Self-Enforcing Climate Coalitions And Preferential Free Trade Arrangements

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Abstract

In this paper, we discuss the endogenous formation of self-enforcing climate coalitions linked to the issue of a free trade agreement. As a framework, a strategic trade model is used in which countries may discourage greenhouse gas emissions by means of an import tariff on dirty goods. In addition, countries can set an emissions cap being effective on a permit market. Our main focus, however, is on the utilization of terms of trade privileges provided to members of a preferential free trade area. We propose evidence for that the welfare gains of trade liberalization are strongly promoting the formation of climate coalitions. In the parametrical simulation of the model, global emissions as well as climate change damages are found significantly reduced compared to the BAU scenario while global welfare is found significantly higher.

JEL classification: Q54, Q56, Q58, F18, F13

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1 Introduction

When it comes to the issue of climate change, broad collective action is called for. In the literature various mechanisms are proposed for the voluntary, self-enforcing formation of climate coalitions to achieve an effective mitigation of global greenhouse gas emissions. Typically, multilateral cooperation among countries is institutionalized in the form of international environmental agreements (IEAs) such as the Kyoto Protocol. In this respect, incentives provided to countries to offset free-riding are crucial. Among the many issues as an incentive device for emissions reduction are secondary benefits like side payments, technology transfer, ancillary effects on health and local pollution hotspots, just to mention the most prominent ones.

This paper naturally is rooted in the tradition of this strand of literature. However, we would like to propose a different kind of incentive mechanism. In our view, it should be beneficial to signature states of a climate coalition if at the same time they could join a free trade arrangement and enjoy the trade privileges provided. Notwithstanding, the potential linkage of free trade arrangements to the formation of climate coalitions, thereby creating so-called 'climate clubs', have been proposed in the literature before (e.g. *Weischer et al.*, 2012, *Leal-Arcas*, 2013, *Hovi et al.*, 2015, *Nordhaus*, 2015). But, to our knowledge, this has not been done so far in a formal way by using an appropriate trade model which is suitable in capturing the relevant environmental aspects. The difficulty one might experience here necessarily lies in identifying the trade pattern prevailing inside the free trade area and outside to properly assign the free trade privileges.

Therefore, in the paper we have tried to build up a model in the tradition of the strategic trade theory which entails the environment in form of an unwanted by-product, greenhouse gas emissions, modeled as a global public bad. Its basic framework goes back to *Eichner and Pethig* (2013a, 2013b). There is a multi-stage Stackelberg leader-follower framework comprising a multi-sectoral international market stage as well as a policy stage on which countries strategically can employ trade measures like tariffs as well as environmental measures like emissions caps. However, in contrast to the existing literature with a focus on analyzing the impact of traditional trade barriers on climate change, we introduce a free trade arrangement as an incentive device for the endogenous formation of climate coalitions. Therefore, we have to trace the trade flows among signatories and non-signatories of a free trade arrangement, as well as those between the two groups. This is basically done by a novel formulation and differentiation of firms' supplies with respect to the various kinds of target markets which also implies an appropriate modification of the equilibrium concept for local markets. As a main result of our analysis we find strong evidence for the thesis that the in a free trade agreement can strongly promote the formation of climate coalitions if trade privileges are linked to that issue.

From the early 1990s onwards, a comprehensive strain of literature has emerged, focusing on the game-theoretic analysis of self-enforcing IEAs. Seminal papers of the non-cooperative literature include *Hoel* (1992), *Carraro and Siniscalco* (1993), and *Barrett* (1994). Their results suggest that self-enforcing IEAs can only be implemented if either the number of signatories is small or if the agreement commits to fairly lax emission reduction targets relative to the business-as-usual emission scenario, irrespective of whether the climate damage function takes a linear or quadratic form (*Hoel*, 1992, *Barrett*, 1994). Put differently, there appears to be a trade-off between the effectiveness of an IEA and its stability (*Finus*, 2003).

In order to pave the way for a global treaty with ambitious emission reduction targets, several treaty mechanisms have been considered. A comprehensive overview of the literature on the proposed compensation measures such as side-payments or non-material payoffs is provided by *Finus* (2003). The findings can be summarized as follows: Since transfers must be self-financed, i.e. they must result from the welfare gain of the coalition, they hardly can improve cooperation among symmetric countries (*Carraro and Siniscalco*, 1993, *Barrett*, 1997a). If countries are heterogeneous, transfers may lead to larger stable coalition structures but the results highly depend on the specific design of both the allocation rules and the coalition formation (*Botteon and Carraro*, 1997, *Barrett*, 1997a, *Eyckmans and Finus*, 2007). According to *Finus* (2003), transfer commitments made before the coalition has formed (ex-ante transfers) turn out to be less effective than transfer commitments made to enlarge an already existing coalition (ex-post transfers), though the term 'commitment' must be conceived as in line with the self-enforcement requirement in order to be credible.[4] Overall, the scope of transfers to improve the prospects of a broad and effective cooperation appears to be rather limited (*Eyckmans and Finus*, 2007).

Other instruments to induce cooperation reviewed in the literature involve punishments and sanctions. Even though trade sanctions such as border tax adjustments are particularly popular as effective threats to combat carbon leakage (*Bucher and Schenker*, 2010, *Fischer and Fox*, 2012), there is a dispute about the imposition concerning their credibility on one

[4] For this purpose, the notion of internal stability has later been modified to a concept of potential internal stability. It is stated that a coalition is *potentially* internally stable if it can be stabilized by a self-financed transfer scheme such that no signatory state – neither the net payers nor the net recipients – has an incentive to behave as a free rider (*Bosetti et al.*, 2013).

hand and their compliance with the non-discrimination rules of the WTO on the other. In this respect, *Barrett* (1997b) argues that, in principle, the use of trade sanctions to increase the provision of a global public good can be welfare-improving and enhance cooperation if the threat of imposition is credible. However, the credibility of trade sanctions is inherently subject to incentives to weaken sanctions whenever they might imply a welfare loss to signatory states, too. Therefore, this instrument is also limited in terms of raising participation in IEAs.

More recently, attention has been paid to the linkage of negotiation issues, or, more precisely, to the linkage of the public-good agreement to a club-good agreement, assuming that a simultaneous membership in both agreements may be in order. Here, the potential for success in terms of participation and stability crucially is depending on the linked issue. In this respect, most papers focus on R&D cooperation such as *Carraro and Siniscalco* (1997), *Carraro* (1999), and *Kemfert* (2004). Two findings are though striking: first, R&D cooperation usually provides a competitive advantage to signatories to produce at lower unit costs by employing a more efficient technology, but, even under most favorable assumptions, that advantage tends to disappear when the number of signatories increases and more countries share the same technology. Hence, the R&D cooperation issue seems to have diminishing returns with respect to the coalition size; thereby it may be optimal to exclude some countries from the joint cooperation on R&D and climate change mitigation. The implication of non-monotonic payoff functions would be that some non-signatories would like to join the coalition but are excluded from doing so (*Carraro*, 1999), leading to a violation of the condition of external stability. In light of these results, the objective of a large, even full participation, that is, a global climate coalition, might not even be desired by the countries which signed the linked agreement. Second, it is reasonable to assume that R&D cooperation entails spillover effects of technological innovations to non-signatories embodied in trade and R&D capital flows (*Kemfert*, 2004). Spillovers of such kind might further reduce the gains from the coupled club good.

This is why trade linkage could be more promising by preserving the excludability of the benefits associated with preferential trade cooperation. Previous approaches by *Barrett* (1997b) and *Finus and Rundshagen* (2000) focused on protectionist trade policies that are implemented vis-à-vis non-signatories. As trade sanctions have already been discussed as a punishment mechanism, we will only refer to the results of an IEA linked to a customs union[5]

[5] While a custom union is typically composed of both a free trade area and a uniform external tariff, the trade arrangement we consider comprises only a regional free trade area with trade policies vis-à-vis non-signatories being imposed arbitrarily by signatory states.

when plant location is endogenous. In such a case, issue linkage can even reduce participation and global welfare if strategically behaving countries face the same environmental preferences (*Finus and Rundshagen*, 2000).

In this paper, in contrast to harmonized trade policies vis-à-vis non-signatories, we employ a model in which climate negotiations are interlinked to negotiations on a preferential free trade arrangement (PFTA) while strategic trade and environmental policies vis-à-vis non-signatories are carried out individually. Thereby, excludable benefits are generated by preferential trade liberalization only. Furthermore, signatories do not necessarily need to harmonize their tariff rates, on the contrary, rates are in fact differentiated for maximizing joint welfare of the coalition. Therefore, incentives to deviate from the policies agreed on do not arise. As proposed by *Leal-Arcas* (2013), such interlinked trade-climate agreements can be implemented by including climate-related provisions within preferential trade agreements like the TTIP.

The paper is organized as follows: the next section provides the model with a focus on the microfoundations of the market equilibria and the trade patterns. In section 3 the strategic policies of fringe and coalition countries are modelled in a Stackelberg leader-follower framework at a given coalition size. The endogenous formation of the stable coalition is then explained in section 4, including a discussion on the internal and external stability. In section 5 the results of the numerical simulation of the analytical model are presented followed by some propositions on the role of the free trade area in section 6. Section 7 provides some concluding remarks.

2 The Model

In the following model, we introduce a regional free trade area which is implemented among the signatories of the IEA. Put differently, the agreements on climate protection and trade liberalization are interlinked. In order to be able to identify the trade pattern inside and outside the free trade area including the trade flows among the non-signatory countries, firms' supplies are differentiated with respect to the target markets. This purpose requires an appropriate change in the framework as stated above which, in our view, is a novel modification. The modelling approach entails an equilibrium concept for local markets that, if prevailing on all local markets, can be aggregated to a global equilibrium.

