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Summary

This paper examines the stability of International Environmental Agreements (IEAs) in an economy with trade. We extend the basic model of the IEAs by letting countries choose emission taxes and import tariffs as their policy instruments in order to manage climate change and control trade. We define the equilibrium of a three-stage emission game. In the first stage, each country decides whether or not to join the agreement. In the second stage, countries choose simultaneously - cooperatively or non-cooperatively - tariff and tax levels. In the third stage, taking countries' decisions as given, firms compete à la Cournot in the product markets. Numerical analysis illustrates that the interaction between trade and environment policies is essential in enhancing cooperation. Contrary to the IEA model, stable agreements are larger and more efficient in reducing aggregate emissions and improving welfare. Moreover, the analysis shows that the size of a stable agreement increases in the number of countries affected by the externalities.

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International Environmental Agreements and Trading Blocks.
-Can issue linkage enhance cooperation?

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Abstract

This paper examines the stability of International Environmental Agreements (IEAs) in an economy with trade. We extent the basic model of the IEAs by letting countries choose emission taxes and import tariffs as their policy instruments in order to manage climate change and control trade. We define the equilibrium of a three-stage emission game. In the first stage, each country decides whether or not to join the agreement. In the second stage, countries choose simultaneously - cooperatively or non-cooperatively - tariff and tax levels. In the third stage, taking countries' decisions as given, firms compete a la Cournot in the product markets. Numerical analysis illustrates that the interaction between trade and environment policies is essential in enhancing cooperation. Contrary to the IEA model, stable agreements are larger and more efficient in reducing aggregate emissions and improving welfare. Moreover, the analysis shows that the size of a stable agreement increases in the number of countries affected by the externalities.

Keywords: Environmental Agreements, *JEL*: D6, Q5, C7

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1

Figure 1

Acknowledgement

1   Introduction

Environmental issues such as climate change, air and water pollution, and deterioration of the ozone layer are transboundary or global in nature. Therefore, countries, by acting alone, can not promote significant environmental protection. Recognizing this, they have already developed a wide range of International Environmental Agreements (IEAs) to enable them to work together on global environmental issues.

A number of IEAs exists trying to implement environmental policies on sovereign countries. For instance, the Kyoto Protocol and its successor the Paris Agreement as well as the Montreal Protocol are some of the most well known environmental treaties. However, there is an important problem associated with their contribution to environmental protection. They ultimately signed only by a limited number of countries and, in general, fail to achieve their targets, thus, climate change is still speeding. There are two important factors responsible for this phenomenon. First, there are strong free-riding incentives created due to the pure public good provision problem. All countries could be better of under full cooperation, but each individual country has incentives to free ride on others' efforts. Second, there is no a supranational authority that could implement and enforce environmental policies on sovereign states. Therefore, environmental treaties should be designed so that they are self-enforced. That is, they should provide countries with incentives to join and remain members of the agreements.

The main body of the literature studies the formation of an IEA as a two-stage non-cooperative game, where in the first stage countries decide whether or not to join the agreement (coalition), while in the second they choose their emissions. In the second stage, it is assumed that countries either choose emissions simultaneously or that the coalition acts as a leader and the non-signatory countries follow. The subgame perfect Nash equilibrium of the resulting two-stage game is usually derived by applying the notions of the internal and external stability conditions (D'Aspremont et al., 1983). An IEA is considered to be stable if none of its participating countries has an incentive to withdraw (internal stability) and none of the non-participating countries has an incentive to further join the agreement (external stability), assuming that the remaining players in the game do not revise their membership decision.

Results reveal that it is very difficult to induce many countries to join an inter-

national agreement with significant reductions in emissions. Assuming quadratic cost and benefit functions and simultaneous choice of emissions, the basic model shows that stable coalitions consist of no more than two countries (De Cara and Rotillon, 2001; Finus and Rundshagen, 2001; Rubio and Casino, 2001; among others). If the coalition is assumed to be a leader, the coalition formation is more successful. Barrett (1994) suggests that a stable coalition may achieve a high degree of cooperation, including the grand coalition. In contrast, Diamantoudi and Sartzetakis (2006), imposing the appropriate positivity constraints on emissions, show that stable coalitions could have no more than four members. Overall, strong free-rider incentives prevent large stable coalitions and/or large gains from cooperation.

In light of all of the above, it is very important to extent the basic model of the IEAs' literature implementing different policies that could successfully promote international cooperation. One issue, linked with climate change, that can play an important role in reducing the free-riding incentives and increasing countries' willingness to cooperate, is trade. Cooperation in international environmental issues differs from most other international problems (Barrett, 2005). Environment is a global public good, and thus in an IEA, members cannot exclude non-members from enjoying the benefits of a better environment. On the other hand, in trade agreements, free trade is not treated as a global public good and non-signatory countries can be excluded from enjoying the benefits of a free trade agreement.

Some of the existing IEAs include provisions that can affect trade. Specifically, trade measures can regulate or restrain the trade in particular materials or products, either between members of the treaty and/or between members and non-members. For example, the Montreal Protocol contains specific trade measures in the form of requirements for a ban on trade between parties and non-parties in products containing or made with ozone-depleting substances (ODS). One of the main goal of those measures was to maximize participation in the Protocol, by excluding non-members from supplies of ODS. According to International Institute for Sustainable Development (IISD), some of the countries that participated in the treaty did so because of the trade provisions. Moreover, trade sanctions have been utilized in the Basel Convention (international transportation of hazardous waste), and the Convention on International Trade in Endangered Species (CITES). With respect to a specific product, the U.S. has applied a penalty tax on foreign automobile manufacturers not meeting the domestic Corporate Average

Fuel Economy (CAFE) standards.

The relevant literature of IEA and trade is surprisingly not so extensive. Initially, Barrett (1997) analyzes an IEA formation problem in a partial equilibrium model with abatement and illustrates that trade sanctions can help to support cooperation, even full cooperation, among countries. Lessmann, Marschinski, and Edenhofer (2009) apply a dynamic model of climate coalition formation and use trade sanctions as an instrument to promote participation. In their model, coalitions are free to impose tariffs on imports from non-cooperating countries. According to their results, participation in the coalition rises and global welfare also rises along with participation.

More recently, Eichner and Pethig (2013) and (2014) study environmental agreements in a model with international trade. Applying a cap and trade regulation, they find that international trade does not improve the conditions for the formation of effective stable climate coalitions. In particular, agreements are very small and hence ineffective in reducing emissions if coalitions play Nash equilibrium (Eichner and Pethig, 2014), however agreements may be larger but also ineffective if coalitions behave as Stackelberg leaders (Eichner and Pethig, 2013). Eichner and Pethig (2015), replacing the cap with a tax policy, demonstrate that, when countries employ carbon taxes to fight climate change, the grand coalition is stable (imposing some necessary and sufficient conditions) whether Nash or Stackelberg approaches are assumed. In all the above-mentioned papers (Eichner and Pethig, 2013, 2014 and 2015), the formation of stable self-enforcing IEAs is examined in a free trade world economy. Finally, another study that has explored this idea is the paper by Nordhaus (2015). He applies a numerical general equilibrium model and uses tariff sanctions, that are taken as exogenous, to encourage participation in climate agreements. He finds that trade penalties on non-participants induce a large stable coalition with high levels of abatement.

The present analysis addresses an the formation of a Global Agreement (GA) where countries (named signatories) that form an environmental agreement form a free trade agreement as well. Nations that remain outside of the agreement (named non-signatories) suffer trade costs. The advantage for the signatories is the tariff-free access to other signatories' markets while at the same time they bare the burden of reducing emissions more. In contrast, the disadvantage for the non-signatories is that they have to pay tariffs on their imports to any other country while free-riding on environmental efforts.

The main objective of the paper is to investigate the effect of trade on the stability and effectiveness of environmental agreements, when all non-cooperative countries and coalition members choose both their terms of trade and climate policy instruments to deal with the environmental pollution. In particular, we are interested in examining whether the presence of trade can enhance cooperation and improve environmental performance as well as welfare relative to the basic model of the IEAs' literature.

Our analysis is mostly related to Eichner and Pethig (2015) in the sense that we study IEAs in a model with symmetric countries, international trade, and emission tax policy, however, they model a free-trade world economy. To our knowledge, there are no relevant studies that examine the formation of GAs in a framework similar to ours. We believe that the existence of the two instruments (i.e. tariffs and taxes), even though adds complexity to the analysis, captures better the real-world situation since trade and environmental problems affect each other. Under the formation of GA, there are two important effects that have to be taken into consideration. In an IEA, the coalition formation creates positive externalities on non-participants. On the other hand, in trade agreements, the coalition formation creates negative externalities on non-participants (Yi, 1997). The interaction between these two effects is essential to determine the stability and effectiveness of an agreement.

The present model is built as follows. There are two goods, one of which is responsible for the environmental problem. We assume that countries are symmetric and goods are produced in each country by a single firm. We consider trade in the good that generates emissions. Consumers benefit from consumption as well as a cleaner environment. The pollution is perfectly transboundary, therefore, every country is equally affected by total emissions. We characterize the equilibrium of a three-stage game. In the first stage, each country decides whether or not to join the agreement. In the second stage, countries choose simultaneously - cooperatively or non-cooperatively - the tariff and tax levels. In the last stage, each firm, taking the policies set by the countries and the output decisions of the other firms as given, maximizes its profits. To obtain the subgame perfect Nash equilibrium, the model is solved by backward induction.

