

6-25-2013

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## Recommended Citation

Sferra, Fabio and Tavoni, Massimo, "Endogenous Participation in a Partial Climate Agreement with Open Entry: A Numerical Assessment" (June 25, 2013). *Fondazione Eni Enrico Mattei Working Papers*. Paper 811.  
<http://services.bepress.com/feem/paper811>

# ENDOGENOUS PARTICIPATION IN A PARTIAL CLIMATE AGREEMENT WITH OPEN ENTRY: A NUMERICAL ASSESSMENT

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May 2013

## Abstract

*Our purpose is to analyse the effectiveness and efficiency of a Partial Climate Agreement with open entry under a non-cooperative Nash-Equilibrium framework. We evaluate a partial agreement policy in which non-signatory countries can decide to join or to leave a coalition of the willing at any point in time. By means of a simple analytical model and of a numerical integrated assessment model, we assess different coalition structures, and different minimum admission requirements. Our results indicate that a Partial Climate Agreement with open entry can be effective, achieving climate stabilization between 2C and 3C depending on the composition of the coalition of the willing. The policy turns out to be also rather efficient, with only minor losses with respect to a full cooperation agreement. Finally, we quantify the optimal admission requirement in about 40-50% of cumulative abatement.*

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## ACKNOWLEDGEMENT:

The research leading to these results has received funding from the European Community's Seventh Framework Programme FP7/2007-2013 under grant agreements n° 282846 (LIMITS) and n° 266992 (Global IQ).

## 1. Introduction

The aim of this paper is to analyse the implications of a Partial Climate Agreement (PCA) with open entry under a non-cooperative Nash-Equilibrium framework. By partial climate agreement with open entry we mean an international climate policy in which a group of willing countries commit to emissions reductions over time, and where the remaining countries can decide to join and leave the coalition at any point in time. Participation in the agreement happens through carbon trading, and admission can be restricted by the coalition of the willing by means of minimum targets of emissions reductions. We aim at understanding to what extent such a PCA can yield emissions reductions which are effective and cost efficient, and to ascertain the optimal admission requirements for non-signatory countries. This set up is motivated by the recognition that even though full cooperation achieves optimality as measured both in terms of effectiveness and efficiency, it is known to be very hard to sustain. The political capital supporting large international climate agreements is low, despite the outcome of the Durban and Doha negotiation rounds. However, some regions or countries continue to show a commitment to reducing their own emissions, most notably the EU, Australia, some US states and maybe also the US as a whole if one is optimistic about the recent statements of the just re-elected president Obama. The extension of the Kyoto protocol in Doha till 2020 ensures that global carbon trading will avoid a sudden collapse, but is unlikely to significantly increase the prices of certificates above their current historical lows due to oversupply and the recent economic downturn in Europe. The future of a global emissions cap-and-trade system is at a crucial point in negotiation, and will depend on what agreement will emerge from the Durban platform, which is ideally designed to involve all the major players (and not just industrialized countries). A bottom up approach of pledge and review might be the most likely outcome, but concerns about cost containment might eventually promote linkage of different carbon markets (as already announced between Europe and Australia). In essence, a partial agreement with some form of international linkage of carbon trading schemes might emerge as a possible outcome in the future of international climate policy, as a compromise between inclusiveness and cost control.

The problem of free riding and of carbon leakage represents the strongest argument against partial climate agreements, since it leads to a relocation of GHG emissions from the group of countries advocating the deal to the non-signatory regions. The idea of this paper is to shed light on the efficiency and effectiveness of a partial agreement with open membership, in which a coalition of willing regions commit to emissions

reductions, and the remaining countries can in any point in time decide whether to join or to leave the coalition, a step intended to reduce cross-border carbon leakage. Our purpose is to detect to which extent an allocation of carbon endowment for the non-signatory nations could provide an encouragement for coalition undertaking that is more attractive than the incentive to free ride.

In such a context, we demonstrate that the regions outside the climate arrangement have a strong incentive in joining the coalition if their commitment is lower than the pledge of the coalition. We also assess the role of admission requirements, in the form of minimum emissions reductions targets, in terms of participation to the PCA and to overall effectiveness in reducing global temperature increase. This policy scheme does not tackle the fundamental problem of why a coalition of the willing should form and remain stable in the first place. It embeds the assumption that some group of countries would commit to climate change mitigation irrespective of what the others would do, a proposition which violates standard economic sense but which can be actually observed in the behaviour of some regions. The main contribution of our work is to lay down a simple model for thinking about the climate and economic consequences of a partial agreement, and to test those using a numerical Integrated Assessment Model (IAM) with a game theoretic set-up which can describe the reality of mitigation in a more accurate fashion.

In particular, this paper addresses the following research questions: are PCAs (Partial Climate Agreements) with open entry more efficient compared to the case without open membership? If a PCA with open entry is implemented, what loss of efficiency compared to an agreement with full (exogenous) participation will we have? What are the optimal entry requirements? What climate target can be attained by such a policy proposal?

The paper is organised as follow: section 2 describes the partial agreement policy and connects it to the literature on climate coalitions, section 3 presents a simple analytical model and describes the implementation WITCH integrated assessment model, section 4 illustrates the results and section 5 concludes.

## **2. Open Partial agreement and relation to the literature**

A bargain for climate change which involves all the main GHG emitters will eventually be needed if we strive to achieve climate stabilization at a safe level (Clarke et. al, 2009).

The main problem regarding optimal emission control strategies concerns the stability of the coalition, which has been analysed in D'Aspremont et al (1983) by providing the definition of internally and externally stable coalition. A coalition is internally stable if no region belonging to the coalition has the incentive to defect, and therefore playing as singleton. It is externally stable if no region outside the coalition is better off to join the coalition. Many authors have analysed the case of a grand coalition, pointing out that is not stable, as the players have the incentive to free ride on that and so defect from the agreement: Carraro and Siniscalco (1993), Eyckmans et al. (1993), Barrett (1994), Nordhaus and Yang (1996), Tol (1999), Bosetti et al (2009).

When stable IEA (International Environmental Agreements) exist, they are endorsed by a limited number of countries: Hoel (1991), Carraro and Siniscalco (1992), Tol (2001), Finus and Altamirano-Cabrera (2006).

Harstad (1997) has analysed the counterproductive role of side-payments in a bargaining context, and Konrad and Thum (2011) have focused on the case of unilateral commitment in a context of asymmetric information, arguing that pre-commitment reduces the potential gains from cooperation. By contrast, our results show that side payments are able to entice non-signatory countries in the coalition and this can be explained by the fact that these are not “take-it-or-leave-it” offers (chosen by the signatory agents to maximise their expected payoff), but they emerge as an outcome of carbon market equilibrium.

Regarding the stability of the scenarios analysed in this paper – they are by definition externally stable since non-signatories can freely join the agreement without the consent of signatories. This concept is also known as ‘stability under open membership’ (Finus et al. 2005). However, we do not focus on the internal stability since we are focusing on a policy in which signatories commit to emission reductions irrespective of the consequences this would have on the climate. That is, the analysis is carried out in a cost effective mode in which we do not consider the benefits associated with the avoided climate change impacts. We justify this assumption by observing that in practice some regions and countries have already committed to individual pledges of emissions reductions, either directly by means of emissions quotas or indirectly through technology policies in favour of low carbon options. This behaviour reflects the high willingness to pay for emissions reductions in some countries and especially by some constituencies, as well as the positive linkage of mitigation policies to other policies of national interest, such as air pollution reduction, energy security, innovation and competitiveness etc.

The literature has indeed provided some motivations about why a subset of countries should contribute with a voluntary provision of public goods. In particular Hirshleifer (1983) has shown that if the global provision of public goods is not given by the sum of the single players, it can explain a large number of unselfish behaviour. Carraro et al (2009 and 2011) suggest that in oligopolistic market a voluntary agreement belongs to equilibrium only if a minimum participation rule is guaranteed. Owen (2008) has also showed that the results in coalition formation games are highly dependent to the initial conditions, suggesting that even a small change can lead to very different results. Sandler (1998) has focused on the facilitator and inhibitors of collective actions at the worldwide level, suggesting that the way single player choose individual provision levels, has a huge role to play for the possibility of a collective actions. Lee (2012) has provided a model in which  $n$  players compete to win a specified social good prize and argued the existence of a unique stable Nash-Equilibrium in which neither any player or group has the incentive to deviate from the equilibrium.

Despite some nations have already announced their plan to promote low carbon technologies and to contain GHG emissions, many other countries have been reluctant to accept mitigation commitments with the fear that those would undermine their economic growth. In such a context, the aim of our work is to focus on a climate policy architecture capable of reconciling reluctant nations with the overall climate change objective. As the problem of carbon leakage could jeopardize the effectiveness of a partial agreement, this policy

scheme entails an accord with open membership which is meant to engage regions in the mitigation efforts while at the same time relieve the welfare losses of the initial ratifiers. The openness of the agreement is intended at cutting barriers between the signatory countries and the unwilling regions, by allowing for a different carbon entitlement allocation which combines the interests of the willing nations and of the remaining regions which are assumed to be more lenient as they could ill-afford the policy cost of a stringent environmental settlement. Taking as given the commitment of the coalition of the willing, the advantages of this scheme lie in the fact that signatory states have the possibility to settle on some unilateral mitigation actions at an affordable cost without fretting on carbon leakage issues, and the developing regions could benefit from carbon revenues. Under this framework, stand-alone policies might hold sway over the adverse countries – as they are cajoled with the possibility of earnings from carbon revenues – by extending the breadth of the coalition. In the model that will be presented in the next sections, the non-signatory regions can endogenously decide whether to enter or not in the emission trading scheme and their choice will be done on the basis of cost-benefit analysis. If the non-signatory countries agree to participate in, the entire world can reap the benefit of a concerted action against global warming. If the adverse nations refuse to take part of the treaty, the outcome will be the same as the case of a partial agreement with no open entry.

Regarding the engagement of the developing countries, Leimbach (2003) and Philiber (2000) have already pointed out that many of them could benefit from joining an emission trading scheme. Buchholz et al. (2012) has also investigated the consequences of partial cooperation between like-minded countries, but not the case where only a subset of the players participates. Montero (1998) has focused on tradable permit system with optimal opt-in using the EPPA model, suggesting that it might be optimal to set the opt-in allocation rule above the expected baseline. Viguier (2004) has proposed a rent-sharing approach, which would guarantee abatement efforts on a voluntary basis for some developing nations. In this paper we build-up on his hint with a model that allows for endogenous participation to a climate agreement with open entry. An important assumption of this scheme, as already noted, is that we take as given the commitment of a group of committed countries. To assess a broad set of potential policies, we assess different sizes and composition of this coalition of the willing. In all cases, we assume that the coalition of the willing (whatever that would be) commits to emissions reductions which are consistent with a 450 ppm-e target on a global basis, in the case of full participation. The 450 ppm-eq target is an important signpost for policy and science, since it is the only climate target which is consistent with a reasonable probability to maintain global temperature increase below 2C. According to the integrated assessment model used in this paper, attaining this global climate target in an idealized setting of global cooperation entails emissions reductions in the order of 70% for the world in 2050 with respect to 2005, and of about 90% for developed countries and 60% for developing ones. These regional emissions commitments are roughly in line with the proposal of the major economies forum meeting of 2009, and it is the one which we adopt for this paper for the coalition of the willing.

