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Costs, Structure and Equity of International Regimes for Climate Change Mitigation

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by

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1. Introduction

Many recent papers have provided, on the basis of the existing scientific evidence, some answers to the most relevant policy questions related to the climate change problem. Issues such as the timing of optimal responses to climate change, the choice between mitigation and adaptation responses, the role of technological innovation and diffusion, the choice between domestic action and the adoption of "flexibility mechanism", the importance of secondary benefits, etc. have been analysed from different perspectives.[1] All these papers recognise that the costs and benefits of different policy options crucially depend on the characteristics of the international agreement on climate change which is adopted. In particular, they depend upon two main features of the international regime: the number of signatories, and the size of their quantitative commitment to control GHGs emissions.

It is therefore impossible to assess costs and benefits of the Kyoto protocol or of other potential agreements on climate change independently of the number of signatories of the agreement and of their abatement targets and/or policy commitments. However, there is an important consequence of this obvious remark which is widely neglected. Indeed, the number of signatories is endogenous and depends on the abatement targets and mitigation policies adopted in various countries. Hence, costs and benefits of different policy options depend on the number of signatories, but the number of signatories depend on the costs and benefits of different policy options.

This two-ways relationship is often forgotten by most of the available literature on costs and benefits of climate change policies, which does not take into account the full interdependency between policies, costs/benefits and signatories. For example, there are studies that analyse the costs of implementing the Kyoto protocol either through a set of domestic policies and measures or through a system of international tradable permits, with a fixed number of signatories. But the adoption of either policy crucially affects the number of signatories, which can be larger or lower under policies and measures than under tradable permits. And the number (and identity) of signatories crucially affects costs and benefits of different agreements.

Therefore, it is important to analyse of the effectiveness of climate policies by focusing on the link between policy options and the structure of the international regime. This is the goal of this paper. We will not produce new empirical evidence, but we will rather review the existing empirical contributions on the costs and benefits of different climate policies, taking into account the interdependency between costs/benefits and the structure of the climate international agreement. We will first discuss the theoretical results which prove this interdependency, and we will then re-organise the existing empirical literature in order to see which information it provides on the policy implications of this interdependency.

In particular, we would like to analyse whether there exist the conditions for an agreement on climate change to be signed by all or almost all world countries (Cf. Carraro and Siniscalco, 1998; Carraro, 1998; Barrett, 1999 for a theoretical analysis of these conditions); and which countries can play a leadership role with respect to the goal of achieving the largest possible coalition by proposing strategies, measures and institutions that help expanding the number of countries which commit to control their emissions (Cf. Gupta and Grubb, 2000). Notice that in this way we also analyse which strategies can be proposed to reduce the costs of mitigation policies. But this is quite a different approach from the ones analysed in most available papers which assess a country's costs and benefits of adopting a given climate policy. The reason is that here a country's goal is not to identify a new climate friendly technology or an

[1] See, for example, the collection of papers contained in Carraro (1997, 1999b, 2000).

adequate re-distribution of costs across sectors. Now the goal is to affect other countries' behaviour in order: (i) to increase the number of those which share the burden and: (ii) to share the burden more equitably.

The equity issue is also very important to understand which countries are going to reduce/control[2] their emissions. As a consequence, given what said above, equity is also crucial to adequately assess the costs/benefits of emission reductions at the global and country level. It has been argued that some countries are allowed to reduce emissions less than other countries, both within (Kram, 1998) and outside the EU bubble (Metz, 1999; Bosello and Roson, 1999; Rose and Stevens, 1999). And that even when applying flexibility mechanisms some countries will benefit from the agreements more than other ones (Nordhaus and Boyer, 1999). It has also been argued that some countries can exploit their monopolistic power in a future trading system (Burniaux, 1998). All these remarks address the problem of the optimal burden-sharing (the distribution of costs) of climate change control. This problem is strictly related to the features of an international agreement on climate for two main reasons. On the one hand, an increasing number of participating countries reduces the burden for each signatory; on the other hand, an agreement in which the burden is equitably shared is more likely to be signed by a large number of countries (Convery, 1999). Therefore, equity and the structure of the international agreement (number and identity of signatories) are strictly linked. But the number of signatories affects and is affected by costs. Hence, equity and efficiency cannot be separated.

These remarks reinforce our previous basic statement. An analysis of the costs and benefits of different policy options cannot be done independently of an analysis of the likely features of the prevailing international regime, i.e. of the incentives that lead countries to sign an international agreement to control GHGs emissions and to set quantitative emission targets.

Notice that the analysis of the features of climate international agreements and of their repercussions on the choice of different policy options (and vice versa) must take into account:

- the basic features of the climate problem, and particularly the public good nature of GHGs abatement in the absence of a supra-national authority;
- the scenarios which describe the future evolution of economic and environmental climate related variables;
- the economic incentives that countries have to sign an international agreement on climate change control, i.e. under what conditions on the number of countries, the damaging effects of free-riding (leakage), the structure of costs and benefits, a coalition, i.e. a group of signatories of the international agreement, can emerge.[3]
- the political and institutional dimension of an international climate agreement, its history, the possibility of monitoring and sanctioning deviations, the links with other agreements.

