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ABSTRACT

Incentives and Stability Of International Climate Coalitions: An Integrated Assessment

This paper analyses the incentives to participate in and the stability of international climate coalitions. Using the integrated assessment model WITCH, the analysis of coalitions’ profitability and stability is performed under alternative assumptions concerning the pure rate of time preference, the social welfare aggregator and the extent of climate damages. We focus on the profitability, stability, and 'potential stability' of a number of coalitions which are 'potentially effective' in reducing emissions. We find that only the grand coalition under a specific sets of assumptions finds it optimal to stabilise GHG concentration below 550 ppm CO2-eq. However, the grand coalition is found not to be stable, not even 'potentially stable' even through an adequate set of transfers. However, there exist potentially stable coalitions, but of smaller size, which are also potentially environmentally effective. Depending on the assumptions made, they could achieve up to 600 ppm CO2-eq. More ambitious targets lead to the collapse of the coalition.

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1. INTRODUCTION

The global public good nature of the climate change and its causes requires cooperation among countries and broad-based participation of at least major economies is required for any coalition to be environmentally effective. However, stable coalitions are generally small and might well not address satisfactorily the environmental problem, especially when they deal with a global externality as in the case of climate change (Barrett 1994, Carraro and Siniscalco 1993, Asheim et al. 2006, Bréchet et al. 2011). When the costs and benefits of international cooperation are large, as in the case of GHG emissions reduction, a stable agreement is hard to achieve, reflecting the difficulty to provide sufficient participation incentives to widely heterogeneous countries. Only when the benefits from cooperation are small, stable coalition can succeed to sustain a large number of signatories (Barret 1994). But in this case, they are not effective in reducing emissions considerably.

A successful international climate policy framework will have to meet two conditions, build a coalition of countries that is potentially effective and give each member country sufficient incentives to join and remain in this coalition. Such coalition should be capable of delivering ambitious emission reduction even if some countries do not take mitigation action. In addition, it should meet the target without exceedingly high mitigation costs and deliver a net benefit to member countries as a whole. The novel contribution of this paper is mostly methodological, but it also adds a better qualification of well-known results that are policy relevant. The use of large scale macroeconomic models calibrated on historical data allow generalising results that have been obtained under more specific, and at times simplifying, assumptions and therefore it represents a complement to the broad literature on coalition theory. To our knowledge only a few studies have used a similar approach to assess climate coalitions. Bosello et la (2003) study the effects of different equity rules on the incentives to cooperate using the dynamic integrated growth and climate model FEEM-RICE. Carraro et al (2006) use a stylized integrated assessment simulation model to show how appropriate transfers may induce almost all countries into signing a self-enforcing climate treaty.

Bréchet et al. (2011) compare different stability concepts using a modified version of Nordhaus and Yang (1996) model . Nagashima et al. (2009) use the STACO model to compare different transfer schemes and their impact on participation incentives, global welfare and abatement efforts. However, the STACO model does not explicitly model the nexus between economy, energy, and climate, but rather relies on reduced-form cost and benefit functions. The ClimNeg World Simulation model used by Bréchet et al. (2011) and Carraro et al. (2006), as well as the FEEM-RICE model, are a step ahead as they encompass economics, climatic, and impact dimensions. However, they do not fully model the energy-emission linkage and they neglect international interactions through the diffusion of clean technologies developed for abatement purpose.

The modelling framework used in this paper represents a step-up over the models just mentioned. The WITCH model, used in the present paper, has two major strengths in this specific context. It belongs to the class of so-called integrated assessment models (IAMs), and therefore it incorporates explicitly the gains from emission reductions in terms of avoided climate change through regional damage functions that feed climate change back into the economy. It has a game-theoretic structure. The 12 model regions and/or coalitions of regions behave strategically with respect to all major economic decision variables, including emission abatement levels, by playing a non-cooperative Nash game. Therefore, when deciding whether or not to cooperate on GHG emission control, countries take into account how their decisions affect all other countries, and whether these countries will cooperate or remain outside the coalition. Mitigation options are fully modelled as investment choices in alternative energy technologies, abatement in non-CO2 gases, and changes in deforestation patterns. Moreover, technological change in energy efficiency and clean technologies is endogenous and reacts to price and policy signals. Technological innovation and diffusion processes are also subject to international spillovers; this means that the model can represent multiple externalities, which can be partly internalized when coalitions are formed.

Bosetti et al. (2009) evaluated the potential environmental effectiveness of all 4069 coalitions that would result from combination of the 12 regions. In particular, all coalition that could in principle deliver the stabilisation targets commonly discussed in the policy arena were identified. In the present paper we take stock of that analysis and, within the set of all possible climate coalitions, we focus on those that have the potential to meet an ambitious enough global mitigation target. These are coalitions whose global emission path would be consistent with long-run stabilisation of global GHG concentration at 550 ppm CO_2-*eq*, despite the BAU emission pathway of non-participating regions. For this subset of coalitions, we evaluate whether the welfare of each participating country is larger than the welfare it would obtain from withdrawing from the coalition and free riding on other participants' abatement efforts (internal stability). We also checked whether there are international financial transfers that can compensate for the free riding incentives (potential internal stability). Given the uncertainties involved in predicting and valuing the future damages and risks from climate change, the analysis is performed under four alternative combinations of damage and discount rate assumptions. A low-damage case is based on the damage assessment in Nordhaus and Boyer (2000), while a high-damage case incorporates the more recent, upward revisions made for instance by Hanemann (2008) or Stern (2007). A low-discounting case assumes a (pure) utility discount rate of 0.1%, in line with Stern (2007), while a high-discounting case takes the 3% value used in Nordhaus (2007). Finally we assess the effect of different weighting in the aggregation of regions' welfare and the effect this has on main findings.

Following a presentation of WITCH's game-theoretic framework in Section 2, Section 3 assesses the basic individual incentives for countries to participate in coalitions. Section 4 brings together the incentive effects associated with damages and abatement costs to analyse coalition formation and stability. Conclusions follow.

2. THE GAME THEORETIC STRUCTURE OF WITCH

The numerical analysis uses the WITCH model[1], an energy-economy model that incorporates a detailed representation of the energy sector into an inter-temporal growth model of the global economy. The emphases on the energy sector and GHG mitigation options allows technology-related issues to be studied within a general equilibrium framework characterised by environmental (expected future climate change damages), economic (exhaustible natural resources), and technology (knowledge and experience spillovers) externalities (Bosetti et al. 2006, 2008). Each region's economy is modelled in line with a Ramsey-Cass-Koopmans model where the representative agent maximizes intertemporal welfare, by optimally

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[1] See www.witchmodel.org for model description and related papers.

choosing the investments path, given a production function for the final good, a budget constrain and kinetic equations for capital accumulation. WITCH can simulate all degrees of cooperation among the 12 macro-regions in which world countries are aggregated. The model can run in a cooperative mode where global social welfare is maximised. In this case, cooperation internalises the environmental externality. The model can also provides a decentralised, or non-cooperative solution, by optimising the welfare of each individual region, taking as given each other region's choice. In between these two extremes it is possible to model all possible combinations of smaller coalitions that coexist with non-cooperating regions.

The scenarios obtained from the WITCH model are thus the outcome of a game in which world regions interact in a setting of strategic interdependence.

Since players/regions are not symmetric in WITCH, both in their climate damages and abatement costs, coalitions are characterized not only by their size but also by their composition. The set of coalitions Γ is therefore composed of 4,095 possible combinations among the 12 regions, including the grand coalition γ_{GC}, which comprises all players. When formed, coalitions become players of the game. Regions that do not join the coalition are said to behave as singletons or as free-riders.

The action of each player consists in choosing the path of investments in the economic variables governing the economy, the energy sector, and technological progress. Investments in the energy sector and in research and development (R&D) determine regional GHG emissions. The accumulation of GHG emissions in the atmosphere and the effects on global mean temperature are governed by a reduced form climate module. A climate change damage function provides the climate feedback on the economic system, in the form of a GDP loss. In this setting, cost-benefit analysis can be performed. Regions choose their investments trading off the costs and the benefits, in terms of reduced damage, of their actions.

