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# Formation of climate coalitions and preferential free trade: the case for participation linkage

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## Abstract

We study the endogenous formation of climate coalitions linked to a preferential free trade arrangement. In a multi-stage, micro founded strategic trade and participation game, coalition and fringe countries dispose of a discriminatory tariff on dirty imports as well as emission permits imposed on domestic producers. Permits are traded on a common permit market inside the coalition and on local markets outside, respectively. We provide an analytical solution for the general equilibrium and the policy game, in the three country case, while the participation game is solved by Monte Carlo simulation. Moreover, conditional probabilities are computed for the transition to coalitions of various sizes induced by free trade. Under various regimes analyzed, we find that preferential free trade can create strong incentives for building effective climate coalitions in terms of depth and breadth. This result even holds if fringe countries are given the option of trade cooperation as a retaliation device and is driven by a favorable shift in the coalition's terms of trade. As a policy implication, negotiations on international climate treaties and free trade arrangements should be interlinked.

**Keywords** Climate change · International environmental agreements · Preferential free trade · Issue linkage · Emission permits

**JEL Classification** Q54 · Q56 · F18 · F15 · Q58

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## 1 Introduction

As the issue of global warming is seen to become increasingly severe, new collective strategies are discussed in international climate policy. Although the Paris Agreement provides a global deal and a more realistic policy framework for post-2020 climate change action, it is also being criticized for the ‘pledge and review’ mechanism which has been adopted to implement the bottom-up approach agreed upon in the 2011 Durban Platform. The problem is that the nationally determined contributions (NDCs) registered at the UNFCCC so far are not considered enough for the ambition required to meet the (‘well below’) two-degree target. A recent synthesis report by the UNFCCC estimates that the current path could lead to an increase in global mean temperatures of 2.5 degrees Celsius by the end of the century (UNFCCC Secretariat 2022). Moreover, insights from experimental game theory on climate negotiations indicate that the review process is unlikely to be able to straighten things out with regard to the climate targets (Barrett and Dannenberg 2016). The Paris Agreement does not seem to have led to a ‘broad-and-deep’ cooperation outcome yet.

Given the broad concern on the state of climate change, there is growing body of economic literature that investigates collective action going beyond the NDCs by including (incentivizing or penalizing) trade-related measures to induce reluctant countries to raise efforts (see below). In this paper, we propose building a link between climate coalitions and a preferential free trade arrangement. The basic idea is to enable coalition members to favorably shift the terms of trade on international markets by trade diversion and trade creation, and hence to discourage fringe countries from free riding on the environment. The objective is to increase both, participation in international environmental agreements (IEAs) and their effectiveness in reducing greenhouse gas emissions on a global scale. Thus, the aim of the present paper is to investigate the effects of linking a free trade agreement with an environmental agreement on coalition size, environmental outcomes and global welfare.

The study of the endogenous coalition formation in the non-cooperative game literature on IEAs<sup>1</sup> is based on the pioneering work of D’Aspremont et al. (1983),<sup>2</sup> which was developed in the context of price cartels and adapted to IEAs on emission reductions by Carraro and Siniscalco (1993), and Barrett (1994), among others. The model essentially consists of two stages: an (open membership) participation stage and a policy stage. In the participation stage, players decide whether to join the IEA. In the policy stage, the signatories (coalition countries) and the non-signatories (fringe countries) set their policies (e.g., abatement, taxes and tariffs) maximizing their aggregate and individual welfare, respectively, in a simultaneous (Cournot/Nash) or sequential mode (Stackelberg).

As free riding incentives are inherent in the provision of a public good like emission reductions, various mechanisms (transfer payments, issue linkages, etc.) have

<sup>1</sup> See Hovi et al. (2014); Marrouch and Amrita (2016) for excellent overviews of the field.

<sup>2</sup> A formal analysis of this type of model is conducted in Karp and Simon (2013).

been investigated with regard to increasing participation and effectiveness of climate coalitions (Hovi et al. 2014; Marrouch and Amrita 2016). Issue linkage<sup>3</sup> is a mechanism whereby the free riding incentives inherent in an IEA are offset by incentives originating from other issues such as R & D or trade, among others (Marrouch and Amrita 2016). Consequently, the basic model above has been extended by a third stage involving trade, typically with segmented markets at the country level, in a partial equilibrium setting with imperfect competition (Barrett 1997; Dong and Zhao 2009; Lui 2010; Al Khourdjie and Finus 2020; Diamantoudi et al. 2020), or in a general equilibrium setting with perfect competition (Eichner and Pethig 2013 (without issue linkage), Eichner and Pethig (2015) (without market segmentation)). In the strategic trade literature, the same three-stage timing was also used by Yi (1996); Conconi (2000) and Melatos and Woodland (2007) to evaluate the effects of free trade and customs unions on coalition formation.

In this paper, the focus is put on a preferential free trade agreement (PFTA) among the members of a climate coalition, adding more realism to the multistage participation game. By preferential free trade, we mean an agreement on the mutual abolishment of tariffs and the coordination of tariffs levied on the non-participants. In the tradition of the literature on participation linkage, we present a micro founded, multi-stage strategic trade model, which, naturally, is giving countries the option of coordinating their environmental policies in form of IEAs to mitigate climate change. Moreover, the model incorporates the possibility of preferential free trade among the signatories of an IEA as well as among the non-signatories. We will consider various regimes allowing for free trade, either inside or outside the climate coalition, or both. The purpose of this approach is to calculate the probabilities of the transition from smaller to larger coalitions and vice versa, induced by preferential free trade.

A crucial question to be solved in our approach is how the preferential free trade area can be modeled in the presence of more than two countries. This requires tracking the trade flows among countries, with respect to the countries of origin as well as with respect to the countries of destination. Hence, there is the challenge to differentiate a country's excess supply with respect to the export destinations, and a country's excess demand with respect to the origins of its imports. In typical trade models<sup>4</sup> with just two countries, this information is naturally given by the trade pattern, but no longer if more than two countries are involved in trade. In the latter case, a scheme of discriminatory tariffs could neither be imposed, nor could the trade pattern be determined. The solution to this problem naturally leads to a segmented market structure which is well in line with Debreu (1959), who differentiates markets with respect to location and time in his Theory of Value, but is also in line with recent literature like, e.g., Shapiro and Walker (xxxx); Lapan and Sikdar (2019).

<sup>3</sup> A comprehensive discussion of the wider topic of issue linkage can be found in Maggi (2016).

<sup>4</sup> See, e.g., the reviews of Bagwell and Staiger (2016); Maggi (2014) on the formation of trade agreements.

An IEA linked to a preferential free trade agreement was introduced in Kuhn et al. (2015, 2018, 2019), and more recently<sup>5</sup> analyzed by Diamantoudi et al. (2020).

In the present paper, we use a different model which in our view goes beyond previous approaches. Most importantly, we try to enhance the negotiation power of fringe countries by giving them the option to forming a free trade area among themselves as a retaliation device. On the side of the coalition, we consider the case of a common market for tradable emission permits implemented among coalition members, which is more efficient than local permit markets are. In addition, permits are issued at a price to producers instead of consumers.

We should in particular emphasize that environmental damages are dealt with in an emission trading system instead of a carbon tax. In contrast to tradable permits, border carbon adjustments (BCA), for instance, are a form of tariff scheme that is imposed on dirty imports to counteract unfair competitive advantages resulting from eco-dumping strategies by non-signatories. In Al Khourdajie and Finus (2020), countries set their carbon prices which in turn determine their tariffs. Al Khourdajie and Finus (2020) find that this design is conducive to increasing participation and effectiveness in climate coalitions. In our model, countries have two policy instruments available. Emission permits impact the carbon price, but tariffs are not coupled with carbon prices and can be set independently. The latter option is a precondition to be able to arrange a free trade area efficiently, because tariffs no longer may have to work in lieu of emission caps.