This paper is devoted to the analysis of the above issues and also aims at providing a framework to understand how future negotiations on climate change can evolve, and how the costs and benefits of climate policies are modified by these possible evolutions.

2. Coalition Formation

If the goal is to understand which international regimes is likely to emerge to control GHGs emissions, game theory is certainly the best tool to deal with it. Indeed, game theory has extensively analysed the possibility of coalition formation in the presence of free-riding (i.e. when parties have to agree on the provision of a public good). Early contributions (Cf. Hardin and Baden 1977) characterised the environmental-game among countries as a prisoners' dilemma, inevitably leading to the so-called "tragedy" of the common property goods. But in the real world, at the same time, a large number of international environmental agreements on the commons was signed, often involving sub groups of negotiating countries and sometimes involving transfers and other links to other policies (trade, technological cooperation, etc.). It was therefore necessary to develop new models which helped us understanding the logic of coalition formation in the presence of spillovers, and the possibility to increase welfare by means of appropriate mechanisms and strategies. These new models were developed in the last decade within a non-cooperative game-theoretic framework, and provide interesting indications on the likely outcomes of climate negotiations.

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[2] When using the word "emission reduction", we mean reduction with respect to the business as usual scenario. As a consequence, emissions in some countries can increase with respect to their 1990 level or other baselines.

[3] In the case of climate negotiations, possible coalitions are Annex B Parties of Kyoto Protocol, the Umbrella Group, UNFCCC Parties, etc.

Consider first the case in which countries negotiate on a single worldwide agreement. Most papers in the game-theoretic literature on coalition formation applied to environmental agreements (Hoel, 1991, 1992; Carraro and Siniscalco, 1992, 1993; Barrett, 1994, 1997b; Heal, 1994) propose the following conclusions:

- the presence of asymmetries across countries and the incentive to free-ride makes the existence of global self-enforcing agreements, i.e. agreements which are profitable to all signatories and stable, quite unlikely (Carraro and Siniscalco, 1993);

- when self-enforcing international environmental agreements exist, they are signed by a limited number of countries (Hoel, 1991, 1994; Carraro-Siniscalco, 1992; Barrett, 1994);

- when the number of signatories is large, the difference between the cooperative behaviour adopted by the coalition and the non co-operative one is very small (Barrett, 1997b).

These results, which are robust with respect to different specifications of countries' welfare function, and with respect to the burden-sharing rule[4] used in the asymmetric case (Barrett, 1997a, Botteon-Carraro, 1997a), suggest that the attempt to negotiate on effective emission reductions is unlikely to lead to a coalition formed by all or by almost all countries, unless more complex policy strategies, in which environmental policy interacts with other policy measures, are adopted.[5]

For these reasons, in the game-theoretic environmental economics literature, two main sets of instruments have been proposed to expand environmental coalitions, i.e. to increase the number of signatories of an environmental agreement. These instruments are "transfers" and "issue linkage". These will be analysed in section 3.3 which deals with partial agreements and the ways to broaden them.[6]

Consider now the case in which countries are free to sign the agreement proposed by a group of countries or to propose themselves a different one to the same or to other countries (Carraro, 1998). This may lead to the formation of multiple climate agreements similarly to what happens in the case of trade blocs (Bloch, 1997; Carraro and Moriconi, 1998; Yi, 1997). The multiplicity of coalitions may allow for region-specific agreements in which the characteristics of countries in the region are better reflected by the contents of the agreement. Even in this case, game-theory provides a clear analysis of the outcome of climate negotiations. Despite the large number of equilibrium concepts,[7] some conclusions seem to be quite robust:

- the equilibrium coalition structure is not formed by a single coalition. In general, many coalitions form at the equilibrium;

- the grand coalition, in which all countries sign the same environmental agreement, is unlikely to be an equilibrium;

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4 In the asymmetric case, the rule which is chosen to divide the gains from co-operation among the countries in the coalition (usually called burden-sharing rule) plays a crucial role because it affects the likelihood that each country decides to sign the agreement. The burden-sharing rule is usually taken from co-operative game theory and Nash's and Shapley's one are the most used. By contrast, in the symmetric case different rules lead to the same outcome (equal shares).

5 Surveys of the above literature are proposed in Barrett (1997b), Carraro (1999a), Tulkens (1998).

6 In the last two decades, political scientists also focused their analyses on the emergence of co-operation in the presence of free-riding (Axelrod, 1984; Brams and Kilgour, 1988; Hampton, 1987; Oye, 1986; Taylor, 1987; Wagner, 1983). Their conclusions are very close to the ones achieved by economists, i.e. even in the case of public good provision, a coalition forms at the equilibrium, but some countries are allowed to defect.