The outcome of the game for each region or group of regions is a consumption path over the whole simulation horizon. Regions $i=1,\ldots,12$ express their preferences over the outcomes of the game using a monotonous, twice continuously differentiable utility function on discounted per capita consumption. If t denotes time, $c_{i,t}$ per capita consumption, W_i the payoff of player i defined as a function of utility of per-capita consumption, u, then

$W_i(\gamma)=\sum_t u(c_{i,t}(\gamma))\frac{1}{(1+\delta_t)^t}$, with $\frac{\partial u(c_{i,t}(\gamma))}{\partial c_{i,t}}>0$ and $\frac{\partial^2 u(c_{i,t}(\gamma))}{\partial c_{i,t}{}^2}<0$, with γ being a coalition in the set of all coalitions, $\gamma\in\Gamma$. In WITCH the utility function is the same for all players and has logarithmic shape. The rate of pure time preference δ_t declines over the century.

Utility functions represent a complete preference ordering over a given set of goods or over an aggregate consumption level. They can be used to assess if a given consumption level $\bar{c}_{i,t}$ is preferred or not with respect to its alternative $\tilde{c}_{i,t}$. Monotonicity implies that $\bar{c}_{i,t}\geq\tilde{c}_{i,t}\Leftrightarrow u(\bar{c}_{i,t})\geq u(\tilde{c}_{i,t})$ but does not allow to evaluate by how much $\bar{c}_{i,t}$ is preferred to $\tilde{c}_{i,t}$: utility is not a cardinal property. Therefore, utility cannot be compared directly among players. This is an important aspect when studying the possibility of sustaining larger coalitions by means of internal transfers.

When coalitions are formed, they act as players and choose actions to maximize joint welfare. It is thus necessary to employ a social welfare aggregator that assigns a social preference to every possible profile of individual preferences. We use the following social welfare aggregator *S*:

$$S(\gamma)=S(W_1(\gamma),W_2(\gamma),\ldots,W_n(\gamma))=\sum_{i=1}^{n}\sum_t\omega_{i,t}u(c_{i,t}(\gamma))\frac{1}{(1+\delta_t)^t}, \qquad \textbf{(1)}$$

where $\omega_{i,t}$ are weights that are used to aggregate regions. Weights, as the discount rate, can be chosen on either normative or positive consideration. We experiment different weights and explicitly look at their effect on results. In particular, we have considered *weights equal to the inverse of marginal utility,* $\omega_{i,t}=\left(\frac{\partial u(c_{i,t}(\gamma))}{\partial c_{i,t}(\gamma)}\right)^{-1}$ and weights proportional to the population share. The first set of weights represents a social welfare aggregation rule which is neutral on the distribution of wealth among coalition members. The weights $\omega_{i,t}$ linearize the contribution of players utility functions to social welfare and avoids wealth transfers from wealthy players to poor players and from the future to the present. Therefore, abatement effort is distributed with the sole objective to minimize coalition's emissions reduction costs, that is to equalise marginal abatement costs across regions. This allocation of abatement effort, and the uniqueness of the shadow value of carbon, is reminiscent of a decentralized solution in which a global market for carbon is implemented. In fact, the social welfare aggregator that we use produces the same actions as in a decentralized solution which internalizes the environmental externality among coalition members and uses an international market of carbon to distribute abatement effort.[2] We also experiment with *weights proportional to population*, which give more emphasis to developing countries, the countries that are going to suffer more from climate change. This is then reflected on the overall environmental objective of the coalition as well as in the distribution of the effort.

The WITCH model analysis assumes a non-cooperative, simultaneous, open membership, Nash game with non-orthogonal free-riding, and allows for the possibility of international transfers to enlarge climate coalitions. It is also possible to simulate issue linkage to increase the profitability and stability of coalitions by letting regions to cooperate on externalities other than the environmental one. In essence, the framework considers immediate, irreversible and self-enforcing participation to climate change mitigation action, and abstracts from other possible bargaining options such as delayed participation, renegotiation, sanctions or joint negotiation in multiple areas (*e.g.* climate and international trade). In order to simulate coalition formation, the model is solved as a one-shot meta-game. In the first stage players decide on their participation and coalitions are formed. In the second stage players choose their optimal emission levels internalizing only the environmental externality. The game is then solved backward. In the second stage, coalition members maximize aggregate joint welfare, whereas non participants behave as singletons and maximize individual welfare. The equilibrium is found employing the γ-characteristic function approach (Chander and Tulkens, 1997): in the unique Nash equilibrium coalition members jointly play their best response to non-coalition members, who adopt individually their best-reply strategies.

The game exhibits positive spillovers. When a new member joins the coalition all countries outside the coalition are better off because they benefit from: (1) a better environment, (2) technology spillovers (knowledge is not a club good) and (3) lower fossil fuel prices.

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[2] The weights $\omega_{i,t}$ are often referred to as the Negishi weights, from Negishi (1960). Negishi weights have the peculiar property of transforming a competitive economy problem into a centralized social planner problem and are sometimes used by Integrated Assessment Models.

Let us now introduce some crucial definitions hat are later used in the paper to study coalitions.

In order to exist, coalitions must be both *profitable* and *stable* (D'Aspremont *et al.*, 1983; D'Aspremont and Gabszewicz, 1986; Donsimoni *et al.*, 1986; Carraro and Siniscalco, 1991). A coalition $\gamma \in \Gamma$ is said to be *profitable* if coalition members have a higher welfare than in a scenario where the coalition is not formed (Nash equilibrium): $W_i(\gamma) \geq W_i^{Nash} \quad \forall i \in \gamma$. Where $W_i(\gamma)$ is the welfare of player *i* that belongs to coalition γ, and W_i^{Nash} is the welfare of player *i* in the fully non-cooperative Nash equilibrium.

This is a necessary, but not sufficient condition for the coalition to be formed. A second requirement concerns *stability*. A coalition γ is said to be *stable* if it is *internally* and *externally* stable. A coalition is *internally stable* if signatory countries do not have the incentive to defect and to behave non-cooperatively when other coalition members cooperate, i.e. $\forall i \in \gamma \quad W_i(\gamma) \geq W_i(\gamma \setminus i)$, where $W_i(\gamma \setminus i)$ denotes the welfare of player *i* when all members but *i* are cooperating. A coalition is *externally stable* if there is no incentive to enlarge the coalition by including non-signatory countries: $\forall i \notin \gamma \quad W_i(\gamma) \geq W_i(\gamma \cup \{i\})$.

Finally, a coalition γ is *potentially internally stable* if it can be turned into a stable coalition through a set of self-financed transfers among coalitions members, $\mu = \left(\mu_{1,t}, \mu_{2,t}, \ldots\right)$ with $\sum_t \sum_{i \in \gamma} \mu_{i,t} \dfrac{1}{(1+r_{i,t})^t} = 0 \; \forall i \in \gamma$, with $r_{i,t}$ denoting region *i* interest rate. This is the case when coalition γ has sufficient resources to pay every member of γ its outside option.

3. ASSESSING THE DRIVERS OF PARTICIPATION IN INTERNATIONAL CLIMATE COALITIONS

The incentives for main emitting countries to participate in climate coalitions ultimately depend on a wide range of economic and political factors, not all of which can be captured by model-based exercises. Bearing this caveat in mind, the analysis carried out in this paper covers the major economic drivers of participation incentives, including the expected impacts of climate change, the influence of distant impacts on current policy decisions (*i.e.* the discount rate), and the costs of mitigation policies. This Section describes how each of these three drivers are captured in the WITCH model analysis undertaken in this paper, and how participation incentives vary across the main world regions.

3.1. Climate change impacts in WITCH

Adequate knowledge of climate change impacts is a prerequisite for well-informed climate change mitigation policies. Alternative assumptions regarding such impacts can lead to profoundly different policy insights, in terms of the outcome of cost-benefit analyses and the incentives for individual regions to participate in climate coalitions.

Estimating the economic impacts of climate change raises a number of difficult issues. First, the knowledge on the physical impacts of climate is limited, especially in relation to nonmarket areas or impacts. Second, assigning monetary values to climate change damages is particularly challenging. Third, the need to identify the global cost-benefit optimal emission level requires defining an indicator of the global benefits of emission reduction in terms of avoided damages. Therefore, impacts have to be aggregated across impacts, across regions, which raises equity issues, and over time, which raises intergenerational issues.