Moreover, in the model we try to rule out any disruptions to be dealt with, which otherwise could interfere with the pure impacts of free trade on climate coalitions. We employ Nash strategies instead of Stackelberg strategies to rule out the first mover advantage to coalition and fringe countries, respectively. On the market level, we assume perfect competition to shift the focus to the strategic policies applied by countries away from the strategic behavior of firms. Last but not least, with respect to the simulation methodology, we employ Monte Carlo simulation techniques which perform better in terms of the generality of the results achieved than a specified parameterization with sensitivity analysis. Yet, the general equilibrium, the comparative statics, and the Nash equilibrium are solved analytically.

We find strong evidence for the hypothesis that a PFTA can promote the formation of a ‘broad-and-deep’ climate coalition [confirming Kuhn et al. (2019); Diamantoudi et al. (2020)], even more, if producers have to face a coalition-wide emission trading system. This finding can be attributed to the fact that coalition countries have more and better options available to channel their policies for governing the market outcomes. In this respect, naturally, terms of trade effects will play a predominant role in deteriorating free riding incentives. Interestingly, even if countries free riding on the environment are given the option to form a trading block among themselves to enhance their negotiation power on international markets, we find that the formation of climate coalitions hardly gets affected.

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<sup>5</sup> A pre-print of the current paper is available at Kuhn et al. (2022).

The paper is organized as follows. In Sect. 2 we describe the model providing the micro-foundation of the market equilibria in accordance with the trade structure. In addition, the policy game and the participation game are formulated. In Sect. 3, comparative statics results for the general equilibrium are discussed. Section 4 presents the results for the endogenous coalition formation under free trade and no free trade, as well as the counteracting impact of a free trade area among fringe countries. Section 5 gives some intuition on the results achieved, followed by some concluding remarks in Sect. 6.

## 2 The model

The following model involves three stages: a coalition participation stage, a policy stage, and a market stage. First, in the participation game, countries decide on whether to join the climate coalition or not (open membership). Taking this decision, a country is able to fully anticipate its optimal Nash strategies given the policies of any other country in the follow-up policy game. In the Nash equilibrium, the optimal policies of all countries (discriminatory tariffs on dirty imports as well as emission caps) get determined simultaneously. Moreover, the coalition is able to exploit the power of coordinating its environmental policy. However, with respect to trade policies, we will allow for the formation of a free trade area not only among coalition countries, but also among fringe countries. On the final stage, the general market equilibrium is determined comprising the world market for a clean good, the local markets for a dirty goods, the common permits market in the coalition countries, and the local permits market in the fringe countries. Accordingly, the trade patterns for all countries are being determined given their optimal strategic policies. As usual, the solution proceeds by backward induction.

### 2.1 Preferential free trade area

As emphasized in the introduction, in our approach we make use of strategic trade models with more than two countries to be extended by preferential free trade arrangements. Modeling a free trade area, we first have to recall from trade theory that there is a fundamental difference between a model with more than two countries and traditional trade models, in particular with respect to the determination of the trade pattern. While in a two-country model, the trade pattern is determined along with the equilibria in international markets, and in the case of more than two countries, excess demand and excess supply do not provide any information on the trade pattern, that is, the destination and origin of trade flows. A preferential free trade area, however, requires to be able to track trade flows with respect to the countries of origin as well as with respect to the countries of destination. Otherwise, tariffs could not be levied selectively on dirty good imports. Equally, in solving a firm's optimization problem, it could not be taken into account that firms are facing different prices on foreign markets because of tariff privileges.

The setup of the model is as follows. We assume  $i = 1, \dots, n$  countries, each maximizing its social welfare. There is international trade in a clean good as well as in a dirty good, where  $p_x$  denotes the price for the clean good. The production  $e_i^S$  of the dirty good is coupled with emissions  $e_i$  one to one,  $e_i(e_i^S) = e_i^S$ . All countries face the same global emissions  $e = \sum_i e_i$  due to the public good characteristics of the global externality, while damages  $D_i(e)$  may be specific. Further, there is a common cap and trade system inside the coalition, while permit markets in fringe countries are local. Hence, each country has two instruments at its disposal: an emission cap  $e_i^6$  and a tariff  $t_i$  imposed on the dirty good. The emission trading system will be described in detail, together with the tariffs, in Sect. 2.2. Moreover, each country has to strategically decide on whether to become a coalition member ( $i \in C$ ) or to stay out as a fringe country ( $i \in F$  with  $C \cap F = \emptyset$ ). Incomes and prices are determined by the conditions of the general equilibrium taking Walras' Law into account.

The incorporation of a preferential free trade area in a model with more than two countries is leading to a segmented market structure, in which the total supply of a firm is decomposed into the supplies to the various destinations, i.e.,  $e_i^S = \sum_{j \in C \cup F} e_{ij}^S$ . Here,  $e_{ij}^S$  denotes the supply of the representative firm located in the origin country  $i$  to destination country  $j$ . In case  $j = i$ , the firm serves the domestic market. Further, we have to differentiate between producers located in coalition countries and those located in fringe countries. Producers  $i$  inside the free trade area receive the foreign consumer price ( $p_j + t_j$ ) for the exports to any other coalition country  $j \in C$  due to tax exemption, while producers outside the free trade area receive the foreign producer price  $p_j$  only.<sup>7</sup> This is what constitutes the advantage and the gains of free trade. In the absence of a free trade area, a coalition producer would only receive the foreign producer price  $p_j$  throughout. The corresponding decision problem of the producers will be described in more detail below.

The advantage of this approach is given by the fact that trade flows can be identified with respect to their origin as well as their destination as a pre-condition for introducing a free trade area with discriminatory tariffs to the model.

## 2.2 Markets

### 2.2.1 Producers

Producers maximize profits  $\Pi_i$  by deciding on the supply of the dirty good,  $e_i^S$ , the supply of the clean good,  $x_i^S$ , and the demand for emission permits. For each unit of the dirty good produced firms have to acquire one permit. The coalition producers  $i \in C$  acquire an emission permit at price  $\pi_c$  on the coalition market, while fringe producers  $i \in F$  have to pay the local permit price  $\pi_i$ . Furthermore, firms have to

<sup>6</sup> We notate  $e_i$  as both, emissions and caps, because for each unit of production firms have to acquire one permit.

<sup>7</sup> Please note:  $p_i$ ,  $p_j$  are the supply prices, not the market prices.

decide on the destinations of the differentiated supply of the dirty good,  $(e_{i1}^S, \dots, e_{in}^S)$ . In their view, policy decisions and prices for goods and permits are taken as given.

Both, coalition and fringe firms face a certain production possibility frontier  $T_i = T_i(x_i^S, e_{i1}^S, \dots, e_{in}^S)$ . With regard to the transformation function, it is quite reasonable to assume that the opportunity costs of shipping the dirty good to the various destinations abroad differ not only because of specific transportation costs, but also because of country-specific import regulations and standards to be met. In comparison, opportunity costs of supplies to the home market may be lower.