In such a context the determination of the admission requirements to the PCA is an important issue, in order to set up an optimal carbon strategy. On one hand if the entrance requisites are too loose, the climate target that would be achieved on a global level will not be significant. On the other hand, if the entry requirements

are too ambitious, the non-signatory countries could resolve to opt out, and carry on with unrestricted emissions, again leading to a warmer climate. This paper focuses on calculating the optimal admittance requirements both analytically or numerically.

The identification of entry requirements embeds the financial flows which will be funnelled to the non-signatory countries (tougher entry requirements imply additional financial transfers), that are also driven by the relative marginal costs of abatement. In our framework we assume that the agents are not identical, as they are characterized by different abatement cost function. Thereby, as already mentioned in Chander and Tulkens (1994) the side-payments play a pivotal role if the climate proposal entails voluntary participation (gamma core stability concept). Finus et al (2006) found that stable coalitions might emerge if the environmental benefits are sufficiently high or if a proper transfer scheme is introduced. Carbone et al (2009) established that emission trade can be effective even if countries are guided by their national self-interest. Moreover they argued that when players choose emission permit non-cooperatively an extension of the coalition might lead to higher global emission levels. Gersbach and Winkler (2011) have shown that a carbon market with refunding leads to a Pareto-superior condition compared to a canonical international market of permits and another paper (Gersbach et al. 2011) provides ways of raising initial fees.

In our model the participation of non-signatory countries reduces the level of domestic abatement required for the initial ratifiers, and thus it can be recognised as a Clean Development Mechanism (CDM) or Joint Implementation (JI). We assume that such markets do not have transaction costs, and that they are perfectly monitorable. This is a strong assumption, especially when compared to the actual experience of the CDM markets, which has highlighted several deficiencies (Wara and Victor 2008). Nonetheless, this flexibility mechanism has remained in place to date (and to 2020), and given its potential for cost containment is likely to remain in some form or another also in the future. According to Michaleowa (2005) the CDM could alleviate poverty in developing nations and that abatement initiatives should be ODA (Official Development Assistance) financed. Financial flows from rich to poor nations arising from a carbon trading scheme, according to Hof et al (2010), can also be viewed as compensation for climate change damages and adaptation costs, since the developing regions are generally exposed more to global warming impacts.

In our paper we do not assume any sanctions or punitive measures for the non-signatory countries which eventually will forsake the coalition. Regarding the effect of sanctions on coalition formation, on one hand they have been shown to potentially have a significant influence on coalition undertaking (Lessmann et al. (2009)); on the other hand, Kemfert et al. (2004, 2005, 2006) has shown that trade restrictions not necessarily are an incentive for non-cooperating countries to adhere to the coalition and that R&D spillovers can promote participation.

Concerning the political feasibility of an environmental treaty, Bosetti and Frankel (2011) have provided a framework for quantitative emission allocations. Flachsland et al. (2009) has analysed different typologies of trading architectures classified in “top-down” approaches (driven by UNFCCC) and “bottom-up” approaches (driven by single countries), by showing a trade-off between political feasibility and climate effectiveness.

To avoid confusion, we would like also to shed light on the terminology used in this paper. We refer to “signatory countries” as the initial ratifiers of the agreement which cannot bail-out the mitigation plan, and that aim at cutting carbon emissions according to the carbon budget just described. We use the term “non-signatory countries” for those regions (typically the emerging economies) which have not ratified the initial agreement but which can join (or desert) the coalition in any point in time. It is important to note that we refer to those regions as “non-signatory countries” even if and when they choose to enrol into the coalition.

### 3 Methodology

In this study we first sketch out a simple static model which we can be solved analytically and then move to the implementation into an advanced intertemporal model which is solved numerically.

#### 3.1 A Simple Analytical Static Model

We begin by sketching a simple static model which allows us to compute analytically the optimal entry requirements for the non-signatories, for specific assumptions about the functional forms of the abatement cost.

In this model we consider two agents: on one hand the subscriber agent ( $s$ ) which cannot defect from the agreement and on the other hand the non-signatory player ( $n$ ) which can decide endogenously whether to participate in or to stay outside of the treaty. For sake of simplicity we do not allow for negative GHG emissions, so we constrain the amounts of relative abatement to be bound between zero and one.

The objective function (total costs to be minimised) for the signatory is as follows:

$$Obj_s = -p(a_s - \bar{a}) + c_s a_s^h \quad 1)$$

where  $p$  is the price of carbon permits,  $a_s$  is the actual level of abatement accomplished,  $\bar{a}$  is the emission target required by the climate agreement (in terms of percent of abatement compared to the BaU scenario),  $c_s$  is a non-negative region specific parameter of the Cost of Abatement and  $h$  is the exponent (we assume  $h > 0$ ). The use of a power law formulation for the abatement cost functions is supported by the literature which calibrates marginal abatement schedules, and also from what is generated from the WITCH integrated assessment model as shown later in the paper. The aim of the signatory player is to minimize total costs under a climate policy agreement, given by the net import of permits  $-p(a_s - \bar{a})$  plus the Cost of Abatement  $c_s a_s^h$ . In this version of the model we do not consider investments (since it is a static model) and we simply assume a cost minimization game considering a marginal cost of abatement (MAC) and the gains/losses from carbon trade activity.

Equation 2 provides the objective function to be minimized by the non-signatory agent:

$$Obj_n = \min[0, -p(a_n - \tilde{a})] + c_n a_n^h \quad 2)$$

The only difference compared to equation 1 is that the contribution of carbon trade activity to the total cost can only be negative (we use a *min* function), as the agent can decide freely to join the climate accord. In such a context, we define  $\tilde{a}$  as the entry requirement for the non-signatory agent, in term of minimum percent of abatement compared to the BaU.

If the non-signatory agent decides to not participate, his optimal abatement is equal to zero, and trade of permits does not take place as the signatory player will accomplish his carbon target only through domestic abatement:  $a_s^* = \bar{a}$ . If the non-signatory player does participate, carbon trade emerges and consequently also financial transfers between the two agents. In this case the price of permit in equilibrium can be determined by imposing the market clearing condition:

$$a_n - \tilde{a} + a_s - \bar{a} = 0 \quad 3)$$

We can easily compute the First Order Condition (FOC) of the two agents to determine the optimal level of abatement for the two agents, as well as the carbon price, as:

Solutions (FOC)	Participation case: <i>If</i> $p(a_n - \tilde{a}) < c_n a_n^h$	Non-Participation case: <i>If</i> $p(a_n - \tilde{a}) > c_n a_n^h$
$a_n^* =$	$\left(\frac{p}{hc_n}\right)^{1/(h-1)}$	0
$a_s^* =$	$\left(\frac{p}{hc_s}\right)^{1/(h-1)}$	$\bar{a}$
$p^* =$	$c_s c_n h \left( \frac{(\tilde{a} + \bar{a})}{c_n^{1/(h-1)} + c_s^{1/(h-1)}} \right)^{h-1}$	—

Table 1: Solutions – First Order Condition (FOC)

It is also trivial to show that the solution we get when the non-signatory agent agrees to participate is more efficient compared to the case of a unilateral effort, as the same climate target can be achieved with a lower marginal cost of abatement

$$. (\tilde{a} + \bar{a}) \frac{cn^{\frac{1}{h-1}}}{\left(\frac{1}{cs^{h-1}} + cn^{\frac{1}{h-1}}\right)} < (\tilde{a} + \bar{a}) \quad 4)$$

Expression 4 demonstrates that a partial climate agreement with open entry is a dominant strategy compared with the case without open entry, as it is able to alleviate the policy cost of the signatory player given the same global climate target (if both  $c_n$  and  $c_s$  are greater than zero).

The model also allows us to ascertain the optimal access requirement set by the signatory countries for the non-signatory one. We define the “optimal entry requirement” from the perspective of the coalition of the willing as the minimum emission reduction target required to be admitted to the climate agreement and which ensures the maximum abatement of the non-signatory player. As the reluctant player will participate only if the revenues from carbon trade activity exceed the cost of abatement, the optimal admittance requirements needs to satisfy the solving equation 5:

$$p(a_n - \tilde{a}) \geq c_n a_n^h \quad 5)$$

By substituting  $a_n$  with  $a_n^*$ , and then  $p$  with  $p^*$ , we can calculate the admission conditions in equation 6 (we have omitted other solutions implying negative entry requirements):

$$\tilde{a}^* \leq \frac{(h-1) \bar{a}}{h \left(\frac{c_n}{c_s}\right)^{\frac{1}{h-1}} + 1} \quad 6)$$

If the aim of the signatory player is to maximize the amount of abatement of the demurring agent (and thus abatement at the worldwide level) the equality holds in equation 6.

The formula reveals that the optimal admittance requisite is a fixed ratio of the commitment of the signatory, which depends on the abatement cost functions in the two regions. Figure 1 plots the behavior of  $\tilde{a}^*/\bar{a}$  as a function of  $h$  and  $c_n/c_s$ . In line with intuition, it shows that a lower cost ratio between non-signatories and signatories  $(c_n/c_s)^1$  implies a higher entry requirement, given that the trading system equalizes marginal abatement costs between the two agents. Interestingly, if this ratio is sufficiently small (below 10%), the optimal admission requirement for the non-signatory player could be more stringent than the commitment of the subscriber agent. Similarly, an increase in  $(h)$  – which implies a reduction of the marginal cost of abatement for both agents<sup>2</sup> – increases the the optimal entry requirement with respect to the target of the signatory player, with equalization of the two at the limit:  $\frac{\tilde{a}^*}{\bar{a}} = 1$  if  $h \rightarrow \infty$ .

<sup>1</sup>  $c_n/c_s$  represents the ratio of total as well as marginal abatement costs for the same level of abatement in the two regions.

<sup>2</sup> We assume that the amount of abatement ( $x$ ) is constrained between 0 and 1. Thus an increase in  $h$  implies a lower marginal cost of abatement.