Surveying the literature on impacts of climate change it is immediately clear damage estimates vary widely and uncertainty in the size of economic impact affects mostly non-market areas (Tol, 2002, Jamet and Jan Corfee-Morlot, 2009)[3]. Non-market impacts are either not considered or underestimated. Most IAMs are indeed based on out-of-date evidence, and most regional estimates are extrapolations from studies that have been carried out for one or two regions, typically the United States (DICE/RICE, MERGE and PAGE) or the United Kingdom (FUND). Most damage functions used in IAMs have not been updated according to latest evidence on climate change, except for the PAGE model used in the Stern Review, which takes into account new evidence on more rapid warming and large-scale changes to the climate system (“system” surprise). As a consequence, previous modeling exercises exhibit impacts that, on average, are quite small compared with the results described in the Stern

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[3] For a detailed survey of the literature on climate change impacts we refer to Appendix 3 in Bosetti *et al* (2009b).

Review, but also compared with the latest estimates such as those reported in the UNFCCC report (UNFCCC, 2007) or in the IPCC's Fourth Assessment Report (IPCC, 2007).

Two alternative damage scenarios are considered here: *i)* a low damage scenario, embedded in the basic version of the WITCH model, which in turn is based on the damage assessment provided by Nordhaus and Boyer (2000); *ii)* a high damage scenario, which incorporates more recent, higher damage estimates in the range of Stern (2007) and UNFCC (2007).

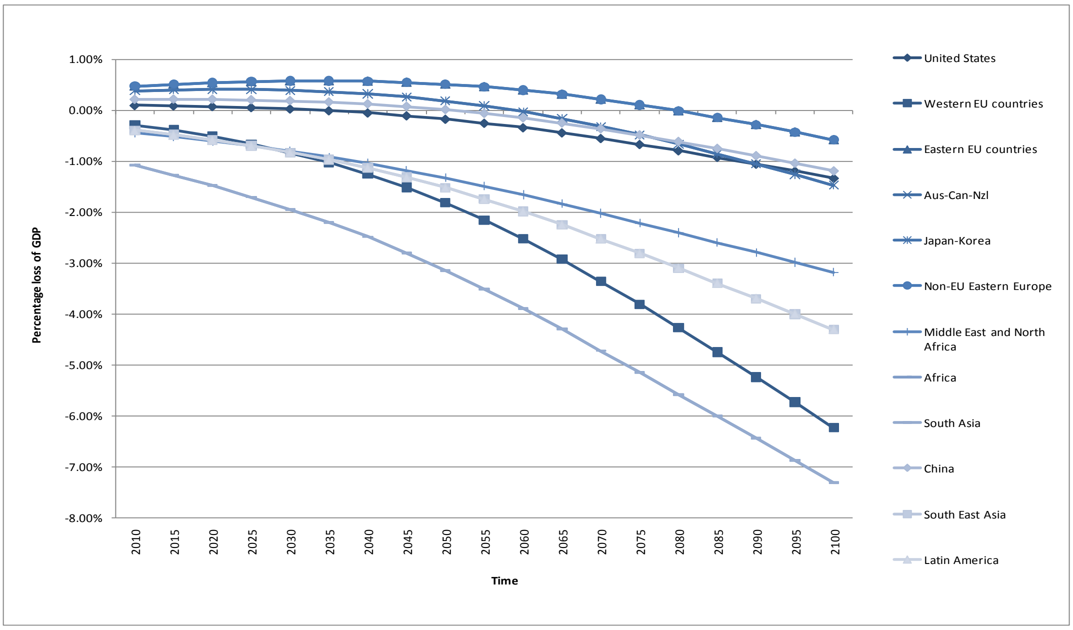
The WITCH model accounts for climate change damages, Ω, by means of regional functions that describe reduced-form quadratic relationship between temperature, T, and gross world product, GDP:

$$\Omega_{i,t} = \frac{GDP_{i,t}}{1+\theta_{1i}T_t + \theta_{2i}T_t^2} \qquad \textbf{(2)}$$

In the low damage scenario, for an increase in temperature below 3°C, climate change impacts on GDP can be either positive or negative, depending on regional vulnerability and geographic location. Above that level, damages are negative throughout the world and increase in a quadratic relationship with temperature. The resulting pattern of regional damages in a baseline as usual scenario shows higher estimated losses in developing countries, in particular South Asia (including India) and Sub-Saharan Africa (Figure 1). These two regions are expected to lose the most from climate change, especially because of higher damages in agriculture and the increase of vector-born diseases (Sub-Saharan Africa) and because of catastrophic climate impacts (South Asia including India). A recent review (Jamet and Corfee-Morlot, 2009) also indicates Africa and South and Southeast Asia as the most vulnerable regions, with GDP losses reaching more than 8% for a temperature increase above pre-industrial levels between 2 and 2.5°C. Damage estimates for agriculture, coastal settlements and catastrophic climate impacts are significant in Western Europe, resulting in higher damages than in other developed regions. In China, Eastern EU countries, non-EU Eastern European countries (including Russia), Japan-Korea, climate change up to 2.5°C would bring small benefits, essentially because of a reduction in energy demand for heating purposes (non-EU Eastern European countries including Russia) or positive effects on agricultural productivity (China).

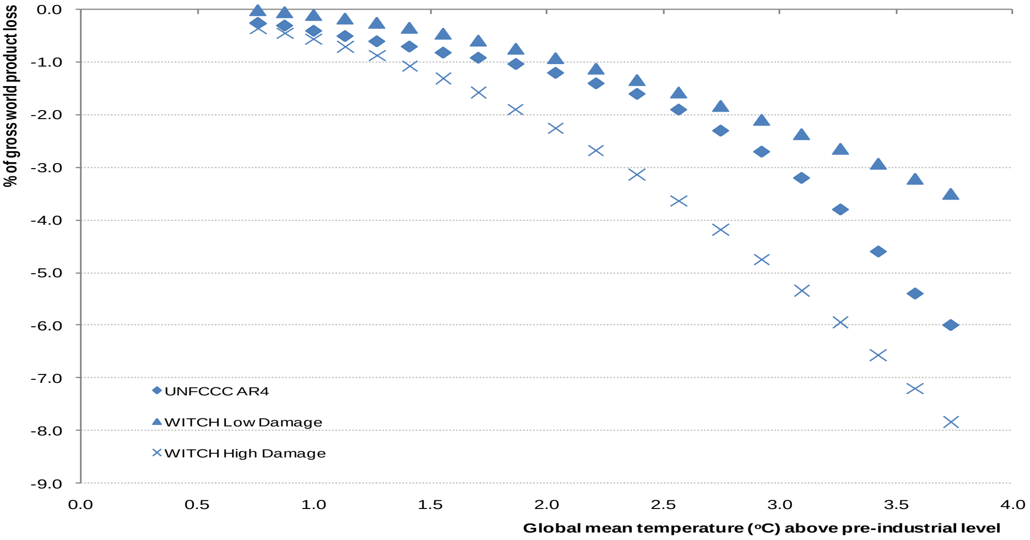
In the alternative, higher damage scenario the threshold above which impacts can only be negative throughout the world is 1°C. Global climate damages are, by the end of the century about twice as large as in the low damage scenario.

Figure 1. **Regional damage functions in the baseline as usual of the WITCH model. Low damage and high discount rate case.**



1. Korea is grouped with Japan, but is not an Annex I country. *Source*: WITCH model simulations.

Figure 2. **Global damage functions in the WITCH model –**



Source: WITCH model simulations and UNFCCC (2007).

Figure 2 illustrates the time profile of the two climate damage scenarios comparing them to climate change damages that can be extrapolated from the IPCC ranges reported in UNFCCC (2007. The WITCH high damage function follows UNFCCC data quite closely until a 1.5°C rise in global temperature, and increases more sharply beyond, moving closer to – but remaining lower than – Stern's (2007) estimates.

3.2. Discounting and pure rate of time preference

When analyzing the inter-temporal effects of climate change damages, the social discount rate and, in particular, the pure rate of time preference plays a crucial role. There is a longstanding controversy regarding the choice of the latter (Weitzman, 2001). Consistent with a long line of economists (*e.g.* Ramsey, 1928; Harrod, 1948; Solow, 1974), Stern (2007) argues on ethical grounds for a near-zero value, while others dismiss this assumption on the grounds that it is inconsistent with actual individual behaviour (*e.g.* Nordhaus, 2007; Weitzman, 2007).