Our findings illustrate the importance of trade and environmental policies working together to improve cooperation in effective agreements. Moreover, contrary to the main conclusion reached in the IEAs' literature, the size of a stable agreement

6

increases in the number of countries participating in the game. Clearly, if world markets do not exist (autarky), the model coincides with the basic model of the IEAs' literature.

The rest of the paper is structured as follows. Section 2 describes the model. Section 3 presents the benchmark case. Section 4 examines the formation of a GA. Section 5 presents the stability conditions. Section 6 analyses numerically the effect of trade on the stability and effectiveness of environmental agreements. Section 7 concludes the paper.

2 The model

We consider an open economy where countries trade with each other. We assume that there are n identical countries, $N = \{1, 2, ..., n\}$. The representative consumer in each country $i \in N$ has a utility function of the form,

$$U_i(e_i^c; K_i) = b\left(ae_i^c - \frac{1}{2}\left(e_i^c\right)^2\right) + K_i, \tag{1}$$

where e_i^c is country i's total consumption of the nonnumeraire good, K_i denotes the numeraire good, and a and b are positive parameters, i.e. $a > 0$ and $b > 0$. The total consumption e_i^c is given by,

$$e_i^c = \sum_{j=1}^{n} e_{ij} = e_i^d + \sum_{j \neq i} e_{ij}^I, \tag{2}$$

where e_i^d is country i's consumption of the domestic product and e_{ij}^I indicates the quantity country i imports from country $j \neq i$ (i.e. quantity sold from country j to country i).

The quasilinear utility function, given by equation (1), is sufficient to derive country i's inverse demand function for the nonnumeraire good, that is,

$$p_i(e_i^c) = b(a - e_i^c). \tag{3}$$

The numeraire good is produced under perfect competition with constant returns to scale and the nonnumeraire good is produced, in each country, by a single profit maximizing firm. For simplicity, the marginal cost of production is assumed

to be constant and equal to zero. We consider that there is no pollution associated with the numeraire good, while each unit of the nonnumeraire good produced generates one unit of pollution emission.

Country i charges a nonnegative tariff at the same rate of τ_i per unit of import from any country j, where $j \neq i$. Then country j's effective marginal cost of exporting to country i is τ_i. Similarly, country i's effective marginal cost of exporting to country j is τ_j. We consider trade only in the good that generates emissions (i.e. nonnumeraire good).

A by-product of production in this model is pollution. Pollution is perfectly transboundary and thus affects widely all countries. Country i's production and as a consequence polluting activity (recall the one-by-one relationship between production of consumption good and pollution) is given by,

$$e_i^p = e_i^d + \sum_{j \neq i} e_{ij}^X. \tag{4}$$

That is, production in country i is the sum of what the country produces and consumes domestically (i.e. e_i^d) and what the country produces domestically and exports (i.e. e_{ij}^X).

The damage from pollution is monotonically increasing and convex in the global emissions, $E = \sum_{i=1}^n e_i^p$. In particular, the damage function is given by,

$$D_i(E) = \frac{1}{2} c E^2, \tag{5}$$

where $c > 0$ is the pollution damage parameter, as well as $D_i(0) = 0$, $D_i' \geq 0$ and $D_i'' > 0$.

The environmental policy in country i is a carbon tax imposed per unit of emission by the domestic firm due to its production. Given our assumption that each unit of the polluting good produced generates one unit of pollution emission, a tax per unit of emission is equivalent to a tax per unit of the polluting good. The pollution (or emission) tax set in country i is denoted by t_i.

We model the process of countries' decision as a non-cooperative three stage emission game and start by solving the third stage where, taking countries' decisions as given, firms compete a la Cournot in the product markets. In the second stage, countries choose simultaneously - cooperatively or non-cooperatively - tariff and tax levels and in the first stage, each country decides whether or not to join the agreement.

Firm's problem

Each firm maximizes profits taking the policies set by the countries and the output decisions of the other firms as given. The total profits for the firm i located in country i consist of the profits of sales in the domestic market i plus the profits of sales (i.e. profits of output exported) in country j, minus the pollution tax imposed on emissions. Thus,

$$\Pi_i = \Pi_i^d + \left(\sum_{j \neq i} \Pi_{ij}^X \right) - t_i e_i^p. \tag{6}$$

Firm i maximizes profits, given by equation (6), by choosing quantity sold in country i, i.e. e_i^d, and quantity sold in country j, i.e. e_{ij}^X, for all $j \neq i \in N$. Given that firm i has a zero marginal cost of producing the homogeneous good while its effective marginal cost of exporting to country j is τ_j, its profits can be written as,

$$\Pi_i = p_i(e_i^c) e_i^d + \sum_{j \neq i} (p_j(e_j^c) - \tau_j) e_{ij}^X - t_i e_i^p, \tag{7}$$

where $e_j^c = \sum_{i=1}^n e_{ji}$ is country j's total consumption of the nonnumeraire good. The maximization problem is,

$$\max_{e_i^d,\ e_{ij}^X \nabla j \neq i \in N} \Pi_i = p_i(e_i^c) e_i^d + \sum_{j \neq i} (p_j(e_j^c) - \tau_j) e_{ij}^X - t_i e_i^p. \tag{8}$$

Country's problem

We assume that firms' profits and tariff and tax revenues are rebated back to the consumers. So that, country i's welfare, denoted by W_i, consists of the domestic consumer surplus CS_i[1], the domestic firm's profits Π_i (net of all taxes), the tariff revenues TR_i, the tax revenues ER_i and the environmental damages due to the aggregate pollution level $D_i(E)$. That is,

$$W_i = CS_i + \Pi_i + TR_i + ER_i - D_i(E). \tag{9}$$

Thus, country i's total welfare can be written as,

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[1] The consumer surplus CS_i is calculated by taking, $U_i(e_i^c; K_i) - p_i(e_i^c) e_i^c$.

$$W_i = \frac{1}{2}b\left(e_i^c\right)^2 + p_i(e_i^c)e_i^d + \sum_{j \neq i}(p_j(e_j^c) - \tau_j)e_{ij}^X + \tau_i \sum_{j \neq i} e_{ij}^I - \frac{1}{2}cE^2, \qquad (10)$$

where the quantity e_{ij}^X indicates country i's exports to country j while the quantity e_{ij}^I indicates country's i imports from country j.

Country i maximizes welfare given by (10) by choosing tariff level τ_i and tax level t_i. Thus, its maximization problem is,

$$\max_{\tau_i, t_i} W_i = \frac{1}{2}b\left(e_i^c\right)^2 + p_i(e_i^c)e_i^d + \sum_{j \neq i}(p_j(e_j^c) - \tau_j)e_{ij}^X + \tau_i \sum_{j \neq i} e_{ij}^I - \frac{1}{2}cE^2. \qquad (11)$$

3 The benchmark case

The non-cooperative outcome arises when each country $i \in N$ chooses its tariff and tax levels taking as given the tariff and tax levels from all the other countries, playing Nash equilibrium.

From the firms' maximization problem (8), the first order condition with respect to the domestic quantity e_i^d gives the following expression,

$$ab - b\sum_{j=1}^{n} e_{ij} - be_i^d - t_i = 0. \qquad (12)$$

Moreover, the first order condition with respect to the quantity exported e_{ij}^X gives the following expression[2],

$$ab - b\sum_{i=1}^{n} e_{ji} - be_{ij}^X - t_i - \tau_j = 0. \qquad (13)$$

Using the first order conditions (12) and (13), we derive country i's reaction functions for the domestic product and the quantity exported in the benchmark case. Thus,

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[2]The quantity sold (exported) from country i to country j indicates also the quantity country j imports from country i, that is $e_{ij}^X = e_{ji}^I$.

$$e_i^d = \frac{ab - t_i - b(n-1)e_{ij}^I}{2b}, \tag{14}$$

$$e_{ij}^X = \frac{ab - t_i - \tau_j - be_j^d}{nb}. \tag{15}$$

Due to symmetry, the reaction function for the quantity exported from country j to country i (i.e. e_{ji}^X), that is the quantity imported to country i, is given by,

$$e_{ij}^I = \frac{ab - t_j - \tau_i - be_i^d}{nb}. \tag{16}$$

Using the reaction functions, we derive the following expressions,

$$e_i^d = \frac{ab - nt_i + (n-1)t_j + (n-1)\tau_i}{(n+1)b}, \tag{17}$$

$$e_{ij}^X = \frac{ab + t_j - 2t_i - 2\tau_j}{(n+1)b}, \tag{18}$$

$$e_{ij}^I = \frac{ab + t_i - 2t_j - 2\tau_i}{(n+1)b}, \tag{19}$$

$$e_i^c = \frac{abn - t_i - (n-1)t_j - (n-1)\tau_i}{(n+1)b}. \tag{20}$$

Country i's maximization problem (11) can be written as,

$$\max_{\tau_i, t_i} W_i = \frac{1}{2}b\left(e_i^c\right)^2 + p_i(e_i^c)e_i^d + (n-1)(p_j(e_j^c) - \tau_j)e_{ij}^X + (n-1)\tau_i e_{ij}^I - \frac{1}{2}cE^2. \tag{21}$$

Before we proceed to the solutions, we define parameter γ as the ratio between environmental damages and benefits due to emissions. Therefore,

$$\gamma = \frac{c}{b}. \tag{22}$$

The first order conditions for the welfare maximization yield two reaction functions corresponding to the equilibrium τ_i and t_i. Since countries are identical, the tariff and pollution tax will be identical for all countries. Hence, imposing $\tau_i = \tau_j$ and $t_i = t_j$ in country i's reaction functions we solve for the Nash equilibrium tariff and tax. The reaction functions (after imposing $\tau_i = \tau_j$ and $t_i = t_j$) are presented in Appendix A.