We draw from the Stackelberg leader-follower framework by *Eichner and Pethig* (2013a, 2013b). The main development in our model consists in the introduction of a preferential free trade area within the climate coalition. We consider a world economy composed of n countries. Each country $i = 1, \dots, n$ has an endowment $\bar{r}$ of a (composite) production factor at its disposal which can be used for the production of either a 'clean' consumer good, x_i, or a 'dirty' consumer good, e_i. The clean good serves as a numeraire while the dirty good may represent an industrially processed form of a product using fossil energy as an input or non-renewable energy itself. In each country, there is a perfectly competitive firm serving the domestic as well as any potential foreign market. The firm's supply of the dirty good is differentiated according to the country of destination because in general firms not only must cover the various transportation costs at least to some extent but as well must meet country-specific import regulations and standards. Therefore, it is reasonable to assume that opportunity costs of the dirty good may crucially depend on the respective market on target.

More precisely, in each country i a representative firm produces a particular amount of a dirty good under a decreasing returns-to-scale technology which is composed of a number of country-specific supplies according to the markets on target. In case of the clean good, a constant returns-to-scale technology is assumed. Formally, let e_{ij} , $i, j = 1, \dots, n$ denote the amount of the dirty good originating in country i and being shipped to country j, so the first index represents the country of origin and the second one represents the country of destination. Further, let α_x, $\alpha_{e_{ij}}$ give the technology coefficients for the clean and the various components of the dirty good, respectively, and let r_x, $r_{e_{ij}}$ give the respective factor inputs. Then the country's factor constraint takes the form:

$$\bar{r} = r_x + r_{e_{i1}} + \cdots + r_{e_{in}}. \qquad (1)$$

Furthermore, the production functions for the clean and the decomposed supply of the dirty good take the form as proposed in the framework by *Eichner and Pethig* (2013a, 2013b):

$$x_i = \alpha_x r_x, \qquad i = 1, \dots, n$$

$$e_{ij} = \sqrt{\frac{r_{e_{ij}}}{\alpha_{e_{ij}}}}, \qquad i, j = 1, \dots, n. \qquad (2)$$

For the sake of simplicity, we make use of the following specific technology coefficients:

$$\alpha_x = 1,$$

$$\alpha_{e_{ij}} = \begin{cases} \alpha_H & if\ i = j \\ \alpha^* & if\ i \neq j \end{cases} \qquad i, j = 1, \dots, n. \qquad (3)$$

In case of the dirty good the assumption $0 < \alpha_H < \alpha^*$ is made, that is, opportunity costs shall not differ among the various foreign destinations but are generally considered being higher for cross-border trade than for domestic trade justified by higher transportation costs as well as greater administrative efforts to comply with country-specific regulation. All in all, together with the identical endowments, symmetry among firms is assumed and justified, given the purpose of explaining trade patterns and environmental impacts solely by the policy measures implemented by the governments. Thereby, we are able to rule out interfering comparative advantages.

From there, taking into account the maximum producible amount of the clean good given by $\bar{x} = \alpha_x \bar{r}$, we can derive the quadratic production possibility frontier[6] for country i:

$$x_i^S = T\left(e_{i1}^S, \dots, e_{in}^S\right) = \bar{x} - \alpha_x \sum_{j=1}^{n} \alpha_{e_{ij}} \left(e_{ij}^S\right)^2 = \bar{x} - \left(\alpha_H \left(e_{ii}^S\right)^2 + \alpha^* \sum_{\substack{j=1, \\ j \neq i}}^{n} \left(e_{ij}^S\right)^2\right), \qquad (4)$$

where T is found a decreasing and strictly concave function in any e_{ij}^S.

With respect to the demand side, we adhere to the framework by *Eichner and Pethig* (2013a, 2013b) and take a representative consumer in country i to maximize a quasilinear utility function[7]

$$U_i\left(x_i^D, e_i^D\right) = V_i\left(e_i^D\right) + x_i^D. \qquad (5)$$

The marginal utility of the dirty good $V(.)$ is positive but decreasing, whereas it is constant in case of the numeraire good x_i^D as usual. Moreover, consumers do not discriminate between domestic supplies and imports since in their view the dirty commodity is homogeneous irrespective of the country of origin. In the following we use the specific form

$$V_i\left(e_i^D\right) = a e_i^D - \frac{b}{2}\left(e_i^D\right)^2, \qquad (6)$$

with parameters a, b being positive.

The reason why e represents a dirty good simply lies in the fact that it is coupled with greenhouse gas emissions like carbon dioxide which naturally are modelled as a global public externality. Hence, the damage function takes the usual form

$$D\left(\sum_{j=1}^{n} e_j^D\right) \qquad (7)$$

[6] Please note that the superscript S indicates quantities supplied.
[7] Please note that the superscript D indicates quantities demanded.

which, later on, will show up in the welfare function of any country. Here, the basic assumption is that the consumption of the dirty good is generating an emission one for one and thus the global emission level is given by the sum $\sum_{j=1}^{n} e_j^D$. Marginal damages are assumed to be increasing and the following specification is adopted:

$$D\left(\sum_{j=1}^{n} e_j^D\right) = \frac{\delta}{2}\left(\sum_{j=1}^{n} e_j^D\right)^2, \quad (8)$$

with parameter $\delta > 0$.

Global damages affect the welfare of any single country and cannot be ignored apart from any free-riding incentives. However, countries which opt for free-riding may view their impact on global warming negligible compared to the cost of emission abatement. This is exactly the challenge in the combat of a global public bad like it is the case with global warming. The more important is the formation of climate coalitions.

National governments in principle have two kinds of policy instruments available: a national system of emission permits trading and a trade tariff. The latter does not simply work in the traditional way but also may address environmental disruptions. In order to reduce carbon emissions by means of emissions permits, each government is able to set a national cap $e_i > 0$ and to auction the number of available emission permits e_i at a permit price π_i. Those households which want to consume the dirty good are required to hold a permit one for one to internalize, more or less perfectly, the externality. Additionally, governments can impose a trade tariff $t_i \in \mathbb{R}$ whose algebraic sign is unconstrained, i.e. it may take the form of an import tariff ($t_i > 0$) or of an export tax ($t_i < 0$). Put differently, an import tariff $t_i > 0$ combines a tax on fuel consumption with a subsidy on local fuel production to the advantage of domestic firms, while an export tax $t_i < 0$ combines a subsidy on fuel consumption with a tax on fuel production to the disadvantage of domestic firms. The tariff design is equivalent to a unit tax that decouples the domestic producer price of the dirty good from the foreign producer price such that domestic producers face the domestic producer price $p_i + t_i$, $t_i \in \mathbb{R}$ whereas foreign producers only receive the producer price p_i net of the import tariff imposed (*Eichner and Pethig*, 2013b).

However, this arrangement gets considerably modified if one intends to establish a free trade area. In this case, policies of countries that are part of the free trade area must discriminate between trade with coalition member states and that with non-member states. This is equally true for a climate coalition which is building upon a free trade area as an incentive to combat global warming as will become obvious below. As a result, on the local market in a coalition country the producer price of the imports from another coalition country is different from the producer price of the imports from a fringe country. Naturally, the free trade arrangement privileges the firms of its member countries.

In a more formal set-up, countries first need to be sorted according to their group membership. If country i is a member of the climate and free trade coalition $C := \{1,2,\dots,m\}$, it will be called a coalition country, $i \in C$. Accordingly, we name country i a fringe country if it is not a coalition member, i.e. $i \notin C$, or, put differently, $i \in F := \{m+1, m+2, \dots, n\}$, $m \leq n$, where F gives the set of fringe countries. Then, the tariff design must take into account that producers in coalition countries, $j \in C$, are generally exempted from any import tariff imposed by any other coalition country, $i \in C$, $i \neq j$, in accordance with the free trade arrangement. Hence, coalition member firms receive the domestic producer price $p_i + t_i$, $t_i \in \mathbb{R}$ for exports to a coalition country i, while producers from fringe countries, $j \notin C$, just receive the producer price p_i.

Therefore, taking the local market prices $p_1, \dots, p_n$ and the tariff rates $t_1, \dots, t_n$ as given, a firm in country i maximizes its profits subject to the production possibility frontier in (4) by optimally choosing the supplies of the clean commodity, x_i^S, as well as the dirty commodity, $e_{i1}^S, \dots, e_{in}^S$, composed of the supplies to domestic and various foreign markets. The profit functions for firms are therefore given as follows:

$$\Pi_i\left(x_i^S, e_{i1}^S, \dots, e_{in}^S\right) = x_i^S + (p_i + t_i)e_{ii}^S + \sum_{\substack{j=1, \\ j \in C, \\ j \neq i}}^{m} \left(p_j + t_j\right)e_{ij}^S + \sum_{\substack{j=m+1, \\ j \notin C}}^{n} p_j e_{ij}^S, \quad \text{for } i \in C \tag{9a}$$

$$\Pi_i\left(x_i^S, e_{i1}^S, \dots, e_{in}^S\right) = x_i^S + (p_i + t_i)e_{ii}^S + \sum_{\substack{j=1, \\ j \neq i}}^{n} p_j e_{ij}^S, \quad \text{for } i \notin C. \tag{9b}$$

The optimal outputs derived from the first-order conditions of the profit maximization problem yield:

$$e_{ii}^S = \frac{p_i + t_i}{2\alpha_H}, \ \left(e_{ij}^S\right)_{\substack{j \in C, \\ j \neq i}} = \frac{p_j + t_j}{2\alpha^*}, \ \left(e_{ij}^S\right)_{j \notin C} = \frac{p_j}{2\alpha^*}, \quad \text{for } i \in C \tag{10a}$$

$$e_{ii}^S = \frac{p_i + t_i}{2\alpha_H}, \ \left(e_{ij}^S\right)_{j \neq i} = \frac{p_j}{2\alpha^*}, \ \text{for } i \notin C. \tag{10b}$$