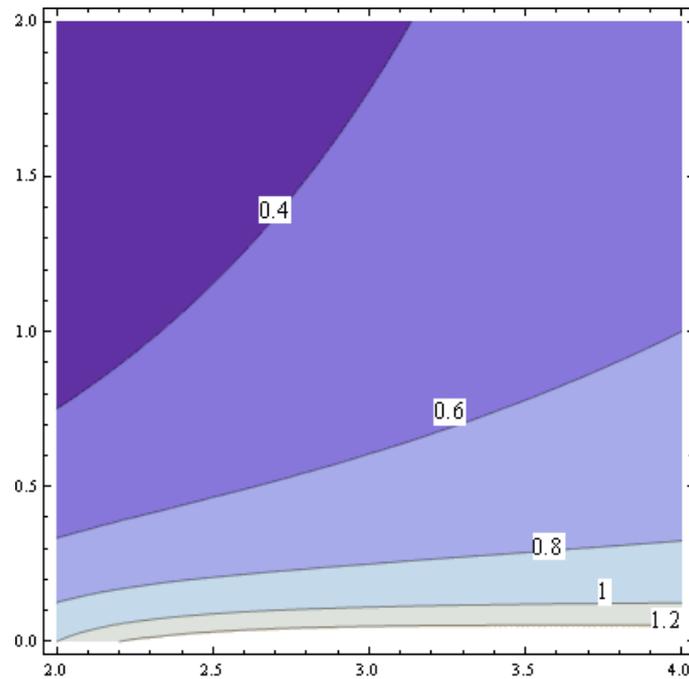


Figure 1: Contour plot of  $\tilde{a}^*/\bar{a}$  as a function of  $h$  (x axis) and  $c_n/c_s$  (y axis).

Ultimately, the optimal entry requirement will depend on the calibration of the abatement cost function for the two regions. If we assume quadratic marginal costs (e.g.  $h=3$ ) and symmetric countries (e.g.  $\frac{c_n}{c_s} = 1$ ), the optimal entry requirement for non-signatories will be exactly half of the commitment of the signatories (e.g.  $\frac{\tilde{a}^*}{\bar{a}} = .5$ ). If the non-signatories have lower abatement costs, as sometimes assumed to be the case in developing economies which have more room for efficiency improvements, with marginal costs 50% lower, then the ratio between the optimal entry and the signatory commitment would be roughly 65%. We will come back to this simple model after the discussion of the numerical integrated assessment model results, calibrating the parameters to the MAC which are generated by the WITCH model.

This model is very simplified, in that it assumes a static setting, specific functional forms for abatement costs, and a two region setting. In the next section we generalize this approach and explain how we have incorporated the partial cooperation agreement into a more sophisticated and realistic dynamic setting .

### 3.2. Implementation in the WITCH model

The WITCH model (World Induced Technical Change Hybrid Model)<sup>3</sup> is an integrated assessment model developed at FEEM with the aim to provide a comprehensive analysis of international climate change policies in terms of optimal mitigation strategies under different policy instruments. The Model is made up of 13 macro-economic regions. It is hybrid since it combines a top-down description of the economic sector

<sup>3</sup> For a full description of the model please refer to Bosetti, Massetti and Tavoni (2007) and Bosetti et al (2009). The website [www.witchmodel.org](http://www.witchmodel.org) contains useful information on the model.

(which is described by a Ramsey-type optimal growth model) and a compact representation of the mitigation options in the energy and land use sectors.

The WITCH model can be run both using a cooperative solution (which internalises all the externalities) or a non-cooperative (decentralised) solution. All the results presented in this paper have been run using a non-cooperative framework, and therefore each region is playing strategically as a response of the other regions' best responses.

When choosing optimal investment paths over the century, each region is forward looking and maximise its social welfare (defined as the logarithm of discounted consumption per capita) given the choice of the other players. As a result the outcome of the model is an Open Loop Nash Equilibrium that takes into account the role of multiple externalities. An interesting feature of the WITCH model is the endogenous technical change and the prominent role of technological spillovers among countries, including both investments in R&D and learning by doing effect. Other externalities comprise, fuel prices and GHG releases, emission permit trading and energy resources use. This version of the model also allows for trade of oil (Massetti and Sferra 2010) and entails dedicated investments in the oil extraction sector.

When a climate policy scenario is run, a carbon trading system allows for transfer of carbon credits across regions, in any time period. The price of permits emerges as an outcome of a Nash Equilibrium, and it is adjusted iteratively according to a Walrasian-Tatônnement process, to yield equilibrium between supply and demand. The time horizon of the model is 2005-2100 using a five-year time step, which makes it well suited to address long-term climate policies.

In this paper we have enhanced the WITCH model by introducing the endogenous participation feature. All the equations regarding the implementation into the WITCH model are reported in Appendix 1. Yet, the equations are different as we distinguish between signatory and non-signatory regions. Basically the signatory countries have an upper bound on carbon emissions (equation A1) which is consistent with a 450 ppm target at the global level (the regional target convergences to an equal per capita scheme in 2050, according to a full participation backdrop at a global level). Then all the regions have full intertemporal flexibility through banking and borrowing. Therefore in each point in time (since the climate accord starts) each region can choose to bank emission permits to the future or to make early use of carbon allowances in case of borrowing. Through banking and borrowing, we intend to allow for the maximum flexibility as possible in the market. Hence, we do also consent to save the carbon permits purchased on the market, and to eventually sell it in the future. Nevertheless, in order to prevent an excess of speculation activities – and then problems in clearing the carbon market – we disqualify the agents from importing more permits compared to their actual needs (cumulative carbon budget) throughout the century (equation A3). In fact, if a region imports more carbon credits than its actual needs (difference between cumulative emissions and its carbon budget) it is only for a pure speculation purpose, inspired by the expectation of selling permits at a higher price. However we it is important to remark that we this condition is not binding if the cumulative amount of net imported permits throughout the century is negative (or in other words if the agent is a net seller of

permits), which can be seen as an incentive for the exporting regions, as they bear the brunt of the stabilisation efforts.

In our scheme we do assume that the commitment  $e$  required to join the coalition for the averse nations will gradually tighten over time, starting from a 0% abatement required when the climate accord starts (2015 in our model), and which will linearly increase up to  $E\%$  in 2100. The reason why the carbon burden is loose in the early periods is to entice the unwilling countries in the treaty. Then, prompt investments in low carbon technologies and energy R&D are likely to trigger the virtuous processes of learning by doing and learning by researching, by making less tempting a breach of the agreement. In the next sections we analyse how a change in the admission requirement  $E$  will influence the participation choice of the outsider players.

Basically, the demurring nations can take advantage from carbon rents only if they are reducing GHG by at least  $e\%$  compared to the BaU scenario, so that any additional amount of abatement can be traded in the carbon market (equation A4). Carbon revenues embody the worth of coalitions for the reluctant countries; in fact we do not consider the damage function, so we are assuming that global warming has no impact on GDP growth.

An interesting feature of our model is that also the non-signatory regions have full intertemporal flexibility through banking and borrowing condition (equation A5) and they can either short sell or hoard carbon credit offsets (and postpone sales when the carbon price is higher). This assumption is quite important since the developing countries are eager to raise funds today, even if that would imply a lower consumption tomorrow as a result of mitigation efforts. Conceivably, the magnitude of this intertemporal effect hinges on the parameterization of objective function, in particular regarding the pure rate of time preference and the elasticity of marginal utility of consumption (see Anthoff et al. 2009 and Dasgupta 2008 for further reference). However some carbon trade limitations should be enshrined in a proper environmental treaty. Conceivably, the regions which are participating in the carbon market, would not accept the intervention of the adverse regions inspired only by speculation purposes without undertaking any abatement action. Consequently we impose two further restrictions 1) the non-signatory regions are eligible to buy permits only if they are actually containing the emissions compared their target, in order to rule out from the trading scheme the countries that are not committed to GHG stabilisation efforts and 2) the maximum amount of imported permits should be proportional to the amount of tradable emission permits. Both of above conditions are imposed by equation A6.

It should be also kept in mind that it is possible to join and quit the mitigation treaty multiple times. Therefore we assume that if the non-signatory countries stumble out the mitigation pact and then decide to embark the climate resolution in a further time period, they cannot eventually use erstwhile carbon credits accrued from a previous participation (equation A7).

When running the WITCH model, we assume that the subscriber countries commit to curtail GHG emissions, according to a path that is consistent with a 450 ppm-e scenario at the international level using a cap and trade framework, which starts in 2015. The players outside the partial environmental arrangement

have no constraints on GHG releases, but they can join it – and exchange permits on the carbon market– if they comply to at least a  $e\%$  of abatement compared to the Business as Usual scenario (BaU); so that any additional amount of GHG abatement can be traded in the carbon market. Of course, this might imply a pouring of money from the signatory to non-signatory countries.

We have run a number of simulations by changing the value of  $E$  (commitment for the non-signatory nations, as a percent of abatement in 2100) to appraise their response in terms of endogenous participation choice. Hence the outcome of the model is a OPANE – Open Partial Agreement Nash Equilibrium – with endogenous participation and the results will be presented in the next section.

We would like also to mention some limitations of our set up. The main caveat of our work is that we are assuming that all the regions are price taker, so that they cannot modify the carbon price by curbing carbon trade. Into the bargain we are not considering many co-benefits linked with GHG mitigation. In particular we are excluding from our analysis the climate change impacts on the economic activity (the damage function that links GHG impacts to the economic activity has been switched off). Other ancillary benefits that are not taken into account in our model are: human health improvements, biodiversity, energy security and other (avoided) cost of adaptation to global warming.

Finally, we assume that the non-signatory countries will adopt individually best-reply strategies as they will play as singletons.

## 4. Results

In this section we provide the results obtained from the Integrated Assessment Model WITCH. Then we compare the admission requirements assessed numerically by the WITCH model with the admission requirements computed analytically with the static model.

### 4.1 Results from the WITCH Model

In numerical simulations of the WITCH model we consider several structures of the partial climate agreement, by varying two dimensions: the first dimension refers to the composition of the coalition of the willing, and the second dimension refers to the entry requirements ( $E$ ) required to join the coalition for the non-signatories.

By varying the first dimension we are able to recognise how the size of the signatory regions will influence the investments decision in the rest of the world. We analyse four different situations by varying the number of countries enlisted among the signatory: EU, OECD, OECD+CHINA, and MEF<sup>4</sup> (Major Economies Forum

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<sup>4</sup> This scenario involves all the states partners of the Major Economies Forum on Energy and Climate (MEF) launched in March 2009. Further information is available at the following website: <http://www.majoreconomiesforum.org>

on Energy and Climate) scenario which includes all the economic aggregates except Middle East and North Africa, Sub-Saharan Africa and South Asia.

