e_i) < 0$ and ${c_i}''(e_i) > 0$ and $D_i(E)$ is the environmental destruction. As in the case of coalition formation we obtain the equilibrium emission level for the non-cooperative and the cooperative. The next step is to define a system of transfers that lead from non-cooperative equilibrium to cooperative Pareto efficient outcome.

For the non-cooperative case, each country minimizes the 5.1 objective function individually

$$min_{e_i} J_i(e_i e_{-i})$$

The first order conditions yield the individual emission level $e_i^{nc}: {c_i}'(e_i) + {D_i}'(E) = 0$

For the cooperative case countries minimize the cost function collectively in the form of:

$$min_{(e_1 \dots e_i)} \sum_{i=1}^{n} J_i(e_i e_{-i})$$

The first order conditions yield the cooperative emission level

$$e_i^c : c_i{}'(e_i) + \sum_{i=1}^{n} D_i{}'(E) = 0$$

As it is for the case in terms of welfare function $e_i^c < e_i^{nc}$

The value function in the latter case is given by substituting the optimal emission level to the objective function, that is:

$$V(n) = \sum_{i=1}^{n} J_i(e_i^c, e_{-i}^c)$$

Chander and Tulkens (1995) assume transfers in the form of side payments, P with purpose to induce free-riders to join the coalition. The sum of all transfers $\sum_{i=1}^{n} P_i = 0$ so that nothing changes in the total welfare after considering this measure. Each country pays a transfer y_i such that $\sum_{i=1}^{n} y_i = V(n)$ and $y_i = J_i(e_i^c, e_{-i}^c) + P_i$. The authors define the size of the payment for each country as:

$$P_i = -[c_i(e_i^c) - c_i(e_i^{nc})] + \frac{D'_i}{D'}\left[\sum_{i=1}^{n} c_i(e_i^c) - \sum_{i=1}^{n} c_i(e_i^{nc})\right] \text{ (5.2)}$$

D'_i is the marginal damage that incurs to country i and $D' = \sum_{i=1}^{n} D'_i$ is the marginal environmental destruction incurred to all countries.

Relation 3.2 determines the allocation mechanism and is consisted of two terms. The first one involves a payment that receives a country to cover the increased abatement cost compared to the non-cooperative state. The second term involves an expense for each country which is proportional to the ratio of its individual environmental damage to the total environmental destruction. If for one country $D'_i=0$, it is not affected by environmental destruction and it receives a transfer to increase its abatement costs (the second term is zero). This relationship is based on the victim’s pay principle, the more a country suffers from environmental destruction the more it has to pay compared to other countries. The model of Chander and Tulkens (1995), though it offers an effective allocation mechanism it yields the unrealistic result that if one country defects then every country in the IEA defects as well. Barrett (2000) attributes the unrealistic finding of Chander and Tulkens (1995) to their assumption that countries are identical.

Barrett (2000) extends the asymmetric model, we presented in the previous section for the case that transfer payments are allowed. As we've already mentioned under strong asymmetry, in the equilibrium a subset of rich countries form a coalition and abate while poor countries are sidelined. If we allow for transfers, under the assumption of strong asymmetry[1], we get Pareto improvement compared to the state without transfers.

Using the notation presented in the previous section the payment to countries of type 1 (poor) is of the form:

$$P^* = c - a_1 b_1$$

Rich countries refurbish each poor country for the abatement cost it bears, reduced by the efficiency it abates and the degree of environmental quality it enjoys. Rich countries that are non-signatories have more incentives to join the coalition as the number of signatories' increases and the total abatement cost is shared by more countries. The main difference of Barrett (2000) with other studies[2] is the allegation that not the design of the transfer per se but the transfer as a tool of commitment under the assumption of asymmetry yields realistic results.