7 Unfortunately, game theory is far from having achieved a well-defined non co-operative theory of coalition formation under the above general assumptions and definitions. There are several stability concepts that can be used and which unfortunately provide different equilibrium coalition structures. Among them, let us recall the concept of equilibrium binding agreements proposed by Ray and Vohra (1997), the concepts of α-stability and β-stability proposed in Hart and Kurz (1983), the sequential stability concept of Bloch (1997), the open-membership stability proposed by Yi (1997) and the farsighted stability concept used in Chew (1994), Mariotti (1997).

- coalitions of different sizes may emerge at the equilibrium (even when countries are symmetric).

The specific results on the size of the coalitions depend on the model structure and in particular on the slope of countries' reaction functions, i.e. on the presence of carbon leakage. If there is no leakage and countries are symmetric, then the Nash equilibrium of the multi-coalition game is characterised by many small coalitions, each one satisfying the properties of internal and external stability (this result is shown in Carraro and Moriconi, 1998).

The remaining question is therefore a policy one. Is countries' welfare larger when one or when several coalitions form? And what about environmental effectiveness? The answer is still uncertain, both because theory provides examples in which a single agreement is preferred, at least from an environmental viewpoint, to many small regional agreements (and vice versa), and because empirical studies have not yet convincingly addressed this issue. Moreover, the conclusion crucially depends on the choice of the equilibrium concept and on the size of leakage.

The consequence of the results discussed above is that the structure of the international environmental agreements is a crucial dimension of the negotiating process. If all countries negotiate on a single agreement, the incentives to sign are lower than those which characterise a multiple agreement negotiating process. But at the equilibrium, the environmental benefit (quality) may be higher.

Can we say something more precise on the likely coalition(s) that can emerge at the equilibrium? Can we use existing studies, albeit not designed to address the above issues, to increase our understanding of the implications of different policy strategies? In the next section, we would like to achieve, at least partially, a synthesis, by exploring the outcomes of the combinations of different coalition structures (international regimes) and of different policy options (with focus on different degrees of adoption of emission trading and other flexibility mechanisms). Table 1 below summarises the main combinations whose impact will be explored. The papers indicated in each cell are just examples and do not cover the whole literature.

Table 1: Coalition Structures and Policy Options

Coalition	*Policy Options*							
		Domestic measures only	**Co-ordinated carbon tax**	**Flexibility mechanisms with ceilings**	**Free flexibility mechanisms**	**Flexibility mechanisms with banking**	**Flexibility mechanisms with R&D**	**Flexibility mechanisms with**
	No Participation	IPCC (1995)						
	Unilateral Participation	Jorgenson-Wilcoxen (1993) Barret (1992)						
	EU only	Carraro-Siniscalco (1992)	Bosello and Carraro (1999) Barker (1998)	Schmidt and Koschel (1998)				
	OECD only	Burniaux et al. (1992)	Capros (1998)		Harrison and Rutherford (1999) Holtzmark (1998) Capros (1998)			
	Annex-1 countries	McKibbin et al. (1998)	Mensbrugghe (1998)	Ellerman et al. (1998,1999) Buonanno et al. (1999) Manne and Richels (1998)	Ellerman et al.(1998) Grubb and Wrolijk (1998) Holtzmark (1998) McKibbin et al. (1998) Manne-Richels (1999a,1999b) Mensbrugghe (1998) Nordhaus and Boyer (1999) Shackleton (1998)	Bosello-Roson (1999) Westskog (1999)	Nordhaus (1997) Buonanno et al. (1999)	Burniaux (1998) Ellerman et al. (1998)
	Double Umbrella				McKibbin et al. (1998) Shackleton (1998)			Ellerman et al. (1998)
	All Countries	Nordhaus-Yang (1996)		Ellerman et al. (1998) Buonanno et al. (1999)	Bohm (1999) Ellerman et al (1998) Manne-Richels (1998,1999a,1999b) Nordhaus and Boyer (1999) Shackleton (1998)	Bosello-Roson (1999) Westskog (1999)	Nordhaus (1997) Buonanno et al. (1999)	

3. International Regimes for Climate Change Control

3.1 No Participation

This case constitutes the benchmark with respect to which evaluating the costs and benefits of policies designed to control GHGs emissions under alternative coalition structures. It is usually named the business as usual scenario, because it identifies the values of the main environmental and economic variables when no coalition forms and no action, unilateral or co-operative, is adopted (the IPCC second assessment report (IPCC, 1995) is a good example of this approach). The construction of the business as usual scenario is very important both to assess the profitability and the stability of a coalition (i.e. whether it is self-enforcing). A coalition is profitable when welfare after the coalition is formed is larger than in the no participation case. A coalition is self-enforcing if there are no incentives to leave or enter the coalition. The business as usual scenario crucially affects also these incentives. If the no participation case is such that emissions are declining and that the target can easily be achieved through small emission reductions, than the incentives to join the coalition (sign the agreement) are much higher, i.e. a coalition with many countries is more likely to form (Barrett, 1997b). Symmetrically, if large emission reductions are necessary, both abatement becomes more costly, and incentives to free-ride increase, thus further increasing costs for co-operating countries (particularly if leakage is high).