The second dimension – admission conditions (*E*) – allows us to analyse the optimal reaction of the non-ratifiers in terms of endogenous participation to the carbon trading scheme. As a result, it is possible to identify an efficient frontier for admission requirements which is aimed at minimising the policy cost of the coalition of the willing compared to the climate goal. In our simulations we consider nine increasing steps ranging from 10% to 90% of abatement required in 2100, to be achieved with a linear schedule starting from 0% in 2015. The next table summarises the main results obtained from the WITCH model for the 4 coalitions of the willing and the nine admission requirements for the non-signatories:

	Entry requirements ( <i>E</i> ): Percent of Abatement in 2100   non signatory countries									No Open Entry
	10%	20%	30%	40%	50%	60%	70%	80%	90%	
Temperature above pre-industrial levels in 2100 [Degree Celsius]										
EU	4.3	4.3	4.2	4.1	4.0	3.9	4.0	3.7	3.9	4.4
OECD	3.6	3.5	3.3	3.2	3.0	2.8	2.7	2.7	3.0	3.8
OECD + CHINA	3.0	2.9	2.8	2.7	2.6	2.4	2.3	2.3	2.5	3.2
MEF	2.2	2.1	2.1	2.0	2.0	1.9	1.9	2.0	2.0	2.2
Average Transfer of Money on yearly basis - from sign. to non-sign. countries [Billion USD]										
EU	1	3	4	5	8	9	16	18	21	0
OECD	25	33	44	57	69	89	108	133	135	0
OECD + CHINA	240	273	341	414	500	608	722	1,056	1,486	0
MEF	728	613	969	1,050	1,144	1,210	1,423	1,585	1,684	0
Cumulative Transfer of Money as a Share of Cumulative GDP (Discounted at 5%)										
EU	0.02%	0.04%	0.06%	0.07%	0.13%	0.15%	0.26%	0.29%	0.34%	0.00%
OECD	0.15%	0.20%	0.27%	0.35%	0.42%	0.55%	0.67%	0.82%	0.95%	0.00%
OECD + CHINA	0.79%	0.90%	1.07%	1.25%	1.42%	1.65%	1.88%	2.41%	3.09%	0.00%
MEF	1.94%	1.88%	1.96%	2.03%	2.05%	2.03%	2.07%	1.80%	1.68%	0.00%
Cumulative Carbon leakage - Non signatory countries [Gt CO <sub>2</sub> ]										
EU	-524	-618	-700	-849	-1,114	-1,368	-1,179	-1,672	-1,364	79
OECD	-1,731	-1,994	-2,247	-2,458	-2,757	-3,037	-3,213	-2,923	-2,181	70
OECD + CHINA	-1,956	-2,070	-2,183	-2,299	-2,400	-2,481	-2,559	-2,523	-1,961	272
MEF	-876	-887	-899	-914	-900	-895	-902	-683	-519	147
Ratio of Abatement: non-signatory vs signatory countries										
EU	41.31	30.59	26.60	30.13	25.29	26.05	12.77	17.07	11.64	-0.21
OECD	8.76	7.79	6.92	5.98	5.64	5.13	4.54	3.24	2.06	-0.04
OECD + CHINA	1.53	1.47	1.43	1.39	1.34	1.26	1.23	1.11	0.81	-0.09
MEF	0.21	0.21	0.21	0.21	0.20	0.20	0.19	0.14	0.11	-0.03
Discounted GDP losses for signatory countries										
EU	-0.10%	-0.07%	-0.06%	-0.05%	-0.01%	0.02%	0.17%	0.20%	0.26%	2.70%
OECD	0.08%	0.14%	0.22%	0.33%	0.42%	0.59%	0.78%	1.10%	1.42%	3.16%
OECD + CHINA	0.79%	0.93%	1.12%	1.33%	1.51%	1.81%	2.07%	2.51%	3.12%	6.77%
MEF	2.91%	3.00%	3.14%	3.31%	3.50%	3.71%	3.86%	3.96%	4.09%	4.40%

**Table 2 Endogenous Participation to a Partial Climate Agreement: Main Numerical Results**

Table 1 provides information on the main variable of interest, namely temperature, financial transfers (or side-payments), carbon leakage, ratio of abatement (signatory vs. non-signatory), and discounted policy cost

for the endorser countries. In the last column on the right we also display the results obtained with a partial climate accord without open entry, in order to appreciate the differences stimulated by the open membership of the treaty.

If we look at the global temperature increase in 2100 one can note that a partial climate agreement with open membership is capable of a lower temperature target compared to the case with no open entry. This improvement hinges on the abatement made on a voluntary basis by the non-signatory nations which endogenously choose to enrol the coalition and take advantage of carbon rents. Thus, an environmental bargain with open entry entails a reduction in emissions of the non-signatories, in contrast with the carbon leakage which would occur in the no open entry case. This result holds for all the considered coalitions of willing.

The mitigation made possible with the enlargement of the coalition, implies a side-payment from signatory to non-signatory nations, which might raise concerns about the political feasibility of such an agreement. If we look at the case where the subscriber states encompass the OECD, we can notice that average annual financial flows (during the period 2005 – 2100) range from 25 to 135 Billion \$/year<sup>5</sup>. In particular a climate target of 2.7° C can be achieved with an average transfer of money of 108 Billion \$/year. With the purpose of detecting whether this amount is politically sustainable, we can compare it with the historical transfer of money to developing countries for official development assistance. According to a paper published by the United Nations<sup>6</sup>, the year which recorded the maximum amount of transfer flows from rich to poor nations was 2010, when they amounted to 129 Billion USD. Therefore, according to our simulations, the same level of transfer would allow the OECD to induce sufficient cooperation to achieve a temperature target in 2100 of 2.7° Celsius above pre-industrial levels. This should be compared to a global temperature target of 3.8° Celsius for the same group of signatories but without the open entry mechanism, a policy which moreover would cost about 3 times the one with open entry. On the other hand, these side-payments would significantly increase when the coalition of the willing enlarges and achieves more stringent climate objectives, in which case they can exceed 1 Trillion per year (not discounted). It is also interesting to note that whilst global temperature shows a U shaped pattern as the admission requirements get stringent, the average transfer of money tends always to increase (with the only exception of the MEF scenarios, especially when  $E > 70\%$ ). This is motivated by the fact that non-signatory countries undertake always a certain degree participation in the agreement, though for a shorter time span. Even in case of stricter entry requirements, the amount of mitigation required in the early period is relatively small and this allow them to sell carbon credits at a high price of carbon (which anticipates the expectation of a future relinquishment of the non-signatory countries).

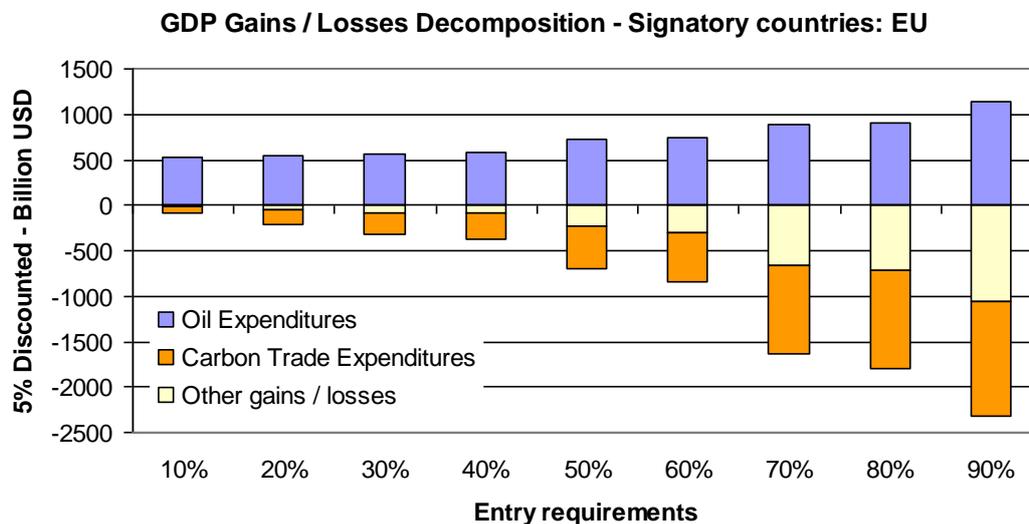
It would be also useful to compare the side-payments from signatory countries as a share of their GDP. To this end we have reported in table 2 the amount of cumulative transfer of money as a share of cumulative GDP (both discounted at a 5% rate). We can notice that an extension of the coalition of the willing leads

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<sup>5</sup> Constant 2005 USD.

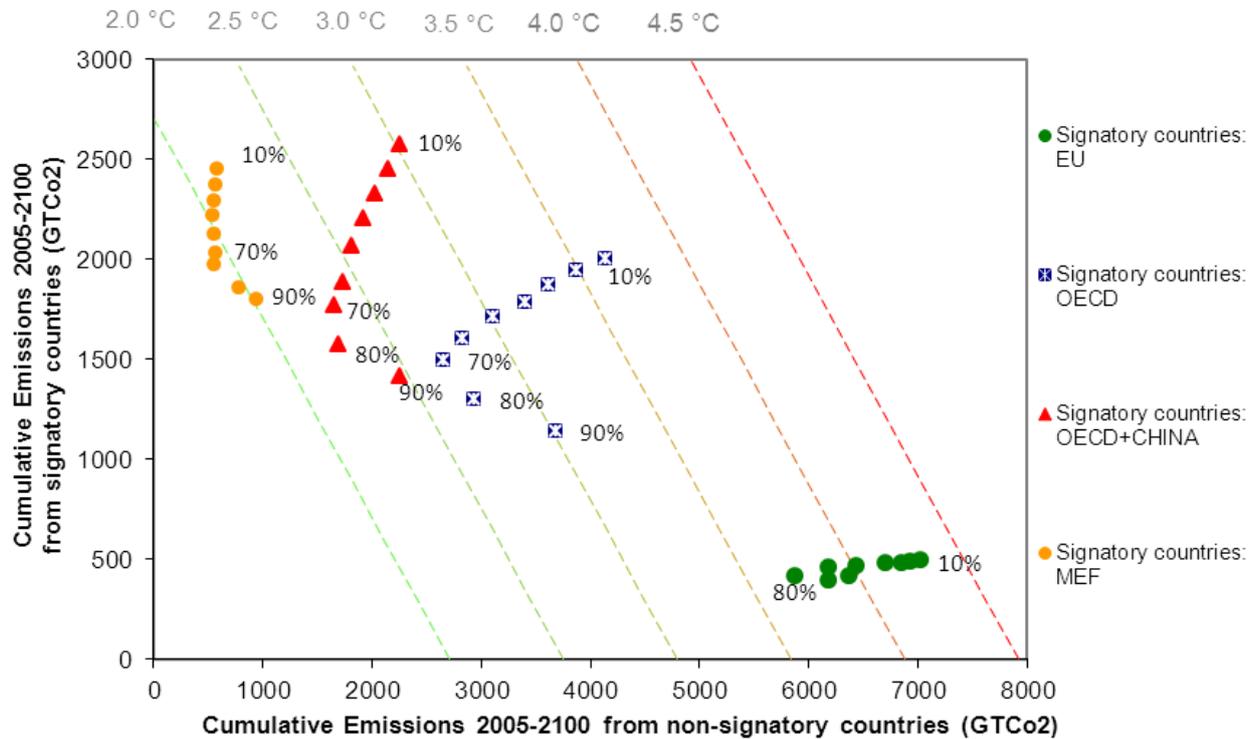
<sup>6</sup> Source: “World Economic Situation and Prospects 2012”. United Nations

always to an increase in the share. If we focus on the OECD case we can also observe that this share reaches 0.67% in the case of  $E=70\%$ . It is interesting to note that this value is in line with the ODA (Official Development Assistance) goal, which aim is to set a 0.7% of transfer from the OECD countries to the developing countries, in order to help them to achieve the MDGs (Millennium Development Goals). Other variable of interests are the amount of abatement carried out by the signatory regions compared to the abatement (or negative carbon leakage) taking place in the non-signatory states. We can notice that the level of abatement achieved by the non-signatory nations is usually higher than that of the signatories, particularly if the size of the signatory regions is small. In fact if only the European Countries are signatory, the abatement initiatives will be accomplished mostly in the developing countries, as a result of carbon trade activity. It is interesting to note that the money transfers (carbon trade expenditures) from the European to non-signatory countries are comparable with the oil rebate expenditures (Figure 2).