Therefore, we have,

$$\tau_i = ab\frac{(2(2n-1)\gamma+1)n^2+3n-2}{2(n+1)(3n+(2n-1)n\gamma-2)}, \tag{23}$$

$$t_i = ab\frac{(4(2n-1)\gamma+(n-6))n+1}{2(n+1)(3n+(2n-1)n\gamma-2)}. \tag{24}$$

The domestic quantity is given by,

$$e_i^d = a\frac{2((2n-3)n+1)n\gamma+(n+6)n-3}{2(n+1)(3n+(2n-1)n\gamma-2)}. \tag{25}$$

The quantity imported from country i is equal to its quantity exported[3]. That is,

$$e_{ij}^I = e_{ij}^X = a\frac{3n-2n(2n-1)\gamma-1}{2(n+1)(3n+(2n-1)n\gamma-2)}. \tag{26}$$

The total quantity consumed in country i is equal to its total quantity produced. That is,

$$e_i^c = e_i^p = a\frac{2n-1}{3n+(2n-1)n\gamma-2}. \tag{27}$$

The aggregate consumption level (which is equal to the aggregate production level) is,

$$E_{nc} = an\frac{2n-1}{3n+(2n-1)n\gamma-2}. \tag{28}$$

Given our assumption that each unit of the nonnumeraire good produced generates one unit of pollution emission, equation (28) represents the aggregate emissions as well.

Country's i welfare is given by,

$$\mathcal{W}_i = a^2b\frac{(2n-1)(4n-((2n-5)n+2)n\gamma-3)}{2(3n+(2n-1)n\gamma-2)^2}. \tag{29}$$

The world market-clearing condition, which requires that global production of the good to be equal to its global consumption, is satisfied.

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[3]Imports are non-negative for all $n > 0$ and $\gamma \leq \frac{3n-1}{2n(2n-1)}$.

4 Coalition formation

We consider that a set of countries signs an GA aiming at controlling emissions and trade. We call those countries signatories, while the non-participants of the agreement are called non-signatories. Signatories trade freely among themselves, while non-signatories are penalized by a tariff on their imports to the members of the agreement. Moreover, non-signatories pay a tariff when they export to other non-signatories. Additionally, signatories choose a common tax level that internalizes the full environmental cost of all coalition members while non-signatories choose individually their emission tax.

In particular, we assume that a set of countries $S \subset N$ signs a GA and the remaining $N \backslash S$ do not. The countries that form an agreement of size $s = |S|$, act cooperatively maximizing the join welfare, while the countries that decide not to participate act non-cooperatively maximizing their own welfare. Thus, there are s signatory countries and $(n - s)$ non-signatory countries. Taking advantage of the symmetry assumption, we treat all signatory countries equally within the coalition.

4.1 Output levels

A signatory country's total consumption of the nonnumeraire good is given by,

$$e_s^c = e_s^d + (s - 1)e_{ss}^I + (n - s)e_{sns}^I, \tag{30}$$

where e_s^d is signatory's domestic product, e_{ss}^I indicates quantity imported from a signatory country, and e_{sns}^I indicates quantity imported from a non-signatory country.

A non-signatory country's total consumption of the nonnumeraire good is given by,

$$e_{ns}^c = e_{ns}^d + (n - s - 1)e_{nsns}^I + se_{nss}^I, \tag{31}$$

where e_{ns}^d is non-signatory's domestic product, e_{nsns}^I indicates quantity imported from a non-signatory country, and e_{nss}^I indicates quantity imported from a signatory country.

Using the first order conditions (12) and (13) from the firm's maximization problem, we derive the domestic product and the quantities imported for each signatory and non-signatory country respectively.

For a signatory country, these quantities take the following forms[4],

$$e_s^d = e_{ss}^I = \frac{ab - (n - s + 1)t_s + (n - s)t_{ns} + (n - s)\tau_s}{(n + 1)b},$$ (32)

$$e_{sns}^I = \frac{ab + st_s - (s + 1)t_{ns} - (s + 1)\tau_s}{(n + 1)b}.$$ (33)

We restrict the parameter values so that imports are non-negative. That is, $ab \geq (s+1)(t_{ns} + \tau_s) - st_s$. If a signatory country raises its tariff on imports from a non-signatory country, i.e. τ_s, then production (as well as consumption) of the domestic good increases, imports from another signatory country increase as well, while imports from a non-signatory country decrease. Similar effects occur when a non-signatory country increases its tax per unit of emission, i.e. t_{ns}. However, an increase in a signatory country's tax per unit of emission, i.e. t_s, will cause a decrease in domestic production and consumption, a decrease in imports from a signatory country and an increase in imports from a non-signatory country.

To derive a signatory country's total consumption of the nonnumeraire good, i.e. e_s^c, we use equations (32) and (33). Therefore,

$$e_s^c = \frac{abn - st_s - (n - s)t_{ns} - (n - s)\tau_s}{(n + 1)b}.$$ (34)

If a signatory country raises its tariff on imports from a non-signatory country, i.e. τ_s, then its total consumption falls. An increase in either a signatory country's tax per unit of emission, i.e. t_s, or a non-signatory country's tax per unit of emission, i.e. t_{ns}, will cause a decrease to its total consumption as well.

For a non-signatory, these quantities take the following forms[5],

$$e_{ns}^d = \frac{ab - (s + 1)t_{ns} + st_s + (n - 1)\tau_{ns}}{(n + 1)b},$$ (35)

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[4]The quantity a signatory country imports from a non-signatory country indicates also the quantity a non-signatory country exports to a signatory country, that is $e_{sns}^I = e_{nss}^X$. Also, signatories exchange an equal quantity among themselves, that is $e_{ss}^I = e_{ss}^X$.

[5]The quantity a non-signatory country imports from a signatory country indicates also the quantity a signatory country exports to a non-signatory country, that is $e_{nss}^I = e_{sns}^X$. Also, non-signatories exchange an equal quantity among themselves, that is $e_{nsns}^I = e_{nsns}^X$.

$$e^I_{nsns} = \frac{ab - (s+1)t_{ns} + st_s - 2\tau_{ns}}{(n+1)b}, \tag{36}$$

$$e^I_{nss} = \frac{ab + (n-s)t_{ns} - (n-s+1)t_s - 2\tau_{ns}}{(n+1)b}. \tag{37}$$

We restrict the parameter values so that imports are non-negative. That is, $ab \geq (s+1)t_{ns} + 2\tau_{ns} - st_s$ and $ab \geq (n-s+1)t_s + 2\tau_{ns} - (n-s)t_{ns}$. If a non-signatory country raises its tariff on imports from another country, i.e. τ_{ns}, then production (as well as consumption) of the domestic good increases, while imports decrease. An increase in a non-signatory country's tax per unit of emission, i.e. t_{ns}, will cause a reduction in domestic quantity and imports from another non-signatory country but an increase in imports from a signatory country. The inverse effect occurs if a signatory country's tax per unit of emission, i.e. t_s, increases. That is, domestic quantity and imports from another non-signatory country increase but imports from a signatory country decrease.

Using equations (35), (36) and (37), we derive the total consumption of a non-signatory country. That is,

$$e^c_{ns} = \frac{abn - (n-s)t_{ns} - st_s - (n-1)\tau_{ns}}{(n+1)b}. \tag{38}$$

If a non-signatory country raises its tariff on imports, i.e. τ_{ns}, then its total consumption falls. An increase in either non-signatory country's tax per unit of emission, i.e. t_{ns}, or a signatory country's tax per unit of emission, i.e. t_s, will cause a decrease to its total consumption as well.

Signatory country's net imports are,

$$(n-s)(e^I_{sns} - e^X_{sns}) = -(n-s)\frac{(n+1)t_{ns} - (n+1)t_s - 2\tau_{ns} + (s+1)\tau_s}{(n+1)b}. \tag{39}$$

Non-signatory country's net imports are,

$$s(e^I_{nss} - e^X_{nss}) = s\frac{(n+1)t_{ns} - (n+1)t_s - 2\tau_{ns} + (s+1)\tau_s}{(n+1)b}. \tag{40}$$

Thus, global net imports sum to zero clearing the markets. That is,

$$s(n-s)(e^I_{sns} - e^X_{sns}) + (n-s)s(e^I_{nss} - e^X_{nss}) = 0. \tag{41}$$

15

Using equations (34) and (38), we derive the aggregate consumption level which is equal to the aggregate production level (due to the world market-clearing condition). That is,

$$E = s\frac{abn - st_s - (n-s)t_{ns} - (n-s)\tau_s}{(n+1)b} + (n-s)\frac{abn - (n-s)t_{ns} - st_s - (n-1)\tau_{ns}}{(n+1)b}.$$

(42)

Rearranging,

$$E = \frac{abn^2 - nst_s - n(n-s)t_{ns} - s(n-s)\tau_s - (n-1)(n-s)\tau_{ns}}{(n+1)b}.$$

(43)

Given our assumption that each unit of the nonnumeraire good produced generates one unit of pollution emission, equation (43) represents the aggregate emissions as well. We observe that aggregate emissions decrease when the tariff and tax levels set by either signatories or non-signatories or both parties increase.

