IEAs
Heterogeneity, Transfers and Issue Linkage

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Presented at the CIRANO–CIREQ Workshop on
International Environmental Agreements – Bridging the Gap

Montreal, Friday, September 21, 2018

1. Introduction

- Some of the most important environmental issues are those related to global pollution.
  - Global warming, acid rain, air and water pollution, waste management, etc.

- Managing environmental issues requires international cooperation.

- International Environmental Agreements (IEAs) have to be designed so that they are self-enforcing.

- Characteristics of international negotiations
  - Absence of an international authority
  - Broad agreement when costs are relatively low
    - Montreal Protocol
  - Difficult to reach agreement when costs are substantial
    - Climate Change

- IEAs suffer from the free-rider problem since abatement effort is a global public good.
  - It is in a country's best interest to forfeit its obligation to reduce emissions so as to minimize costs while enjoying benefits of lower emissions by the other countries

Literature review – symmetric countries

- Cooperative games
  - Adopting a cooperative game-theoretic framework, Chander and Tulkens (1992) and (1997), assert the formation of the grand coalition and the attainment of efficiency

- Non-cooperative myopic games
  - The non-cooperative game theoretic approach, supports the pessimistic view that IEAs will be signed by very few countries and this is independent of whether we adopt a simultaneous a la Cournot model (De Cara and Rotillon 2001; Finus and Rundshagen 2001; Rubio and Casino 2001) or a leadership a la Stackelberg model (Barrett (1994) and Diamantoudi and Sartzetakis (2006))

✓ While the cooperative approach assumes that if one country leaves the coalition the coalition dissolves, the non-cooperative assumes that no other country will follow

- Non-cooperative farshighted games
  - Diamantoudi and Sartzetakis (2015) and (2017) show that larger coalitions, relative to those predicted by the myopic non-cooperative models, can be stable, including the grand coalition. de Zeeuw A. (2008) examines farshightness in a dynamic context.

Literature review – asymmetric countries

- One of the most restrictive and unrealistic assumptions of the above literature is the homogeneity of countries' costs and benefits. In reality, both damages suffered from a global pollutant and benefits derived from emitting the pollutant (related to production and consumption) differ among countries.

- The literature with asymmetric countries (with and without direct monetary transfers) is growing in recent years.
- Barrett (1997) finds no substantial difference in the size of the stable coalition relative to the homogeneous case.
- On the contrary, McGinty (2007), allowing for transfer payments through a permit system among *n* asymmetric nations, finds that asymmetries can increase the coalition size.
- Fuentes-Albero and Rubio (2010) consider asymmetries with respect to either abatement costs or environmental damages.
  - Heterogeneity does not improve cooperation.
    - Transfers: the level of cooperation increases with the degree of asymmetry (different environmental damages).
- Pavlova and Zeeuw (2013) consider asymmetries in both emission benefits and environmental damages.
  - Large stable coalitions are possible if the asymmetries are strong.

Literature review – issue linkage

- An extension of the basic model is to link participation in the IEA to other issues such as trade agreements or R&D agreements.

- The relevant literature of IEAs and trade is surprisingly not so extensive.
  - Barrett (1997) examines IEAs with trade and shows that trade sanctions can support even full cooperation among countries.
  - Folmer et al. (1993) and Folmer and van Mouche (1994) consider both multiple isolated one-shot games and repeated games and show that connecting the environmental and the trade agreement games improves the possibility of cooperation.
  - Carraro and Marchiori (2004) consider two isolated games an environmental agreement game and a trade agreement game and introduce an initial stage at which countries decide whether to link negotiations of the two games and show that countries decide to link the two games only if benefits from large environmental coalitions are substantial.
  - Eichner and Pethig (2015) study IEAs in a free trade economy where countries set carbon taxes and show that the grand coalition is stable (under some conditions).
  - Nordhaus (2015) uses a numerical GE model with exogenous tariff sanctions, to encourage cooperation and shows that trade penalties on non-participants induce a large stable coalition with high levels of abatement.