**Figure 2 GDP Gains / Losses Decomposition: EU Scenario**

Our numerical simulation also allows us to establish a clear relationship between the size of the coalition of the willing, the admission requirements and the optimal strategic response of the opposed regions in terms of GHG emissions.

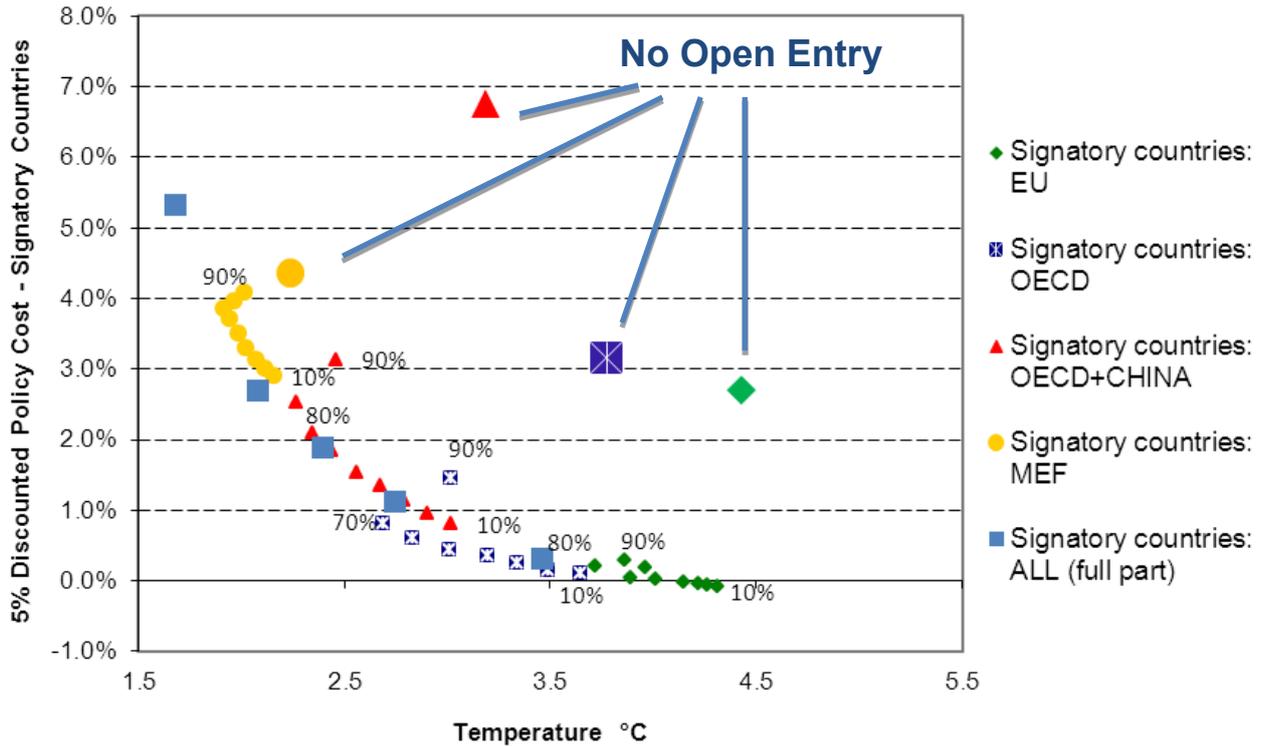


**Figure 3 Optimal Reaction function for the various PCAs simulated.**

Figure 3 reports the results. The Y axis measures the size of the signatories, in terms of cumulative emission from 2005 to 2100 (or, in other words, the Carbon Budget), and the horizontal axis represents the optimal response – in terms of GHG releases – of the laggard states, for different targets of admission requirements. The lines show the associated level of the global temperature increase (degree Celsius above pre-industrial level)<sup>7</sup>. The graph identifies a U-shaped relationship: as the admission requirement ( $E$ ) gets stricter, global GHG emissions (and the resulting temperature increase) decrease, till an admission requirement threshold is reached (usually corresponding to  $E=70-80\%$ ). For stricter entry requirements, some players do not participate to the agreement, and the effectiveness of the partial climate agreements drops. The chart indicates that if the entry requirement is chosen optimally, global temperature can be kept below 2, 2.3 and 2.7 degree C for coalitions of the willing of MEF, OECD+China and OECD respectively.

Moving from effectiveness to efficiency, in Figure 4 we draw a relationship between the policy cost of the signatory countries and the temperature target achieved in 2100, so as to establish an efficient frontier for admission requisites.

<sup>7</sup> We assume that global temperature increase is linearly related to global cumulative emissions, in line with the carbon budget approach according to which each 1000GtCO<sub>2</sub> generates about 0.45 of equilibrium temperature increase (Matthews et. al 2012).

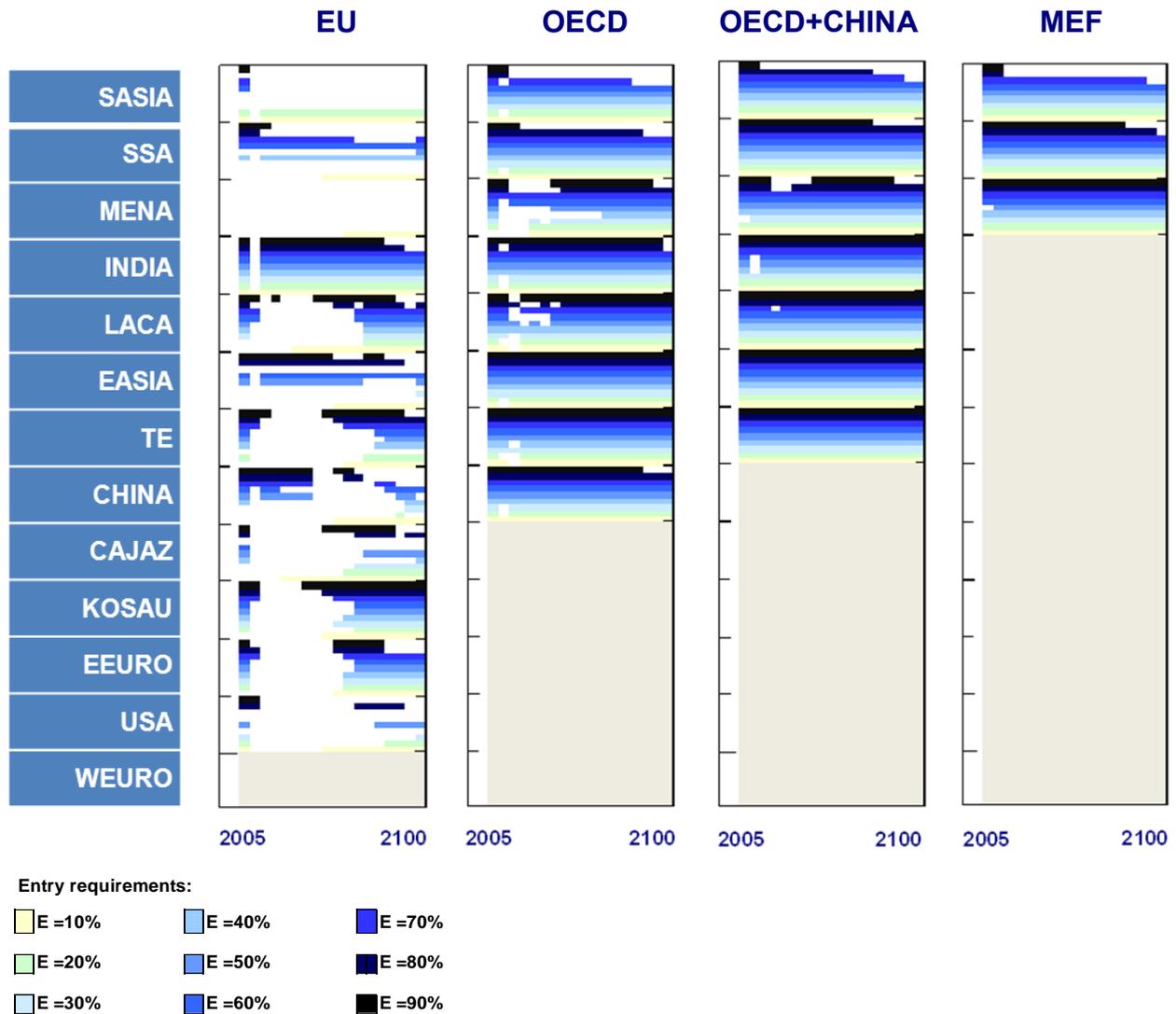


**Figure 4 Efficient Frontier**

The vertical axis represents the policy cost (5% discounted GDP losses) for the signatory regions, and the horizontal axis reports the climate target (in terms of temperature above pre-industrial levels) in 2100. We report all the PCAs scenarios, as well as the case of partial climate agreement without open entry and the first best case of full cooperation. Two main results emerge from the graph. First, as already noted and as expected, the open entry option allows achieving substantial efficiency gains. Second, and most importantly, the PCAs attains efficiency very close to that of the benchmark full participation case, especially if the admission requirement is chosen optimally and the climate objective is not too stringent. This is an important result, and is due to the ability of the PCAs to induce a relatively high level of cooperation, as will be shown below<sup>8</sup>. The high efficiency performance of the PCAs is also due to the fact that the WITCH model features multiple externalities, and that as a result a second best policy framework can not be necessarily welfare decreasing, in so far the innovation market externality is internalized. See DeCian and Tavoni (2012) for an application to the carbon market.

Finally we analyse the temporal and regional rates of the endogenous participation choice in order to identify “when” and “which” of the non-signatory nations decide to undertake the climate accord or to walk away from it. Figure 5 reveals the timeline of the participation choice for each region and in each period for all of the 36 PCA scenarios analysed in this paper:

<sup>8</sup> Some discrepancies might be also due to the different timing of the policy cost paths, which are here collapsed in NPV terms at 5% discounting. The results are confirmed even when measuring policy costs as consumption losses.