4.2 Tariff and tax levels

Under the formation of a GA of size $s = |S|$, signatories abolish tariffs among themselves and jointly choose their external tariff (i.e. tariff to the non-signatories) and tax level to maximize the aggregate welfare of the members. On the other hand, non-signatories choose their tariff and emission tax to maximize their own welfare.

Signatories maximize the aggregate coalition welfare $\sum_{i \in S} W_i = sW_s$ with respect to τ_s and t_s. Their maximization problem is,

$$\max_{\tau_s, t_s} sW_s = s \left(\begin{array}{c} \frac{1}{2}b\left(e_s^c\right)^2 + sp_s(e_s^c)e_s^d + (n-s)(p_{ns}(e_{ns}^c) - \tau_{ns})e_{sns}^X + \\ (n-s)\tau_s e_{sns}^I - \frac{1}{2}cE^2 \end{array} \right).$$

(44)

Note that a signatory's profits from exporting to other signatories are equal to its domestic profits since $e_s^d = e_{ss}^X$ as per equation (32). Moreover, it receives profits from exporting to the non-signatories after taking into account the export related costs. There are also tariff revenues per unit of import from the non-signatories.

The first order conditions for the welfare maximization yield two reaction functions. The signatories' reaction function for the equilibrium tariff $\tau_s(t_s, \tau_{ns}, t_{ns})$

16

which is a function of signatories' tax t_s, non-signatories' tariff τ_{ns}, non-signatories' tax t_{ns}, and the other parameters in the model. The signatories' reaction function for the equilibrium tax $t_s(\tau_s, \tau_{ns}, t_{ns})$ which is a function of signatories' tariff τ_s, non-signatories' tariff τ_{ns}, non-signatories' tax t_{ns}, and the other parameters in the model. The corresponding second order conditions for the welfare maximization problem are satisfied (see Appendix B).

Non-signatories maximize their own welfare W_{ns} with respect to τ_{ns} and t_{ns}. Their maximization problem is,

$$\max_{\tau_{ns}, t_{ns}} W_{ns} = \left(\begin{array}{c} \frac{1}{2}b\left(e_{ns}^c\right)^2 + p_{ns}(e_{ns}^c)e_{ns}^d + (n-s-1)p_{ns}(e_{ns}^c)e_{nsns}^X + \\ \\ s(p_s(e_s^c) - \tau_s)e_{nss}^X + s\tau_{ns}e_{nss}^I - \frac{1}{2}cE^2 \end{array} \right). \quad (45)$$

A non-signatory's profits from exporting to other non-signatories are different from its domestic profits since $e_{ns}^d \neq e_{nsns}^X$ as per equations (35) and (36). Notice that the costs related to those exports are equal to the tariff revenues from the other non-signatories' imports since they all exchange an equal quantity among themselves. Additionally, it receives profits from exporting to the signatories after taking into account the export costs. There are also tariff revenues per unit of import from the signatories.

The first order conditions for the welfare maximization yield two reaction functions as well. The non-signatories' reaction function for the equilibrium tariff $\tau_{ns}(t_{ns}, \tau_s, t_s)$ which is a function of non-signatories' tax t_{ns}, signatories' tariff τ_s, signatories' tax t_s, and the other parameters in the model. The non-signatories' reaction function for the equilibrium tax $t_{ns}(\tau_{ns}, \tau_s, t_s)$ which is a function of non-signatories' tariff τ_{ns}, signatories' tariff τ_s, signatories' tax t_s, and the other parameters in the model. The corresponding second order conditions for the welfare maximization problem are satisfied (see Appendix B).

The reaction functions for the tariff, τ_s and τ_{ns}, and tax, t_s and t_{ns}, levels are presented in Appendix C. Moreover, the equilibrium levels of tariffs and taxes are presented in Appendix D due to the length of their expressions.

4.3   Full cooperation case

In the full cooperation case, countries abolish tariffs and jointly choose their tax level to maximize the aggregate welfare. Under the full cooperation assumption,

17

tariffs are eliminated from our analysis and all countries choose the tax t_c that maximizes aggregate welfare. In this case, the model is simplified to the basic full cooperation model (socially optimal outcome) of the IEAs' literature. As a result the tax level imposed by a country is given by,

$$t_c = \frac{ab(n^3\gamma - 1)}{n(1 + n^2\gamma)}. \tag{46}$$

The quantities produced and traded are all equal and thus total quantity consumed in each country is equal to its total quantity produced. That is,

$$e_c^c = e_c^p = n\frac{a}{n + \gamma n^3}. \tag{47}$$

The aggregate emissions are given by,

$$E_c = \frac{an}{1 + \gamma n^2}. \tag{48}$$

Each country receives welfare given by,

$$\mathcal{W}_c = \frac{a^2 b}{2(1 + \gamma n^2)}. \tag{49}$$

The derived solutions for the total emissions and welfare are equivalent to the solutions presented in Rubio and Casino (2001)[6] where they calculate the full cooperative level of emissions and net benefits of each country in the IEA model.

5 The stability of an agreement

In the IEAs' literature, the existence and stability of an environmental agreement is determined using the notions of internal and external stability as was originally developed by D'Aspremont et. al (1983) and extended to IEAs by Carraro and Siniscalco (1993) and Barrett (1994). Internal stability implies that no coalition member has an incentive to leave the coalition, while external stability implies that no country outside the coalition has an incentive to join the coalition, assuming

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[6]In our model, a representative consumer in country i has a utility function of the form $U_i(e_i^c; K_i) = b\left(ae_i^c - \frac{1}{2}(e_i^c)^2\right) + K_i$ while Rubio and Casino (2001) assume that the quadratic benefit function for each country takes the form, $B_i(q_i) = aq_i - \frac{b}{2}q_i^2$, where q_i denotes emissions by country i, $a > 0$ and $b > 0$. It is trivial to derive the equivalence between the parameters.

that the remaining players in the game do not revise their membership decision. We denote the size of a stable agreement by s^*.

Formally, the internal and external stability conditions take the following form: internal stability condition,

$$\mathcal{W}_n(s^*) \geq \mathcal{W}_{ns}(s^* - 1), \tag{50}$$

external stability condition,

$$\mathcal{W}_{ns}(s^*) \geq \mathcal{W}_s(s^* + 1). \tag{51}$$

where $\mathcal{W}_s$ is the welfare of a signatory country and $\mathcal{W}_{ns}$ is the welfare of a non-signatory country.

The present model examines the formation of IEAs in an economy with trade. Therefore, we have to take into consideration two effects. The first effect, referred to as environmental effect, is related to the pure public good provision problem. Since environment is a global public good, countries have strong free-riding incentives especially when compliance with an IEA is costly to them. That is, the coalition formation generates positive externalities for non-participants. Thus, a free-rider country, acting in a self-interest manner, can increase its own emissions and enjoy the benefits from the overall pollution reduction brought about by the coalition. In terms of stability, non-signatories' strong free-riding incentives imply a violation of the internal stability condition (50).

The second effect is related to the presence of trade and henceforth referred to as trade effect. In trade agreements, the coalition formation generates negative externalities on non-participants reducing their welfare (Yi, 1997). Thus, trade measures can be a key factor in increasing cooperation incentives. The intuition is that, if non-signatories expect trade barriers, they may have incentives to join IEAs. In this case, the external stability condition (51) is violated.

Even though in IEAs, members cannot exclude non-members from enjoying the benefits of a better global environment, in trade agreements, non-members can be excluded from enjoying the benefits of free trade. Free trade is not treated as a global public good, thus, when non-signatories express interest to cooperate (i.e. condition (51) is violated), they will not be admitted to the agreement if this action makes the existing members worse off. To that extent, we add one more condition, called admissibility condition. The admissibility condition takes

the following form,

$$\mathcal{W}_s(s^*) > \mathcal{W}_s(s^* + 1), \tag{52}$$

and implies that even if external stability is violated and non-signatories wish to join, signatories oppose to the enlargement.

Considering the trade aspect in isolation, suppose that an agreement consisting of $n-1$ signatory countries is internally but not externally stable. That is, the last country has strong incentives to join the agreement as well. If the existing members admit the last country as a new member, they will gain tariff-free access to one new member country, but they grant the new member tariff-free access to $n-1$ countries. The new member must be better off, however, there is no guarantee that the existing members become better off (Yi, 1996). The admissibility condition is needed to ensure that existing members will admit a new member if they become better off by expanding the coalition.