A careful definition of the no participation case is therefore very relevant to assess the likelihood of large coalitions and thus the efficiency of a climate agreement. But it is also very relevant in terms of equity. When the burden of emission abatement has to be equitably shared, it is important to distribute emissions reductions with reference to the business as usual scenario. Each country has therefore an incentive to pretend that its own business as usual scenario implies larger emissions than what is actually true (Bohm,1999; Grubb, 1998). In this way, the actual cost for the country would be lower. An optimistic scenario in which predicted emissions are lower than "true" emissions (as measured ex-post), leads countries to agree on low emission reduction targets, but forces countries to reduce more later and to pay abatement costs larger than expected. A pessimistic scenario makes the agreement more difficult because larger emission reduction have to be agreed upon, but countries find themselves in a better situation and pay lower costs ex post. Hence, if a country succeeds in convincing the other ones that its own business as usual emissions are larger than the "true" ones, than this country achieves a relative benefits in terms of less stringent emission targets and lower abatement costs.

The definition of a business as usual scenario has therefore a strategic dimension and can hardly be defined as an "objective" evaluation of future economic and environmental cycles and trends. It is therefore important to collect the largest amount of information from different sources and to identify the scenario more as an average of many scattered information than as a subjective analysis of likely future events. This may reduce the likelihood of strategic definitions of the business as usual scenario and may partly prevent the consequent impacts on the equilibrium coalition and on the assessment of costs and benefits of climate policies.

3.2 Unilateral participation

There is a wide literature that analyses the costs and sometimes the benefits of introducing policies to control GHGs emissions in a single country (Bucholz and Konrad, 1994; Endres and Finus, 1998; Hoel, 1991; Hoel and Schneider, 1997; Porter and Van Linde, 1995). Given the arguments proposed in the Introduction, and the results summarised in section 2, this type of exercise may seem unreasonable. There are however two main justifications for undertaking it. The first one, is that domestic abatement costs (related to domestic policies and measures) hardly depend on the coalition structure. Indeed, only if leakage is large, and if climate policies have a large impact on trade and financial flows, than the costs of domestic abatement policies are significantly affected by the size of the coalitions and by the agreed emission targets. Hence, it may be useful to compute the costs of unilateral participation as a benchmark case, which identifies costs that can only be reduced when a coalition forms and flexibility mechanisms are implemented among signatory countries. Notice the importance of a careful assessment of leakage and of trade and financial repercussions of climate policies (McKibbin et al. 1998; Rutherford et al. 1998). Notice also that the above arguments concern costs but not benefits of climate policies. Indeed the benefits of unilateral participation are likely to be zero or almost zero for all or almost all countries (a possible exception is the U.S.) given the global nature of the climate problem (Hoel 1991, Bucholz and Konrad 1994, Endres and Finus 1998).

A second reason for undertaking the assessment of the cost of a unilateral participation is that it could lead to identify a series of low costs (or no cost) options (the so called low hanging fruits or no regret actions) that could be implemented independently of the formation of a climate coalition. It could also help identifying policy mixes that help restructuring

the fiscal system and public regulatory and incentive schemes in such a way that emission abatement costs are more than compensated by other economic (non environmental) benefits (the so-called double dividends).[8]

There are also cases in which unilateral actions have been analysed under a very specific view point. For example, Bucholz and Konrad (1994) analyse the detrimental effect of pre-negotiations actions (more bargaining power can be achieved by unilaterally increasing emissions before negotiating. Endres and Finus (1998) examine the negative effects on negotiations of a higher environmental consciousness in one country, Hoel (1991) analyses the costs of unilateral actions, Hoel and Schneider (1997) the role of social norms, Porter and Van Linde (1995) focus on the advantage of being a leader by adopting emission reductions before the other countries.

3.3 Partial Agreements

The case of partial agreements is most often analysed in the recent empirical literature. The reason is twofold. On the one hand, as shown in section 2, theory suggests that a partial coalition forms at the equilibrium. Hence, the climate problem is neither a "tragedy of commons", nor a situation in which there are clear incentives to co-operative emission control. On the other hand, the history of international environmental negotiations, and of climate negotiations in particular, is a history of partial agreements that are slowly broadened as more and more countries decide to join the group of signatories. In the case of climate, moreover, the Kyoto agreement can be seen as a first partial climate agreement. Therefore, there have been many papers that have dealt with the costs and benefits of the Kyoto agreement and with the possible strategies to increase the number of countries which commit themselves to emission control targets (see the papers gathered in OECD, 1998 and in Carraro, 1999b, 2000; see also Burniaux 1998, Capros 1998, Carraro, 1999, Ellerman et al. 1998, Grubb and Vrolijk 1998; Holtzmark 1998, Manne and Richels 1998, Mensbrugghe 1998, Nordhaus and Boyer 1999, and the surveys by Metz, 1999; Convery, 1999).