**Figure 5** Timing and composition of the participation in the partial cooperation agreement

Figure 5 displays four panels with the four cases analysed in this study (EU, OECD, OECD+CHINA and MEF). Each row represents a different admission requirement for each region (darkest colours indicate tougher entry requirements,  $E$ ), and the horizontal axis reports the time periods (from 2005 to 2100). The coloured areas indicate that the region is undertaking the climate policy initiative, in that period. As the policy agreement starts in 2015, the first two periods (2005 and 2010) are always depicted in white. Finally, the signatory countries are portrayed with a grey area, as they are obliged to a wholehearted adoption of the environmental accord.

If we look at the “EU” only coalition of the willing, we can notice that the engagement of the non-signatory regions tend to occur mostly in the early periods (when the amount of abatement required is particularly loose<sup>9</sup>) and then in the second half of the century, when the low carbon technologies and energy-efficient technologies become competitive due to the rising costs of fossil fuel energy, and also because of the

<sup>9</sup> As a reminder, the admission requirement linearly ramps up from 0% in 2015 to  $E\%$  in 2100.

learning processes due to the innovation and adoption processes carried out mainly by the signatory nations (in this case Europe, which has lowered the price of backstop to around 40-50\$/Mwh in 2100). Interestingly, there are two main forces (interrelated to each other) that drive the participation choice of the adverse countries: the availability of the low carbon technologies and the admission requisites. On one hand higher admission requirements underpins the amount of domestic GHG reduction undertaken by the initial subscriber of the treaty, which has positive fallout on the development of low carbon technologies (by means of learning by doing and learning by researching). Then the expectation of a full deployment of low carbon technologies makes more attractive a late participation in the agreement for the non-signatory countries, as they wait until the low-carbon technologies will be available at an affordable price. On the other hand as the entry conditions ( $E$ ) are getting stricter, non-signatories tend to anticipate their involvement to the climate agreement, to take advantage of the earlier periods in which the entry requirement is still low. The first effect tends to prevail when the admission requirements are low (ranging from 10% - 30%), then when they are getting stricter (from 40-90%) the second effect triumph. This pattern is particularly clear in CHINA, KOSAU (South Korea, South Africa and Australia), TE (Transition Economies, mainly formed by Former Soviet Union regions) and EEURO (Eastern European countries).

Another clear message that the graph reveals is that the major oil exporting regions – MENA (Middle East and North African regions) in particular – are the most reluctant states in participating to the PCA (especially if the size of the initial coalition is small) since their decision is affected by oil demand dynamics at the international level, and the extent to which the energy terms of trade effects can be compensated by the revenues from the carbon market. MENA has to decide whether to continue to produce oil (both for domestic consumption and oil exports) or to enforce the mitigation plan that requires a relocation of oil investments towards low carbon technologies. This second case is justified only when the prices of carbon permits rise sufficiently and when oil demand drops sufficiently, e.g. when a large coalition exists and a low temperature target is attained. This is for example the case of a “OECD” coalition of the willing, in which case MENA participates more actively in the climate agreement.

Apart from MENA, the “OECD” scenarios are also able to entice large GHG emitters such as CHINA, and INDIA. It is also interesting to note that the aggregate TE and EASIA (Eastern Asian nations) are willing to participate in almost all the OECD scenarios. The case “OECD+CHINA” confirms that EASIA and TE are virtually always in the treaty and also INDIA and LACA (Latin and Central American states) appear to be keen in participating.

## 4.2 Comparison with the static model

In the previous sections we have analysed the results obtained from the WITCH model. An interesting result is that the optimal entry requirements ( $E^*_{max}$ ) is robustly found to be in the range of 70-80% which corresponds to a 42-50% of cumulated abatement. We can compare this result with those of the simple static

model which allows us computing the admission requirements analytically. In order to make these calculations, the analytical model requires an estimation of the abatement cost parameters  $c_n$ ,  $c_s$  and  $h$ .

To this end we have run a number of carbon tax scenarios to estimate the marginal abatement costs of the WITCH model. We have estimated those parameters using both a simple OLS (Ordinary Least Square) and SUR (Seemingly Unrelated Regressions) system. All the parameters are statistically significant at the 1% level, and additional information is provided in appendix 2.

We have fed those parameters into the analytical model to compute analytically the optimal entry requirements, which are reported in Table 3, alongside with the estimates of the abatement costs parameters for the four coalitions of the willing considered in the scenario analysis.

	EU	OECD	OECD+CHINA	MEF
Results from WITCH				
$\bar{a}$	81%	86%	86%	83%
$E^*$	80%	70%	80%	70%
$\tilde{a}_{max}^*$	47%	42%	50%	43%
$\tilde{a}_{max real}^*$	19%	38%	40%	38%
OLS estimation				
Cn	193	344	796	7697
Cs	69924	3330	960	271
H	2.95	3.07	3.15	3.06
Results from the analytical model using OLS estimation:				
$\tilde{a}_{max real}^*$	9%	32%	43%	46%
SUR estimation				
Cn	178	292	1028	8490
Cs	42964	2304	1263	280
H	2.82	2.89	3.35	3.10
Results from the analytical model using SUR estimations				
$\tilde{a}_{max real}^*$	8%	30%	45%	46%

**Table 3 Entry requirements computed analytically (static model) and numerically (WITCH model).**

The first part of the table summarises the result obtained from the WITCH model, in particular regarding the cumulative target – in terms of per cent of abatement – of the signatory countries  $\bar{a}$  and the optimal entry conditions for the non-signatory agent (regional percent of abatement required to participate). Since  $E^*$  corresponds to the percent of abatement required to participate in 2100, we have also computed the corresponding level of per cent of abatement required during the period 2005-2100 ( $\tilde{a}_{max}^*$ ). However it should be noted that ( $\tilde{a}_{max}^*$ ) does not exactly coincide with the actual level of abatement of non signatories. In fact in WITCH these nations can freely decide to withdraw from the coalition at any point in time. As a

result many of them do not participate for the entire period (2015-2100), as shown in Figure 5. Hence we have computed another parameter which considers only the actual level of abatement accepted by the opposed regions in the WITCH model:  $\tilde{\alpha}_{\max real}^*$ <sup>10</sup>.

Table 4 shows a relatively good agreement between the static and the numerical model regarding the entry requirement, with an abatement goal in the range of 40-50% (in cumulative terms) as being the optimal one. Some variations can nonetheless be observed, given the different nature of the two models. If the coalition of the willing is small (EU and OECD case) the admittance requirements computed analytically  $\tilde{\alpha}_{\max real}^*$  are lower than the numerical (WITCH) estimations. On the other hand as the size of the signatory countries tends to increase, the WITCH model envisages lower admission requirements compared to that computed analytically (either using OLS or SUR estimates).

## 5. Conclusions

In this paper we have investigated the efficiency and effectiveness of a PCA with open entry, using a game theory approach. The novel feature of our study is the endogenous participation choice to a partial climate accord, which can in any point in time decide to sign up or to exit the coalition, as well the methodology, which employs a simple static model in conjunction with a fully-fledged integrated assessment numerical model.

We provide positive evidence of the implications of a partial climate bargain with open membership. First, it is more efficient in tackling the problem of global warming, compared to the case with no-open membership. A partial climate resolution with open entry is able to overcome the problem of carbon leakage: the possibility of joining the agreement, translates the climate change problem into an economic opportunity for the non-signatory countries, as they can take advantage of a lower commitment by exporting carbon credits with a low associated cost of abatement, which also reduces the policy cost of the initial ratifiers under the hypothesis of perfect competition in the markets. The open membership of the deal manages to largely avoid carbon leakage and to significantly climate effective at the global level. In fact if we consider the case of a coalition of the willing formed by the OECD, an environmental treaty with (without) open entry is able to achieve a climate target of 2.7° (3.8°) in 2100 with an associated policy cost of 0.78% (3.16%) for the underwriter regions. If along with the OECD countries we adjoin China, a target of 2.3° (3.2°) could be attained in 2100, with a policy cost of 2.07% (6.77%) for the signatory nations.

The choice of an admission requirement in the form of a minimum target for abatement has been shown to be an important driver of the effectiveness of the partial climate agreement. We have provided evidence of a U shaped relation between the stringency of the admission requirement and the global effectiveness of the PCAs, with an optimal entry level of about 70-80% of emissions reductions in 2100, or equivalently of 40-

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<sup>10</sup> If a region withdraws from the agreement in a certain year we consider the actual level of emission as carbon target in order to compute  $\tilde{\alpha}_{\max}^*$

50% in cumulative terms. These results are quite robust across different sizes of the coalition of the willing, and hold both in the static analytical and inter-temporal numerical models.

We have also presented an efficient frontier for the identification of the cost effectiveness of the PCA scheme. Our numerical results indicate that a partial climate agreement would fare quite well, with only minor losses with respect to the full cooperation case for most of the scenarios analysed.

The application of a partial accord with open entry might raise some concerns about the required financial flows from signatory to non-signatory countries. If we consider the case of the OECD, the transfer of money to the rest of the world is comparable to the existing ODA (Official Development Assistance) program. The Green Climate Fund drafted in the last Climate Change Summit at the end of 2011 (Durban Climate Change Conference), was aimed at providing 100 Billion USD at year from rich to poor regions, and this amount of financial flow is in line with the side-payments required by our proposal (from OECD to the rest of the world), ranging from 25 to 135 Billion USD at an yearly basis, which would attain a target of 2.7° at the global level. However it is important to remark that in our simulation, the volume of transactions in the emission trading scheme – and then the transfer of money – is not uniform across the whole time horizon, as it is considerably higher in the early periods. Another way to assess the political feasibility of these scenario is to compute the ratio of financial transfer compared to the GDP of the signatory countries which in the OECD scenarios varies from 0.15 to 82% of cumulative GDP (discounted at 5%). Again, this range is in line with the ODA goal, which aim is to provide 0.7% of national income from the OECD to the developing countries.

Another key message is the ability of stand-alone policies to shift world energy market dynamics. In such a context we have analysed the case in which the European States alone (EU scenarios) will commit themselves to a stringent emission reduction target (which is roughly in line with the EU Roadmap 2050), with open entry. Our simulations show that the European countries have the financial clout to enhance the worldwide temperature by 0.9° Celsius in 2100 (3.7° against 4.6° in the BaU scenario). Therefore also unilateral policies – under a cap and trade scheme with open membership – can strikingly influence the global temperature by inducing broad-based participation worldwide, due to the role played by carbon finance.

On top of that, the worth of coalition for the non-signatory countries stems from carbon revenues arising from carbon trading activity. Then, all the simulations with open membership presented in this paper are – by definition – externally stable, since the nations outside the treaty can freely decide to embrace or revoke the pact at any point in time.