Contribution of the current work

- Examines the stability of IEAs among heterogeneous countries in a two-stage emission game, with and without monetary transfers.

- Main assumptions:
  - There are two types of countries, differing mainly in environmental damages.
  - All countries make their decisions simultaneously (Cournot model).
  - Quadratic benefit and environmental damage functions of emissions.

- Returning to symmetric countries, examines the effect of forming an agreement that specifies both an environmental tax and a import tariff, on the size of the coalition.

- Emission choice model with heterogeneous countries.
- Two types of countries $j=\{A,B\}$.
- Each country's i [illegible] $N^j = \{1,2,\ldots,n\}$ emissions level is e_i^j
- Benefit function: $B_i^j(e_i^j) = b^j(a^j e_i^j - \frac{1}{2}(e_i^j)^2)$
- Environmental damage function: $D_i^j(E) = \frac{1}{2}c^j E^2 = \frac{1}{2}c^j(\sum_{j,i=1}^{n^j} e_i^j)^2$
- Social welfare function: $W_i^j = b^j(a^j e_i^j - \frac{1}{2}(e_i^j)^2) - \frac{1}{2}c^j(\sum_{j,i=1}^{n^j} e_i^j)^2$
- with: $j = \{A, B\}, i \in N^j = \{1, 2, 3, \ldots, n^j\}$

- We assume that countries make their decisions simultaneously: they play a Cournot game on emissions
- From each group of countries, type $j=\{A, B\}$, a set of countries S [?] N^J signs the agreement, while the rest do not.
- Signatories of type j emit e^j_s
- Non-signatories of type j emit e^j_{ns}
- Therefore, aggregate emissions are:

$$E = s^A e_s^A + s^B e_s^B + (n^A - s^A) e_{ns}^A + (n^B - s^B) e_{ns}^B$$

- Signatory countries behave cooperatively, choosing their emissions level by maximizing their aggregate welfare,

$$\max_{e_s^j} s^A[B_s^A(e_s^A) - D_s^A(E)] + s^B[B_s^B(e_s^B) - D_s^B(E)]$$

- Non-signatory countries act non-cooperatively, choosing their emission level by maximizing their own welfare,

$$\max_{e_{ns}^j} B_{ns}^j(e_{ns}^j) - D_{ns}^j(E)$$

- Signatories

$$e_s^A = a^A - \frac{\gamma^A\left(a^A n^A + a^B n^B\right)\left(s^A + c^{-1}s^B\right)}{\Psi} \qquad e_s^B = a^A - \frac{\gamma^B\left(a^A n^A + a^B n^B\right)\left(cs^A + s^B\right)}{\Psi}$$

- Non-signatories

$$e_{ns}^A = a^A - \frac{\gamma^A\left(a^A n^A + a^B n^B\right)}{\Psi} \qquad e_{ns}^B = a^A - \frac{\gamma^B\left(a^A n^A + a^B n^B\right)}{\Psi}$$

- Aggregate emissions

$$E = \frac{(a^A n^A + a^B n^B)}{\Psi}$$

- Notation: $\gamma^j = \frac{c^j}{b^j}, \quad c = \frac{c^A}{c^B}, \quad b = \frac{b^A}{b^B}$

$$X = 1 + \gamma^A\left(n^A - s^A\right) + \gamma^B\left(n^B - s^B\right)$$

$$\Psi = X + \gamma^A\left(s^A\right)^2 + \gamma^B\left(s^B\right)^2 + \gamma^A\left(b + c^{-1}\right)s^A s^B$$

- Substituting the equilibrium values of the choice variables into the welfare function, we derive the indirect welfare functions of signatories and non-signatories

- Signatories

$$W_s^A = \frac{1}{2} b^A \left[\left(a^A\right)^2 - \frac{\gamma^A \left(a^A n^A + a^B n^B\right)^2 \left(1 + \gamma^A \left(s^A + c^{-1} s^B\right)^2\right)}{\Psi^2} \right]$$

$$W_s^B = \frac{1}{2} b^B \left[\left(a^B\right)^2 - \frac{\gamma^B \left(a^A n^A + a^B n^B\right)^2 \left(1 + \gamma^B \left(c s^A + s^B\right)^2\right)}{\Psi^2} \right]$$