Aggregate discounted impacts are vastly increased if greater weight is assigned to the far future, when damages are expected to be higher. Combining about hundred estimates from 27 studies to form a probability distribution for the marginal cost of carbon, Tol (2005) finds that the median value of the social cost of carbon – an estimate of the marginal impact caused by one additional ton of carbon – increases from $US7 to 39 per ton of carbon when the pure rate of time preference declines from 3% to 0%, *i.e.* when it declines from the value used in Nordhaus' DICE/RICE model to that used in the Stern Review. This implies that cost-benefit considerations would lead to very different abatement, depending on the value of pure rate of time preference. Indeed, in our subsequent analysis we show that only if future damages are given enough weight, i.e. a 0.1% pure rate of time preference is adopted, the grand coalition endogenously achieve stabilisation targets that are in line with those discussed in the policy debate, e.g. 550ppme (see Section 4).

In order to take into account the existing debate on the choice of the social discount rate, we perform our analyses under two different assumptions regarding the pure rate of time preference, namely 3% and 0.1%.[4]

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[4] Following Weitzman (2001), the pure rate of time preference is also assumed to be time-declining.

3.3. Abatement costs

The incentives to participate in climate coalitions are also shaped by mitigation policy costs. One determinant of these costs is the shape of the aggregate marginal abatement cost curve (MAC), which is a reduced-form relationship between the cost of abating an extra unit of emissions and cumulative abatement. In WITCH, mitigation costs are the result of energy switching, energy intensity improvement and innovation investments. It is possible to compute and compare MACs across countries by running a range of global carbon tax scenarios and report the resulting abatement. By repeating this exercise for a wide set of carbon taxes, it is possible to draw a relationship between marginal abatement costs and cumulative emissions abatement for the 12 regions of the model.[5] Figure 3 reports the marginal abatement costs as a function of relative abatement with respect to baseline. WITCH's MACs show the usual convex relation due to increasing marginal abatement costs. A $US100 tax per ton of CO_2eq achieves a cumulative CO_2 abatement between 53% and 73%, depending on the region. China and the United States have relatively lower/flatter marginal abatement curves, compared with other regions. MACs tend to become steep in all regions beyond a tax of $US150 per ton of CO_2eq.

One can also look at the cost, measured in terms of the discounted consumption loss, alternative world carbon tax scenarios imply, Figure 4. Developing countries are found to incur larger losses than their developed counterparts, due to their higher energy/carbon intensity. Fossil fuel producers such as the Middle East and non-EU Eastern European countries (including Russia) are the biggest losers, reflecting both terms-of-trade losses and their very high energy/carbon intensity. Within the group of developed regions, Western Europe and Japan-Korea would face smaller costs than the United States despite steeper MACs, reflecting their lower energy/carbon intensity.

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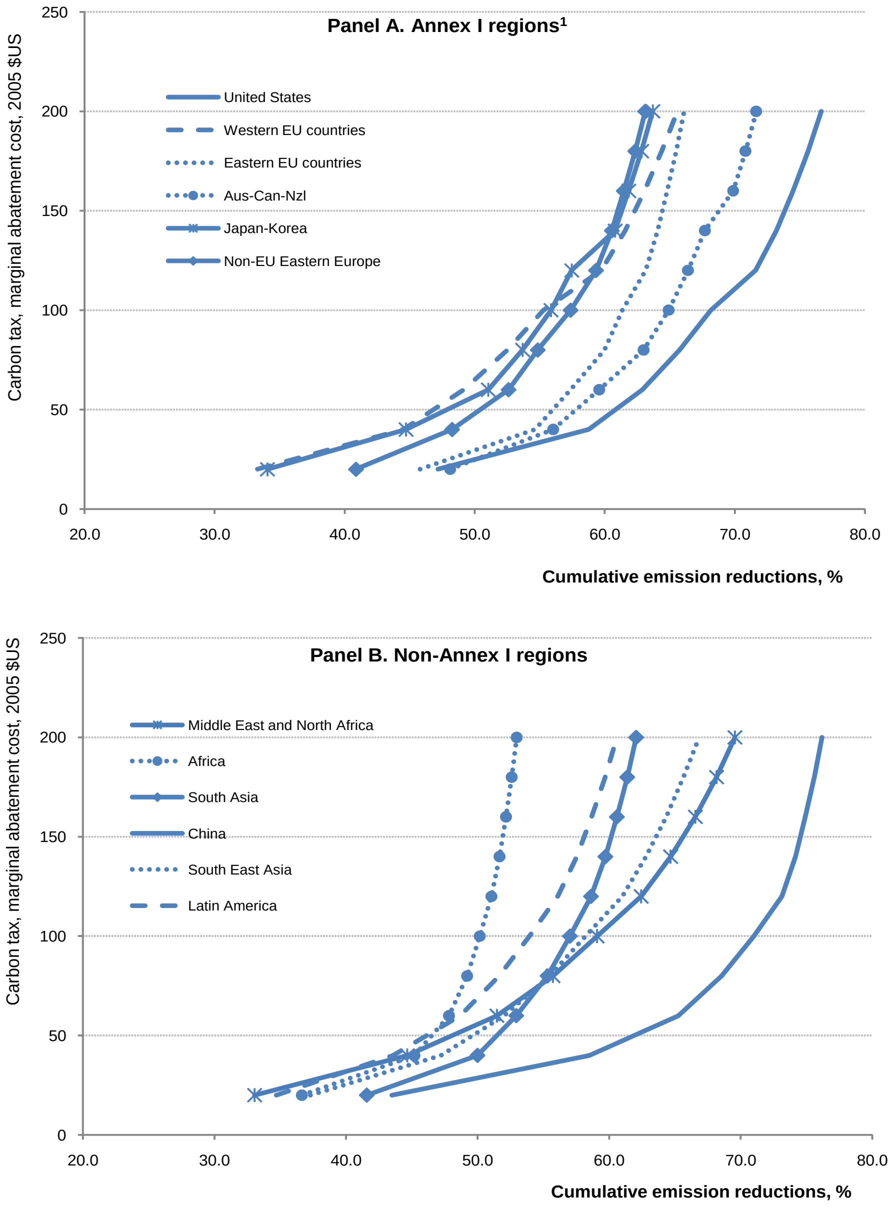
[5] Each carbon tax path considered is not constant, but instead is assumed to grow over time at the rate at which marginal abatement costs grow in the cooperative solution of the model. Obviously different dynamics of the tax would imply different MACs. For the sake of the analysis though we find it useful to report representative MACs. In order to focus only on abatement costs, all damages from climate change are excluded from this exercise.