Two remarks are important. First, even if most recent analyses deal with the Kyoto agreement, there are studies that try to compute the optimal coalition structures, both in terms of participation and in terms of targets, independently of the decisions taken in Kyoto (a recent attempt is in Nordhaus and Boyer, 1999). Usually the conclusion that can be derived from these papers is that Kyoto is neither economically nor environmentally optimal. However, the notion of optimality is not very useful when analysing coalition formation. Indeed, what matters is the notion of stability of a coalition, which identifies which countries have an incentive to join the coalition (sign the agreement) for different membership rules (Carraro and Moriconi, 1998, Carraro and Botteon 1997a,b), business as usual scenarios, abatement costs (and therefore climate policies, including the degree of adoption of flexibility mechanisms), environmental benefits (and therefore impacts, adaptation costs, etc.).

Second, the Kyoto agreement can be interpreted as a partial (Carraro, 1998) or as a global agreement (Chander et al. 1999). It is interpreted as a global agreement when all countries are seen as committed to emission targets. Those in Annex B are committed to emission targets with respect to 1990, the other ones are "committed" to emissions levels evolving as in the business as usual scenario. This second interpretation is useful to show that:

- optimal emissions targets are not necessary because the same outcome can be achieved through a global unrestricted emission trading scheme among all countries (Chander et al., 1999);

- the resulting outcome can be profitable to all countries if an appropriate transfer schemes is adopted (Chander and Tulkens, 1995, 1997; Germain et al. 1997; Markusen 1975).

As a consequence, even a "partial", sub-optimal agreement like Kyoto can be transformed into a "global" optimal agreement (see section 3.4).

Leaving this ideal world in which perfectly competitive and global market mechanisms are at work, we are left with the analysis of coalitions which, like the coalition formed by Annex 1 countries of the FCCC or Annex B countries of the Kyoto protocol, are partial, i.e. formed by a subgroup of the negotiating countries. Are these partial coalitions effective? Are they too costly for the signatory countries? Can they be enlarged by inducing other countries to join?

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[8] See Goulder (1995), Bovenberg (1997), Bosello, Carraro and Galeotti (1999) for surveys of this literature.

The answer to the first question depends on two main factors: (i) the baseline scenario; (ii) the degree of leakage. If the baseline scenario is very ambitious and leakage is high, on the one hand countries find it difficult to undertake large emission reductions, and on the other hand their effort is offset by the leakage effect (the increased emissions by free-riding countries).

As for the second question, there are many studies that try to assess the cost for Annex 1 countries of achieving given emission targets under alternative policy options. These policy options include the timing of the mitigation responses (see the special issue of Energy Economics edited by Carraro and Hourcade, 1999), the degree of adoption of flexibility mechanisms and their features, e.g. banking, (see the papers in OECD, 1998; Carraro, 1999), the role of complementary industrial policies, mainly designed to foster innovation (see Nordhaus, 1997; Goulder and Schneider, 1998; Kopp et al, 1998; Buonanno et al. 1999), the effects of uncertainty about climate impacts or abatement costs (Carraro and Hourcade, 1999), etc.

The main result can be summarised as follows. Despite their high variability, all studies show that the Kyoto flexibility mechanisms sensibly reduce the costs of compliance, whatever the coalition structure. Shogren (1999) notes that "it is estimated that any agreement without the cost flexibility provided by trading will at least double the USA costs, … the key is to distribute emissions internationally so as to minimise the costs of climate policy". Manne and Richels (1999) state that "losses in 2010 are two and one-half times higher with the constraint on the purchase of carbon emission rights; international co-operation through trade is essential if we are to reduce mitigation costs". Hence, emission trading, and more generally the application of the flexibility mechanisms, can reduce overall mitigation costs without reducing the effectiveness of the climate policy (see also Burniaux, 1998; Capros, 1998; Ellerman, 1998; Glomstrod, 1992; Mensbrugghe, 1998; Nordhaus, 1999; Rose and Stevens, 1999; Hourcade *et al.*, 1999; Tol, 1999a,b; Kverndokk, 1998).

If flexibility mechanisms can fully exploit both their intertemporal (banking or banking and borrowing) and geographical dimensions (global emission trading) than compliance costs are further lowered. This result is shown in Bosello and Roson (1999) for banking, Westskog (1999) for banking and borrowing, Manne and Richels (1999a,b), McKibbin et al. (1998) and many others for global emission trading. If in addition the incentives to innovation provided by flexibility mechanisms are taken into account, then compliance costs are even lower (Buonanno et al. 1999).

However, all the above papers also show that the size of the coalition crucially affects the size of the benefits deriving from the adoption of flexibility mechanisms. The larger the number of participating countries, and the higher the variability of marginal abatement costs across them, the larger the benefits from emission trading, JI and CDM. Hence, in order to reduce abatement costs and increase environmental benefits, policies, rules and institutions should be designed to achieve the largest possible coalition.

The third question, how to broaden a coalition, is often related to the issue of the links between the climate agreement and other international agreements. Indeed, two types of policy options, based respectively on economic transfers and on issue linkage, are often proposed as the way to achieve larger climate coalitions. These policies imply that links must be established between different multilateral agreements, e.g. agreements on climate and on free-trade or on technological co-operation.