- Non-signatories

$$W_{ns}^A = \frac{1}{2} b^A \left[\left(a^A\right)^2 - \frac{\gamma^A \left(a^A n^A + a^B n^B\right)^2 \left(1 + \gamma^A\right)}{\Psi^2} \right]$$

$$W_{ns}^B = \frac{1}{2} b^B \left[\left(a^B\right)^2 - \frac{\gamma^B \left(a^A n^A + a^B n^B\right)^2 \left(1 + \gamma^B\right)}{\Psi^2} \right]$$

4. First stage: coalition's membership

- In the absence of transfers the internal and external stability conditions are used to determine the size of stable coalitions (s^{A*}, s^{B*})

- Internal stability for type A and B countries respectively:

$$W_s^A(s^{A*}, s^{B*}) \geq W_{ns}^A(s^{A*}-1, s^{B*}) \text{ and } W_s^B(s^{A*}, s^{B*}) \geq W_{ns}^B(s^{A*}, s^{B*}-1)$$

- External stability for type a and B countries respectively:

$$W_s^A(s^{A*}+1, s^{B*}) \leq W_{ns}^A(s^{A*}, s^{B*}) \text{ and } W_s^B(s^{A*}, s^{B*}+1) \leq W_{ns}^B(s^{A*}, s^{B*})$$

- In order to derive analytical results we restrict the asymmetry between the two types of countries in the environmental damage function, that is, we assume $c^A \neq c^B$ while $\alpha^A=\alpha^B=\alpha$ and $b^A=b^B=b^I$.

- For simplicity and without any loss of generality we assume $n^A=n^B=n$. Furthermore, without any loss of generality, we assume that $c>1$, implying that $c^A>c^B$ and since $b=b^A/b^B=1$, we have $\gamma^A>\gamma^B$.

- **Lemma:** For all $s^j \geq 3$, the internal stability condition is not satisfied. That is, when we have two types of countries, no coalition can contain more than two countries of the same type.

- **Proposition 1:** i) The mixed coalition ($s^A=1, s^B=1$) is stable only under minimal asymmetry, that is, when countries are almost identical (c^A very close to c^B).

  ii) When asymmetry increases, the coalition consists only of one type of countries, When the coalition ($s^A=0, s^B=2$) is stable, the coalition ($s^A=2, s^B=0$) is stable as well.

  iii) When the mixed coalition is stable, the other two coalitions, ($s^A=0, s^B=2$) and ($s^A=2, s^B=0$), are stable as well.

Possible Coalitions

- We first prove the Lemma, so that any coalition with $s^j>2$ is not stable.
- Then we proceed by proving that coalitions (1.2), (2,1) and (2,2) are not stable either.
- Finally we prove that (1,1), (0,2) and (2,0) are stable coalitions

		s^B			
s^A		**0**	**1**	**2**	$s^B \geq 3$
	0		(0,1)	(0,2)	$(0, s^B \geq 3)$
	1	(1,0)	(1,1)	(1,2)	$(1, s^B \geq 3)$
	2	(2,0)	(2,1)	(2,2)	$(2, s^B \geq 3)$
	$s^A \geq 3$	$(s^A \geq 3, 0)$	$(s^A \geq 3, 1)$	$(s^A \geq 3, 2)$	$(s^A \geq 3, s^B \geq 3)$

- **Proposition 2:** Assuming heterogeneous countries, a stable agreement where $s^{j*}>1$ for some $j=\{A,B\}$ may not exist, unlike the case of homogeneous countries.

- We prove the above proposition by offering a counterexample, where we prove that introducing heterogeneity drives the coalition to the trivial one, of one country.

5b. Asymmetric countries with transfers

- We incorporate into the model the possibility of welfare transfers T_i^j, which can be either positive, i.e. $T_i^j > 0$, when a country i of type j receives a payment, or negative, i.e. $T_i^j < 0$, when a country i of type j submits a payment, with $\sum T_i^j = 0$.