Formally, producers face the following optimization problems:

$$\max_{x_i^S, e_i^S} \Pi_i = p_x x_i^S + (p_i + t_i - \pi_c) e_{ii}^S + \sum_{\substack{j \in C, \\ j \neq i}} (p_j + t_j - \pi_c) e_{ij}^S + \sum_{j \in F} (p_j - \pi_c) e_{ij}^S \quad \text{for } i \in C$$

$$\text{s.t. } T_i(x_i^S, e_{i1}^S, \dots, e_{in}^S) = 0,$$

$$\max_{x_i^S, e_i^S} \Pi_i = p_x x_i^S + (p_i + t_i - \pi_i) e_{ii}^S + \sum_{\substack{j \\ j \neq i}} (p_j - \pi_i) e_{ij}^S \quad \text{for } i \in F$$

$$\text{s.t. } T_i(x_i^S, e_{i1}^S, \dots, e_{in}^S) = 0.$$

In case of fringe countries forming a free trade area among themselves (see Sect. 4), the objective function in the second optimization problem takes the form:

$$\Pi_i = p_x x_i^S + (p_i + t_i - \pi_i) e_{ii}^S + \sum_{\substack{j \in F, \\ j \neq i}} (p_j + t_j - \pi_i) e_{ij}^S + \sum_{j \in C} (p_j - \pi_i) e_{ij}^S \quad \text{for } i \in F.$$

The differentiated supply of the dirty good as introduced here, in a sense, is comparable to the iceberg approach widely used in trade theory. In case of iceberg costs, only a fraction of the good originally produced and shipped abroad reaches the respective markets in the destination countries, (i.e., a fraction “melts off” during transport). Then, firms have to produce more than one unit of the good if they want to sell one unit abroad. Hence, the opportunity costs of shipping the goods to different destinations, inclusive of transaction costs, are different, and so are firms’ supplies at a given world market price. Or, in case of segmented markets, supply prices for the respective markets have to be differentiated according to the shares lost in transport. Compared to the iceberg approach, in our model the transaction costs of shipping goods abroad are reflected in a firm’s transformation function rather than in terms of exogenous shares in quantity. That problem naturally would disappear in a two-country setting which, however, is not at all suitable to our research agenda.

## 2.2.2 Consumers

Consumers try to maximize utility  $U_i$  by deciding on the optimal demand for the dirty good  $e_i^D$  as well as for the clean good  $x_i^D$ , taking the level of income  $y_i$ , the



price for the dirty good  $p_i + t_i$ , and the world market price for the clean good  $p_x$  as given. The consumer's optimization problem can therefore be written as follows:

$$\begin{aligned} \max_{x_i^D, e_i^D} \quad & U_i(x_i^D, e_i^D) \\ \text{s.t.} \quad & p_x x_i^D + (p_i + t_i) e_i^D = y_i, \end{aligned}$$

where  $p_i$  denotes the local market price. We will turn to the markets in the next section.

### 2.2.3 Markets

The general equilibrium can now be characterized by the following set of equations:

$$\begin{aligned} \text{Coalition permits market:} \quad & \sum_{i \in C, j \in C \cup F} e_{ij}^S = e_c, \\ \text{Fringe permits markets:} \quad & \sum_j e_{ij}^S = e_i \quad \forall i = m + 1, \dots, n, \\ \text{Local markets for the dirty good:} \quad & e_i^D = \sum_j e_{ji}^S \quad \forall i = 1, \dots, n, \\ \text{Global market for the clean good:} \quad & \sum_j x_j^D = \sum_j x_j^S, \\ \text{Coalition countries' incomes:} \quad & y_i = \Pi_i + t_i \sum_{j \in F} e_{ji} + \frac{\pi_c e_c}{m} \quad \forall i = 1, \dots, m, \\ \text{Fringe countries' incomes:} \quad & y_i = \Pi_i + t_i \sum_{j \neq i} e_{ji} + \pi_i e_i \quad \forall i = m + 1, \dots, n. \end{aligned}$$

The first four (sets of) equations simply state the market equilibrium conditions for permits, the dirty good, and the clean good. In case of the coalition permit market, please recall that the amount of permits supplied is given by the emission caps set by the member countries:  $e_c = \sum_{i \in C} e_i$ . The last two sets of equations describe consumer incomes, which consist of profits  $\Pi_i$ , tariff incomes  $t_i \sum e_{ji}$ , and the share of revenues from the permit markets ( $\frac{\pi_c e_c}{m}$  and  $\pi_i e_i$ ,  $i \in F$ ). Obviously, coalition countries lack tariff revenues from the other coalition members because of free trade.

### 2.2.4 Walras' law

It can be shown that Walras' law applies, hence we may take the clean good as numeraire with  $p_x = 1$ . This follows from the fact that consumers will expend their entire income. We will therefore have  $p_x x_i^D + (p_i + t_i) e_i^D = \Pi_i + t_i \sum_{j \in F} e_{ji} + \frac{\pi_c e_c}{m}$  and  $p_x x_i^D + (p_i + t_i) e_i^D = \Pi_i + t_i \sum_{j \neq i} e_{ji} + \pi_i e_i$  for coalition and fringe consumers, respectively. Now, assuming that all markets except that for the clean good are in equilibrium, substituting the firms' profits for  $\Pi_i$ , and aggregating the income equations over all countries, we get after some elementary algebraic operations  $p_x \sum_i x_i^D = p_x \sum_i x_i^S$ , i.e., the market for the clean good is also balanced.

### 2.3 Policy game

The social welfare function  $W_i := U_i(x_i^D, e_i^D) - D_i(e)$  of any country  $i = 1, \dots, n$  takes into account the consumption utility  $U_i(x_i^D, e_i^D)$  net of global environmental damages  $D_i(e)$ . When countries decide on their participation in a climate coalition, they have to trade off the gains from free trade including the benefits of coordinated emission policies on the one hand, and the rents from free riding on the environment on the other hand. This framework is modeled as a simultaneous moves game with joint decision making on the side of the coalition players and individual decision making on the side of the fringe players, for any given coalition size  $m$ . The optimization problem for a coalition  $C$  of member size  $m$  is thus:

$$\max_{e_c, (t_i)_{i \in C}} \sum_{i \in C} W_i(e_c, (t_i)_{i \in C}; (e_i)_{i \in F}, (t_i)_{i \in F}, m) \quad \text{with } C = \{1, \dots, m\}.$$

Here, welfare  $W_i$  depends on the policy instruments only since market reactions are already endogenized in the general equilibrium at this stage. Precisely,  $x_i^D = x_i^D((e_j)_{j=1 \dots n}, (t_j)_{j=1 \dots n}; m)$ ,  $e_i^D = e_i^D((e_j)_{j=1 \dots n}, (t_j)_{j=1 \dots n}, m)$ ,  $e = e((e_j)_{j=1 \dots n}, (t_j)_{j=1 \dots n}, m)$ , where  $e_c = \sum_{i \in C} e_i$  stands for the coalition-wide cap and  $e$  for global emissions. The coalition welfare does not depend on the individual caps,  $(e_i)_{i \in C}$ , because a common permit market will assure for an efficient allocation of permits among the local producers. The decisions of the fringe countries  $(e_i)_{i \in F}, (t_i)_{i \in F}$  and the coalition size  $m$  are taken as given. Please note that local consumption of dirty goods may deviate from local production due to international trade, and thus may go beyond the local cap.

Fringe countries maximize their individual welfare in the policy game

$$\max_{e_i, t_i} W_i(e_i, t_i; (e_j)_{j \neq i}, (t_j)_{j \neq i}, m).$$

Here, the decisions of all other countries  $(e_j)_{j \neq i}, (t_j)_{j \neq i}$ , and the coalition size  $m$  are taken as given. Further, as above, market reactions are again considered as endogenized. Because of the interdependence of the optimal policies, countries get involved in a strategic trade and environmental policy game.