Hoel and Schneider (1997), investigate the incentives a country may have to join the coalition in a scheme with transfers compared to one without side-payments. When no transfers are considered, signatories punish the defectors by increasing the total emission output level. When transfers are considered, they find that the larger the number of signatories the higher the cost to be off the agreement. The major finding of this study confirmed also by their empirical example is that under a scheme without transfers, participation in the coalition is higher and aggregate emission level is lower, the larger the

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[1] b_2 is significantly larger than b_1

[2] Carraro and Siniscalco (1993), Chander and Tulkens (1995)

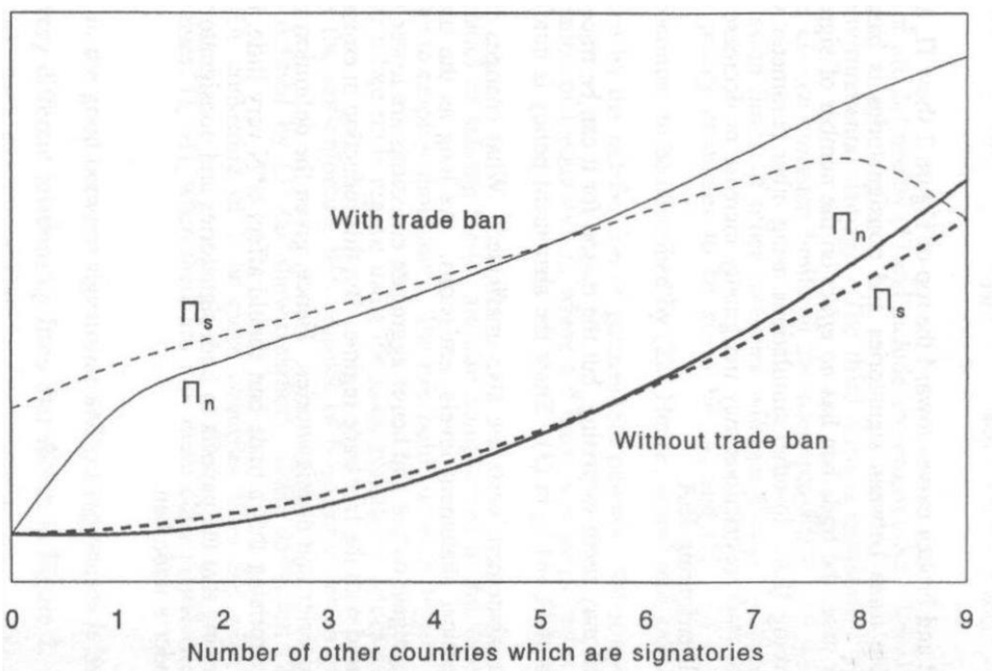
number of countries under scrutiny. They argue that the existence of payments deter countries from entering the coalition. As the number of countries in the analysis increases the wedge regarding the signatories in the two schemes increases too.

6. Issue Linkage and Trade Sanctions.

Issue linkage refers to the association of a trade or technological agreement with an environmental agreement. The purpose is to induce singletons to enter an environmental agreement and gain by entering into another agreement that gives them access to an excludable good. Carraro and Siniscalco (1995) consider issue linkage a measure capable of eliminating the asymmetries among countries and expanding the size of coalition.

Carraro and Siniscalco (1997) examine the linkage of an environmental agreement with an agreement on R&D. Assuming symmetric players they find that the size of the equilibrium is smaller than the stable self-enforcing agreements. This is attributed to the fact that each country's payoff depends on the formation of the two agreements. Assuming low R&D spillovers to the non-signatories, R&D agreement offer comparative advantage to its members such as lower costs and innovative products. If the impact of R&D has higher effect than environmental quality to signatories' payoff function then in the equilibrium IEA has less members than the case without linkage. When the assumption of symmetric countries is relaxed another issue arises. Countries that constitute the R&D agreement disagree on the countries that want to join them.