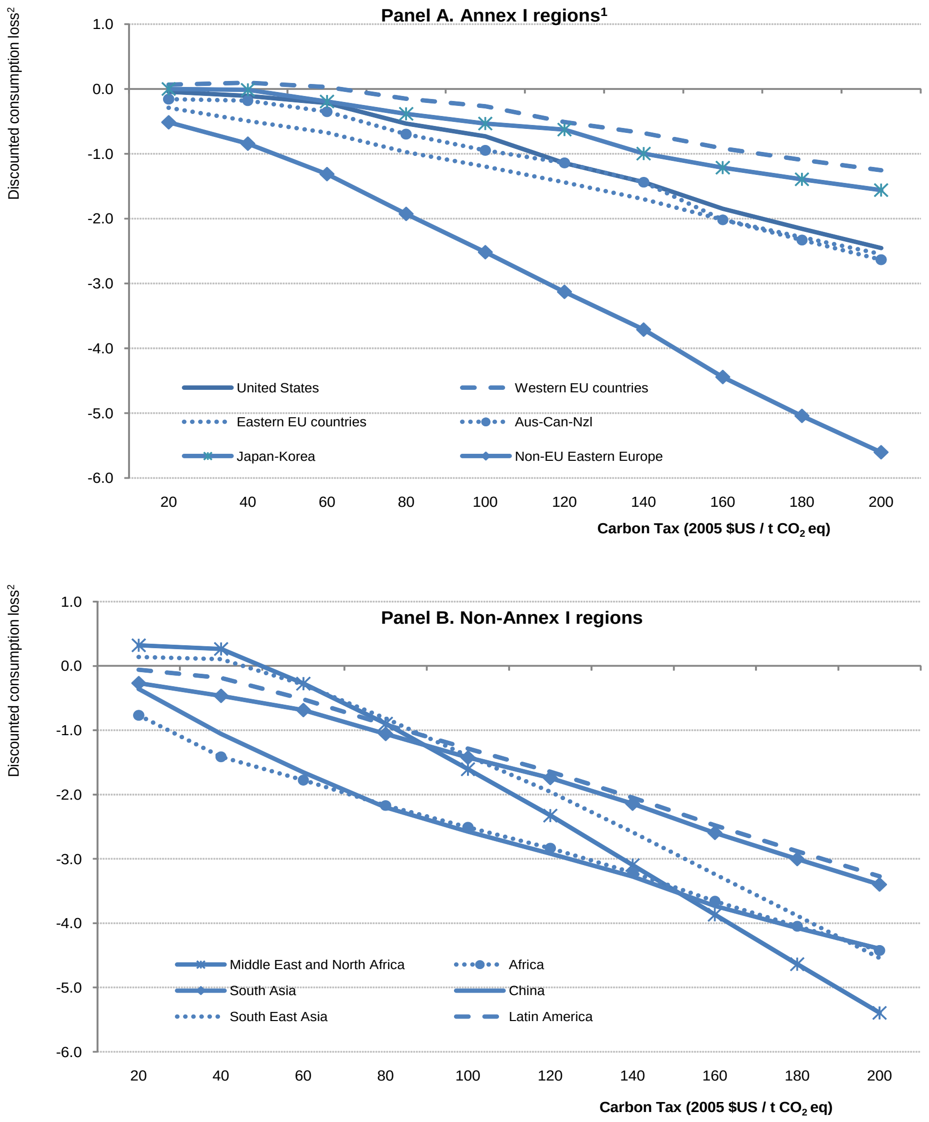
Figure 3. **Marginal abatement cost curves (all GHGs included)**



1. Korea is grouped with Japan, but is not an Annex I country.

Source: WITCH model simulations.

Figure 4. **Discounted regional abatement costs under a range of world carbon tax scenarios**


Panel A. Annex I regions[1]

Panel B. Non-Annex I regions

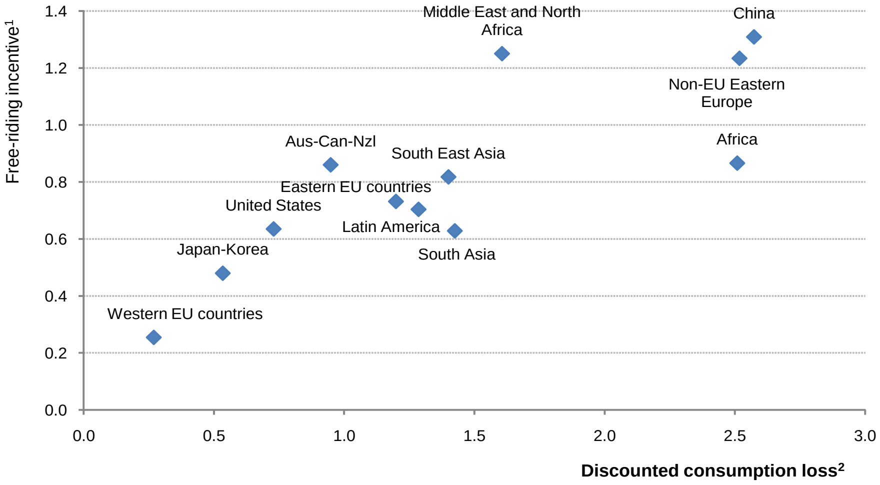
1. Korea is grouped with Japan in the WITCH model, but is not an Annex I country.

2. Cumulative consumption gap relative to baseline in present value terms over 2015-2100, using a 3% annual discount rate.

Source: WITCH model simulations.

The larger a region's mitigation costs under a global carbon tax, the smaller its incentives to participate in a climate coalition, *ceteris paribus*. One possible measure of free-riding incentives that will be introduced and discussed below is the difference (in %) between a region's welfare (defined as the discounted sum of the logarithm of future domestic per-capita consumption) if it free rides on a world coalition of acting countries, and its welfare if it participates in that coalition. As Figure 5 shows, there is a strong positive relationship between that synthetic indicator of free-riding incentives and the overall consumption loss induced by a given world carbon tax – set here at $US100 per ton of CO_2eq. This is because climate coalitions are assumed to implement an efficient climate policy, *i.e.* to equalise marginal abatement costs across all participating regions.[6] As a result, countries that face larger costs from a given world carbon price can expect to gain less from joining an international coalition, and therefore have larger incentives to defect, *ceteris paribus*.

Figure 5. **Mitigation policy costs and free-riding incentives**



1. The free-riding incentive is computed as the difference in % between a region's intertemporal welfare if it withdraws from a world coalition of acting countries (the so-called “grand-coalition”, see Section 3), and its intertemporal welfare if it participates in the world coalition. A 0.1% annual pure rate of time preference is used to compute the present value of welfare.

2. Cumulative consumption gap relative to baseline in present value terms over 2015-2100, using a 3% annual discount rate.

Source: WITCH model simulations.

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[6] This is a consequence of using Negishi weights to aggregate welfare.

4. ANALYSING COALITION FORMATION AND STABILITY

4.1. Cooperative versus non-cooperative outcomes

We start our analysis from the most environmental effective coalition, namely the grand coalition. A world social planner maximizes the aggregate global welfare, which is defined as the weighted sum of regional welfares, using the Negishi weights to ensure equal marginal abatement costs worldwide. Later we see the effect of changing aggregating weights on coalitions.[7]

We compare this optimal outcome with the non-cooperative outcome where each of the 12 regions is assumed to choose the optimal path of a set of choice variables (investments in physical capital, in different energy technologies, in R&D, *etc.*) so as to maximize its own social welfare function. In this framework, each region takes its decisions individually, given the action of the other players. The outcome of this non-cooperative game is an open loop Nash equilibrium.

Figure 6 shows the implications of the two solution concepts for global GHG emissions under the different assumptions about the damage and discounting assumptions. In the non-cooperative case, upper panel, world emissions grow throughout the century. Little abatement is undertaken since individual regions do not internalise the negative externality they impose on other regions, taking only into account the domestic ancillary benefits of their climate policy. The choice of the pure rate of time preference or of the damage scenario, in this instance, do not make much of a difference. In addition a higher discount rate implies not only a higher weight on future damages – which should favour emission reductions – but also a higher consumption path – which leads to higher emissions. When regions only see their own damage, the relative strength of the second factor is larger, determining higher emissions.

If instead countries gather in a climate grand coalition, the environmental externality is fully internalised, and emissions are reduced drastically (lower panel of Figure 6). In addition,