In this context, stability is defined as follows:

Definition 1 *A GA of size s^* is stable if either,*
(i) $\mathcal{W}_n(s^*) \geq \mathcal{W}_{ns}(s^* - 1)$ and $\mathcal{W}_{ns}(s^*) \geq \mathcal{W}_s(s^* + 1)$ or,
(ii) $\mathcal{W}_n(s^*) \geq \mathcal{W}_{ns}(s^* - 1)$, $\mathcal{W}_{ns}(s^*) < \mathcal{W}_s(s^* + 1)$ and $\mathcal{W}_s(s^*) > \mathcal{W}_s(s^* + 1)$.

Furthermore, we want to point out that there is an important difference between environmental and trade agreements. In environmental agreements, countries can freely enjoy the benefits of a better environment free-riding on others efforts. Also, they can promote environmental quality by reducing their emissions even though they may not belong to an agreement. However, in trade agreements, countries can benefit from free trade only if they are members of the agreement.

Solving analytically for the stability conditions under the two policies, i.e. tariffs and emission taxes, has proven impossible thus far.

6 Numerical analysis

In this section, we demonstrate a numerical analysis to study the model and to provide further intuitions. We are interested in examining the effect of trade on

the stability and effectiveness of environmental agreements. Therefore, we focus on studying whether the formation of a GA can increase participation incentives, decrease global emissions and improve welfare relative to the corresponding outcomes of the basic model of the IEAs' literature.

6.1 The effect of trade on stability for $n = 10$

We use the following baseline parameter values: $n = 10$, $a = 1$, $b = 1$ and $\gamma = 0.045$[7]. Recall that parameter γ measures the impact of environmental damages to benefits due to emissions. In the IEA model, a stable agreement exists, though small, if that impact is low enough[8]. In the present analysis, we set a parameter value such that environmental damages have a more important effect on countries' welfare. Therefore, environmental pollution matters and countries apply strong enough environmental policies (emission taxes) to fight climate change. That is, we limit the range of the values of the parameter γ so that we generate interior equilibrium values for taxes for most coalition sizes. When the coalition size is expanded considerably, the equilibrium taxes of the non-signatories take a corner solution. In the present analysis, given that $n = 10$, $a = 1$ and $b = 1$, equilibrium taxes are mainly positive for $\gamma \geq 0.0415$. For that reason we choose $\gamma = 0.045$. Moreover, working with parameters that in the IEA model generates no stable coalition only strengthens our hypothesis that trade enhances cooperation.

Table 1 presents the production levels, net imports and consumption levels for each signatory and non-signatory country respectively[9]. The production and consumption levels for a signatory are given by the following equations, $e_s^p = e_s^d + (s-1)e_{ss}^X + (n-s)e_{sns}^X$ and $e_s^c = e_s^d + (s-1)e_{ss}^I + (n-s)e_{sns}^I$. On the other hand, the production and consumption levels for a non-signatory are given by the following equations, $e_{ns}^p = e_{ns}^d + (n-s-1)e_{nsns}^X + se_{nss}^X$ and $e_{ns}^c = e_{ns}^d + (n-s-1)e_{nsns}^I + se_{nss}^I$. The net imports for a signatory are equal to $(n-s)(e_{sns}^I - e_{sns}^X)$ while net imports for a non-signatory are equal to $s(e_{nss}^I - e_{nss}^X)$[10].

The analysis shows that trade between signatories and non-signatories takes place only for small coalitions such that $s = 2$ and $s = 3$. In particular, signatories

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[7]Note that $\gamma = 0.045$ fails to satisfy the constraint (69) since $\gamma > 0.0433$. That is, in the IEA model the outcome is the global non-cooperation case, instead of the typical coalition of size 2.

[8]Parameter γ should satisfy the constraint (69).

[9]Values are rounded to four decimal places.

[10]Based on our notation, $e_{ss}^I = e_{ss}^X$ and $e_{nsns}^I = e_{nsns}^X$.

Table 1: Production, consumption and trade activities

s	Signatory Country			Non-signatory Country		
	Production	Net Imports	Consumption	Production	Net Imports	Consumption
1	–	–	–	0.5198	–	0.5198
2	1.3913	−0.7251	0.6661	0.4591	0.1813	0.6404
3	0.6643	−0.0213	0.6430	0.6246	0.0091	0.6337
4	0.5793	–	0.5793	0.6642	–	0.6642
5	0.5007	–	0.5007	0.7043	–	0.7043
6	0.4225	–	0.4225	0.7314	–	0.7314
7	0.3647	–	0.3647	0.6657	–	0.6657
8	0.3094	–	0.3094	0.5726	–	0.5726
9	0.2511	–	0.2511	0.5000	–	0.5000
10	0.1818	–	0.1818	–	–	–

export while non-signatories import. For larger coalitions, net imports are zero (i.e. $e_{sns}^{I} = 0$ and $e_{nss}^{I} = 0$), however, trade still takes place but only among coalition members (i.e. $e_{ss}^{I} > 0$) and among non-members (i.e. $e_{nsns}^{I} > 0$).

Notice that, when members and non-members engage in trade activities, signatories report higher production and consumption levels. That is, the trade effect prevails. The inverse holds when they stop exchanging goods. In that case, signatories, controlled by the environmental policy[11], tend to gradually reduce their polluting activities while non-signatories due to free-riding incentives increase theirs. For coalition with size $s > 6$ we observe a decrease in non-signatories' production and consumption levels. The intuition is as follows: even though non-signatories increase the quantity they produce and consume domestically (i.e. e_{ns}^{d}) the total volume of trade among them gradually decreases since there are less countries outside the agreement.

Figure 2 displays the aggregate emissions, i.e. E (solid line). Additionally, we include in the graph the global emissions (dashed line) of the IEA model under

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[11]Signatories set a tax level that internalizes the full environmental cost of all coalition members. Thus, the larger is the coalition, the higher will be the emission tax.
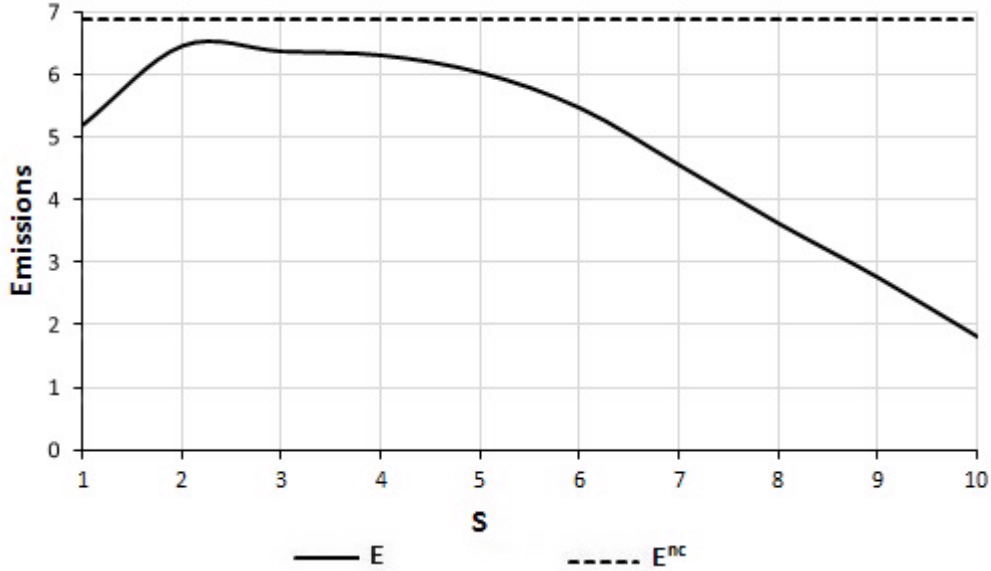
Figure 2

the non-cooperative case i.e. $E^{nc} = 6.8966$ [12]. Note that the dashed line does not denote the level of emissions per coalition, it denotes only the benchmark Nash equilibrium case.

Results show that aggregate emissions decrease as we move to larger coalitions. Clearly, the environmental policy incites signatories to reduce significant their polluting activities. Moreover, as indicated in the graph, aggregate emissions in the GA model are lower than aggregate emissions in the IEA model. That is, the formation of a GA agreement can significantly improve on the basic model of the IEAs' literature in terms of environmental performance, especially when the coalition size increases.

The following Remark summarizes the aforementioned results.

Remark 1 *Regardless of stability, the interaction between trade and environment policies is essential to improve environmental protection.*

The following table, Table 2, presents the total welfare for each signatory country, i.e. $\mathcal{W}_s(s)$, and non-signatory, i.e. $\mathcal{W}_{ns}(s)$, country respectively, for any coali-

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[12] Global emissions in the non-cooperative case are calculated using equations (70).

tion size s[13]. Additionally, we include in the table the global welfare defined by $\mathcal{W}_T = s\mathcal{W}_s + (n-s)\mathcal{W}_{ns}$.