### 2.4 Participation game

After the policy decisions have been endogenized, the individual welfare  $W_i$  of a country  $i$  will only depend on  $m$  and on whether a country is a coalition member or not. Therefore, in the participation game, each country has to decide whether to participate in a coalition of size  $m$  or to stay out, fully anticipating the potential gains and losses of this move. For the symmetric case, a coalition of size  $m$  is said to be internally and externally stable if there is no incentive for countries to leave or join (D'Aspremont et al. 1983), that is:

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

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

Finally, these inequalities together determine the stable coalition size  $m^*$ .<sup>8</sup>

In the following, throughout, we will study stable coalitions under various regimes in the three-country-case.<sup>9,10</sup> In particular, we will consider three different trade regimes: (a) coalition and fringe without free trade, (b) coalition with and fringe without free trade, (c) coalition and fringe with free trade. The comparison between the first two trade regimes will reveal the effect of free trade on coalition formation, while the comparison between the third and second regime reveals the countervailing effects of free trade among the fringe on coalition formation with free trade. For each case, we calculate the probability of the transition from smaller to larger coalitions and vice versa. We will also consider the BAU regime and as the benchmark the SP regime. The social-planner-solution (SP) here is defined as the global welfare maximizing grand coalition. The BAU solution, for the purpose here, is given by countries maximizing their individual welfare in the Nash equilibrium. The absolute probability for achieving the SP solution will be calculated too.

### 3 General equilibrium and comparative statics results

#### 3.1 General equilibrium solution

An analytical solution for the general equilibrium in the three-country case,  $n = 3$ , is obtained for the following specifications (see Appendix 1). The utility function is taken as a quasi-linear function with a saturating non-linear term in the dirty good,  $U_i(x_i^D, e_i^D) = ax_i^D + be_i^D - c(e_i^D)^2$ . The production possibility frontier is given by

<sup>8</sup> Since a coalition of  $m = 1$  is not meaningful, the internal stability criterion for this border case actually reads  $W_{i \in C}(2) \geq W_{i \notin C}(0)$ .

<sup>9</sup> The fact that we consider only the three country case might raise some hesitations. Although coalitions of size three can be stable without the additional incentives of free trade, this is not always true, as will be seen in the results. So, on the one hand, there is still “room” for free trade to improve the situation. On the other hand, it is a priori not clear whether introducing free trade might not actually reduce the stable coalition size (which is not the case as we will see). Importantly, fringe countries are given the option of free trade too to potentially counteract the formation of climate coalitions.

<sup>10</sup> Also note that in the case  $n = 3$  with stable coalition size  $m^* = 2$ , the remaining fringe country does free ride on the coalition countries in the following sense. Let  $w_i(m)$  denote the individual welfare of countries  $i = 1, 2, 3$ . In  $m = 3$  global welfare,  $w_1(3) + w_2(3) + w_3(3)$ , is maximized and since the countries are symmetric they obtain each the same welfare,  $w_i(3) = w_j(3)$ . Now, let  $i = 3$  be the fringe country in  $m = 2$ . Because  $m = 3$  is internally unstable, this means that the fringe country obtains a higher welfare in  $m = 2$ , i.e.,  $w_3(3) < w_3(2)$ . This means that the welfare of the two coalition countries together has to be lower than in  $m = 3$ ; if it were higher, then global welfare would be higher in  $m = 2$  than in  $m = 3$ . Again, since the coalition countries are symmetric:  $w_1(2) = w_2(2)$ , and  $w_1(2) + w_2(2) = 2w_1(2) < w_1(3) + w_2(3) = 2w_1(3)$ , i.e., the individual welfare of the coalition countries is lower in  $m = 2$  than in  $m = 3$ . Thus, we can say that the fringe country obtains a higher welfare at the cost of the coalition countries (when compared to the social planner regime).

**Table 1** Price reactions to policy changes in a coalition country  $i \in C$  and fringe country  $j \in F$ 

Derivatives	$d/de_c$	$d/de_j$	$d/dt_i$	$d/dt_j$
$p_i$	$< 0$	$< 0$	$> 0$	$< 0$
$p_k, k \in C, k \neq i$	$< 0$	$< 0$	$< 0$	$< 0$
$p_j$	$< 0$	$< 0$	$< 0$	$> 0$
$\pi_c$	$< 0$	$< 0$	$= 0$	$< 0$
$\pi_j$	$< 0$	$< 0$	$< 0$	$= 0$

$T_i(x_i^S, e_{i1}^S, \dots, e_{in}^S) = \bar{x} - \alpha x_i^S - \beta \sum_{j=1}^n (e_{ij}^S)^2 = 0$ . And finally, the damage function

with increasing marginal damages is given by  $D(e_1^D, \dots, e_n^D) = \delta \left( \sum_{j=1}^n e_j^D \right)^2$ .

The comparative statics results can easily be calculated from the price equations (see Appendix A) (Table 1). The findings for the interesting case of free trade and  $m = 2$  are summarized in the following table<sup>11</sup>:

### 3.2 Comparative statics for tariffs

In general, we find that the domestic price of the dirty good is falling in response to a higher foreign tariff rate, and rising in response to a higher domestic tariff rate. But, the implications of this result for producers are quite different depending on where they are located. Fringe exporters, on the one hand, receive just the foreign producer price net of the tariff which is lower than before, whatever the destination may be. On the other hand, coalition exporters earn the higher foreign consumer price.<sup>12</sup> Consequently, a shift in trade away from fringe countries toward coalition members takes place.

Moreover, we find that the foreign tariff rates have a depressing impact on domestic permit prices. Obviously, if foreign tariff rates increase, domestic producers face a loss in producer rents due to fewer exports at lower foreign producer prices. Then, producers want to shift production back to the home market, which however cannot fully compensate for the loss in export revenues. As a consequence, their demand for permits is decreasing, inducing the permit price to fall. However, in this situation, coalition producers are again better off than fringe producers. Besides the home market, they have available the option to redirect exports to other coalition countries, where they earn the foreign consumer price, which probably is higher due to tariff privileges. Again, trade is shifted away from fringe countries and incentives to join a climate coalition under free trade are created. The equalities in the table are explained by the fact that the change in prices in home/coalition and foreign markets

<sup>11</sup> This is the most interesting case. The results for the other cases may be calculated analogously.

<sup>12</sup> This does not hold if the coalition does not have free trade. Then  $\frac{d(p_i)}{dt_i} < 0$  holds also for coalition exporters.

are such that producers shift their supply from foreign markets to their home, or resp. coalition, markets one to one.<sup>13</sup>

### 3.3 Comparative statics for emission caps

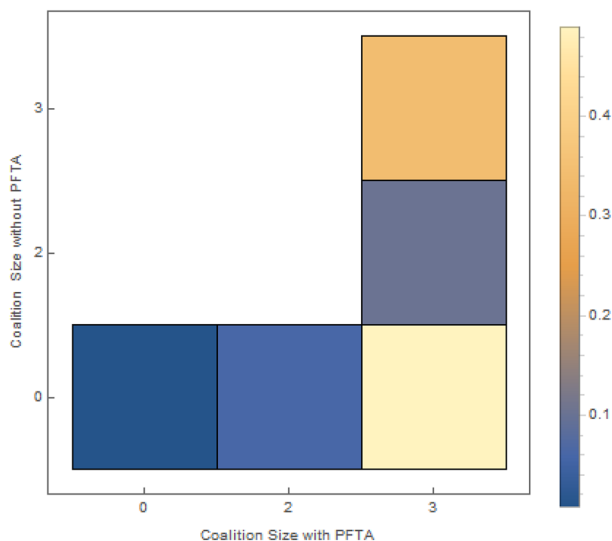
The impacts of an increasing amount of permits on permit prices as well as on prices for the dirty good are throughout negative, for coalition as well as for fringe countries, whichever country is issuing more permits. This result may have been widely expected from the background of the theory on trade and the environment. Let us just consider the more interesting case of foreign policy affecting domestic goods prices. Here, in fact, permit prices are falling due to higher import competition leading to a higher market share of foreign producers. Consequently, domestic producers demand less permits, such that the price for permits decreases too. But, a follow-up eco-dumping policy aimed at improving the terms of trade does not work out. This is true in particular for the fringe countries because export promotion by means of eco-dumping at the same time lowers the foreign producer price. Hence, environmental measures cannot be employed in lieu of tariffs, which in turn neither work properly as explained above. In contrast, for coalition producers the domestic consumer price may even increase in a free trade area, in particular when tariff rates are employed as a retaliation device. We can conclude: by the comparative statics results channels are opened up to countries for the implementation of strategic policies in particular in favor of the climate-free trade linkage.