Turning to the demand side, a representative consumer in a coalition or a fringe country i is naturally facing the domestic consumer price $p_i + t_i + \pi_i$ which comprises the tax-inclusive price of the dirty good charged by all suppliers, irrespective of their origin, and the permit price π_i. Since global emissions and their impact on climate change are external in the consumers' view and thus are not taken into account, the demands for the clean and dirty good, x_i^D and e_i^D, respectively, are chosen to maximize utility, $U_i(.)$, subject to the budget constraint

$$y_i = x_i^D + (p_i + t_i + \pi_i)e_i^D. \quad (11)$$

The income of a representative consumer in country i, denoted by y_i, is defined as the sum of producer rents, permit income, as well as tariff income because of the instantaneous transfer of all kinds of income generated in the economy back to the consumer. According to this definition, the income functions read

$$y_i := x_i^S + (p_i + t_i)e_{ii}^S + \sum_{\substack{j=1, \\ j\in C, \\ j\neq i}}^{m} (p_j + t_j)e_{ij}^S + \sum_{\substack{j=m+1, \\ j\notin C}}^{n} p_j e_{ij}^S + \pi_i e_i^D + t_i \sum_{\substack{j=m+1, \\ j\notin C}}^{n} e_{ji}^S, \text{ for } i \in C \quad (12a)$$

$$y_i := x_i^S + (p_i + t_i)e_{ii}^S + \sum_{\substack{j=1, \\ j\neq i}}^{n} p_j e_{ij}^S + \pi_i e_i^D + t_i \sum_{\substack{j=1, \\ j\neq i}}^{n} e_{ji}^S, \quad \text{for } i \notin C \quad (12b)$$

This particular income will get determined along with the market equilibria later on. The consumer in this model, however, takes income as given.

The demand for the dirty good arises from the first-order conditions of the utility maximization problem:

$$e_i^D(p_i, t_i, \pi_i) = \frac{a-(p_i+t_i+\pi_i)}{b}. \quad (13)$$

As the demand for the dirty good also invokes an equal demand for permits in the national emissions trading scheme, the local permit market is in equilibrium if the following condition holds:

$$e_i^D(p_i, t_i, \pi_i) = e_i, \quad (14)$$

with e_i being the emission cap set by the national government. This yields the equilibrium permit price π_i^*.

Furthermore, there is a world market for good X, the numeraire good, sold at world price set to $p_x \equiv 1$, and, moreover, in each country i, there is a local market for the dirty good sold at local price p_i. These markets are in equilibrium if the following conditions hold simultaneously:

$$\sum_{j=1}^{n} x_j^D = \sum_{j=1}^{n} x_j^S, \qquad e_i^D = \sum_{j=1}^{n} e_{ji}^S, \qquad \forall i = 1, \dots, n. \quad (15)$$

One should note that the total supply on the local market in country i originates from the aggregated exports of all $j \neq i$ firms into country i in addition to the supply of the domestic firm i, and can be itemized as:

$$\sum_{j=1}^{n} e_{ji}^{S} = e_{ii}^{S} + \sum_{\substack{j=1, \\ j\in C, \\ j\neq i}}^{m} e_{ji}^{S} + \sum_{\substack{j=m+1, \\ j\notin C, \\ j\neq i}}^{n} e_{ji}^{S}. \quad (16)$$

The equilibrium outcome on a local market can be determined by substituting the firms' supplies from (10) for the RHS in (16), and by substituting demand from (13) for the LHS in the second equation of (15) along with the emission cap from (14). The resulting local equilibrium prices of the dirty good are

$$p_i^*(e_i, t_i) = \frac{2\alpha_H \alpha^* e_i - \alpha^* t_i - (m-1)\alpha_H t_i}{(n-1)\alpha_H + \alpha^*}, \qquad \text{for } i \in C \quad (17a)$$

$$p_i^*(e_i, t_i) = \frac{2\alpha_H \alpha^* e_i - \alpha^* t_i}{(n-1)\alpha_H + \alpha^*}, \qquad \text{for } i \notin C. \quad (17b)$$

From there, the optimal output of the dirty good produced by the representative firm in country $i = 1, \dots, n$, (and in part exported) can be determined by substituting the equilibrium prices:

$$\left(e_i^S\right)^* = e_i^S(p_1^*, \dots, p_n^*). \quad (18)$$

where e_i^S is defined by

$$e_i^S = e_{ii}^S + \sum_{\substack{j=1, \\ j\in C, \\ j\neq i}}^{m} e_{ij}^S + \sum_{\substack{j=m+1, \\ j\notin C}}^{n} e_{ij}^S, \qquad \text{for } i \in C \quad (19a)$$

$$e_i^S = e_{ii}^S + \sum_{\substack{j=1, \\ j\neq i}}^{n} e_{ij}^S, \qquad \text{for } i \notin C. \quad (19b)$$

As far as the world market for good X is concerned, the equilibrium output can be obtained by simply replacing the equilibrium quantities of the dirty good from (19a) and (19b) into the production possibility frontier:

$$\left(x_i^S\right)^* = T\left(\left(e_i^S\right)^*\right), \qquad i = 1, \dots, n. \quad (20)$$

Combining the budget constraint (11) with the income functions (12a) and (12b) respectively[8], we get:

$$x_i^D = x_i^S + p_i e_{ii}^S + \sum_{\substack{j=1, \\ j\neq i}}^{n} p_j e_{ij}^S - p_i e_i^D + \left(\sum_{\substack{j=1, \\ j\in C, \\ j\neq i}}^{m} t_j e_{ij}^S - t_i \sum_{\substack{j=1, \\ j\in C, \\ j\neq i}}^{m} e_{ji}^S \right), \qquad \text{for } i \in C \quad (21a)$$

$$x_i^D = x_i^S + p_i e_{ii}^S + \sum_{\substack{j=1, \\ j\neq i}}^{n} p_j e_{ij}^S - p_i e_i^D, \qquad \text{for } i \notin C. \quad (21b)$$

[8] By doing so, it can also be shown that Walras' Law holds for both the coalition and the fringe countries since, in (21a), the difference in parentheses which indicates the net tariff income of a coalition country i coming from the other coalition members $j \in C$, $j \neq i$ will be equal to zero. Hence, if all local markets of the dirty good are in equilibrium, the world market for X must be in equilibrium as well.

Makin use of (14), (20), and the equilibrium prices $p_1^*, \ldots, p_n^*$ in the equations (21a) and (21b) yields $\left(x_i^D\right)^*$ for both the coalition and the fringe countries:

$$\left(x_i^D\right)^* = x_i^D(e_1, \ldots, e_n, t_1, \ldots, t_n). \tag{22}$$

Turning to the policy stage, welfare in this model is given solely by consumer rents net of environmental damages since all other kinds of income generated anywhere in the economy are redistributed and thus reflected in the consumer's budget. Hence, the welfare function W_i of country i is given by the net utility

$$W_i\left(e_1^D, \ldots, e_n^D, x_i^D\right) = U_i\left(x_i^D, e_i^D\right) - D\left(\sum_{j=1}^n e_j^D\right) \tag{23}$$

and can be derived by substituting equation (22) as well as the functional specifications from (6) and (8), in accordance with condition (14), such that the welfare of country i is depending on the policy schemes of all the other countries:

$$W_i(e_1, \ldots, e_n, t_1, \ldots, t_n) = ae_i - \frac{b}{2}(e_i)^2 + x_i^D(e_1, \ldots, e_n, t_1, \ldots, t_n) - \frac{\delta}{2}\left(\sum_{j=1}^n e_j\right)^2. \tag{24}$$

As a matter of course, the welfare of a coalition member is found different from that of a fringe country due to the term $x_i^D(.)$ being different.

Now, we are in a position where we can deal with the strategic policy decisions of countries. The benchmark for the subsequent analysis is the non-cooperative Nash equilibrium, i.e. the situation in which every country i chooses a policy scheme (e_i, t_i) that maximizes the country's individual welfare function, taking as given the other countries' policy choices. We refer to this situation as the business-as-usual (BAU) scenario. The optimal BAU emission caps $(e_i)_{BAU}$ and tariff rates $(t_i)_{BAU}$ are obtained from the first-order conditions of the welfare maximization problem for country i:

$$\frac{\partial W_i}{\partial e_i} = a - be_i + \frac{\partial x_i^D}{\partial e_i} - \delta\sum_{j=1}^n e_j = 0 \tag{25}$$

$$\frac{\partial W_i}{\partial t_i} = \frac{\partial x_i^D}{\partial t_i} = 0. \tag{26}$$

Since countries face the same endowments and production technology by the assumption of symmetry, the BAU scenario is the outcome of a symmetric Nash game, yielding

$$(e_i)_{BAU} = \frac{a(2\alpha^* + (n-1)\alpha_H)}{(n-1)(b+\delta n)\alpha_H + 2\alpha^*(b+\delta n+2\alpha_H)} \tag{27}$$

$$(t_i)_{BAU} = \frac{2a\alpha^*\alpha_H}{(n-1)(b+\delta n)\alpha_H + 2\alpha^*(b+\delta n+2\alpha_H)}. \tag{28}$$

As a consequence of symmetry, countries choose the same emission caps and tariffs in the absence of a coalition which leads to identical output and consumption levels. Apparently, even with policies being chosen independently, countries like to discriminate against foreign suppliers by imposing a positive tariff rate $(t_i)_{BAU} > 0$, or, put differently, there are incentives to favorably shift the terms of trade, that is the price of the dirty good relative to the price of the clean one. As a consequence, with respect to the environment, total emissions $n \cdot (e_i)_{BAU}$ will exceed the socially optimal level as countries ignore the transboundary externality and hence the induced welfare loss abroad.