Table 2: Welfare levels

s	W_s	W_{ns}	W_T
1	$-$	-0.2233	-2.2329
2	-0.4270	-0.5188	-5.0046
3	-0.4721	-0.4799	-4.7759
4	-0.4821	-0.4501	-4.6289
5	-0.4414	-0.3605	-4.0096
6	-0.3376	-0.2069	-2.8536
7	-0.1676	-0.0217	-1.2385
8	-0.0334	0.1138	-0.0395
9	0.0482	0.2036	0.6375
10	0.0909	$-$	0.9091

When trade between signatories and non-signatories is present, the former are better off than the latter. Specifically, signatories receive higher welfare than non-signatories for coalitions with size $s = 2$ and $s = 3$. For those coalitions, the trade effect dominates the environmental effect. On the other hand, in the absence of trade, non-signatories become better off. Due to free-riding incentives, they report higher economic (polluting) activities than the coalition members receiving higher welfare. We want to point out that in trade agreements, the welfare of the non-signatories decreases in the size of the coalition (Yi, 1996). Moreover, notice that the expansion of the agreement improves the global welfare. That is, the global welfare is maximized under the grand coalition[14].

Remark 2 *Regardless of stability, the formation of GA improves welfare relative to the basic model of the IEAs' literature.*

Figure 3 depicts countries' welfare and is used to illustrate the effect of trade on stability. The welfare for the signatories, i.e. $\mathcal{W}_s(s)$, is depicted by the solid

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[13]Values are rounded to four decimal places.

[14]In the non-cooperative case of the IEA model, each country receives welfare $\mathcal{W}^{nc} = -0.6183$ (calculated using equation (71)). The global welfare is $\mathcal{W}_T^{nc} = -6.1831$.
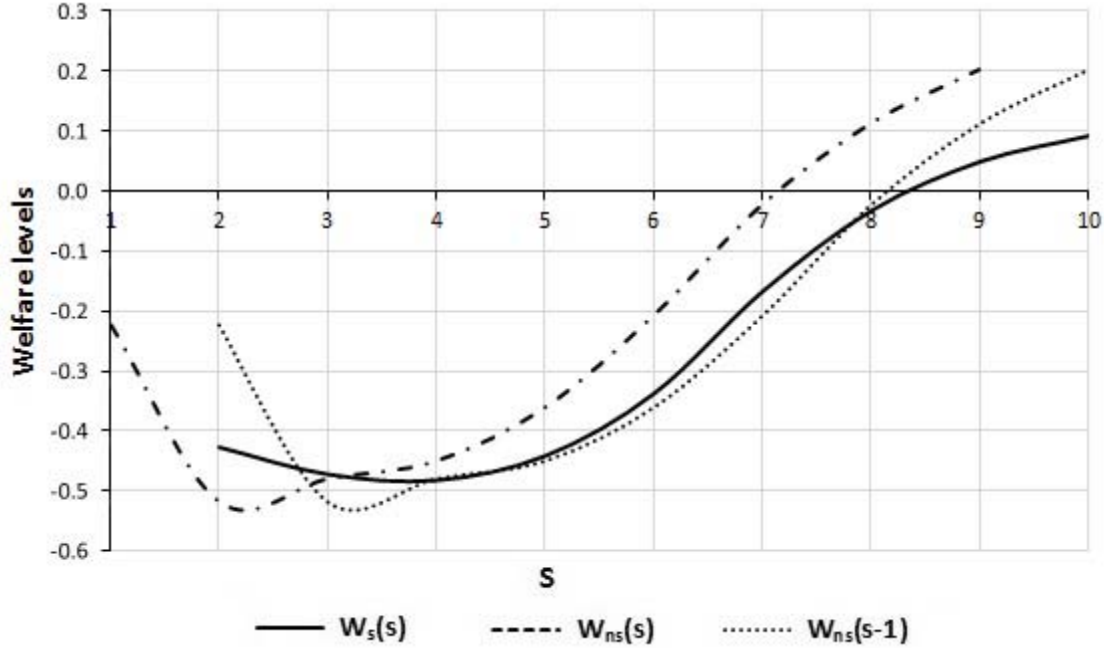
Figure 3

line and the welfare for the non-signatories, i.e. $\mathcal{W}_{ns}(s)$, is depicted by the dot-dashed line. Moreover, the welfare $\mathcal{W}_{ns}(s-1)$ is depicted by the dotted line and represents the welfare for the non-signatories shifted by one. We use such line to represent graphically the internal stability condition as the vertical distance captures $\mathcal{W}_n(s) \lesseqgtr \mathcal{W}_{ns}(s-1)$.

Signatories receive higher welfare than non-signatories when the trade effect prevails (the solid line is above the dot-dashed line), while the inverse holds when the environmental effect prevails (the dot-dashed line is above the solid line). The welfare level of non-members increases in the size of the coalition, that is, starting from the coalition of size two and gradually expanding the agreement makes non-members better off. The welfare level of members increases also in the size of the coalition but only for $s > 4$. As long as the trade affect prevails, the global emission level is still high and as a consequence high environmental damages affect their welfare. For larger coalition ($s > 4$) we observe a significant decrease in global emissions and thus the expansion of the agreement makes members better off.

As indicated in the graph, a stable agreement is achieved at $s^* = 7$. The agreement $s^* = 7$ is stable according to Definition: part (i), meaning that none of its participating countries has an incentive to withdraw (internal stability) and none of the non-participating countries has an incentive to further participate (external stability). That is, at $s^* = 7$, the solid line in above the dotted line (i.e. $\mathcal{W}_s(7) > \mathcal{W}_{ns}(6)$). Thus, internal stability is satisfied. Also, $s^* = 7$ is externally stable (i.e. $\mathcal{W}_{ns}(7) > \mathcal{W}_s(8)$). There exists also a small coalition that is also stable (according to Definition: part (i)) at $s^* = 3$ for the same reasoning as previously mentioned. Note that the coalitions with sizes $s = 5$ and $s = 6$ are not stable because they violate Definition: part (i) and (ii). That is, at those coalitions the internal stability is satisfied, the external stability is violated and also the admissibility condition is violated as well since $\mathcal{W}_s(5) < \mathcal{W}_s(6)$ and $\mathcal{W}_s(6) < \mathcal{W}_s(7)$ respectively. Hence, coalition members become better off by expanding the coalition.

The following Remark summarizes our findings.

Remark 3 *The size of a stable coalition increases when trade policies are included in the formation of an environmental agreement. Emissions are significantly lower and welfare higher at the stable coalition when compared to the corresponding outcomes of the IEA model.*

6.2   The effect of trade on stability for larger n

In order to provide further implications of our study, we present two indicative examples with different parameter values and examine their effect on the derived results. In both cases, we use a graph, similar to the one presented in Figure 3, to illustrate how trade affects the stability of an agreement. We plot the welfare for the signatories $\mathcal{W}_s(s)$ (solid line), the welfare for the non-signatories $\mathcal{W}_{ns}(s)$ (dot-dashed line) and the welfare $\mathcal{W}_{ns}(s-1)$ (dotted line) which represents the welfare for the non-signatories shifted by one.

In the first numerical exercise, Example 1, we set $n = 15$, $a = 1$, $b = 1$ and $\gamma = 0.025$[15]. The welfare levels presented in Figure 4. Trade between signatories and non-signatories takes place for coalitions with size $s = \{2, 3, 4\}$. In particular,

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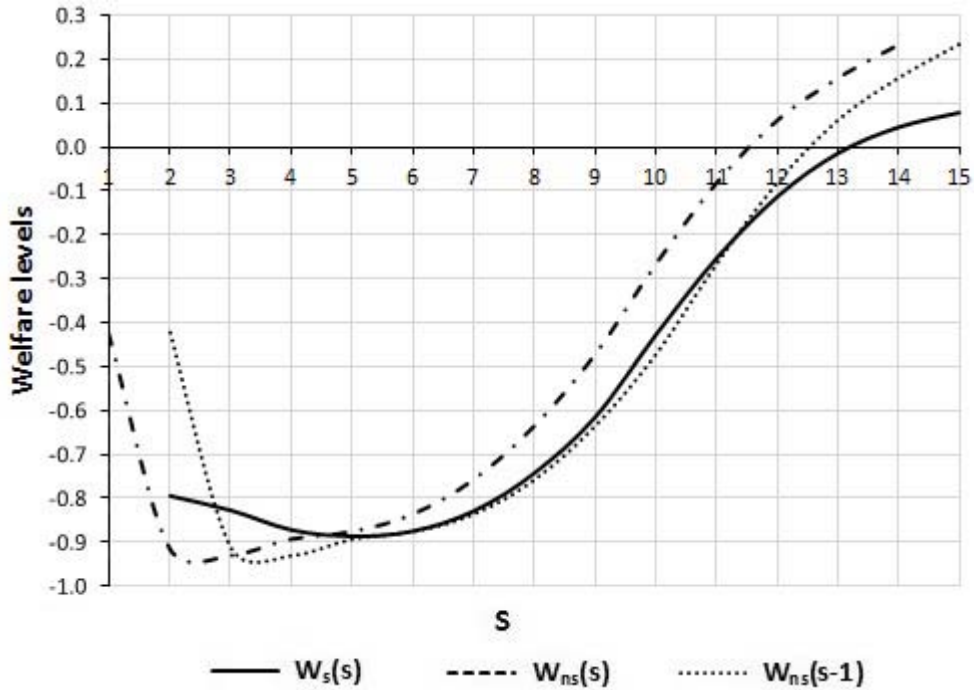[15]Given that $n = 15$, $a = 1$ and $b = 1$, equilibrium taxes are mainly positive for $\gamma \geq 0.0216$.