Let us consider transfers first. It is quite natural to propose transfers to compensate those countries which may lose by signing the environmental agreement. In other words, a re-distribution mechanism among signatories, from gainers to losers, may provide the basic requirement for a self-enforcing agreement to exist, i.e. the profitability of the agreement for all signatories. Therefore, if well-designed, transfers can guarantee that no country refuses to sign the agreement because it is not profitable. Moreover, Chander and Tulkens (1995, 1997) and Chander et al. (1999) show that there exist transfers such that not only is each country better off with global co-operation than it is with no co-operation at all (the no participation case), but it is also better off with global co-operation than it is in any sub-coalition, provided the remaining countries behave non-cooperatively (see also Germain et al. 1997, Markusen 1975). This result is important because it implies that no country or group of countries has an incentive to exclude other countries from the environmental coalition, i.e. the grand coalition is optimal (but it may not be stable).

Transfers play a major role also with respect to the stability issue (Carraro and Siniscalco, 1993; Petrakis et al 1996; Schmidt 1997). Indeed, it is not sufficient to guarantee the profitability of the environmental agreement. Incentives to free-ride must also be offset. The possibility of using self-financed transfers to stabilise environmental agreements is analysed in Carraro and Siniscalco (1993), Hoel (1994) which show that transfers may be successful only if associated with a certain degree of commitment. For example, when countries are fairly symmetric, only if a group of countries is committed to co-operation, another group of uncommitted countries can be induced to sign the agreement by a system

of transfers (Carraro and Siniscalco, 1993).[9] This gives developed countries the responsibility to lead the expansion of the coalition. However, the amount of resources that would be necessary to induce large developing countries to join the agreement may be such that some developed countries perceive the economic costs of a climate agreement larger than its environmental benefit. In this case, the transfer mechanism would undermine the existence of the leader coalition and would therefore be ineffective. This is why countries in the leader coalition must be strongly committed to co-operation on emission control.

Another general conclusion emerges from the analysis carried out in Carraro and Siniscalco (1993): both the existence of stable coalitions, and the possibilities of expanding them, depend on the pattern of interdependence among countries. If there is leakage, i.e. a non co-operating country expands its emissions when the coalition restricts them, thus offsetting the effort of the co-operating countries, then environmental benefits from co-operation are low, the incentive to free-ride is high, and conditions for transfers to be effective are unlikely to be met. If, on the contrary, there is no leakage, i.e. the free-riders simply enjoy the cleaner environment without paying for it, but do not offset the emission reduction by the co-operating countries, then environmental benefits are larger, free-riding is less profitable and transfers may achieve their goal to expand the coalition.

A second policy strategy aimed at expanding the number of signatories of the climate agreement is based on the idea of designing a negotiation mechanism in which countries do not bargain only on GHGs reductions, but also on another interrelated (economic) issue. For example, Barrett (1995, 1997) proposes to link climate negotiations to negotiations on trade liberalisation, Carraro and Siniscalco (1995, 1997), Katsoulacos (1997) propose to link them to negotiations on R&D co-operation, Mohr (1995), Mohr et al. (1998) propose to link climate negotiations to international debt.

Again we must distinguish the profitability from the stability problem. The idea of "issue linkage" was originally proposed by Folmer *et al.* (1993) and Cesar and De Zeeuw (1994) to solve the problem of asymmetries among countries. The intuition is that some countries gain on a given issue, whereas other countries gain on a second one. By "linking" the two issues it may be possible that the agreement in which the countries decide to co-operate on both issues is profitable to all of them. The idea of "issue linkage" can also be used to achieve the stability goal. If countries that do not sign the climate agreement do not enjoy the benefits arising from signing simultaneously other multilateral agreements, e.g. the ones on technological co-operation, then there is a strong incentives for all countries to sign the linked agreement.

This approach is likely to function when the negotiation on an issue with excludable benefits (a club good in economic words) is linked to the climate negotiation (which, if successful, typically provides a public good, i.e. a non-excludable benefit). An example could be the linkage of environmental negotiations with negotiations on technological co-operation whose benefits are largely shared among the signatories whenever innovation spillovers to non-signatories are low (Cf. Carraro and Siniscalco, 1997).[10]

Therefore, issue linkage may be a powerful tool to address the enlargement issue. If the developed countries (US, EU and Japan above all) on the one hand increases their financial and technological support to developing countries, and on the other hand makes this support conditional on the achievement of given environmental targets, then a number of countries is likely to be induced to join the environmental coalition, i.e. to sign a treaty in which they commit themselves to adequate emission reductions.[11]

3.4 Global agreements

The difficulty of achieving a global agreement on climate change underlined in the previous sections depends on four main factors:

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[9] This condition is less stringent when countries are asymmetric. See Botteon-Carraro (1997a).

[10] An extension to the case of structurally asymmetric countries is provided in Botteon and Carraro (1997b), whereas information asymmetries are accounted for in Katsoulacos (1997).