## 4 Coalition formation, welfare gains, and environmental outcomes

### 4.1 Monte Carlo simulation

Having obtained a solution for the market equilibrium, we proceed to analyze the coalition formation. For this purpose, we first solve for the optimal policies in the Nash equilibrium, given the coalition size  $m$  (see Appendix 1). In the next and final step, the participation game, we observe the effects of free trade on coalition formation, welfare, and the environment by means of a Monte Carlo simulation on a subset of the parameter space,  $\mathcal{P} = \{(a, b, c, \alpha, \beta, \delta) \in [0, 10]^6\}$ . To be more precise, we draw a random sample of parameter values  $S \subset \mathcal{P}$  from the uniform distribution over  $\mathcal{P}$ . For reasons of computational tractability, we focus on the interior solutions for the producers' and consumers' problems,  $I \subset S$ , only. Finally, every parameter sample which gives an interior solution gets evaluated with respect to its internal and external stability, welfare gain, and environmental outcome under the trade regimes defined above. For  $|S| = 100.000$  samples drawn  $|I| = 20651$  interior solutions were found.

<sup>13</sup> This can be seen from the price equations for home and foreign markets in Appendix 1, and considering that the producer supply is linear in the prices in the interior.



**Fig. 1** Incentive to join the climate coalition with and without free trade

**Table 2** Conditional probabilities for  $P(m_{PFTA} = k | m_{\neg PFTA} = l)$

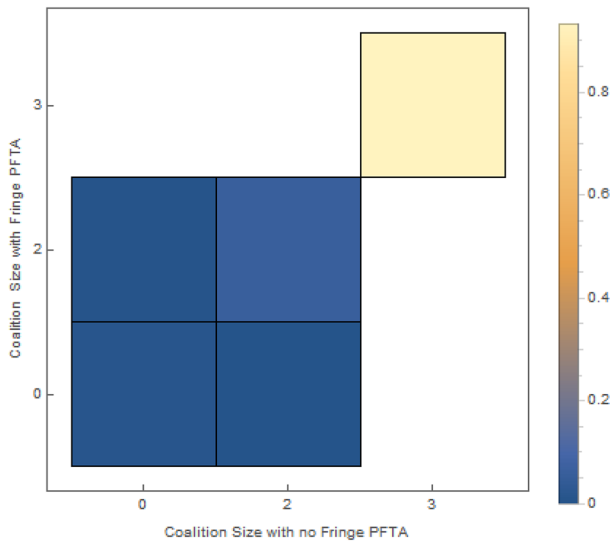
$P(m_{PFTA} = k   m_{\neg PFTA} = l)$	$k = 0$	$k = 2$	$k = 3$
$l = 3$	0	0	1
$l = 2$	0	0	1
$l = 0$	0.01	0.11	0.88

## 4.2 Formation of climate coalitions

### 4.2.1 Free trade among coalition countries

In the following, we present the results for the effects of free trade on coalition formation. Let us define  $m_{PFTA} : \mathcal{P} \mapsto \{0, 2, 3\}$ , and  $m_{\neg PFTA} : \mathcal{P} \mapsto \{0, 2, 3\}$  to be functions that map the parameter space  $\mathcal{P}$  onto the stable coalition size  $m \in \{0, 2, 3\}$  under free trade and no free trade, respectively. Then, Fig. 1 depicts the histogram of  $M(p) := (m_{PFTA}(p), m_{\neg PFTA}(p))$  over the interior solutions  $I$ . Each element  $(k, l)$  gives the absolute probability,  $P(M = (k, l))$ , of observing a transition of coalition size  $l$  to coalition size  $k$  as a consequence of free trade (see appendix C for the numerical values).

On the diagonal  $((0, 0), (2, 2), (3, 3))$ , we see the outcomes where free trade does not have any impact on coalition formation (approx. with probability 0.35). Above left the diagonal  $((0, 2), (0, 3), (2, 3))$ , we find the probabilities for a decreasing size of the climate coalition due to free trade (prob. 0.00), while below right the diagonal  $((2, 0), (3, 0), (3, 2))$  we find the probabilities for an increasing size of the coalition (approx. with probability 0.65).



**Fig. 2** Stable coalition sizes with and without free trade among fringes; coalition with free trade

**Table 3** Conditional probabilities for  $P(m_{PFTA}^* = p | m_{PFTA} = q)$

$P(m_{PFTA}^* = k   m_{PFTA} = l)$	$k = 0$	$k = 2$	$k = 3$
$l = 3$	0	0.0019	0.9981
$l = 2$	0.03	0.97	0.00
$l = 0$	0.95	0.05	0.00

From these results, we can derive the conditional transition probabilities from coalition size  $l$  to coalition size  $k$ , summarized in Table 2.

As we easily can see, the conditional probability for transitions from coalitions of size 2 to the grand coalition is  $p = 1$ , and from coalitions of size 0 it is around  $p = 0.88$ . Once established, grand coalitions never get smaller since  $P(m_{PFTA} = 3 | m_{PFTA} = 3) = 1$ . For the conditional transition probability from coalition size 0 to coalition size 2, we get  $p = 0.11$ . As an important result, we can state that the formation of climate coalitions is either unaffected or even more is fostered by free trade, but never is it hampered.

#### 4.2.2 Free trade among fringe countries

This picture, however, might change if we allow for free trade among fringe countries as a counteracting strategy to favorably shift the terms of trade on

**Table 4** Absolute probabilities for achieving a given coalition size  $i$  for the various scenarios

$i$	0	2	3
$P(m_{PFTA} = i)$	0.01	0.06	0.93
$P(m_{\neg PFTA} = i)$	0.56	0.10	0.34
$P(m_{PFTA}^* = i)$	0.01	0.06	0.93

international markets.<sup>14</sup> In this case, let  $m_{PFTA}$  again be defined as above, and let  $m_{PFTA}^* : \mathcal{P} \mapsto \{0, 2, 3\}$  be a function that maps the parameter space  $\mathcal{P}$  onto the stable coalition size  $m^* \in \{0, 2, 3\}$  when coalition countries as well as fringe countries can take a free trade arrangement among themselves. Then, Fig. 2 depicts the histogram of  $M^*(p) = (m_{PFTA}(p), m_{PFTA}^*(p))$  over the interior solutions  $I$ , and Table 3 again depicts the conditional transition probabilities. Both illustrate the impact of free trade among fringe countries on the size of the climate coalition.

By account of the diagonal (0,0), (2,2), (3,3), as well as by the diagonal in Table 3, we see that the absolute and conditional probabilities for the coalition size remaining unchanged is nearly 1 when fringe countries engage in free trade. In the lower left quadrant, we find mixed results. On the one hand, the coalition size slightly increases, with conditional transition probability  $p = 0.03$ . On the other hand, the coalition size slightly decreases with conditional transition probability  $p = 0.05$ . The intuition behind this result is as follows: free trade in the dirty good among fringe countries can generate only very weak incentives and disincentives for the formation of climate coalitions, dependent on whether the increasing consumption utility does fully compensate for the higher environmental damages or not. Otherwise, climate coalitions are even slightly incentivized. But, given the very low probabilities in these cases, we can conclude, that the ability of fringe countries to counteract climate coalitions by establishing their own free trade area, in fact, does not really exist.