3 The Stackelberg Game

The set-up of the Stackelberg game consists of two stages. On the first stage countries are involved in a strategic policy game and on the second stage agents maximize their rents from the production and consumption of commodities. Agents on the second stage behave perfectly competitive by taking into account any given policy measures. Governments on the first stage behave strategically as they respond to the policy measures applied by all the other countries in an optimal way. In particular, we assume that members of a free trade area can coordinate their policies in terms of maximizing joint welfare. However, this does not necessarily mean that policies have to be harmonized. In any case, coalition countries can employ the first-mover advantage of a Stackelberg leader.

With regard to the second stage, the stage of the various global and local markets, we already have determined the respective equilibrium quantities and equilibrium prices in the last section. In the policy game on the first stage we must take these results into account. That is why countries are considered being able to anticipate the impact of their own policies on the subsequent decisions of agents in the market and the resulting terms of trade shift.

For the analysis of the policy game, first, we have to compute the welfare function of a coalition country as well as the one of a non-coalition country. Formally, the individual welfare functions for coalition and fringe countries, respectively, are given by equation (24) which can be specified as $W_{i \in C}$ for the coalition countries and as $W_{i \notin C}$ for the fringe countries by substituting the equilibrium quantities from (14) for e_i^D, $i = 1, \ldots, n$ as well as x_i^D from (22). This yields the expressions

$$W_{i \in C}(e_1, \ldots, e_n, t_1, \ldots, t_n) = ae_i - \frac{b}{2}(e_i)^2 + \left(x_i^S\right)^*(e_1, \ldots, e_n, t_1, \ldots, t_n) + \Pi_i^*(e_1, \ldots, e_n, t_1, \ldots, t_n) -$$

$$p_i^*(e_i, t_i) \cdot e_i + \sum_{\substack{j=1,\\ j\in C,\\ j\neq i}}^{m} \left(t_j \cdot \left(\frac{p_j^*(e_j, t_j) + t_j}{2\alpha^*}\right)\right) - (m-1)t_i \cdot \left(\frac{p_i^*(e_i, t_i) + t_i}{2\alpha_H}\right) - \frac{\delta}{2}\left(\sum_{j=1}^{n} e_j\right)^2 \qquad (29a)$$

and

$$W_{i \notin C}(e_1, \ldots, e_n, t_1, \ldots, t_n) = ae_i - \frac{b}{2}(e_i)^2 + \left(x_i^S\right)^*(e_1, \ldots, e_n, t_1, \ldots, t_n) + \Pi_i^*(e_1, \ldots, e_n, t_1, \ldots, t_n) -$$

$$p_i^*(e_i, t_i) \cdot e_i - \frac{\delta}{2}\left(\sum_{j=1}^{n} e_j\right)^2 \qquad (29b)$$

where the variables with the asterisk denote the equilibrium levels of the quantities and prices given by equations (17a), (17b), and (20).

For the solution of the Stackelberg Game, by backward induction, the welfare of any fringe country has to be maximized with respect to its cap and its tariff rate, taking the policies of all other countries as given. In this respect, fringe countries are viewed as behaving as non-cooperative Nash players, facing the optimization problem

$$max_{e_i, t_i} W_{i \notin C}(e_i, t_i; \varepsilon_{-i}, \tau_{-i}), \qquad i \notin C, \qquad (30)$$

where $\varepsilon_{-i} = (e_1, \ldots, e_{i-1}, e_{i+1}, \ldots, e_n) \geq 0$ and $\tau_{-i} = (t_1, \ldots, t_{i-1}, t_{i+1}, \ldots, t_n)$ denote the other countries' environmental and trade policies. Differentiating the welfare function above with respect to the policies e_i, t_i gives the first-order conditions (which will not be stated explicitly at this stage but a simulation approach later on will be used):

$$\frac{\partial W_{i \notin C}}{\partial e_i} = 0, \qquad \frac{\partial W_{i \notin C}}{\partial t_i} = 0. \qquad (31)$$

Solving the first-order conditions for e_i, t_i yields the individual reaction function of a fringe country $i \notin C$ with respect to the policies of other fringe as well as coalition countries

$$\mathcal{R}_{e_i} = e_i(\varepsilon_{-i}, \tau) \qquad (32)$$

$$\mathcal{R}_{t_i} = t_i(\varepsilon, \tau_{-i}) \qquad (33)$$

where $\varepsilon = (e_1, \ldots, e_n) \geq 0$ and $\tau = (t_1, \ldots, t_n)$ indicate the environmental and trade policy vectors.

For maximizing the welfare of coalition countries a different approach has to be taken. First of all, coalition countries can take advantage of anticipating how fringe countries will react to their strategies. That is how the fringe reaction functions enter the welfare of coalition countries. Secondly, as members of a coalition, in a sense, they take account of the impact of their policies on the group welfare of the coalition by internalizing any externalities they may impose, leading to the following optimization problem:

$$max_{\varepsilon_C,\tau_C} W_C(\varepsilon_C,\tau_C;\varepsilon_F,\tau_F) \tag{34}$$

where W_C is the joint welfare of a coalition C, $\varepsilon_C=(e_1,\dots,e_m)\geq 0$ and $\tau_C=(t_1,\dots,t_m)\geq 0$ indicate the environmental and trade policies of the coalition members, and $\varepsilon_F=(e_{m+1},\dots,e_n)\geq 0$ and $\tau_F=(t_{m+1},\dots,t_n)$ name the policy vectors of the fringe countries.

Replacing the individual coalition policies and the fringe reactions from (32) and (33), respectively, for the policy vectors in the welfare functions of the coalition countries, $W_{i\in C}$ yields the joint coalitional welfare

$$W_C=\sum_{i=1}^{m} W_{i\in C}\,(e_1,\dots,e_m,t_1,\dots,t_m;$$

$$\mathcal{R}_{e_{m+1}}\big(\varepsilon_{-(m+1)},\tau\big),\dots,\mathcal{R}_{e_n}(\varepsilon_{-n},\tau),\mathcal{R}_{t_{m+1}}(\tau_{-(m+1)},\varepsilon),\dots,\mathcal{R}_{t_n}(\tau_{-n},\varepsilon)). \tag{35}$$

As a consequence of the identical endowments and production technologies, the solution of these optimization problems brings about symmetric policy choices for the group of coalition countries (e_C,t_C) on the one hand, and for that of the fringe countries (e_F,t_F) on the other hand.

4 Self-enforcing IEAs

So far, we have dealt with an arbitrary, exogenously given number of coalition countries within the Stackelberg leader-follower framework. In doing so, considerations on the endogenous formation of a coalition and its stability have been omitted from the analysis. Hence, we need to examine which one of the potential coalition sizes $m\in[0,n]$ assures for a stable cooperation among member countries, or, put differently, which one constitutes a self-enforcing IEA. In the non-cooperative IEA literature, the notion of stability has proven to be a canonical requirement for environmental treaties to ensure the long lasting existence of climate coalitions of a particular size.[9] *Carraro and Siniscalco* (1993) put forth the profitability as a minimum requirement for coalition formation, although this does not prevent countries from free-riding. A coalition of size m is defined to be profitable if it brings about a welfare gain for its members compared to their BAU situation:

[9] The stability concept was originally elaborated by *d'Aspremont et al.* (1983) for the analysis of cartel formation in an oligopoly and later adapted to the IEA context (*Carraro and Siniscalco*, 1993, *Barrett*, 1994). The cooperative IEA literature introduced another notion of stability called the concept of the (gamma) core (*Finus*, 2003) which does not focus on individual player's strategies and payoffs along any coalition size but only on the countries' payoffs in the grand coalition compared to defection strategies such as joining sub-coalitions or unilateral free-riding (*Bréchet, Gerard and Tulkens*, 2011).

$$W_{i\in C}(m) \geq (W_i)_{BAU} \quad (36)$$

In our framework, the stability requirement is met if a coalition of a certain size is found to be both internally and externally stable.[10] In this respect, a coalition country i is defined to be internally stable if it does not have an incentive to leave the coalition C of size m, that is, if the following condition holds:

$$W_{i\in C}(m) \geq W_{i\notin C}(m-1) \quad (37)$$

A coalition C of size m is defined to be externally stable if no fringe country i has an incentive to join the coalition, or, put formally, if

$$W_{i\notin C}(m) \geq W_{i\in C}(m+1) \quad (38)$$

Based on these considerations, all coalitions of integer size $m \in [0, n]$, that satisfy the equations $W_{i\in C}(m) - W_{i\notin C}(m-1) \geq 0$ and $W_{i\notin C}(m) - W_{i\in C}(m+1) \geq 0$ simultaneously, are found to be both internally and externally stable. As an illustration, please consider the findings depicted in **Figure 1** and **Figure 2** which give the results of the simulation we have run for our model. We find the stable coalition at size $m^* = 7$.