Issue linkage refers also to the case in which signatories stabilize and attempt to expand IEA by using trade sanctions. Barrett (1994b) assuming identical countries and a minimum participation clause for an IEA to be formed, shows that a ban on imports from non-signatories and a ban on exports partially from signatories to non-signatories generate a credible threat able to sustain full-cooperative outcome. In the equilibrium trade exists and the threat of trade sanctions deters free-riding. The most significant findings of his study is that under trade the leakage attributed to free-riding is higher under autarky compared to free trade. That makes easier the formation of an IEA under the latter regime. However, due to free trade the competition is more intense leading to higher emission output. When one country joins the agreement, signatories reward that country by decreasing the emission level. On the other hand, when a country defects signatories punish that country by increasing their emission output. These adjustments on the emission level or abatement efforts of the signatories are considered credible since they are in line with their optimization behavior. Despite the credibility of signatories' actions when non-orthogonal free- riding behavior is assumed, leakage generates issues in the formation of coalition. When signatories decrease the total emission level to reward the new member, non-signatories find it optimal to increase their emission output. This issue can be handled by considering for trade restrictions in the model. Barrett (1994b) finds that when trade bans are considered, ban of imports can increase the welfare and the number of signatories significantly whereas sanctions on exports have little effect.



Self-Enforcing IEAs with and without trade bans
Source: Barrett (1994b)

Figure 2.

Figure 2 depicts the welfare of signatories (Π_s) and the welfare of non-signatories (Π_{ns}) for the case with and without trade ban. Finally if minimum clause participation is considered in IEA coupled with trade ban is able to sustain the full cooperative outcome in the equilibrium.

Barrett (1997) employing abatement efforts as an instrument expands the model of Barrett (1994) and Carraro and Siniscalco (1993) for the case of international trade and the effect of trade restrictions imposed from signatories to non-signatories. He finds that under the credible threat of sanctions that is guaranteed by a minimum participation clause, free-riding can be deterred. In the equilibrium trade is not restricted and full cooperative outcome is possible depending on the parameters. When trade sanctions are imposed both signatories and non-signatories deteriorate their welfare.

In a dynamic context, Breton et al (2010) assume a form of punishment from the signatories to defectors with this action bearing a cost to the formers proportionate to the magnitude of punishment and a case in which signatories can punish defectors without bearing any cost. In the first case, if the punishment is strong and the costs linked to that punishment is small, partial cooperation with many members in IEA is a feasible outcome. If the signatories are able to sanction defectors without incurring any cost then partial cooperation and full cooperative case are feasible outcomes whereas full defection is unsustainable equilibrium Bahn et al (2009) extend the punishments in dynamic models considering for asymmetric countries. Their finding confirm Breton (2010) except for the steady state with partial equilibrium which is not a feasible outcome due to the small number of countries under scrutiny.

Blonski and Spagnolo (2003) assume two identical countries that negotiate on N linked issues. They model the negotiation process through a dynamic prisoner's dilemma game. Assuming no linkage between the negotiating issues the equilibrium is as in the static case defection by both parties. They expand the simple model to consider for issues that are linked. The result is cooperation in multiple agreements but not all of them. If they consider the agreements to be substitutes the cooperation among issues increases. Finally, free riding incentives are eliminated if the agreements apart from substitutes are also linked to political issues.

Kemfert (2004) investigates the effects that technological spillovers have on climate control agreements. More specifically employing a four-region world consisting of USA, European Union, Japan and Russia and Eastern world develops a model that explain the free-riding behavior of USA and how technological spillovers through cost efficiency can affect this equilibrium. The study entails a two-stage model in which at the first stage countries decide whether to join the coalition and in the second stage through a non-cooperative open loop Nash game they select their policy variable. The available instruments are either trade restrictions or R&D development. Technological spillovers increase free-riding incentives since emission output decreases. However, if R&D development is linked to environmental agreement countries that want to defect have to face the cost of excludability from the technological spillovers. If trade sanctions are the policy variable of signatories then both signatories and non-signatories deteriorate their level of welfare. One of the main objectives of the study is to explain why USA did not ratify the Kyoto protocol. As the model shows, USA has higher payoffs out of the agreement as the benefits of trade are higher than R&D development and environmental quality. Kemfert (2004) assumes that signatories allocate their resources through a permits system and the revenues are invested in R&D. The study though it finds multiple combinations of coalition that are profitable through issue linkage stability applies only for the case that Europe Japan and Russia cooperate. However in the latter case the payoffs are not as high as in other coalition formations.