[11] It is however important to keep in mind the negative impact which such linkages may have on the (perceived) fairness of the envisaged enlarged regime: there are possible linkages which could easily be perceived as 'black mail' on part of the Parties with strategic advantages.

- *the heterogeneity of countries with respect to the causes of climate change, the impacts, the mitigation and adaptation costs*. This factor mainly influences the profitability of the decision to sign a climate agreement. Some countries may loose when signing the agreement even when environmental benefits are fully accounted for. As shown by Chander and Tulkens (1995, 1997) there always exist a system of transfers that may make all countries gain. But this opens again the door to the equity problem and the related burden-sharing issue. Equity may have a large impact on the existence and size of a climate coalition. As shown in Carraro and Botteon (1997a,b) and as argued by many policymakers and scientists, the way in which the burden of controlling emissions is shared across countries crucially affects a country's decision to join a coalition. On the one hand, if the burden is not equitably shared, some countries may not find it profitable to sign the agreement. Profitability depends indeed on two main factors: (i) the distribution of costs within the coalition.; (ii) the size of the coalition. It is indeed possible that there exists a minimum size of the coalition above which it becomes profitable. And these two factors are strictly interdependent. On the other hand, equity also affects the free-riding incentives. As seen in the previous section 3.3, in some cases it may be reasonable for some countries to transfer resources to other countries to induce them to join the coalition on which they would otherwise free-ride. In this case, the final outcome is not equitable -- free-riders would gain more than countries in the starting coalition -- but it may be environmentally and economically efficient.

- *The strong incentives to free-ride on the global agreement and the lack of related sanctions.* When all countries accept to control emissions, a defecting country achieves the whole benefit, because its incidence on global emission is marginal (with a few exceptions) and pays no cost. Hence, a defection with respect to a large coalition is the optimal strategy if there are no sanctions. However, credible sanctions are difficult to design (Barrett. 1994). Emissions themselves are hardly a credible sanction, because countries are unlikely to sustain self-damaging policies. Moreover, in this case, asymmetries play a double role. On the one hand, some countries may not gain from signing the environmental agreement; on the other hand, some countries, even when gaining from environmental co-operation, may lose from carrying out the economic sanctions (Barrett, 1997; Schmidt 1997).

- *The absence of environmental leadership.* It has been shown that the process of achieving a global agreement can be a sequential one (Carraro and Siniscalco, 1993). In this case a group of countries take the leadership, start reducing/controlling emissions and implement strategies such to induce other countries to follow.[12] The presence of low costs climate policies and equitable burden sharing (Schmidt, 1998) are again important elements for the formation of an initial profitable coalition. As said., our definition of profitability accounts for the environmental benefits of emission control. Hence, on the one hand, benefits should be increased by increasing the number of countries that control emissions. On the other hand, abatement costs should be minimised by exploiting all possible opportunities (including emission trading). This a pre-requisite to achieve a strong leader coalition that can then exert its leadership through the design of better negotiation rules, the implementation of transfer mechanisms, the credibility of international issue linkages. A preliminary modelling of the effects of leadership is Jacoby et al. (1998) where it shown how and when developing countries may join a leader coalition formed by Annex 1 countries.

- *The focus on a single international climate agreement*. As explained in section 2, if countries may join different coalitions, which means that several agreements can be signed by groups of countries in the same way as countries form trade blocs, then the likelihood that all or almost all countries set emission reduction targets increases (Bloch, 1997; Carraro, 1997, 1998; Yi, 1999, Yi and Shin 1994). The outcome of negotiations in which more agreements can be signed is usually a situation with several small environmental blocs (Carraro and Moriconi, 1998; Yi, 1999), but this can be considered another step in the right direction. If all or almost all countries set emission reduction targets within their own bloc (e.g. regional environmental agreements are signed), then, in a subsequent phase, negotiations among blocs may lead to more ambitious emission reductions.

Despite the warning that global agreement may be difficult to reach, many articles analyses the costs of agreements in which all countries participate, in one form or another (see e.g. Bosello and Roson 1999; Capros 1998, Ellerman et al. 1998; Manne and Richels 1998, Nordhaus and Boyer 1999; Shakleton, 1998). The weakest form is the one, already discussed in section 3.3, in which a few countries commit to emission reductions, but all accept to trade emissions in a single global market. The strongest form is the one in which a central planner is assumed to set optimal emission levels for all world countries. This optimal solution is often proposed as a benchmark for actual negotiations and was often analysed before Kyoto (see the collection of papers in Carraro, 1999).

12 See Carraro (1999b) and Grubb(1999) for a more detailed analysis.

More interesting is the attempt made by Peck and Teisberg (1999) to model the negotiations between developed and developing countries to achieve a global agreements. This paper shows the potential for co-operation to be achieved – the Pareto frontier is small, but not empty – but does not analyse the incentives to actually sign the agreement. However, the paper suggests a research direction which at least helps identifying the optimal emission reductions which are profitable for all negotiating countries.