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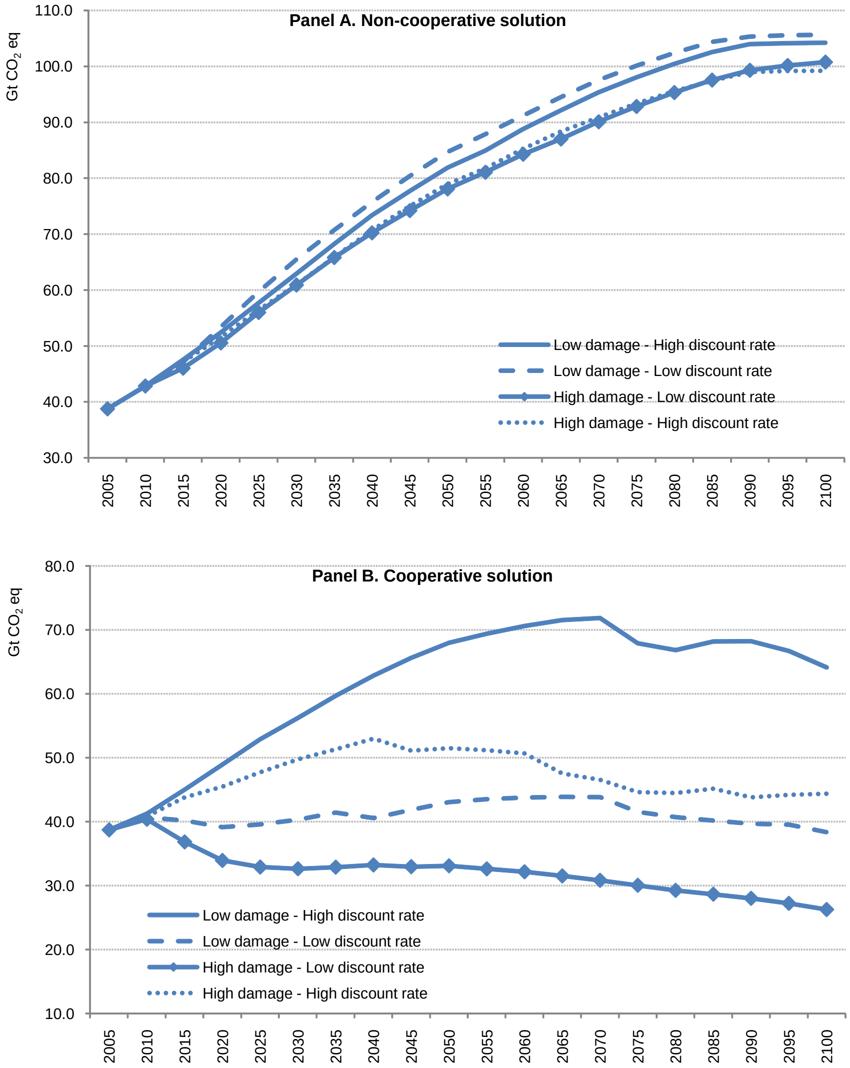
[7] In this analysis we assume cooperation is on the climate externality only. The WITCH model incorporates other economic externalities related to the use of natural resources and to the production and diffusion of knowledge and experience. However, this paper analyses the incentive to form climate coalitions, independently from linkages with other issues. In that context, it is assumed that countries decide whether or not to cooperate on the environmental externality only. Cooperation on technological externalities and on the use of natural resources is not considered.

sensitivity to underlying assumptions is far greater than in the non-cooperative case. Under these damage/discounting assumptions, the optimal emission path would be such to stabilise long-run GHG concentration at about 546 ppm CO_2-eq, when the pure rate of time preference is 0.1%, and 676 ppm CO_2eq when it is 3%. When looking at the relative effect of lower discounting and of higher damages, the former has a sizeable greater impact, in particular on short term emissions.

Figure 6. **Sensitivity of the cooperative and non-cooperative solutions to alternative damage and discount rate assumptions**



Source: WITCH model simulations.

The difference between the cooperative and non-cooperative outcomes gives an indication of the gains from cooperation, which are substantial. The theory of self-enforcing agreements teaches us that the larger the potential benefits of cooperation, the stronger the incentive to free ride (Barrett 1994). The damage and discounting assumptions also affect the size of cooperation gains. A high discount rate reduces the benefits from cooperation, the more so when damages are low.

4.2. Environmental effectiveness, profitability and stability of climate coalitions

With 12 regions the number of possible coalition is very large. However, we focus on a subset of large coalitions that would have the potential to endogenously produce targets commonly discussed in the policy arena (e.g. in line with the 600 and 550 ppm CO2 eq 2100 atmospheric targets). We perform the cost-benefit analysis of each of these coalitions under different assumptions on the pure rate of time preference, damage scenario, and weighting assumptions.[8] We first discuss the environmental effectiveness of this subset of coalition and then look at their profitability and stability.

Among the larger coalitions, only the grand coalition is found to stabilise GHG concentration below 550 ppm CO_2-eq by 2100. This is illustrated in Table 1, which shows the environmental performance of the grand coalition together with 6 large coalitions that have the technical potential to meet similar targets at the 2100 horizon. The composition of these coalitions suggests that large emitters such as China and India are to be included. We always exclude Sub-Saharan Africa from all these sub-coalitions as it is realistic to assume that, if any other region will stay out, then Sub-Saharan Africa will necessarily follow, invoking equity arguments such as the right to grow. Even if only Sub-Saharan Africa behaves as a singleton, the 550 ppm CO_2-eq target in 2100 is no longer reached. Leaving an additional region out of the coalition raises GHG concentration above the target 600 ppm.

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[8] In what follows we only report results for the high damage scenario which is most conducive to significant emission reductions by the coalition considered. If a coalition is not environmentally effective in this case, it cannot be either under lower damages.

Table 1. **Analysis of the environmental achievements of potentially effective coalitions, cost-benefit mode, high-damage/low-discounting case**

Overall GHG concentration (ppm CO_2 eq)	2050	2100
Non-participating regions:		
None (Grand coalition)	507	546
Africa	518	603
Africa, Latin America	532	612
Africa, Non-EU Eastern Europe	531	603
Africa, Middle East and North Africa	529	609
Africa, South East Asia	526	598
Africa, South East Asia, Non-EU Eastern Europe	529	603

Source: WITCH model simulations.

Two main factors explain the failure of smaller coalitions to achieve the 550 ppme concentration target:[9]

1. Smaller coalitions internalise only a fraction of the environmental externality. The fraction of damage that is not internalised drives a gap between the coalition and the global marginal benefit of emission reduction. The larger this gap, the smaller the emission cut that the coalition achieves. However, there is not a clear relationship between coalition size, coalition marginal damage, and emission reductions, because damages are not evenly distributed among world regions. This implies that the inclusion in the coalition of regions facing larger damages from climate change increases coalition's marginal damage, and the optimal level of emission cuts, *ceteris paribus*.

2. As coalitions get less inclusive, the number of free-riders obviously increases; these countries might simply keep emission unchanged, or even undertake some small abatement due to the lower price of carbon-free technologies, but most likely they rather increase emissions and undo some of the coalition reduction.

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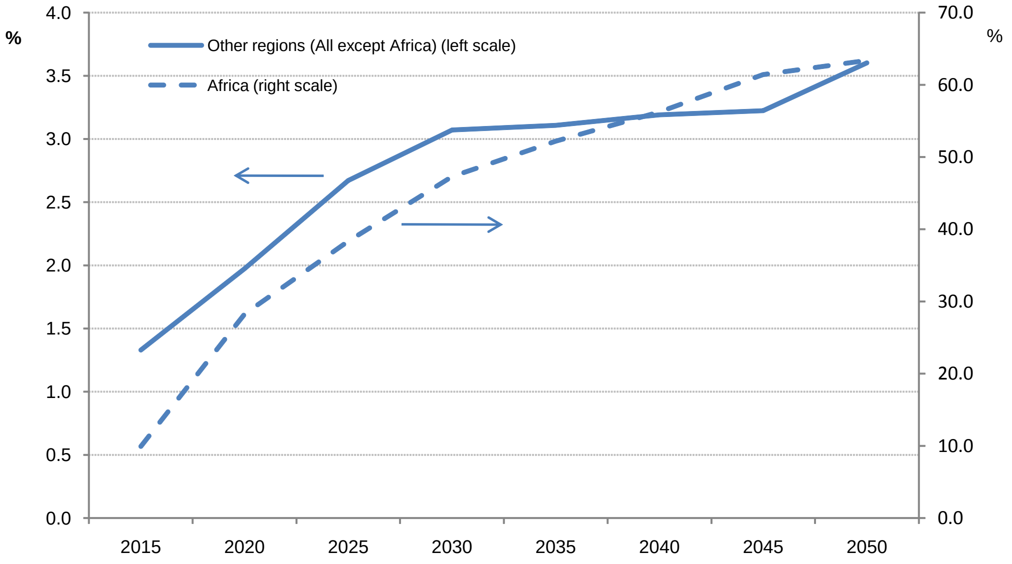
[9] One assumption is crucial here and may alter these results: the absence of negative emissions technologies, or any other technology that might alter the climate (i.e. geo-engineering). If one assumed that by means of bioenergy and carbon capture and sequestration, or direct CO2 capture, or other technologies that alter the incoming solar radiation, cooperating countries could dramatically change the climate, than the requirements on the dimension and composition of a coalition to endogenously produce the 550 ppm CO2eq by 2100 target would be substantially different.