For the energy sector, Bosetti et al. (2008) investigate the impact of R&D international spillovers may have on GHG emission level. They model the absorption capacity of each country and distinct the world into high and low income countries. R&D efforts are concentrated among high income countries and diffuse to the rest of the world through new products and exchange of ideas. Diffusion of technological advance allow countries to lower the production cost in the energy sector. The policy mix they propose involves enhancement of the absorption rate of technology motivated by a scheme of transfers, knowledge flows and policies to reduce free-riding incentives. The result is stabilization of GHG concentrations and cost efficiencies in the energy sector. High income countries converge to the same level of R&D and low income countries as they increase their knowledge pool they enhance their absorption rate of new technologies.

Hoel and de Zeeuw (2009) examine the impact that a technological breakthrough can have on the stabilization and expansion of international agreements when R&D agreement is linked with IEA. The former base their study on Barrett (2006) who finds that R&D agreement reinforces IEA only if the technological breakthrough is characterized by increasing return to scale. Both studies assume that countries instead of abatement cost, minimize the individual cost of R&D investment and adoption. Authors of both studies assume also that a minimum level of investment in R&D M is necessary for the development of the technology. Barrett (2006) assume that individual cost is independent of the level of adoption cost and that in the two stage game R&D investment decision precedes the decision of whether countries will cooperate or not. On the other hand Hoel and de Zeeuw (2009) assume that adoption cost to R&D is a function of the total level of investment and in the two-stage game, countries in the first stage decide whether they will cooperate or not and in the second stage they decide on the expense they incur. Benefits of breakthrough technology can be erased if the level of investment is too high, whereas if it is too low breakthrough technology cannot be realized. Finally both studies assume that R&D is a public good with positive externalities. In the non-cooperative Nash equilibrium game Hoel and de Zeeuw (2009) find that it is optimal for each country to adopt its share on minimum investment level necessary for the technology to be realized. This is a stable result since if one country decides to lower its costs then minimum investment level cannot be met whereas if it increases its costs above the prerequisite it erases its benefits.

When coalition formation is considered two cases emerge. The first one considers overinvestment in breakthrough technology and the results are in line with Barrett (2006) i.e. R&D investment do not affect the coalition formation and the size of IEA is the same with the case of self-enforcing IEA. The second case refers to underinvestment in breakthrough technology two scenarios are possible. The first one entails that each country bears its own cost and in the equilibrium coalition is dissolved and the outcome is no cooperation. The second scenario involves that coalition bear the cost of adoption and R&D development. The outcome of the latter scenario involves a larger stable coalition compared to the case of Barrett (2004) with higher benefits for signatories and nonsignatories.

Conclusion

The purpose of this analysis is to summarize the main studies involved in the formation and expansion of International Environmental Agreements based on non-cooperative game theory. The findings indicate that self-enforcing agreements consist equilibrium under certain assumptions. In the one-shot prisoner's dilemma, all countries defect though it would be Pareto efficient for them to cooperate. Free-riding effects make the transition to a Pareto optimal state an inevitable outcome. In a two-stage framework, where countries negotiate in the first stage whether they will cooperate and in the second stage their emission output results are slightly better compared to the simple case. A stable coalition may emerge but its size is small and the welfare gains compared to non-cooperative outcome are low. When asymmetric and farsighted agents are considered cooperation involves more members and the welfare gains are higher.

Studies that account for time dimension find that stable coalitions with many members is a feasible outcome as long as trigger strategies are renegotiation-proof.

We also review transfers as a mechanism that allows signatories to induce singletons to join coalition. Depending on the assumptions, in some cases cost-sharing rules can increase the number and the welfare of coalition (Barrett 2000), whereas in other cases where there are many agents the transfer scheme can be welfare deteriorating (Hoel and Schneider 1997).

Issue linkage is another policy tool of signatories to induce non-signatories to join coalition. It refers to the case where an environmental agreement is linked to another agreement that involves the provision of an excludable good. The major finding are pessimistic. As the number of signatories in the IEA increases, the good in the other agreement loses its excludability. In the equilibrium environmental agreement has less members than without issue linkage. If positive spillovers are considered and R&D diffuses from signatories to defectors then in the equilibrium production is cost effective and total emission level is lower compared to the case without issue linkage. Finally trade sanctions under certain circumstances make feasible the full-cooperative outcome in the equilibrium.

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