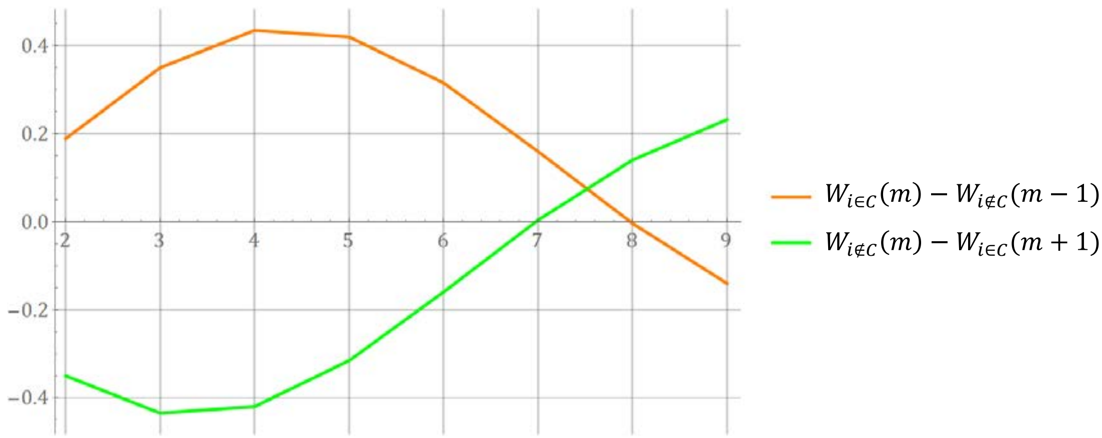

Figure 1: Internal and external coalition stability of the Stackelberg equilibrium with PFTA

[10] Please note that the stability conditions are formulated for the symmetric case, implied by identical endowments and production technologies. An adaptation is required if heterogeneous countries are considered.

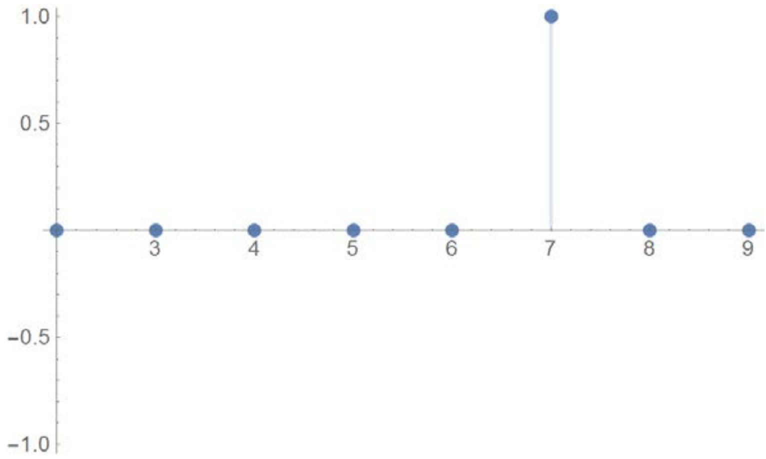

Figure 2: Stable coalition sizes of the Stackelberg equilibrium with PFTA

The details of the parameterization, a deeper discussion as well as some additional results are presented in the following section.

5 Simulation Results and Interpretation

Given the complexity of the model due to the fact that the market equilibria, welfare and response functions depend on the exogenous coalition size m in a complex way, an analytical solution may be hard to compute, if not impossible. Nevertheless, in order to state some propositions on the role of the free trade arrangement for the formation of climate coalitions, we refer to numerical simulations exemplified by a run with the parameter values: $a = 100$, $b = 20$, $\bar{x} = 20$, $\alpha_H = 2000$, $\alpha^* = 2200$, $\delta = 10$ and $n = 10$. We consider a variation in coalition sizes in the range of $m \in [1{,}10]$ to examine its impact on emissions, damages and welfare. In each case, the results of the Stackelberg scenario are compared with either the BAU scenario only or with both the BAU and the social planner scenario.

For this purpose, we use some effectiveness and efficiency measures proposed in the literature (*Eichner and Pethig*, 2013b). The e-gap measures the difference in global emissions between the BAU scenario and the social planner scenario. The latter is equivalent to the computation of the emissions in the Stackelberg game with exogenous coalition size $n = 10$, that is, in the absence of any fringe countries. Thereby, this measure represents the coalition's scope of potential emissions reductions. The emission gap is defined by:

$$e\text{-gap} = ne_{BAU} - ne_{SP} \tag{39}$$

The w-gap indicates the potential maximum welfare gain from cooperation and is measured by the welfare gap between the social planner scenario and the BAU scenario:

$$w\text{-gap} = nw_{SP} - nw_{BAU} \quad (40)$$

At the same time, these gaps will be used as benchmarks in the computation of two efficiency measures.[11] The ratio RE measures the relative efficiency of emissions reductions of the climate coalition as it is defined as the emissions gap between BAU and the climate coalition in relative to the e-gap:

$$RE = \frac{ne_{BAU} - (me_C + (n-m)e_F)}{ne_{BAU} - ne_{SP}} \quad (41)$$

The ratio RW measures the relative welfare efficiency of the climate coalition in terms of the welfare gap between the coalition and BAU relative to the w-gap, i.e.

$$RW = \frac{(mw_C + (n-m)w_F) - nw_{BAU}}{nw_{SP} - nw_{BAU}} \quad (42)$$

However, we should keep in mind that only a coalition of endogenous size $m^* = 7$ turns out to be stable. That is why, in the following, the results for this particular coalition receive our special attention.

Total Emissions. First of all, let us have a look at the total reduction of emissions achieved by the climate coalition viewed against the BAU and the social planner scenario. As can be seen in **Figure 3**, coalitions of size $m \geq 4$ fairly reduce total emissions, the more the bigger is the coalition. For the stable coalition the reduction, that is the relative emissions efficiency RE, amounts to 56.07 per cent of the e-gap.

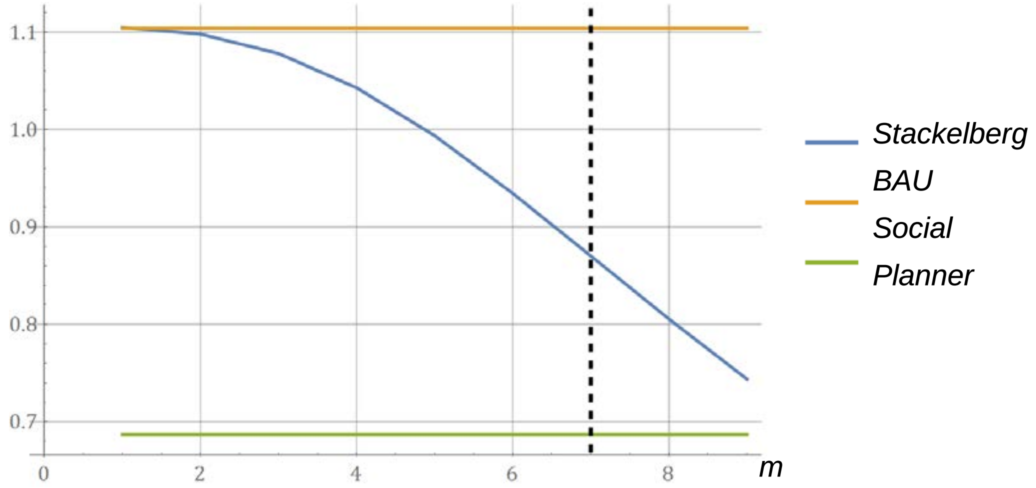

Figure 3: Total Emissions in the Stackelberg Equilibrium with PFTA

[11] Again, it is important to stress that the efficiency measures RE and RW are only defined for the symmetric case. An analysis involving heterogeneous countries requires a reformulation.

Put differently, at $m^* = 7$, the climate coalition brings total emissions down to a level of 78.82 per cent compared to the non-cooperative outcome while the social optimum requires a mitigation of global emissions down to 62.22 per cent of the BAU level.

Permits. **Figure 4** shows the emission caps set by each individual fringe and coalition country dependent on the coalition size.

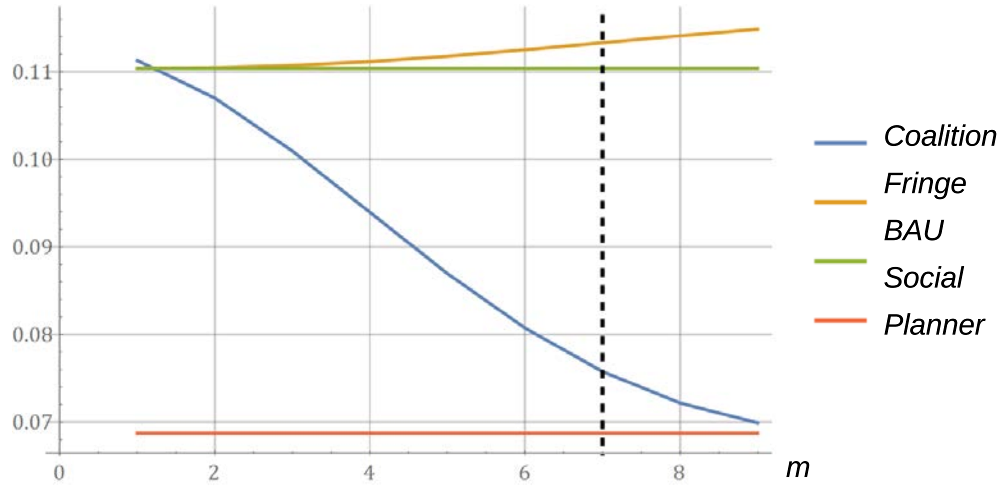

Figure 4: Individual Caps in the Stackelberg Equilibrium with PFTA

Apparently, as the size of the coalition is increasing, member countries reduce their individual emissions substantially, by 31.39 per cent below the BAU level in case of the stable coalition. Later on, we will see that the reason for that is to be found in a shift to the consumption of the clean good away from the consumption of the dirty good. Even a social planner would lower individual emission levels only a bit more, by 37.78 per cent below the BAU outcome, if she had the means to enforce a cap on all countries. Fringe countries increase their emissions only slightly above the BAU level. Nevertheless, consumption in the fringe countries turns out to be much dirtier. Overall, this is an indication of the effectiveness of the free trade agreement for the mitigation of global warming.