Figure 4

the former export while the latter import. For those coalitions, members receive higher welfare than non-members (the solid line is above the dot-dashed line). For larger coalitions, such that $s > 4$, non-members become better off. In this example, a stable agreement is achieved at $s^* = 11$ (according to Definition: part (i)). As indicated in the graph, at $s^* = 11$, the solid line in above the dotted line (i.e. $\mathcal{W}_s(11) > \mathcal{W}_{ns}(10)$). Thus, internal stability is satisfied. Moreover, $s^* = 11$ is externally stable (i.e. $\mathcal{W}_{ns}(7) > \mathcal{W}_s(8)$). There exists also a small coalition (according to Definition: part (i)) that is internally and externally stable at $s^* = 5$.

Example 2, presents the case where $n = 20$, $a = 1$, $b = 1$ and $\gamma = 0.015$[16]. Figure 5 illustrates the welfare levels. Signatories and non-signatories engage in trade activities for coalitions with size $s = \{2, 3, 4, 5\}$. In particular, the former export while the latter import. For those coalitions, members receive higher welfare than non-members. For larger coalitions such that $s > 5$, non-members become

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[16]Given that $n = 20$, $a = 1$ and $b = 1$, equilibrium taxes are mainly positive for $\gamma \geq 0.013$.
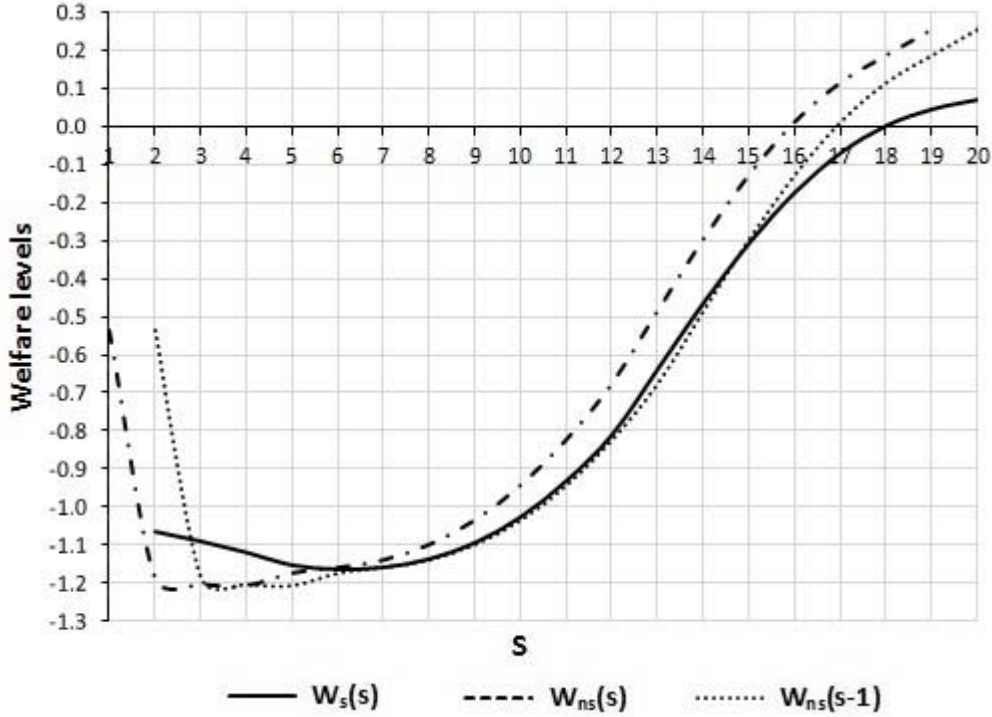
27

Figure 5

better off. In this case, a stable agreement is achieved at $s^* = 14$ (according to Definition: part (i)). There exists also a small coalition (according to Definition: part (i)) that is internally and externally stable at $s^* = 6$.

When we increase the number of countries (i.e. n), setting parameter values (i.e. γ) such that environmental pollution is important for them and so they take the necessary environmental policies to fight climate change[17], we find that the size of a stable agreement increases as well. This result appears to contradict the main conclusion reached in the IEAs' literature stating that in a Cournot-IEA the maximum level of cooperation consists of two members, independently of the number of countries. However, the close to 70% participation seems to be quite robust against changes in n when other parameters are kept same.

To summarize, results illustrate that trade along with environmental policies have an important impact on the stability and the effectiveness of IEAs.

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[17]There are interior equilibrium values for taxes for most coalition sizes.

7 Conclusions

There has been considerable debate on the extent to which trade and environmental problems affect each other. Clearly, trade measures affect countries' production and consumption activities. Therefore, if these activities affect the environmental quality, trade will affect the environment. Similarly, environmental policies aiming to protect countries' environment influence the volume of trade.

The present paper examines the formation and stability of GAs. We extent the basic model of the IEAs' literature by letting homogeneous countries apply policy instruments such as emission taxes and tariffs in order to tackle the climate change problem and control trade. In this framework, countries are either members of a GA or outsiders. Each member (signatory country) has tariff-free access to other members' markets. On the other hand, each non-member (non-signatory country) pays tariffs on its imports to the other countries.

Results are optimistic when the IEA model is extended to incorporate trade. That is, the formation of an environmental agreement can be more successful when environmental policies are linked with trade policies. Countries have stronger incentives to cooperate and take the necessary measures to protect the environment. Thus, we can achieve larger stable agreements that reduce substantially aggregate emissions and improve welfare. Moreover, the analysis illustrates that the size of a stable agreement increases in the number of countries affected by the externalities. The main limitation of our study is that the robustness of the derived results is not clear because analytical complexity requires resorting to numerical calculations.

To sum up, trade measures in IEAs can be an effective tool. Put in other words, the recommendation that stems out of this paper is that countries should not negotiate over environmental issues only. Rather, they should negotiate global agreements over at least two issues. The main concern is that trade policies applied in environmental agreements should be always compatible with the World Trade Organization (WTO) rules and its non-discrimination principle known as "most favoured nation treatment", which requires countries to grant equivalent treatment to the same products imported from any WTO member country (General Agreement on Tariffs and Trade (GATT)).

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9   Appendices

9.1   Appendix A

Recall that, we define parameter γ as the ratio between environmental damages and benefits due to emissions. That is,

$$\gamma = \frac{c}{b}. \tag{53}$$

The reaction function for the equilibrium τ_i (after imposing $\tau_i = \tau_j$ and $t_i = t_j$) is given by,

$$\tau_i = \frac{ab(\gamma n^2 + 3) + (n - 2 - \gamma n^2)t_i}{n + 7 + (n-1)n\gamma}. \tag{54}$$

The reaction function for the equilibrium t_i (after imposing $\tau_i = \tau_j$ and $t_i = t_j$) is given by,

$$t_i = \frac{ab(\gamma n^3 + (n-6)n + 4) - (n-1)(\gamma n^2 + 2n - 9)\tau_i}{(4n-5)n + 2 + \gamma n^3}. \tag{55}$$

9.2 Appendix B

The second order condition for the signatories' welfare maximization problem with respect to τ_s is satisfied,

$$\frac{\partial^2(sW_s)}{\partial^2\tau_s} = -(n-s)s\frac{n + 2 + (2s+3)s + (n-s)s^2\gamma}{(n+1)^2 b} < 0. \tag{56}$$

The second order condition for the signatories' welfare maximization problem with respect to t_s is satisfied,

$$\frac{\partial^2(sW_s)}{\partial^2 t_s} = -s^2\frac{2(n-s+1)n + (n^2\gamma - 1)s}{(n+1)^2 b} < 0. \tag{57}$$

The second order condition for the non-signatories' welfare maximization problem with respect to τ_{ns} is satisfied,

$$\frac{\partial^2 W_{ns}}{\partial^2 \tau_{ns}} = -\frac{(n-2)n + 8s + 1 + (n-1)^2(n-s)\gamma}{(n+1)^2 b} < 0. \tag{58}$$

The second order condition for the non-signatories' welfare maximization problem with respect to t_{ns} is satisfied,

$$\frac{\partial^2 W_s}{\partial^2 t_{ns}} = -(n-s)\frac{n + (2n+1)s + (s+1)(n-s)n\gamma}{(n+1)^2 b} < 0. \tag{59}$$

9.3 Appendix C

The reaction function for the signatories' equilibrium tariff $\tau_s(t_s, \tau_{ns}, t_{ns})$ is given by,

$$\tau_s(t_s, \tau_{ns}, t_{ns}) = \frac{\left(\begin{array}{c} ab(1 + (2 + \gamma n^2)s) - ((n-s)ns\gamma - ((n-2(s+1))s - 1))t_{ns} \\ -((n\gamma - 2)s - 1)st_s - (n-1)(n-s)s\gamma\tau_{ns} \end{array}\right)}{\gamma(n-s)s^2 + (2s+3)s + n + 2}. \tag{60}$$