These two forces undermining the achievement of sub-coalitions can be illustrated by looking at a coalition structure under which only Sub Saharan Africa does not participate and behaves as a singleton (Figure 7). First, leaving out Sub-Saharan Africa means not internalising a large share of the global damage (see Figure 1, together with South Asia, Sub Saharan countries would suffer the largest damage). As a consequence, such coalition would achieve significantly lower abatement effort compared to the grand coalition. Second, the emissions of Sub Saharan Africa itself increase dramatically when it behaves as a singleton. It is worth noting that, although the emissions of the Sub-Saharan African region are larger than in the grand coalition, they are lower than in the non-cooperative scenario. Although Africa could emit as much as in the non-cooperative scenario or even more, it does not find it optimal to do so. The reason is the presence of international technology transfers from the cooperative bloc that reduces the costs of carbon-free technologies outside the coalition itself.[10]

Figure 7. **An illustration of free-riding incentives: the case of Africa**

Difference in GHG emissions between the grand coalition without Africa and the grand coalition, %



Source: WITCH model simulations.

An important factor in shaping the effectiveness of coalition is the weight given to future damages by setting the pure rate of time preference. A higher rate implies, for the grand coalition, an addition of GHG concentration in the atmosphere equal to 125 ppm CO_2-eq

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[10] Depending on the stringency of the target and the characteristic of the free riding countries either the energy market or the innovation effect may prevail, see Bosetti and DeCian (2011) for a thorughout discussion of these competing effects.

compared to the low discounting case approximately equivalent to an additional warming of 0.5°C. Smaller coalitions, already reaching more than 600 ppm CO_2-eq with a low discount rate, would lead to an increase of 80 ppm CO_2-eq or more.

Finally, the coalition effectiveness is obviously affected by the weights used to aggregate different regions when maximizing aggregate welfare. The results discussed so far are based on Negishi weights, which implies a cost-efficient allocation of abatement within the coalition. Table 2 looks again at the grand coalition and compares the solution based on Negishi weights with that based on a weighting scheme more favourable to developing countries, proportional to the population share. This aggregation scheme increases the environmental effectiveness of the coalition in the short and medium term, and also in the long term with a sufficiently high discount rate. However, with low discount rate the population social welfare aggregator yields higher GHG emissions concentrations in 2100.

Table 2. **Analysis of the environmental achievements of potentially effective coalitions, cost-benefit mode, high-damage/low and high discounting using different weights**

Overall GHG concentration (ppm CO2 eq)				
		2030	2050	2100
Negishi weight- 0.1%		480	507	546
Population weight - 0.1%		473	502	556
Negishi weight - 3%		506	574	672
Population weight- 3%		489	538	622

Source: WITCH model simulations.

International climate coalitions need not only to be environmentally effective, but should also be self-enforcing. In technical terms, this means that a coalition should be profitable and stable, or at least potentially stable. As noted in Section 2, a coalition is profitable if each cooperating player has a welfare larger than that she would get in the non-cooperative scenario. A coalition is internally stable if the welfare of each participating region is larger or equal to the welfare she would obtain from staying out of the coalition and free riding on participants' abatement efforts. As an example, when we check the stability of the grand coalition we need to run simulations in which either of the 12 regions is assumed to deviate, while the others continue to cooperate. By comparing discounted consumption in the cooperation and non-cooperation case and we can then check whether and how many countries have an incentive to abandon the grand coalition. Although not stable, a coalition might be Potentially Internally Stable (PIS) if there is a transfer scheme that gives each member at least her free-riding pay-off and shares the remaining surplus.

For different coalitions Table 3 reports profitability, internal and potential internal stability. As expected, all large coalitions considered in the analysis are not profitable, as there is always at least one region, namely China and Sub-Saharan Africa when it applies, which is worse off than in the non-cooperative case.

Table 3. **Profitability and Stability of potentially effective coalitions**

Non-participating regions	Profitability	Internal Stability	Potential Stability
Low PRTP (0.1%) - Negishi Weighted			
None (Grand coalition)	NO (Africa, China)	NOT STAB (All)	NOT PIS
Africa	NO (China)	NOT STAB (All)	NOT PIS
Africa , Latin America	NO (China)	NOT STAB (All)	PIS
Africa , Non-EU Eastern Europe	NO (China)	NOT STAB (All)	PIS
Africa , Middle East and North Africa	NO (China)	NOT STAB (All)	PIS
Africa , South East Asia	NO (China)	NOT STAB (All)	PIS
Africa , South East Asia, Non-EU Eastern Eu	NO (China)	NOT STAB (All)	PIS
High PRTP (3%) - Negishi Weighted			
None (Grand coalition)	YES	NOT STAB (All but China and Latin America)	PIS
Low PRTP (0.1%) - Population Weighted			
None (Grand coalition)	NO (All but Africa, South Asia, South-East Asia)	NOT STAB (All but Africa)	NOT PIS

In parenthesis countries for which coalitions are not profitable or internally stable

Source: WITCH model simulations.

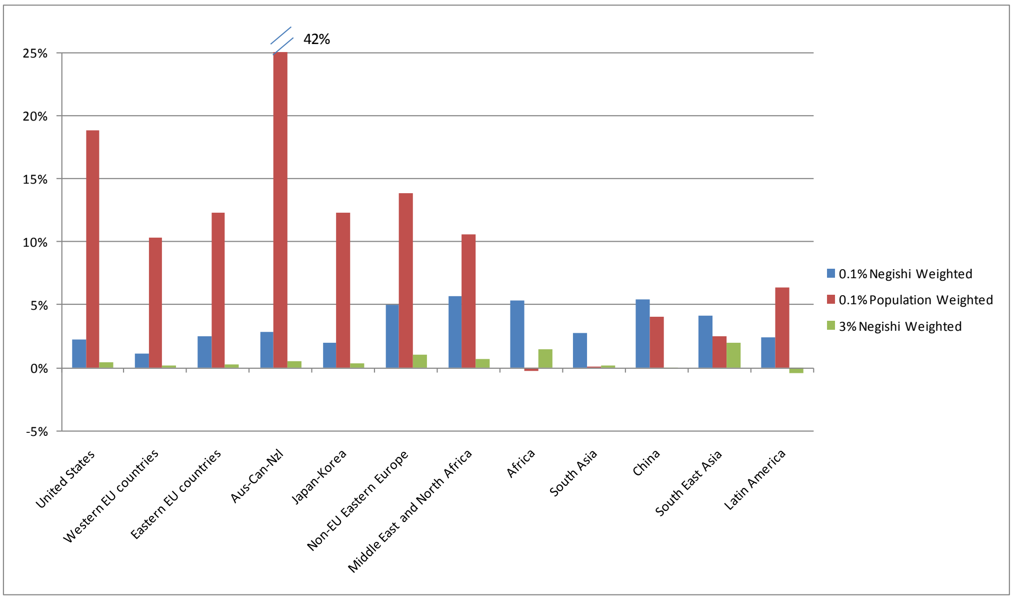
Last column in table 3 report results on whether coalition can be stabilized through transfers, i.e. they are potentially internally stable. We do this by checking if the aggregate residual surplus of consumption in the coalition is greater than the sum of the discounted consumption gains that countries have when they free-ride . We find that the grand coalition is not PIS. The aggregate, discounted surplus from cooperation is equal to 477 USD trillions over the 2005-2100 time horizon, while the sum of the gains from free-riding is equal to 680 USD trillions. We then test the coalition that includes all regions but Africa, the most environmental effective of all partial coalitions. We find that this coalition also is not potentially internally stable, but the gap is now only 2% of the aggregate discounted consumption gain of the coalition. The smaller PECs are PIS. Therefore we find that the lowest level of GHG concentration that can be achieved by a stable coalition is slightly above 518 ppm CO_2-eq in 2050 and around 600 ppm CO_2-eq in 2100.

To provide greater insight on internal stability, and how this interplays with crucial assumptions on the aggregation and discounting choices, Figure 8 reports free-riding incentives across regions, based on the difference in welfare between free riding on and participating to the grand coalition. Let us start by looking at the blue bars, that refer to the central case of 0.1% discounting and Negishi weights.

The Middle East-North Africa region, China, the rest of Africa, and non-EU Eastern European countries are estimated to have the largest incentive to free ride. By contrast, developed countries have the lowest free-riding incentives, with the exception of the Australia-Canada-New Zealand region.

Figure 8. Estimated ranking of free-riding incentives across regions

% Difference in welfare per capita between free-riding on and participating in the grand coalition



Source: WITCH model simulations.