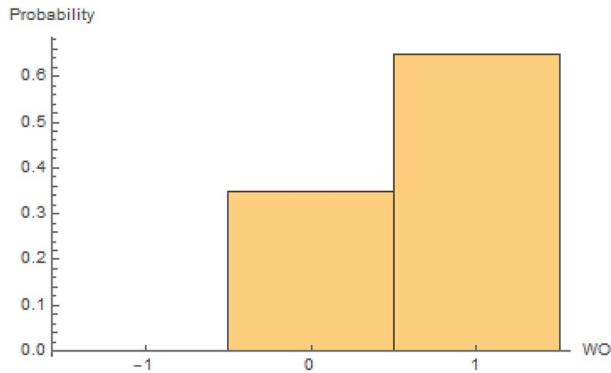
#### 4.2.3 Social-Planner- and BAU solution

Table 4 depicts the absolute probabilities for achieving a given coalition size  $i$  for the various scenarios.

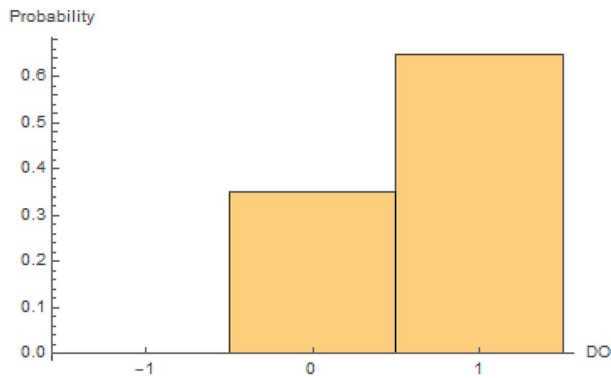
In Table 4, the SP corresponds to the third column. We can conclude from this table that though first best can never be achieved with certainty, it is much more likely for the free trade–climate linkage (see the first and second row). Moreover, for the case when the fringes have a free trade arrangement among themselves (third row), the absolute probabilities of reaching the SP solution are hardly affected. Not at all surprising, it is just the other way round for the BAU solution (first column) which is much more likely when the free trade–climate linkage is missing.

<sup>14</sup> Note that this strategy affects only the stability of coalition sizes,  $m = 0$ ,  $m = 2$ , since in the last case the welfare results are compared with those of  $m = 0$ , while  $m = 3$  is unaffected by free trade among the fringe as there is no free trade among the fringe in the case  $m = 2$  and  $m = 3$ .





**Fig. 3** Global welfare outcomes,  $WO$



**Fig. 4** Global damages outcomes,  $DO$

### 4.3 Welfare gains

Next, we analyze the effect of a climate coalition linked to free trade on global welfare compared to the unlinked case. For fringe countries, free trade is ruled out here by assumption. Let global welfare be defined as the sum over the welfare of the individual countries, and let  $W_G^{PFTA} : \mathcal{P} \mapsto \mathbb{R}$ ,  $W_G^{PFTA} := \sum_i W_i^{PFTA}$ , and  $W_G^{\neg PFTA} : \mathcal{P} \mapsto \mathbb{R}$ ,  $W_G^{\neg PFTA} := \sum_i W_i^{\neg PFTA}$  be functions that map the parameter space onto the welfare outcomes for the stable coalition size, with and without free trade, respectively. Figure 3 then shows the histogram of global welfare outcomes,  $WO$  over  $I$ , defined as:

$$WO = \begin{cases} 1 & W_G^{PFTA} > W_G^{\neg PFTA} \\ 0 & W_G^{PFTA} = W_G^{\neg PFTA} \\ -1 & W_G^{PFTA} < W_G^{\neg PFTA} \end{cases}.$$

Here, the values 1, 0,  $-1$  indicate whether free trade has a positive, negative, or neutral effect on global welfare. We can conclude that global welfare never gets reduced by free trade, but is either unaffected or is increased with probability 34.96% and 65.04%, respectively.

#### 4.4 Environmental outcomes

Finally, let us take a look on how the environmental outcomes are affected by free trade. Consider the damages functions  $D_G^{PFTA} : \mathcal{P} \mapsto \mathbb{R}$ ,  $D_G^{PFTA} := \sum_i D_i^{PFTA}$  for the free trade szenario, and  $D_G^{-PFTA} : \mathcal{P} \mapsto \mathbb{R}$ ,  $D_G^{-PFTA} := \sum_i D_i^{-PFTA}$  for the szenario without free trade. Figure 4 then shows the histogram of the damages outcomes  $DO$  over  $I$ , defined as:

$$DO = \begin{cases} 1 & D_G^{PFTA} < D_G^{-PFTA} \\ 0 & D_G^{PFTA} = D_G^{-PFTA} \\ -1 & D_G^{PFTA} > D_G^{-PFTA} \end{cases}.$$

Here, like above, the values indicate whether global environmental damages are decreased, unchanged, or increased by free trade. Again, most probably, i.e., in the vast majority of cases, environmental pressures are reduced by linking free trade with climate negotiations.<sup>15</sup>

As a main result of the paper, we can conclude that linking free trade to climate negotiations leads to more comprehensive and more effective climate coalitions.<sup>16</sup>

## 5 Discussion

What is the economic intuition behind the propositions stated? Although both, coalition and fringe countries, have two policy tools available, they use these instruments very differently to maximize welfare, as comparative statics results indicate.

On the one hand, coalition countries opt for pretty strict emission caps to internalize the climate externality while implementing highly distortionary tariffs. This finding is clearly a result of the fact that, as the coalition grows in size, the environment gets more and more valued. However, such a sound environmental policy puts coalition firms in a worse position compared to their fringe competitors due to

<sup>15</sup> However, we should notice that with a low probability of approx. 0.10%, free trade leads to bigger environmental damages. However, these reductions are sub-optimal from a global perspective, as these cases only occur when a small coalition without free trade transitions to the grand coalition with free trade, the latter being the globally optimal outcome.

<sup>16</sup> The results show in particular that the larger the coalition size, the larger is the share of global welfare that is realized, and the larger is the share of emissions that is controlled and internalized. This might lead one to suspect that bigger coalition sizes lead to better outcomes (in terms of welfare and the environment). Regardless whether this is the case or not, what is more important for judging the effects of free trade in this study is the comparison of the outcomes in the stable coalition size between different trade regimes.

higher permit costs. Coalition countries are thus forced to pursue strict protectionist trade policies to improve their terms of trade, but, remarkably not at the expense of environmental quality. This gives rise to a trade barrier between the coalition and the fringe countries which reduces inter-group trade flows substantially. At the same time, a high degree of interdependency between markets for the dirty good and the permit markets enables the coalition to exert environmental discipline on the fringe caps (the more the larger is the coalition size) by depressing the fringe permit prices.<sup>17</sup> As a consequence of the trade-diverting effects of the free trade area, coalition members succeed, to some degree, in insulating their local markets and the coalitional permit market from the impact of the fringe policies.

On the other hand, from the viewpoint of the fringe countries, the situation of being exposed to price pressures<sup>18</sup> without being able to retaliate against coalitional tariffs leads to a considerable welfare loss due to the deterioration of consumption possibilities in both goods. After all, that might explain why fringe countries find it optimal to join the coalition. Yet, even when fringes are taking the option to form a free trade area themselves, they hardly are able to behave as free riders by opting for pretty lax caps and high tariff rates. So, they do not really succeed in undermining any environmental efforts made by the coalition members.

All in all, these outcomes finally illustrate how a free trade area can provide strong incentives to the formation of climate coalitions.

## 6 Concluding remarks

The objective of this paper has been to address the role of a preferential free trade arrangement for the endogenous formation of climate coalitions. A cap-and-trade emission trading scheme is implemented on the supply side as well as on a coalitional scale to internalize climate damages. Moreover, fringe countries are given the power to retaliate by forming a free trade area themselves, while coalition countries no longer can take advantage of the Stackelberg leadership. From a methodological point of view, the model could be solved analytically up to the policy game, while the solution of the participation game has been obtained by Monte Carlo simulation.