The reaction function is for the signatories' equilibrium tax $t_s(\tau_s, \tau_{ns}, t_{ns})$ is given by,

$$t_s(\tau_s, \tau_{ns}, t_{ns}) = \frac{\left(\begin{array}{c} abn(n + 1 - (1 + \gamma n^2)s) + (n - s)((\gamma n^2 s + (n - s) + (n - 2s)n)t_{ns} \\ +((n-1)ns\gamma - 2(n+1-2s))\tau_{ns} - ((2 - \gamma n)s + 1)s\tau_s) \end{array} \right)}{(s(2n+1) - 2n(n+1) - n^2 s\gamma)s}.$$

(61)

The reaction function is for the non-signatories' equilibrium tariff $\tau_{ns}(t_{ns}, \tau_s, t_s)$ is given by,

$$\tau_{ns}(t_{ns}, \tau_s, t_s) = \frac{\left(\begin{array}{c} ab((n-1)(\gamma n^2 - 1) + 4s) - (n-s)((n-1)(1+\gamma n) - 4s)t_{ns} \\ -((3n+1-4s) + (n-1)n\gamma)st_s - (n-1)(n-s)s\gamma\tau_s \end{array} \right)}{(n-1)^2((n-s)\gamma + 1) + 8s}.$$

(62)

The reaction function is for the non-signatories' equilibrium tax $t_{ns}(\tau_{ns}, \tau_s, t_s)$ is given by,

$$t_{ns}(\tau_{ns}, \tau_s, t_s) = \frac{\left(\begin{array}{c} abn(s+1)(n(n-s)\gamma - 1) + ((n(n-2s)-s) - (n-s)(s+1)n\gamma)st_s \\ -(n-s)(n-1-4s+(n-1)(n-s)(s+1)\gamma)\tau_{ns} \\ -(s+1)(n-1-2s+(n-s)^2\gamma)s\tau_s \end{array} \right)}{(n-s)((n-s)(s+1)n\gamma + n + (2n+1)s)}.$$

(63)

9.4   Appendix D

The equilibrium levels of the tariffs, τ_s and τ_{ns}, for a signatory and non-signatory country respectively, are the following,

$$\tau_s = \frac{A_\tau}{D} \text{ and } \tau_{ns} = \frac{B_\tau}{D},$$

(64)

where the expression A_τ is given by,

$A_\tau = ab((s+1)n^5 + (-s^2 + 2s + 3)n^4 - (2s^2 + s - 3)n^3 - (s^3 - 4s^2 + 4s - 1)n^2 + 2(-3s^2 + 5s + 1)sn - 3(3s + 1)s^2 + \gamma(sn^7 + (5s + 1)n^6 + (-12s^2 + 3s + 1)n^5 + (12s^3 - 11s^2 + 2s - 1)n^4 + (8s^4 + s^3 - 29s^2 - 4s - 1)n^3 + (-5s^4 + 34s^3 + 53s^2 + 13s + 1)sn^2 - (14s^3 + 22s^2 + 11s + 1)s^2 n + (3s^2 + 4s + 1)s^3))$,

33

the expression B_τ is given by,

$B_\tau = ab(s(2n^4 + (s^2 - s + 6)n^3 + (-s^3 + 6s^2 + 5)n^2 + (-5s^3 + 6s^2 + 6s + 3)n - (6s^2 + 5s + 1)s) + \gamma(n^7 + 2(s^2 + s + 2)n^6 + (-7s^3 - 5s^2 + s + 5)n^5 + (4s^4 + s^3 - 7s^2 - 4s + 2)n^4 + (4s^4 - 2s^3 - 11s^2 - 18s - 8)sn^3 + (-2s^5 + 13s^4 + 37s^3 + 37s^2 + 8s - 1)sn^2 - (5s^3 + 19s^2 + 20s + 4)s^3n + (3s^2 + 4s + 1)s^4))$,

and the expression D is given by,

$D = \gamma(n^7 + (3s^2 + 3s + 4)n^6 + (-5s^3 + 2s + 5)n^5 + (s^4 - 17s^3 - 25s^2 - 13s + 2)n^4 + (8s^4 + 18s^3 + 28s^2 + 11s - 8)sn^3 + (-8s^4 + 23s^3 + 17s^2 + 6s + 12)s^2n^2 + (2s^5 - 26s^4 - 14s^3 - 5s - 1)s^2n + (6s^4 + 2s^3 - s^2 + 1)s^3) + n^6 + 2(s^2 + s + 2)n^5 - (4s^3 + s^2 + 2s - 5)n^4 + 2(s^4 - 2s^3 + 2s^2 - 4s + 1)n^3 + (5s^3 + 20s + 4)sn^2 + 2(-s^4 + 4s^3 + s + 2)sn - 3(2s^3 + s^2 + 1)s^2$.

The equilibrium levels of the taxes, t_s and t_{ns}, for a signatory and non-signatory country respectively, are the following,

$$t_s = \frac{A_t}{D} \text{ and } t_{ns} = \frac{B_t}{D}, \tag{65}$$

where the expression A_t is given by,

$A_t = -ab(n^5 + (s^2 + 1)n^4 + (-3s^2 + 5)sn^3 + (2s^4 - 2s^3 - 7s^2 - 1)n^2 + (2s^4 + 13s^3 + 14s^2 + s - 1)n + 2(-2s^3 + 4s + 1)s + \gamma(n^7 + (s^2 - 4s + 3)n^6 - 2(7s^3 + 5s^2 + 10s + 2)n^5 + (26s^4 + 27s^3 + 60s^2 + 27s - 4)n^4 + (18s^5 + 18s^4 + 97s^3 + 54s^2 - 17s - 3)n^3 + (4s^6 - 10s^5 + 64s^4 + 27s^3 - 35s^2 - 7s + 1)n^2 + (6s^5 - 30s^4 - 2s^3 + 27s^2 + 6s - 1)sn + 2(3s^3 - s^2 - 3s - 1)s^3))$,

and the expression B_t is given by,

$B_t = -ab(n - s)(n^4 + (2s^2 + 3s + 4)n^3 + (-2s^3 + 3s^2 + 3s + 5)n^2 + (-4s^3 - 7s + 2)n - (2s^2 - 7s - 1)s - \gamma(n^5(3s + 1) + 2(3s^3 + 3s^2 + 5s + 2)n^4 - (12s^4 + 16s^3 + 27s^2 + 4s - 5)n^3 + (4s^5 - 3s^4 + 48s^3 + 31s^2 + 2)n^2 + (4s^4 - 20s^3 - 10s^2 - 3s - 1)sn) - (s^2 - 4s - 1)s^2))$.

9.5   Appendix E

For comparison purposes, we present the solutions of the basic model where a Cournot-IEA consisting of two countries is the unique self-enforcing IEA. In particular, we lay out the solutions derived by Rubio and Casino (2001).

Total emissions are given by,

$$E^c = \frac{an}{1 + n\gamma + s(s-1)\gamma}. \tag{66}$$

Signatories receive welfare given by,

$$\mathcal{W}_s^c = \frac{1}{2}a^2b\left(1 - \frac{n^2\gamma}{(1 + n\gamma + s(s-1)\gamma)^2}(s^2\gamma + 1)\right). \tag{67}$$

Non-signatories receive welfare given by,

$$\mathcal{W}_{ns}^c = \frac{1}{2}a^2b\left(1 - \frac{n^2\gamma}{(1 + n\gamma + s(s-1)\gamma)^2}(\gamma + 1)\right). \tag{68}$$

A coalition consisting of two countries is the unique self-enforcing IEA if and only if parameter γ satisfies the following condition,

$$\gamma \leq \frac{1}{n - 4 + 2\sqrt{n^2 - 3n + 3}}. \tag{69}$$

In the non-cooperative case, the basic model gives the following solutions. Total emissions are given by,

$$E^{nc} = \frac{an}{1 + n\gamma}. \tag{70}$$

Countries receive welfare given by,

$$\mathcal{W}^{nc} = \frac{a^2b(1 - (n-2)n\gamma)}{2(1 + n\gamma)^2}. \tag{71}$$

9.6   Appendix F

The following list, presented in Table 3, includes the main variables used in the paper. Note that it is not exhaustive.

Table 3: List of selected notation

Notation	Explanation
e_i^d	Country i's quantity produced and consumed domestically.
e_s^d	Signatory's quantity produced and consumed domestically.
e_{ns}^d	Non-signatory's quantity produced and consumed domestically.
$e_{ij}^I (= e_{ji}^X)$	Quantity country i imports from country j.
$e_{ij}^X (= e_{ji}^I)$	Quantity country i exports to country j.
$e_{ss}^I (= e_{ss}^X)$	Signatory's imports from another signatory country.
$e_{sns}^I (= e_{nss}^X)$	Signatory's imports from a non-signatory country.
$e_{nss}^I (= e_{sns}^X)$	Non-signatory's imports from a signatory country.
$e_{nsns}^I (= e_{nsns}^X)$	Non-signatory's imports from another non-signatory country.
e_i^p	Country i's total production of the nonnumeraire good.
e_s^p	Signatory's total production of the nonnumeraire good.
e_{nc}^p	Non-signatory's total production of the nonnumeraire good.
e_i^c	Country i's total consumption of the nonnumeraire good.
e_s^c	Signatory's total consumption of the nonnumeraire good.
e_{nc}^c	Non-signatory's total consumption of the nonnumeraire good.

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