Damages. The reduction in climate damages brought about by the emission reduction can be seen in **Figure 5**:

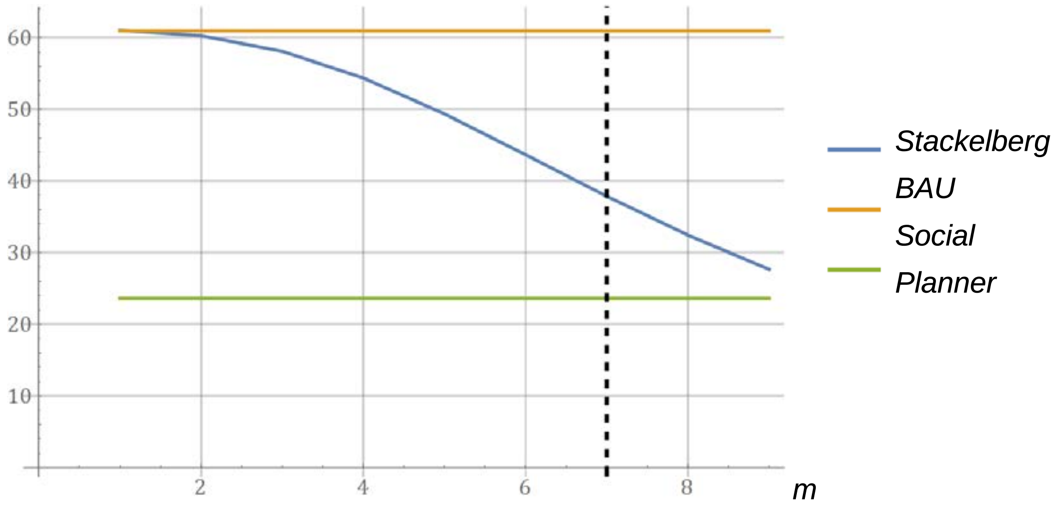

Figure 5: Total Climate Damages in the Stackelberg Equilibrium with PFTA

In the stable case, damages are reduced by 37.88 per cent compared to the BAU scenario for the quadratic damage function assumed. This mitigation of damages corresponds to 61.81 per cent points of the socially optimal rate of reduction.

Global Welfare. The previous findings raise the issue of the induced change in welfare from a local as well as a global perspective. Firstly, let us have a look on global welfare as shown in **Figure 6**.

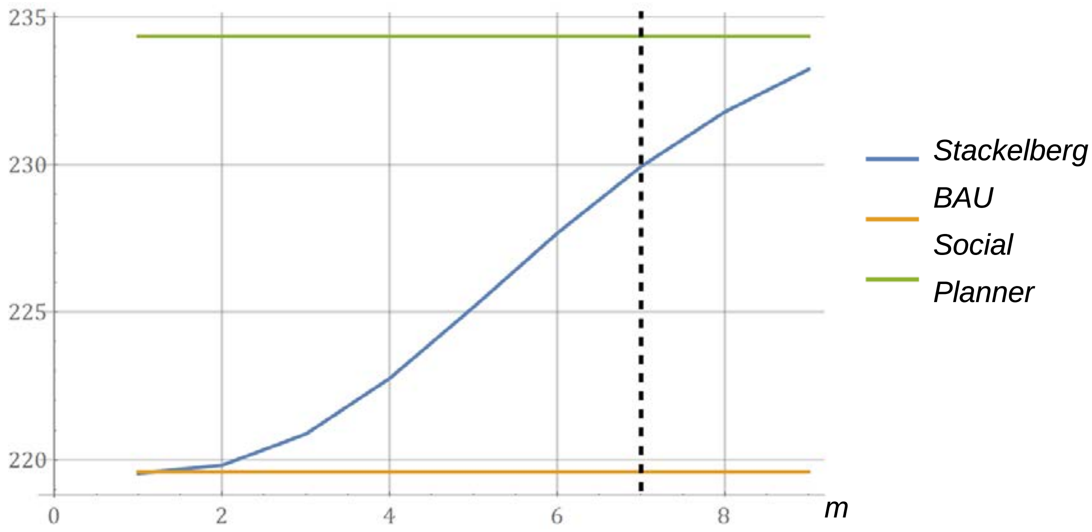

Figure 6: Total Welfare in the Stackelberg Equilibrium with PFTA

As can be seen, the free trade area as an incentive device for the formation of climate coalitions can lead to a considerable increase in welfare efficiency. In the stable case, global welfare is increased by 70.11 per cent of the w-gap which, in turn, gives the maximum achievable welfare gain of a social planner compared to BAU. One might argue the reason for that may be primarily rooted in the trade liberalization prevailing in a free trade area in the usual welfare enhancing way. However, this is not the only reason, as **Figure 5** indicates. Even more important is the reduction in global damages to the advantage of all countries. Hence, global welfare appears to be in part driven by the development of climate welfare, $-D(.)$, that is the climate component of the welfare function.

Local Welfare. **Figure 7** shows how the welfare levels of the individual countries evolve dependent on the coalition size:

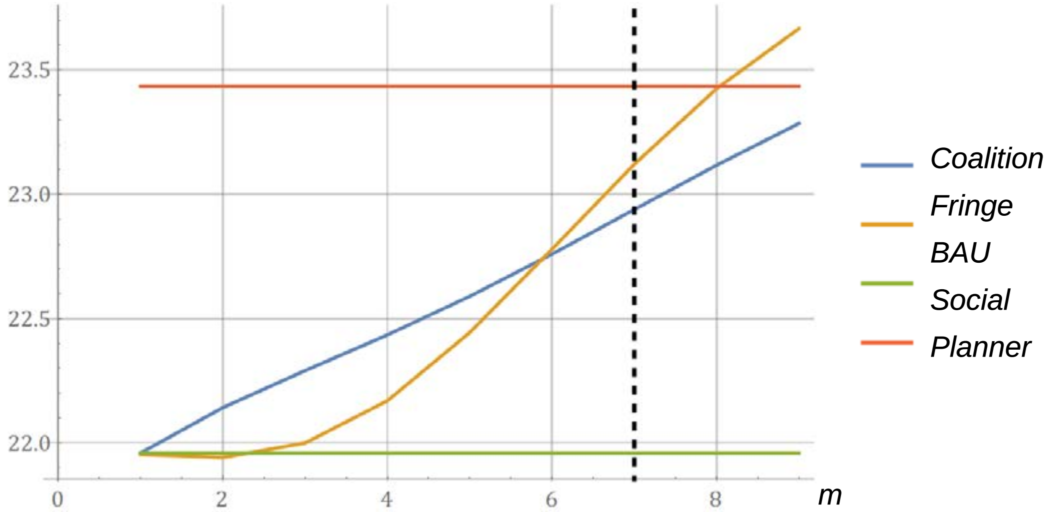

Figure 7: Individual Welfare in the Stackelberg Equilibrium with PFTA

Figure 7 reveals that, for all $m \leq 5$, clearly, fringe countries would gain if they joined the coalition while coalition members would lose if they left. However, this relation changes for coalition sizes of $m \geq 6$. Then, fringe countries face higher welfare than coalition members. This is the case primarily because they do not restrict the consumption of the dirty good as much as the coalition countries, as **Figure 8** below is illustrating. There, consumption utility (i.e. welfare net of damages) is shown:

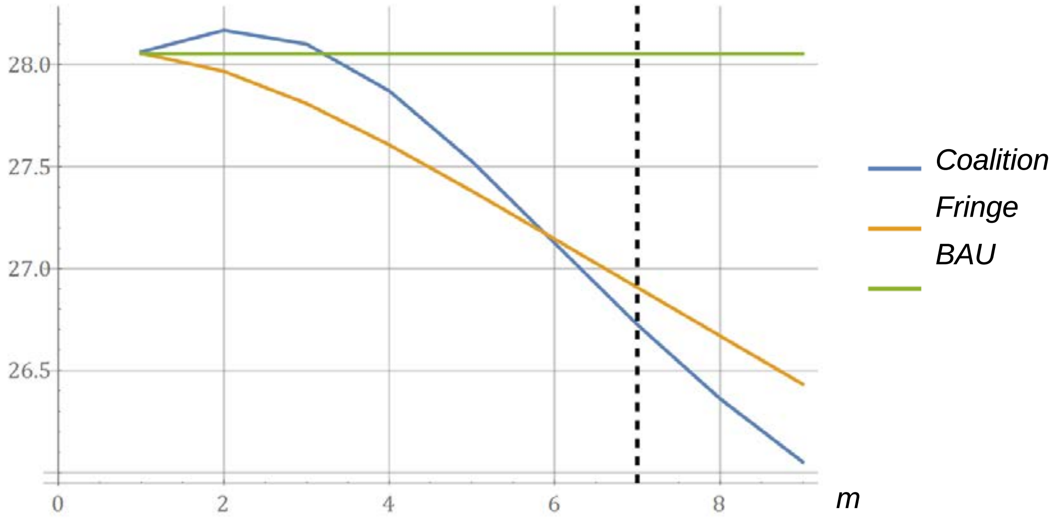

Figure 8: Individual Consumption Utility in the Stackelberg Equilibrium with PFTA

Consumption Utility. Except for coalition size $m \leq 3$, both coalition and fringe countries suffer a loss in consumption utility compared to the strategy of free-riding. Again, this fact indicates that welfare outcomes in **Figure 7** are largely determined by climate welfare. For size $m \geq 6$, fringe countries yield higher welfare than coalition countries which will be explained in the following by the policy mix chosen by the two groups of countries.

As a result of the optimization problem in section 3, both fringe and coalition countries implement a positive emission cap and an import tariff rate, that is $t_C, t_F > 0$, for the present parametrization. **Figure 9** depicts the resultant permit prices prevailing in the coalition and fringe countries dependent on the coalition size while the tariff policy outcomes are shown below in **Figure 10**.