We find strong support for joint negotiations on climate change mitigation and preferential free trade if producers participate in a coalition-wide permit market. This result can be explained by the behavior of perfectly competitive firms which is determined not only by the local prices for the dirty good, but also by the domestic permit price to be paid. Thereby, strong possibilities for effective price discrimination against non-coalition countries are created. Compared to the case of national emission trading schemes obligating consumers, trade privileges can be better exploited by the climate coalition. Moreover, the additional arbitrage opportunities on the coalition wide

<sup>17</sup> For more information on the impacts of policies on the markets, please again inspect the comparative statics analysis in Sect. 3

<sup>18</sup> As a matter of fact, even for those countries a certain degree of emission reduction is welfare enhancing, which is why fringe countries do not find it optimal to let permit prices fall to zero.

permit market lead to an equalization of the opportunity costs of producing the dirty good among coalition producers as the most efficient allocation of resources.

Therefore, the PFTA serves quite well as an incentive mechanism to discourage free riding behavior and incentivizes coalition formation in the Monte Carlo simulation, with a positive impact on global welfare and climate mitigation. Moreover, it has been shown that the advantage provided by a PFTA can be sustained for a large variation in the opportunity costs of the dirty good as well as in the other parameter values.

These results are, of course, driven by a favorable shift in terms of trade. The coalition is able to shift a considerable part of the burden of climate mitigation onto the group of fringe countries by manipulating the prices on the fringe markets. Coalition countries thus succeed in insulating their own markets comparably well against leakage effects. The tightening of the cap is accompanied by a trade barrier established vis-à-vis free riders which makes fringe consumers much worse off since they must curb demand for both, the dirty and the clean good. That is why countries find it beneficial to join the coalition.

Although, in our framework, issue linkage with trade liberalization is found to have the potential to promote and sustain a broad and deep international cooperation on climate change, it represents a double-edged sword with regard to the policy implications. More precisely, the coalition's strategy of imposing protectionist tariff policies is likely to give rise to conflict with the current WTO framework.<sup>19</sup> At the same time, it is obvious that discriminative trade tools must be given legal space in the WTO [as suggested by Leycegui et al. (2015)] if dirty products should be dealt with effectively. Then, sooner or later, an explicit amendment to the WTO regulatory framework is inevitable to be able to cope with externalities arising from climate change with appropriate trade-related incentives.

A note on the limitations of the paper might be in order. Considering the symmetric three-country case only does not allow for statements on how the stable coalition sizes, and consequently the welfare and environmental outcomes, are affected by a growing number of maybe asymmetric countries in the frame of a single, particular regime. A higher number of countries would also increase the number of fringe countries and thereby the size of their free trade area. Further, the analysis of the strategic interactions among players in such a regime is restricted to the solution of the Nash equilibria, while due to the complexity of the model the reaction functions would require a deeper analysis. However, we think these limitations do not diminish the significance of the main results of the paper, since the focus is put much more on the properties of the transition between regimes, and thus, in fact, on the transition from smaller to larger coalitions as fostered by preferential free trade. Any future developments of climate negotiation models that elegantly address these and related issues are of course most welcome.

<sup>19</sup> Even though there are numerous exemptions from the Most-Favoured-Nation principle, all of them are subject to strict requirements with regard to the establishment of trade barriers vis-à-vis other WTO members. That is why the linked free trade area can neither be considered consistent with GATT Art. XXIV nor with GATT Art. XX.

## Appendix A: Market solutions

The formulas for the prices were obtained by first solving the first-order conditions of producers and consumers for their demand and supply functions, respectively. Then, we substituted these equations into the general equilibria conditions and solved for the prices. The calculations were done with a computer algebra system.<sup>20</sup>

### 1. Climate coalition with free trade

$m = 0$ :

$$p_i = \frac{3ab\beta + 9abc}{3a(a\beta + 3ac)} - \sum_j \frac{2a\beta c + 6ac^2}{3a(a\beta + 3ac)} e_j + \frac{4ac}{3(a\beta + 3ac)} t_i - \sum_{j \neq i} \left( \frac{2ac}{3(a\beta + 3ac)} t_j \right) \quad i = 1, 2, 3,$$

$$\pi_i = \frac{b}{a} - \frac{2a\beta + 2ac}{3aa} e_i - \sum_{j \neq i} \left( \frac{2c}{3a} e_j + \frac{1}{3} t_j \right) \quad i = 1, 2, 3.$$

$m = 2$ :

$$p_i = \frac{3ab\beta + 9abc}{3a(a\beta + 3ac)} - \frac{2a\beta c + 6ac^2}{3a(a\beta + 3ac)} e_c - \frac{2a\beta c + 6ac^2}{3a(a\beta + 3ac)} e_3 + \frac{2ac}{3(a\beta + 3ac)} t_i - \frac{ac}{3(a\beta + 3ac)} t_j \\ - \frac{2ac}{3(a\beta + 3ac)} t_3 \quad i, j \in C, j \neq i,$$

$$\pi_c = \frac{b}{a} - \frac{a\beta + 2ac}{3aa} e_c - \frac{2c}{3a} e_3 - \frac{1}{3} t_3,$$

$$p_3 = \frac{3ab\beta + 9abc}{3a(a\beta + 3ac)} - \frac{2a\beta c + 6ac^2}{3a(a\beta + 3ac)} e_c - \frac{2a\beta c + 6ac^2}{3a(a\beta + 3ac)} e_3 - \sum_{j \in C} \left( \frac{ac}{3(a\beta + 3ac)} t_j \right) + \frac{4ac}{3(a\beta + 3ac)} t_3,$$

$$\pi_3 = \frac{b}{a} - \frac{2c}{3a} e_c - \frac{2a\beta + 2ac}{3aa} e_3 - \sum_{j \in C} \frac{t_j}{3}.$$

$m = 3$ :

$$p_i = \frac{b}{a} - \frac{2c}{3a} e_c \quad i = 1, 2, 3,$$

$$\pi_c = \frac{b}{a} - \frac{2a\beta + 6ac}{9aa} e_c.$$

### 2. Climate coalition without free trade

$m = 0$ : Same as in the previous case.

$m = 2$ :

$$p_i = \frac{3ab\beta + 9abc}{3a(a\beta + 3ac)} - \frac{2a\beta c + 6ac^2}{3a(a\beta + 3ac)} e_c - \frac{2a\beta c + 6ac^2}{3a(a\beta + 3ac)} e_3 + \frac{4ac}{3(a\beta + 3ac)} t_i \\ - \sum_{j \neq i} \left( \frac{2ac}{3(a\beta + 3ac)} t_j \right) \quad i \in C,$$

$$\pi_c = \frac{b}{a} - \frac{2a\beta + 4ac}{6aa} e_c - \frac{2c}{3a} e_3 - \sum_{i \in C} \frac{1}{6} t_i - \frac{t_3}{3},$$

$$p_3 = \frac{3ab\beta + 9abc}{3a(a\beta + 3ac)} - \frac{2a\beta c + 6ac^2}{3a(a\beta + 3ac)} e_c - \frac{2a\beta c + 6ac^2}{3a(a\beta + 3ac)} e_3 + \frac{4ac}{3(a\beta + 3ac)} t_3 - \sum_{j \in C} \left( \frac{2ac}{3(a\beta + 3ac)} t_j \right),$$

$$\pi_3 = \frac{b}{a} - \frac{2c}{3a} e_c - \frac{2a\beta + 2ac}{3aa} e_3 - \sum_{j \in C} \frac{t_j}{3}.$$

$m = 3$ :

$$p_i = \frac{3ab\beta + 9abc}{3a(a\beta + 3ac)} - \frac{2a\beta c + 6ac^2}{3a(a\beta + 3ac)} e_c + \frac{4ac}{3(a\beta + 3ac)} t_i - \sum_{j \neq i} \frac{2ac}{3(a\beta + 3ac)} t_j \quad i = 1, 2, 3,$$

$$\pi_c = \frac{b}{a} - \frac{2a\beta + 6ac}{9aa} e_c - \sum_{i \in C} \frac{2}{9} t_i.$$

### 3. Fringe countries with free trade

$m = 0$ :

<sup>20</sup> Mathematica v.12

$$\begin{aligned}
 p_i &= \frac{b}{a} - \sum_{i \in C} \frac{2c}{3a} e_i \quad i = 1, 2, 3, \\
 \pi_i &= \frac{b}{a} - \frac{2a\beta + 2ac}{3aa} e_i - \sum_{j \neq i} \frac{2c}{3a} e_j \quad i = 1, 2, 3. \\
 m &= 2, 3: \text{ Same as in the first case.}
 \end{aligned}$$

## Appendix B: Nash equilibria

The analytical solutions of the Nash equilibria were obtained with the help of a computer algebra system<sup>21</sup> by substituting the market solutions into the welfare functions and solving the Nash equilibrium conditions for the policy decision variables. Solutions for  $n > 3$  can also be found, but have even higher complexity.