As the aim of the UN climate talks is to avert world temperature increase by more than 2 degrees Celsius, we have also analysed a broader policy initiative which entails all the major economies of the World. According to our results, it is possible to conquer this target with a partial environmental resolution that involves all regions with the exception of SSA (Sub-Saharan Africa), MENA (Middle East and North Africa) and SASIA (South Asian Countries) with admittance requirements ranging from 40% to 90% (MEF Scenarios). In such a

context it is interesting to examine the decision choice of the oil exporting countries (MENA aggregate), since a reduction of GHG emissions would imply also a shrink of oil extraction activities and then oil revenues. Consequently there is a trade-off between oil revenues and carbon revenues. It is interesting to note that flagging global oil demand – driven by the climate policy actions of the MEF regions – is also an incentive for the exporting countries to scale down carbon-intensive oil extraction processes and get carbon revenues by undertaking the agreement. Thus the gains associated with carbon trade activities are in these scenarios more appealing for them as they will participate actively in the agreement.

The results of our study go in the direction of filling the gap between the observed fact that some countries are undertaking some unilateral actions and theory which predicts that this not rational (as mentioned in Kolstad 2011). Our work provides evidence that unilateral actions can be a viable solution if “open” to engage other countries. In particular the decision of a single country can influence other’s decision, as the climate initiative could spill across borders. A direct policy recommendation is to provide a better integration of the carbon markets (the European Emission Trading Scheme, the Australian trading system) as well as other instruments such CDM and Joint Implementation.

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## Appendix 1

In this appendix we provide the equation governing endogenous participation implemented in the WITCH model. The equations are different as we distinguish between signatory and non-signatory countries.

The first equation presented applies only for the endorser regions. Then equations A2 and A3 apply for both the endorser and non-signatory nations. Finally equations A4-A7 apply only for non-signatory countries. The time period is indexed by  $t$ , while the regions are indexed by  $n$ .

$$EMI(t, n) \leq EMI\_TARGET(t, n) + NIP(t, n) - SAV(t, n) \quad \forall t \quad A1)$$

Equation 1 sets exogenously a constraint on GHG releases and thus it applies only for the signatory countries. Basically the amount of GHG emissions ( $EMI$ ) should not exceed the amount of allocated permits ( $EMI\_TARGET^{11}$ ) plus Net Import of Permits in the carbon market ( $NIP$ ) and by subtracting transfer of credit offsets over time ( $SAV$ ) as we allow for intertemporal flexibility through banking and borrowing. The intertemporal flexibility option requires a terminal condition in period  $T$  (equation A2), as each region have to clear all the amount of savings eventually banked or borrowed from the future.

$$\sum_{t=tp1}^T SAV(t, n) \geq 0 \quad \text{When: } t = T \quad A2)$$

$$\sum_{t=tp1}^T \max[0, NIP(t, n)] \leq ABS \sum_{t=tp1}^T [TRP(t, n)] \quad \text{When: } t = T \quad A3)$$

Also equation A3 imposes a constraint in the final period: the amount of cumulative import of permit should not exceed the amount of cumulative carbon permits tradable in the market – in absolute value – throughout the century.  $TRP$  (Tradable Emission Permits) represents the difference between the level of domestic GHG emissions ( $EMI$ ) and the emission target ( $EMI\_TARGET$ ), and therefore it represents the trading potential of each country (without considering banking and borrowing).

Now we introduce the equations applying only for the non-signatory countries, which can opt in any point in time whether to sign-up or betray the environmental deal;

$$NIP(t, n) \geq \min[0, (-TRP(t, n) + SAV(t, n))] \quad \forall t \quad A4)$$

$$SAV(t, n) \leq \max[0, (TRP(t, n) + NIP(t, n))] \quad \forall t \quad A5)$$

<sup>11</sup> As far as the signatory countries are concerned, the parameter  $EMI\_TARGET$  is set exogenously according to an emission path which is consistent with a 450 ppm-e scenario at the global level (if all the countries are assumed to be signatory). For the non-signatory countries the emission target amounts to the level of the BaU emission multiplied by  $(1-e(t))$ , where  $e$  represents the admission requirement to participate in the Emission Trading Scheme.

$$NIP(t,n) \leq \gamma \max[0, TRP(t,n)] \quad \forall t \text{ and with } \chi > 0 \quad A6)$$

$$SAV(t,n) + \sum_{t=tp1}^{t-1} SAV(t,n) \leq \max[(1 + \gamma)TRP(t,n), \min(0, -TRP(t,n))] \quad \forall t \quad A7)$$

Please note that in our simulations we assume  $\gamma=2$

We would like also to provide some additional explanations regarding the intertemporal flexibility (banking and borrowing option), and the possibility for the non-signatory regions to refrain from the agreement at any point in time. In such a context equation A7 imposes that: 1) if  $TRP$  is positive, the cumulative amount of carbon offsets eventually banked to the future should be always inferior or equal to  $(1 + \gamma)TRP(t,n)$ ; and 2) if  $TRP$  is negative the amount of cumulative savings must be lower or equal to zero. As a result, if a region backslides on carbon intensive technology ( $TRP < 0$ ), has to clear the banking and borrowing position (cumulative net of savings lower or equal to zero) before shrinking from the coalition. It should be noted that this condition is not binding when  $TRP$  is positive and the cumulative amount of savings is equal to zero, as it intersects equations 5 and 6 in a unique point.

In order to ease the comprehension of the model we provide a geometrical representation of the equations by showing the feasible area of the problem:

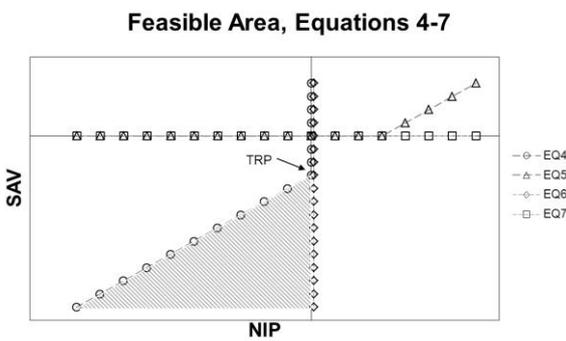


Figure A1

Subjected to conditions:

1)  $TRP(t,n) < 0$ ;

2)  $\sum_{t=tp1}^{t-1} SAV(t,n) = 0$

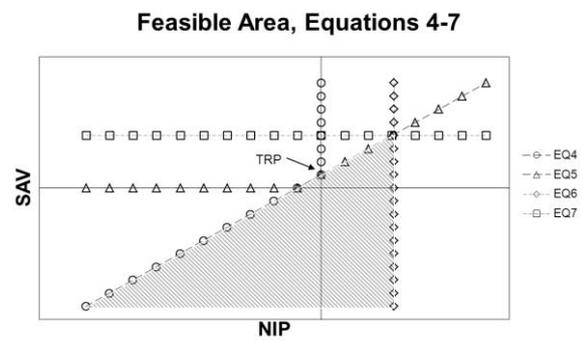


Figure A2

Subjected to conditions:

$TRP(t,n) > 0$ ;

$\sum_{t=tp1}^{t-1} SAV(t,n) = 0$

The graphs above reveal the area of feasibility (shaded) of the problem for the non-signatory countries, which can choose endogenously to participate in the climate accord. We have omitted equations A2 and A3, since they are binding only in the last period of the time horizon  $t=T$ .

The horizontal axis represent the amount of *NIP* (Net import of permits), and the vertical axis corresponds to the amount of *SAV* (carbon credit savings from banking and borrowing). The graph on the left characterize a situation in which the non-signatory countries are not reducing GHG emission compared to their target ( $e$ ). In this condition they cannot buy permits (condition imposed by equation A6) and they can sell permits only if they borrow ( $SAV < 0$ ) carbon credits from the future (they short sell carbon permits today by promising to cut GHG emissions tomorrow). Another option is to not to sell permits and continue to emit GHG without any constrain (this situation is represented by the origin of the axes, which is part of the feasible area since all the equations are specified with the less or equal condition).

The panel on the right depicts a scenario in which the non-signatory countries are containing the emission compared to their target ( $TRP > 0$ ). In this situation, they can choose whether to sell permits and not make use of banking and borrowing ( $SAV = 0$ ) for a maximum amount equal to  $TRP$ , or to increase their selling today by borrowing carbon credits from the future ( $SAV < 0$ ) or to save permits for the future ( $SAV > 0$ ). In principle they can even choose to curb GHG emissions compared to their climate target and not to get involved in the environmental agreement (origin of axes).

## Appendix 2

In this section we provide the estimates of the Abatement cost parameters for the analytical model. Since the parameter  $h$  is common to the signatory and non-signatory countries, the system that has been estimated is the following:

$$\begin{cases} ctax = c_n h a_n^{h-1} \\ ctax = c_s h a_n^{h-1} \end{cases}$$

This can be rewritten as:

$$\begin{cases} \log(ctax) = (c1) + \log(c(2)) + (c(2) - 1)\log(a_s) \\ \log(ctax) = (c3) + \log(c(2)) + (c(2) - 1)\log(a_n) \end{cases}$$

Where:

$C(1) = \log(C_n)$     logarithm of percent of global cumulated abatement of non-signatory countries as a whole

$C(2) = h$             exponent of the Abatement Cost curve

$C(3) = \log(C_s)$     logarithm of percent of global cumulated abatement of signatory country as a whole

$ctax$  = Net present value of the carbon tax (\$\text{Gtco}\_2\$)

It should be also noted that in the static model we assume that the two agents (signatory and non-signatory) have the same size in terms of GHG emissions in the BaU scenario. This assumption implies that when the non-signatory agent participates in, the global amount of emission is given by  $(\tilde{a} + \bar{a})$ . Of course this assumption does not hold in the WITCH model. Therefore, in order to estimate the parameters  $c_n$ ,  $c_s$  and  $h$  we have translated the target of the signatory agent  $\bar{a}$ , in the equivalent target in terms of percent of global abatement, and then we have computed the optimal entry requirements  $\bar{a}$  in terms of % of global abatement. Once we have calculated the optimal entry requirements (in terms of per cent of global abatement required to participate), these values have been transformed in the equivalent regional level (percent of regional abatement required to participate), and reported in table 3.