What happens if the pure rate of time preference used in the analysis is 3% instead of 0.1% (see second row in Table 3)? Not only each region's welfare is larger in the grand coalition than in the non-cooperative case, i.e. the grand coalition is profitable, but the incentives to free ride are now much smaller, although the coalition is not stable, nor internally stable. We find that the discounted surplus, in consumption terms, generated by cooperation (133 USD trillions) is four times greater than the discounted aggregate surplus from free-riding (35 USD trillions).

This result confirms a well-established result in coalition theory. When gains from cooperation are large, as in the 0.1% case, free riding incentives are also likely to be high. On the contrary, when gains from cooperation are small, as in the 3% case, free riding incentives are reduced significantly. Figure 8 reiterates this by showing incentive to free ride when the discount rate is higher, green bars There is a clear message that emerges from our analysis. Cooperation is indeed possible, profitable and potentially stable, but only if the environmental target is moderate (at least compared to what currently discussed in the policy debate), i.e. around 600 ppm CO_2-eq by 2100.

Finally, we test how using a different set of weights affects the results (see the last row in Table 3). When using population-based weights, the grand coalition is profitable only for Africa, South Asia, and South-East Asia and it is not internally stable (only Africa sees welfare gains from cooperation that compensate incentives to deviate). Figure 8 (red bars) shows that when population weights are used, the regional pattern of free-riding incentives is reversed with respect to the cost-effective abatement allocation implemented through Negishi weights. First, with population weights the abatement allocation is no longer the efficient one. In addition, perceiving a larger damage, the grand coalition abates more. The effort is shared across all members, which all abate more compared to the Negishi aggregation, with the exception of Africa, South Asia, and South-East Asia. These regions have two characteristics. Because of their high population they receive the largest weights in the social welfare function, together with China. They have the largest benefits from cooperation, and in fact, cooperation results profitable for them. This characteristics lead to a high benefit-cost ratio, which explains their very low free riding incentives. This result suggests that a different allocation of the effort can have important implication on countries incentives to participate.

5. Conclusions

This paper has studied the incentives to participate in and the stability of international climate coalitions using the integrated assessment model WITCH. The WITCH model has a game-theoretic structure in which different degrees of international cooperation can be simulated. When countries decide whether or not to cooperate on GHG emission control, they take into account how their decisions affect all other countries, and whether these countries will cooperate or remain outside the coalition. The optimal level of abatement in each coalition has been derived in a cost-benefit framework. The main incentives to participate in climate coalitions mainly depend in WITCH on two major economic drivers, namely the abatement costs incurred and the damages avoided both within and outside a coalition. We have performed the analysis of coalitions profitability and stability under four alternative combinations of damage and discount rate and assessed the effect of two different schemes of aggregating welfare across countries. The high damage-low discount rate combination is the most conducive to cooperation for emissions control because it increases in both directions the size of expected present value of climate change damages. The low damage-high discount rate combination is instead the less conducive to international cooperation. The weighting scheme that is proportional to population size also increases the effort of the coalition by giving greater weight to developing countries, where most of climate damages are projected to occur. We have confined the analysis of profitability and stability only to the subset of coalitions that could attain effective emission reductions, defined as those that have the potential to stabilise global GHG concentration between 550 and 600 ppm CO_2-eq. The focus on a subset of policy-relevant coalitions is particularly convenient and avoids uninteresting cumbersome numerical exercises. When account is made for free-riding behaviours of non-participating regions, only a very broad international coalition excluding no region other than Sub-Saharan Africa could achieve meaningful stabilisation targets by 2100.

Cost-benefit analysis suggests that only the grand coalition finds it optimal *as a whole* to stabilise overall GHG concentration below 550 ppm CO_2-eq in the high-damage/low-discounting case. Smaller coalitions, including the grand coalition excluding Africa, achieve less ambitious targets, above 600 ppm CO_2-eq. This is because they do not fully internalise the global environmental externality and allow a larger number of (non-participating) countries to free ride. Although the grand coalition *as a whole* has an incentive to achieve the

550 ppm CO_2eq target, it is not internally stable. Most regions gain more from non-participation than from participation to the grand coalition. This is true also for smaller coalitions. The grand coalition is not *potentially* internally stable (PIS) either, *i.e.* no set of international financial transfers can be found that would offset the free-riding incentives of *all* participating countries *simultaneously*. This is because the overall welfare gain from the grand coalition relative to the non-cooperative outcome is not large enough to give each country her free-riding pay off. After compensating all losers in the coalition, the remaining coalition surplus is too small to offset free-riding incentives. The coalition that includes all regions but Africa is also not PIS, but the gap between the consumption level after the redistribution of cooperation gains is only 2% lower than the consumption level that regions achieve when they do not cooperate. All other analysed coalition, that can attain around 600 ppm $CO_2\text{-}eq$ are PIS.

There is a clear message that emerges from our analysis. Cooperation is indeed possible and profitable, but only if the environmental target is moderate (at least compared to what currently discussed in the policy debate). In fact, stability, even potential, is ensured only when the coalition stabilises GHG concentrations in 2100 above 600 ppm CO_2eq. Sensitivity of environmental effectiveness, stability concepts, and free riding incentive to different manners of weighting regional welfare in the coalition indicate that more ambitious targets become optimal when regions with high damages have larger influence. We also show that different allocation of the effort could have important implication on countries incentives to participate.

Our findings are subject to a number of limitations. Even though some sensitivity analysis has been carried out to assess the robustness of the main results, it should be acknowledged that the model-based analysis relies on strong assumptions. In particular, there are wide uncertainties in practice surrounding future emission trends,[11] the market and non-market impacts from climate change, the likelihood and effect of catastrophic risks, and the cross-country distribution of these damages and risks.

Furthermore, the analysis focuses on immediate, irreversible and self-enforcing participation to mitigation action, thereby abstracting from other possible bargaining options including

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[11] For instance, projected world BAU emission growth is somewhat higher in WITCH than in the OECD model ENV-Linkages as featured in Burniaux *et al.* (2008) (100% versus 85% over the period 2005-50).

e.g. delayed participation, renegotiation, sanctions or joint negotiation in multiple areas (*e.g.* linking climate and international trade negotiations. If feasible, these alternative bargaining options which might yield different results (see Carraro and Massetti, 2010). For instance, a major emitting country may have greater participation incentives than found here if it expects its withdrawal to prevent the formation of *any* coalition.

The co-benefits from mitigation action, *e.g.* in terms of human health, energy security or biodiversity, are not taken into account. Other studies suggest that such co-benefits are large, although the participation incentives they provide are dampened by the fact that some of these co-benefits could be reaped through direct policy action – in particular, local air pollution might be reduced at a lower cost through direct policy action than through reductions in GHG emissions (Bollen *et al.* 2009; Burniaux *et al.* 2008).

Removal of fossil fuel subsidies, one of the few policies to yield potentially both climate and economic benefits, is also omitted from the analysis. Insofar as phasing out subsidies would bring an economic gain and lower the carbon intensity of a number of (mainly developing) countries, incentives to participate in international mitigation action could improve.

Another potential limitation of the analysis is to assume that even if a country benefits from an international coalition relative to a BAU scenario, it will always prefer to free-ride if that option is even more profitable. While this assumption merely derives from individual welfare maximisation, current international redistributive policies such as official development aid point instead to some degree of altruism. Against this background, there might be a possibility for some countries to sign an agreement even if they could in principle gain more from free riding on other countries' abatement efforts. We test this possibility by computing the cost for developed countries of using additional resources (additional to the coalition surplus) to stabilise the grand coalition, *i.e.* to give each other region its free-riding pay off. These calculations show that with a 3% loss in the discounted value of their consumption levels, industrialised countries could stabilise the grand coalition in the high-damage/low-discounting case, *i.e.* all other participating regions could be fully compensated for their free-riding incentives through financial transfers, thereby bringing them into an agreement.

Finally, two crucial assumptions affect the results presented in the paper. The absence of negative emissions technologies or any other technology that might alter the climate (i.e. geo-engineering), and the absence of adaptation policies. If one assumed that by means of bioenergy and carbon capture and sequestration, or direct CO2 capture, or other technologies that alter the incoming solar radiation, cooperating countries could unilaterally change the climate, than the requirements on the dimension and composition of a coalition to endogenously produce the 550 ppm CO_2eq by 2100 target would be substantially different. Adaptation policies, by providing benefits that are local, at least within the boundary of macro-regions considered in this model, could also change free riding incentives and thus the willingness to cooperate on climate change mitigation as well.

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