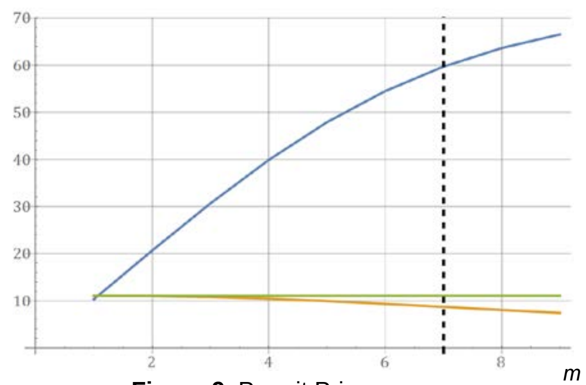

Figure 9: Permit Prices

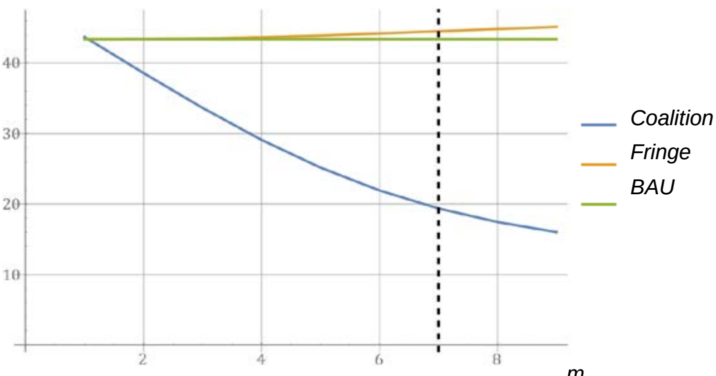

Figure 10: Tariff Rates

Permit Prices. **Figure 9** suggests that, as a consequence of a progressively tight cap, coalitional permit prices are above the BAU level, with the price increase diminishing in coalition size. Permit prices of the fringe lie slightly below BAU level and even fall as the coalition gains in size due to the weak environmental policy. Precisely, in the stable case, permit prices in the coalition are more than five times higher than the BAU permit price whereas, in the fringe countries, they are just about a fifth of the BAU.

Tariff Rates. As **Figure 10** illustrates, tariff rates imposed by the coalition are low and decreasing in coalition size, at a rate of only 44.68 per cent of the BAU level in the stable case. Obviously, the coalition pursues a less protectionist trade policy. Fringe countries on the other hand do not seem to be able to take advantage and to raise their tariffs rates much above the BAU level, but only slightly.

Interpretation. How can these policy outcomes be explained and how will policies govern prices and the trade pattern? Literally, policies are chosen just as one would expect from the theory of international trade and environmental economics. And, above all, the outcomes are perfectly in line of what we had in mind with the implementation of a free trade area as an incentive device for climate mitigation. In short, we simply may state, coalition countries are much in favor to protect the environment and they are fairly successful while fringe countries are still taking a free ride on the environment. Both in fact have two measures available, a highly disruptive one serving as a devise for rent seeking activities in international markets and one for protecting the environment.

Therefore, it isn't at all the surprising that coalition countries opt for pretty strict emission caps and keep distortionary tariffs moderate while fringe countries on the contrary opt for pretty lax caps but high tariff rates. That finding clearly is a result of the importance the environment entails in the welfare functions of the respective types of countries. As the coalition grows in size the weight of climate utility component in the welfare function increases since a coalition country is aware of the emission externality imposed on the other member states of the coalition. Consequently, caps are strictly set to internalize the externality. In contrast, despite of the fact that a fringe country is equally faced with the global damage but in its view damages are almost external and their reduction do not enhance welfare significantly. Therefore, a fringe country is much more focused on the welfare impact of favorably terms of trade shifts arising from a strict retaliation policy in the tariff game.

The only finding still left to be explained is why fringe countries do not lift up their tariff rates even more above the BAU level than the one observed and why coalition countries seem to apply only moderate trade barriers to the favor of their own industry? As will be shown in the following figures depicting trade patterns and prices the answer simply may be found in the fact that there will be intra-industry trade and the tariffs chosen obviously assure for an optimal shift of the respective terms of trade.

Trade Pattern. Let us have a look at consumer prices and the intra-industry trade in **Figure 11** and **Figure 12**.

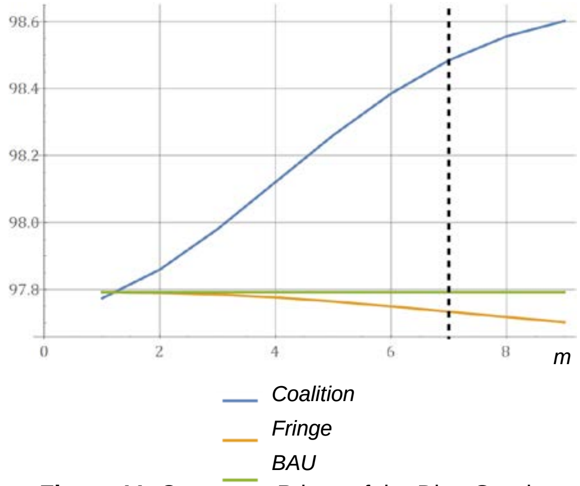

Figure 11: Consumer Prices of the Dirty Good

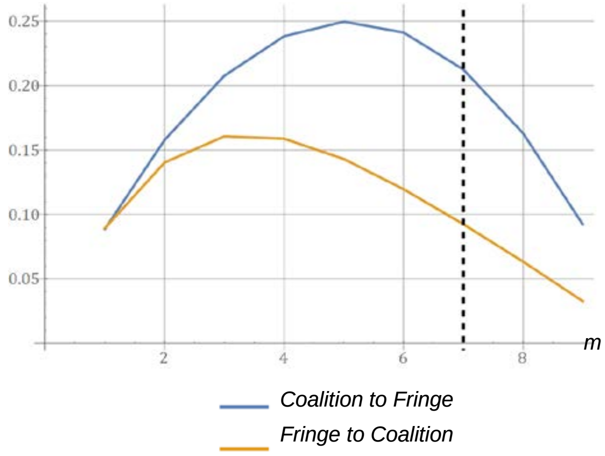

Figure 12: Inter-group Exports of the Dirty Good

As we might recall, consumer prices are composed of permit prices, tariff rates, and the opportunity cost in production. **Figure 11** suggests that the impact of the two policy instruments on consumer prices evens out to some degree since in both, coalition and fringe countries, these come out very close to the BAU level in the stable case. Hence, there must be other factors than consumer prices leading to the intra-industry trade[12] in the dirty good as depicted in **Figure 12**. The coalition acts as the net exporter to the group of fringe countries, with net exports peaking at size $= 6$. Of course, this result must be largely driven by domestic and foreign producer prices presented in **Figure 13** and **Figure 14,** respectively.

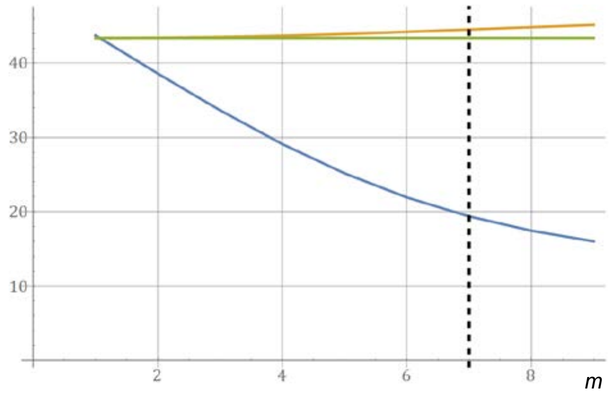

Figure 14: Foreign Producer Prices of the Dirty Good

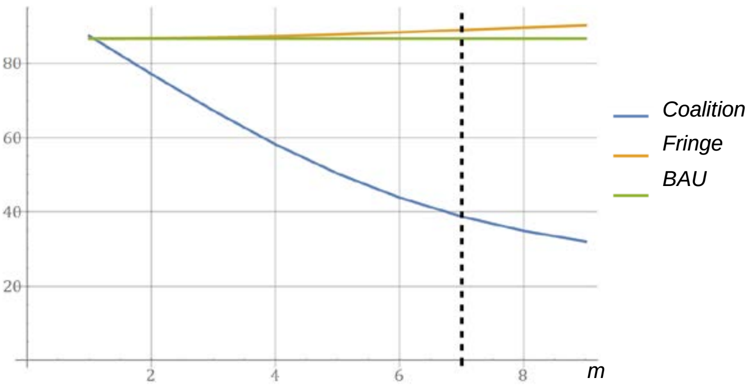

Figure 13: Domestic Producer Prices of the Dirty Good

Producer Prices. A comparison of foreign producer prices, p_C and p_F, with domestic producer prices, $p_C + t_C$ and $p_F + t_F$, reveals that, as the size of the coalition is increasing, both fall

[12] Please note that intra-industry trade is a result of the differentiation in terms of supplies of the dirty good. However, no intra-coalitional trade takes place due to the situation of identical endowment.

considerably in the coalition while in the fringe countries, they are raised slightly above the BAU level. This price differentiation induced by the respective policies brings about a substantial flow of export from the coalition to the group of fringe countries. On the other hand, producers based in fringe countries have a strong incentive to offer the dirty good primarily on the domestic market because they can earn around 4.5 times more of what they would achieve as exporters to the coalition. Only, at a point where prices abroad and locally equalize exports take place. For coalition firms the incentive to export the dirty good is much weaker since in the stable case prices in the domestic and the foreign markets are nearly the same.

From there the specialization of the countries and their sectoral structure are quite easy to understand. Let's have a look at the trade flows of the clean good in **Figure 15** and **Figure 16**.