OLS estimation:

System: EU\_CASE  
 Estimation Method: Iterative Least Squares  
 Date: 01/16/13 Time: 11:32  
 Sample: 1 9  
 Included observations: 9  
 Total system (balanced) observations 18  
 Convergence achieved after 2 iterations

	Coefficient	Std. Error	t-Statistic	Prob.
C(1)	11.15516	0.431614	25.84521	0.0000
C(2)	2.953913	0.114715	25.75006	0.0000
C(3)	5.264330	0.133516	39.42850	0.0000
Determinant residual covariance		0.005334		

Equation:  $\text{LOG}(\text{CTAX}) = (\text{C}(1)) + \text{LOG}(\text{C}(2)) + (\text{C}(2) - 1) * \text{LOG}(\text{A\_S})$

Observations: 9

R-squared	0.960440	Mean dependent var	4.483081
Adjusted R-squared	0.954789	S.D. dependent var	1.484418
S.E. of regression	0.315631	Sum squared resid	0.697360
Prob(F-statistic)	1.497384		

Equation:  $\text{LOG}(\text{CTAX}) = (\text{C}(3)) + \text{LOG}(\text{C}(2)) + (\text{C}(2) - 1) * \text{LOG}(\text{A\_NS})$

Observations: 9

R-squared	0.941237	Mean dependent var	4.483081
Adjusted R-squared	0.932842	S.D. dependent var	1.484418
S.E. of regression	0.384686	Sum squared resid	1.035881
Prob(F-statistic)	0.451563		

System: OECD

Estimation Method: Iterative Least Squares

Date: 01/16/13 Time: 11:34

Sample: 1 9

Included observations: 9

Total system (balanced) observations 18

Convergence achieved after 2 iterations

	Coefficient	Std. Error	t-Statistic	Prob.
C(1)	8.110703	0.259627	31.23981	0.0000
C(2)	3.074756	0.119419	25.74756	0.0000
C(3)	5.840117	0.152194	38.37280	0.0000
Determinant residual covariance		0.002633		

Equation:  $\text{LOG}(\text{CTAX}) = (\text{C}(1)) + \text{LOG}(\text{C}(2)) + (\text{C}(2) - 1) * \text{LOG}(\text{A\_S})$ 

Observations: 9

R-squared	0.964579	Mean dependent var	4.483081
Adjusted R-squared	0.959519	S.D. dependent var	1.484418
S.E. of regression	0.298664	Sum squared resid	0.624401
Prob(F-statistic)	1.273206		

Equation:  $\text{LOG}(\text{CTAX}) = (\text{C}(3)) + \text{LOG}(\text{C}(2)) + (\text{C}(2) - 1) * \text{LOG}(\text{A\_NS})$ 

Observations: 9

R-squared	0.940738	Mean dependent var	4.483081
Adjusted R-squared	0.932272	S.D. dependent var	1.484418
S.E. of regression	0.386315	Sum squared resid	1.044675
Prob(F-statistic)	0.610842		

System: OECD\_CHINA  
 Estimation Method: Iterative Least Squares  
 Date: 01/16/13 Time: 11:41  
 Sample: 1 9  
 Included observations: 9  
 Total system (balanced) observations 18  
 Convergence achieved after 2 iterations

	Coefficient	Std. Error	t-Statistic	Prob.
C(1)	6.867374	0.200645	34.22654	0.0000
C(2)	3.148005	0.125240	25.13587	0.0000
C(3)	6.679153	0.191659	34.84914	0.0000
Determinant residual covariance		0.000121		

Equation:  $\text{LOG}(\text{CTAX}) = (\text{C}(1)) + \text{LOG}(\text{C}(2)) + (\text{C}(2) - 1) * \text{LOG}(\text{A\_S})$

Observations: 9

R-squared	0.957943	Mean dependent var	4.483081
Adjusted R-squared	0.951935	S.D. dependent var	1.484418
S.E. of regression	0.325439	Sum squared resid	0.741372
Prob(F-statistic)	0.864603		

Equation:  $\text{LOG}(\text{CTAX}) = (\text{C}(3)) + \text{LOG}(\text{C}(2)) + (\text{C}(2) - 1) * \text{LOG}(\text{A\_NS})$

Observations: 9

R-squared	0.945020	Mean dependent var	4.483081
Adjusted R-squared	0.937166	S.D. dependent var	1.484418
S.E. of regression	0.372095	Sum squared resid	0.969181
Prob(F-statistic)	0.990688		

System: MEF

Estimation Method: Iterative Least Squares

Date: 01/16/13 Time: 11:43

Sample: 1 9

Included observations: 9

Total system (balanced) observations 18

Convergence achieved after 2 iterations

	Coefficient	Std. Error	t-Statistic	Prob.
C(1)	5.602679	0.156490	35.80205	0.0000
C(2)	3.060663	0.130082	23.52871	0.0000
C(3)	8.948590	0.332916	26.87945	0.0000
Determinant residual covariance		0.002041		

Equation:  $\text{LOG}(\text{CTAX}) = (\text{C}(1)) + \text{LOG}(\text{C}(2)) + (\text{C}(2)-1) * \text{LOG}(\text{A\_S})$ 

Observations: 9

R-squared	0.950811	Mean dependent var	4.483081
Adjusted R-squared	0.943784	S.D. dependent var	1.484418
S.E. of regression	0.351953	Sum squared resid	0.867099
Prob(F-statistic)	0.631907		

Equation:  $\text{LOG}(\text{CTAX}) = (\text{C}(3)) + \text{LOG}(\text{C}(2)) + (\text{C}(2)-1) * \text{LOG}(\text{A\_NS})$ 

Observations: 9

R-squared	0.936384	Mean dependent var	4.483081
Adjusted R-squared	0.927296	S.D. dependent var	1.484418
S.E. of regression	0.400255	Sum squared resid	1.121427
Prob(F-statistic)	1.147064		

SUR estimation:

System: EU\_CASE

Estimation Method: Seemingly Unrelated Regression

Date: 03/04/13 Time: 12:15

Sample: 1 9

Included observations: 9

Total system (balanced) observations 18

Iterate coefficients after one-step weighting matrix

Convergence achieved after: 1 weight matrix, 4 total coef iterations

	Coefficient	Std. Error	t-Statistic	Prob.
C(1)	10.66811	0.449117	23.75351	0.0000
C(2)	2.819467	0.121577	23.19070	0.0000
C(3)	5.182628	0.134540	38.52112	0.0000
Determinant residual covariance		0.004062		

Equation: LOG(CTAX) = (C(1))+LOG(C(2))+C(2)-1)\*LOG(A\_S)

Observations: 9

R-squared	0.966630	Mean dependent var	4.483081
Adjusted R-squared	0.961863	S.D. dependent var	1.484418
S.E. of regression	0.289888	Sum squared resid	0.588247
Prob(F-statistic)	1.218955		

Equation: LOG(CTAX) = (C(3))+LOG(C(2))+C(2)-1)\*LOG(A\_NS)

Observations: 9

R-squared	0.926043	Mean dependent var	4.483081
Adjusted R-squared	0.915478	S.D. dependent var	1.484418
S.E. of regression	0.431561	Sum squared resid	1.303711
Prob(F-statistic)	0.264936		

System: OECD

Estimation Method: Seemingly Unrelated Regression

Date: 03/04/13 Time: 12:17

Sample: 1 9

Included observations: 9

Total system (balanced) observations 18

Iterate coefficients after one-step weighting matrix

Convergence achieved after: 1 weight matrix, 4 total coef iterations

	Coefficient	Std. Error	t-Statistic	Prob.
C(1)	7.742537	0.252295	30.68839	0.0000
C(2)	2.886360	0.121708	23.71536	0.0000
C(3)	5.678129	0.153539	36.98172	0.0000
Determinant residual covariance		0.001525		

Equation:  $\text{LOG}(\text{CTAX}) = (\text{C}(1)) + \text{LOG}(\text{C}(2)) + (\text{C}(2) - 1) * \text{LOG}(\text{A\_S})$ 

Observations: 9

R-squared	0.965484	Mean dependent var	4.483081
Adjusted R-squared	0.960553	S.D. dependent var	1.484418
S.E. of regression	0.294824	Sum squared resid	0.608448
Prob(F-statistic)	0.757705		

Equation:  $\text{LOG}(\text{CTAX}) = (\text{C}(3)) + \text{LOG}(\text{C}(2)) + (\text{C}(2) - 1) * \text{LOG}(\text{A\_NS})$ 

Observations: 9

R-squared	0.924123	Mean dependent var	4.483081
Adjusted R-squared	0.913283	S.D. dependent var	1.484418
S.E. of regression	0.437128	Sum squared resid	1.337563
Prob(F-statistic)	0.303857		

System: OECD\_CHINA

Estimation Method: Seemingly Unrelated Regression

Date: 03/04/13 Time: 12:18

Sample: 1 9

Included observations: 9

Total system (balanced) observations 18

Iterate coefficients after one-step weighting matrix

Convergence achieved after: 1 weight matrix, 4 total coef iterations

	Coefficient	Std. Error	t-Statistic	Prob.
C(1)	7.141173	0.181785	39.28362	0.0000
C(2)	3.352925	0.114871	29.18868	0.0000
C(3)	6.934997	0.181240	38.26424	0.0000
Determinant residual covariance		5.35E-05		

Equation: LOG(CTAX) = (C(1))+LOG(C(2))+C(2)-1)\*LOG(A\_S)

Observations: 9

R-squared	0.952292	Mean dependent var	4.483081
Adjusted R-squared	0.945477	S.D. dependent var	1.484418
S.E. of regression	0.346614	Sum squared resid	0.840988
Prob(F-statistic)	1.270817		

Equation: LOG(CTAX) = (C(3))+LOG(C(2))+C(2)-1)\*LOG(A\_NS)

Observations: 9

R-squared	0.933352	Mean dependent var	4.483081
Adjusted R-squared	0.923831	S.D. dependent var	1.484418
S.E. of regression	0.409681	Sum squared resid	1.174868
Prob(F-statistic)	1.303324		

System: MEF

Estimation Method: Seemingly Unrelated Regression

Date: 03/04/13 Time: 12:19

Sample: 1 9

Included observations: 9

Total system (balanced) observations 18

Iterate coefficients after one-step weighting matrix

Convergence achieved after: 1 weight matrix, 3 total coef iterations

	Coefficient	Std. Error	t-Statistic	Prob.
C(1)	5.633983	0.161918	34.79520	0.0000
C(2)	3.101765	0.163072	19.02085	0.0000
C(3)	9.046631	0.406722	22.24277	0.0000

Determinant residual covariance	0.002010
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Equation:  $\text{LOG}(\text{CTAX}) = (\text{C}(1)) + \text{LOG}(\text{C}(2)) + (\text{C}(2) - 1) * \text{LOG}(\text{A\_S})$ 

Observations: 9

R-squared	0.952527	Mean dependent var	4.483081
Adjusted R-squared	0.945745	S.D. dependent var	1.484418
S.E. of regression	0.345760	Sum squared resid	0.836849
Prob(F-statistic)	0.729480		

Equation:  $\text{LOG}(\text{CTAX}) = (\text{C}(3)) + \text{LOG}(\text{C}(2)) + (\text{C}(2) - 1) * \text{LOG}(\text{A\_NS})$ 

Observations: 9

R-squared	0.933917	Mean dependent var	4.483081
Adjusted R-squared	0.924476	S.D. dependent var	1.484418
S.E. of regression	0.407941	Sum squared resid	1.164913
Prob(F-statistic)	1.216853		