**1. Climate coalition with free trade** For the case where coalition countries have free trade among themselves, we obtain the following results.

$$\begin{aligned}
 m = 0: \quad t_i &= \frac{3b\beta}{5a\beta + 9a(c+3\epsilon)} \quad e_i = \frac{9ab}{2(5a\beta + 9a(c+3\epsilon))} \quad i = 1, 2, 3 \\
 m = 2: \\
 t_i &= \frac{3b\beta(15a^3\beta^3 + 6aa^2\beta c(8c+41\epsilon) + 4a^3c^2(4c+45\epsilon) + a^2a\beta^2(47c+72\epsilon))}{60a^4\beta^4 + 48a^4c^3(2c+9\epsilon) + a^3a\beta^3(323c+666\epsilon) + 3a^2a^2\beta^2c(199c+697\epsilon) + 2aa^3\beta c^2(215c+927\epsilon)} \quad i = 1, 2, \\
 e_c &= \frac{12ab(12a^3\beta^3 + a^2a\beta^2(37c-18\epsilon) + 3aa^2\beta c(11c-13\epsilon) + 2a^3c^2(4c-9\epsilon))}{60a^4\beta^4 + 48a^4c^3(2c+9\epsilon) + a^3a\beta^3(323c+666\epsilon) + 3a^2a^2\beta^2c(199c+697\epsilon) + 2aa^3\beta c^2(215c+927\epsilon)}, \\
 t_3 &= \frac{3b\beta(12a^3\beta^3 + 2a^3c^2(4c-63\epsilon) + 3aa^2\beta c(14c-37\epsilon) + a^2a\beta^2(43c-18\epsilon))}{60a^4\beta^4 + 48a^4c^3(2c+9\epsilon) + a^3a\beta^3(323c+666\epsilon) + 3a^2a^2\beta^2c(199c+697\epsilon) + 2aa^3\beta c^2(215c+927\epsilon)}, \\
 e_3 &= \frac{3ab(30a^3\beta^3 + 16a^3c^2(2c+9\epsilon) + 6aa^2\beta c(19c+52\epsilon) + a^2a\beta^2(109c+144\epsilon))}{2(60a^4\beta^4 + 48a^4c^3(2c+9\epsilon) + a^3a\beta^3(323c+666\epsilon) + 3a^2a^2\beta^2c(199c+697\epsilon) + 2aa^3\beta c^2(215c+927\epsilon))}. \\
 m = 3: \quad e_c &= \frac{9ab}{2a\beta + 6a(c+9\epsilon)}.
 \end{aligned}$$

**2. Climate coalition without free trade** In the case where the climate coalition has no free trade area, the equilibria are given as follows.

$m = 0$ : Same as in the previous case.

$m = 2$ :

$$\begin{aligned}
 t_i &= \frac{3b\beta(a\beta + ac)(15a^2\beta^2 + aa\beta(23c+72\epsilon) + 2a^2c(4c+81\epsilon))}{2(45a^4\beta^4 + 42a^4c^3(2c+9\epsilon) + 3aa^3\beta c^2(107c+450\epsilon) + a^3a\beta^3(233c+513\epsilon) + a^2a^2\beta^2c(425c+1497\epsilon))} \quad i = 1, 2, \\
 e_c &= \frac{3ab(69a^3\beta^3 + aa^2\beta c(191c-282\epsilon) + 12a^2a\beta^2(17c-12\epsilon) + 14a^3c^2(4c-9\epsilon))}{2(45a^4\beta^4 + 42a^4c^3(2c+9\epsilon) + 3aa^3\beta c^2(107c+450\epsilon) + a^3a\beta^3(233c+513\epsilon) + a^2a^2\beta^2c(425c+1497\epsilon))}, \\
 t_3 &= \frac{3b\beta(21a^3\beta^3 + aa^2\beta c(65c-144\epsilon) + 2a^3c^2(10c-81\epsilon) + 6a^2a\beta^2(11c-3\epsilon))}{2(45a^4\beta^4 + 42a^4c^3(2c+9\epsilon) + 3aa^3\beta c^2(107c+450\epsilon) + a^3a\beta^3(233c+513\epsilon) + a^2a^2\beta^2c(425c+1497\epsilon))}, \\
 e_3 &= \frac{3ab(30a^3\beta^3 + 14a^3c^2(2c+9\epsilon) + 3aa^2\beta c(31c+94\epsilon) + a^2a\beta^2(95c+144\epsilon))}{2(45a^4\beta^4 + 42a^4c^3(2c+9\epsilon) + 3aa^3\beta c^2(107c+450\epsilon) + a^3a\beta^3(233c+513\epsilon) + a^2a^2\beta^2c(425c+1497\epsilon))}. \\
 m = 3: \quad t_1 = t_2 = t_3 &= 0 \quad e_c = \frac{9ab}{2a\beta + 6a(c+9\epsilon)}.
 \end{aligned}$$

The identical results for  $m = 0$  are due to the fact that there are only fringe countries, with the same trade arrangements.

For  $m = 3$ , the difference to the previous case lies in the fact that the coalition countries still have tariffs available, but (endogeneously) choose to set them to 0.

<sup>21</sup> Mathematica v12

**3. Fringe countries with free trade** Finally, for the case where the fringe countries have free trade among themselves the results read:

$$m = 0: e_i = \frac{3ab}{2a\beta + 6\alpha(c+3\epsilon)} \quad i = 1, 2, 3.$$

$m = 2, 3$ : Same as in the first case.

The identity of the last two cases results from the fact that there is either one ( $m = 2$ ) or no fringe country ( $m = 3$ ). In both cases, the coalition countries have the same trade arrangements, while there is no (other) fringe country to have free trade with.

## Appendix C: Numerical probabilities

See Tables 5, 6 and 7.

**Table 5** Coalition size outcomes with and without free trade

$m_{\sim PFTA}/m_{PFTA}$	0	2	3
3	0 %	0 %	34.1485 %
2	0 %	0 %	10.1496 %
0	0.81352 %	5.85928 %	49.0291 %

**Table 6** Coalition size outcomes with fringe PFTA and without fringe PFTA

$m_{\sim PFTA}/m_{PFTA}$	0	2	3
3	0 %	0 %	93.3272 %
2	0.154956 %	5.82538 %	0%
0	0.658564 %	0.0338967 %	0 %

**Table 7** Changes global welfare and damages

	Decrease	Unchanged	Increase
<i>WO</i>	0 %	34.962 %	65.038 %
	Increase	Unchanged	Decrease
<i>DO</i>	0.10169 %	34.962 %	64.9363 %

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## Declarations

**Conflict of interest** The authors declare that they have no conflict of interest.

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