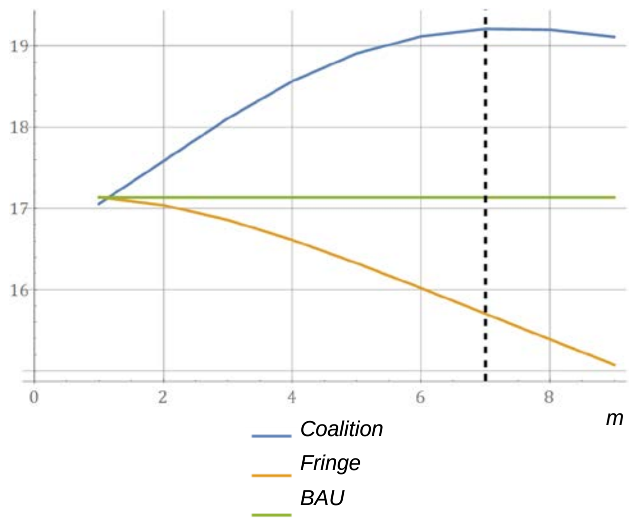

Figure 15: Individual Consumption of the Clean Good

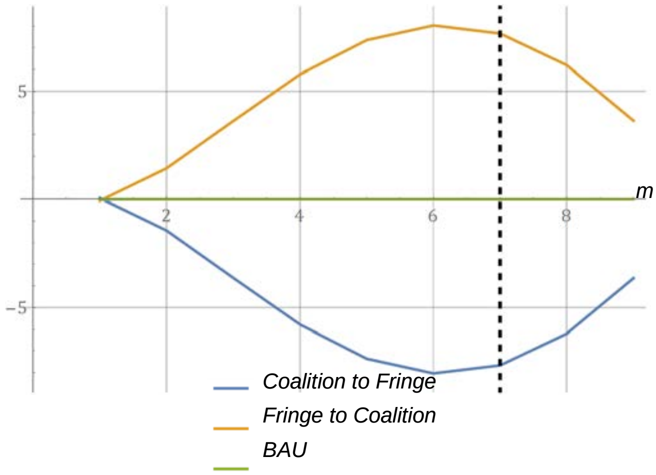

Figure 16: Inter-group Net Exports of the Clean Good

In general, both coalition and fringe countries wish to produce and consume the clean good. **Figure 15** suggests that, compared to the BAU scenario, coalition members considerably shift consumption away from the dirty good to the clean good due to the tightened cap. (After peaking at size $m = 7$ with a quantity of 112.09% of BAU, consumption altogether declines.) In contrast, fringe countries reduce their consumption of the clean good below the BAU level (to 91.65% of that level). Since the supply structure shows a rather reversed picture, the coalition has to net import the clean good from the fringe countries to meet its excess demand as can be seen in **Figure 16**. (The maximum amount is found for the stable size $m = 6$.)

6 The Importance of the Free Trade Area

In this section, we once again would like to demonstrate the advantage of a free trade area from another perspective. This is preferably done by conducting a sensitivity analysis. In order to isolate the welfare gains stemming from trade liberalization, we run another simulation of the Stackelberg game without the implementation of a preferential free trade area, which we call $\neg PFTA$.[13] In this way, we should be able to assess to what extent the results are driven by the assumptions with respect to the production technologies. The results for a variation in the parameters α_H and α^* are shown in **Table 1** below.

α_H	500	1000	1250	1500	1750	2000	2250	2500
α^*	550	1100	1375	1650	1925	2200	2475	2750
e-gap	2.274	1.142	0.863	0.667	0.525	0.417	0.334	0.268
w-gap	296.3	83.98	50.96	32.55	21.60	14.76	10.34	7.395
m^*	3	3	4	5	6	7	10	10
RE	13.71%	10.94%	20.75%	31.76%	43.56%	56.72%	100.00 %	100.00 %
RW	24.24%	19.13%	33.56%	47.22%	59.40%	70.11%	100.00 %	100.00 %
$m^*_{\neg PFTA}$	3	3	3	3	3	3	3	3
$RE_{\neg PFTA}$	14.56%	12.70%	11.87%	11.18%	10.62%	10.17%	9.802%	9.513%
$RW_{\neg PFTA}$	25.67%	22.49%	21.04%	19.81%	18.79%	17.91%	17.16%	16.49%
$RE/RE_{\neg PFTA}$	0.942	0.862	1.749	2.840	4.101	5.515	10.20	10.51
$RW/RW_{\neg PFTA}$	0.944	0.851	1.595	2.383	3.162	3.915	5.828	6.063

Table 1: Variations of $\boldsymbol{\alpha_H}$ and $\boldsymbol{\alpha^*}$

Table 1 reveals that, for the scenario with the preferential free trade agreement, the stable coalition size m^* grows as the opportunity cost of the dirty good, α_H and α^*, increase. This is an expected outcome because, as the dirty good becomes more expensive in terms of the clean good, the incentives of the countries to take a free ride decrease. Since this effect does not occur if trade is not liberalized in the coalition, it indicates that only the free trade arrangement can make use of this improved incentive situation.

Table 1 allows further insights into the interrelation between the emission and welfare outcomes and the parametrization: In the first place, one can see that the advantage of the social planner scenario over the BAU is diminishing since the dirty good is already consumed

[13] Accordingly, the main difference consists in the circumstance that firms exporting to coalition countries always receive the foreign producer price, irrespective of whether they are located in a coalition or a fringe country. Put differently, in the alternative scenario, there is no trade liberalization among coalition countries.

less in the BAU scenario due to its cost-intensive production. This can be seen by the decreasing e-gaps and w-gaps along with α_H and α^*. At the same time, the relative efficiency of the climate coalition is increasing as measured by RW and RE (except for the case of $\alpha_H = 1000$ and $\alpha^* = 1100$). It can also be shown that, by linking the climate treaty with a free trade agreement, the grand coalition can be stabilized with the technology parameters of $\alpha_H = 2250$ and $\alpha^* = 2475$ which brings about the social planner solution in a self-enforcing way.

Most interestingly, the findings of the parametric variation turn out to be much less favorable if the Stackelberg game is conducted without a preferential free trade area. For the values considered, the stable coalition always includes three members and does not grow with an increase in opportunity costs which contrasts with the outcome above. In addition, the relative efficiency in emissions as well as in welfare is somewhat decreasing in α_H and α^* which clearly implies that the incentives to abate emissions diminish if the dirty good becomes more expensive in terms of the clean good.

Finally, we compare the relative efficiency measures between the scenarios by putting them in relation to each other. This ratio indicates how efficient the implementation of a free trade area among members of the climate coalition is compared to the situation in which no issue linkage takes place. For values below (above) 1, the free trade agreement brings about a less (more) efficient outcome vis-à-vis the benchmark scenario. The results suggest that, except for parameter values less than or equal to $\alpha_H = 1000$ and $\alpha^* = 1100$, the preferential free trade area always performs better than unilateral trade policy among coalition countries, for the parameters considered. However, if the opportunity costs of the dirty good are too low in terms of the clean good, the gains from trade liberalization within the coalition cannot be brought to bear. From these findings, we can conclude that, in light of the externality, the more expensive the production of the dirty good, the more efficient is a free trade based climate coalition.

7 Concluding Remarks

This paper addresses the role of trade liberalization on the endogenous formation of a self-enforcing climate coalition. We propose linking climate negotiations to negotiations on a PFTA while strategic trade and environmental policies vis-à-vis non-signatories are carried out individually. By doing so, we tried to examine how the benefits resulting from the preferential trade liberalization affects the size, effectiveness, and stability of the climate coalition.

The model applied is an extension and modification of the Stackelberg leader-follower framework by *Eichner and Pethig* (2013a, 2013b) in which countries have two policy instruments at their disposal to strategically influence greenhouse gas emissions. On the one hand, they can discourage greenhouse gas emissions by means of an import tariff on dirty goods. They can, on the other hand, set an emissions cap affecting a national permit market. In order to identify the trade pattern within the free trade area and strictly distinct it from the trade patterns existing outside the area, we introduce a novel modeling of firms' supplies in accordance with the target markets. This implies a modification of the equilibrium concept for local markets.

The main focus of the analysis is on the exploitation of trade privileges given to members of the climate and free trade coalition that turns the PFTA into an incentive device for the formation of climate coalitions. The parametrical simulation shows evidence that the welfare gains provided by linking the IEA to the PFTA improve not only the effectiveness of the climate coalition in terms of emission reductions but also the stability by discouraging free-riding which entails a stable coalition size of $m^* = 7$. In addition, global emissions and consequently climate change damages are found significantly reduced in the numerical simulation compared to the BAU scenario, while global welfare is found growing.

Moreover, the findings of the sensitivity analysis suggest that the gains from the free trade agreement correlate with the size of the opportunity costs of the dirty good. For most of the parameter values considered, the preferential free trade area outperforms the scenario without trade liberalization in terms of emission and welfare efficiency. Only in the unlikely case that the production of the dirty good is very cheap relative to the clean good, outcomes turn out to be in disfavor of the free trade agreement. But all in all, in our framework, issue linkage with trade liberalization is found to have the potential to promote and sustain broader international cooperation on climate change.

Regarding the policy implications of our analysis, it might be argued that climate- and trade-related issues should, at any rate, be dealt with together in international negotiations, irrespective of how such linkage is implemented. Issue linkage following a top-down approach could involve joint multilateral negotiations of both the UNFCCC and WTO regimes. However, given the slow progress of multilateral trade negotiations within the WTO context, a bottom-up approach could be even more effective for the short-term implementation of mitigation measures (*Kernohan and De Cian*, 2007). In this respect, our findings make a good case for *Leal-Arcas* (2011, 2013) who claims that regional free trade agreements should be designed as an attractive package of trade- and climate-related topics so that on one hand, they settle trade-offs and conflicts and, on the other hand, they facilitate the creation of a global climate regime by building regional blocks which, later on, can be globalized.

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