The conclusions that can be derived from this type of empirical analyses are similar to the ones already mentioned when discussing partial agreements. In the scenario in which BAU emissions are lower, it is easier to achieve a global agreement because lower emissions reductions are necessary (Barrett, 1997b) and consequently abatement costs are lower. Optimal emissions targets are such to equalise marginal abatement costs. This optimal, cost minimising solution, can also be achieved through an unconstrained emission trading system (Chander et al., 1999). Hence, either emission targets are optimally set, or countries are allowed to trade emissions for any given set of targets through which a global consensus can be achieved. Of course, these two options have different impacts on equity. As shown in Bosello-Roson (1999), starting from the Kyoto targets, global unconstrained emission trading achieves optimality but reduces equity.

4. Conclusions

The costs and benefits of different policy options (i.e. the timing of optimal responses to climate change, the choice between mitigation and adaptation responses, the role of technological innovation and diffusion, the choice between domestic action and the adoption of "flexibility mechanism", the importance of secondary benefits, etc.) crucially depend on the characteristics of the international agreement on climate change which is adopted. In particular, they depend upon two main features of the international regime: (i) the number of signatories; (ii) the size of their quantitative commitment to control GHGs emissions.

It is therefore impossible to assess costs and benefits of the Kyoto protocol or of other potential agreements on climate change independently of the number of signatories of the agreement and of their abatement targets and/or policy commitment. But at the same time the number of signatories is endogenous and depends on the abatement targets and mitigation polices adopted in various countries. Hence, the weakness of most of the available literature on costs and benefits of climate change policies, which widely neglects the full interdependency between policies, costs/benefits and signatories (more generally the structure of the climate agreement). Let us make an example. There are studies that analyse the costs of implementing the Kyoto protocol either through a set of domestic policies and measures or through a system of international tradable permits, keeping as given the number of signatories. But the adoption of either policy crucially affects the number of signatories which can be larger or lower under policies and measures than under tradable permits. And the number (and identity) of signatories crucially affects costs and benefits of different agreements.

Therefore, in this paper we provided an analysis of the effectiveness of climate policies by focusing on the link between policy options and structure of the agreements and of the international regimes. First, we reviewed some of the most important theoretical results and then we re-organised the existing literature in order to see which information it provides on the interdependencies described above. In particular, this paper analysed whether there exist the conditions for an agreement on climate change to be signed by all or almost all world countries; and which countries can play a leadership role with respect to the goal of achieving the largest possible coalition by proposing strategies, measures, institutions that help expanding the number of countries which commit to control their emissions. Notice that in this way this paper also analysed which strategies can be proposed to reduce the costs of mitigation policies. But this is quite a different way from the ones analysed in other papers on climate policy. The reason is that here a country's goal is not to identify a new climate friendly technology or an adequate re-distribution of costs across sectors. Now the goal is to affect other countries' behaviour in order to increase the number of those which share the burden and to make this burden more equitable shared.

There are some relevant guidelines that emerge from the literature surveyed in this paper. Two main dimensions have been identified (see Table 1). The policy dimension moves from domestic to global policies. The coalition dimension moves from unilateral to global actions. It is not necessary to move along both dimensions to achieve optimality. Even a sub-optimal distribution of targets across countries can be consistent with optimal emission reduction schemes if coupled with a global policy (e.g. a global system of emission trading). Alternatively, a global coalition can optimally set emission targets in order to minimise abatement costs. Hence, the move along one dimension may be sufficient.

However, it is quite difficult to identify as likely a scenario in which either a global coalition forms or a global and perfectly competitive emission trading system is implemented. Hence, we are left with a world in which only a subset of

countries may decide to commit themselves to emission control and only a subset of countries, not necessarily the same countries, may decide to participate in a freely competitive trading system. In this case, there are two options:

- One option is to design policies that induce countries which are not committed to emission control to accept this commitment. This can be done through appropriate policies that, on the one hand reduce the cost of the commitment (e.g. competitive emission trading again) and on the other hand increase the benefit of the commitment by means of transfers or by linking the climate agreement to other economic agreements (e.g. on technological co-operation).

- A second option is to recognise that countries' main incentive is to form several coalitions which may adopt different policy measures. Is there any evidence that it is optimal to force countries to a single coalition? The answer is negative, but from the reviewed studies we can conclude that it is optimal, at least in terms of costs, to induce countries to adopt a single competitive market for emission permits. Hence, countries could be freer to design regional agreements which adopt the cost minimising policy options to combat climate change.

The common denominator of these two options is that the attention should move from targets to policy (the same point was also made by Nordhaus, 1999). An adequate choice of policy measures can indeed offset the inevitable (because of political reasons) and possibly welcome (because it makes the process start) sub-optimality of choices made on emission targets. If the optimal policy can hardly be adopted for political or equity reasons, countries can use transfers or issue linkage strategies to achieve both a better cost distribution and a larger number of signatories. These policy strategies, when coupled with cost minimising abatement policies (e.g. emission trading), can achieve both economic efficiency and environmental effectiveness.

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