- Stability conditions with transfers:
- Internal

$$W_s^A(s^A, s^B) + T_s^A(s^A, s^B) \geq W_{ns}^A(s^A - 1, s^B)$$
$$W_s^B(s^A, s^B) + T_s^B(s^A, s^B) \geq W_{ns}^B(s^A, s^B - 1)$$

- External

$$W_s^A(s^A + 1, s^B) + T_s^A(s^A + 1, s^B) \leq W_{ns}^A(s^A, s^B)$$
$$W_s^B(s^A, s^B + 1) + T_s^B(s^A, s^B + 1) \leq W_{ns}^B(s^A, s^B)$$

- To explore the scope of cooperation when countries use transfers, we apply the Potentially Internally Stability (PIS) condition.

$$PIS(s^A, s^B) = s^A\left[W_s^A(s^A, s^B) - W_{ns}^A(s^A - 1, s^B)\right] + s^B\left[W_s^B(s^A, s^B) - W_{ns}^B(s^A, s^B - 1)\right]$$

- Substituting the values of the indirect welfare functions, we derive the PIS condition as function of the models parameters

- We restrict the heterogeneity between the two types of countries in the environmental damage function, that is, we assume $c^A \neq c^B$ while $a^A = a^B = a$ and $b^A = b^B = b^I$.
- For simplicity and without any loss of generality we assume $n^A = n^B = n$.
- Furthermore, without any loss of generality, we assume that $c > 1$, implying that $c^A > c^B$ and since $b = b^A / b^B = 1$, we have $\gamma^A > \gamma^B$.

- Therefore, in this context, type *A* countries have a steeper marginal environmental damage function compared to type *B* countries, i.e. type *A* countries have higher marginal environmental damages. Hence, the former are more sensitive to environmental pollution.

- It is not possible to derive analytical results when transfers are introduced and thus, we resort to simulations.

- We get the following results:

Remark. Allowing for transfers among heterogeneous countries increases cooperation. However, the increase in the coalition size does not come from countries belonging to the type suffering the higher damages (type *A*), but only from countries of type *B*, drawn into the coalition by the transfers offered.

Corollary. A higher degree of heterogeneity is required in order to achieve larger stable agreements. The rate of the required increase in heterogeneity is higher if there are two relative to only one type-*A* signatories.

- Results of simulations

		Agreement $(1, n)$				Agreement $(2, n)$		
n		γ^A	$max\ \gamma^B$	γ		γ^A	$max\ \gamma^B$	γ
3		0.9999	0.0375	26.62		0.01989	$4.85 * 10^{-4}$	40.97
4		0.4557	0.0133	34.13		0.01093	$1.51 * 10^{-4}$	72.32
5		0.2719	0.0070	38.53		0.00679	$6.19 * 10^{-5}$	109.65
6		0.1978	0.0044	44.85		0.00473	$2.99 * 10^{-5}$	157.98
7		0.1468	0.0030	48.53		0.00341	$1.62 * 10^{-5}$	209.84
8		0.1218	0.0022	55.24		0.00263	$9.58 * 10^{-6}$	275.38
9		0.1071	0.0017	63.92		0.00208	$6.01 * 10^{-6}$	347.24
10		0.0920	0.0013	69.65		0.00183	$3.95 * 10^{-6}$	463.15

The table summarizes all possible stable coalitions that can be achieved for $n \in \{3,4,\ldots,10\}$ and $s^A \in \{1,2\}$.

A larger coalition requires stricter constraints for the parameters of the model, i.e. γ^A *and* γ^B.

$\gamma = \gamma^A / \gamma^B$

We can demonstrate the fact that larger coalitions are stable only when the degree of heterogeneity increases, by choosing a specific value for the parameter γ^A=0.0015 and calculate the required degree of heterogeneity to support different sizes of stable agreement.

		Agreement $(1, n)$	Agreement $(2, n)$
		$\gamma^A = 0.0015$	
n		γ	γ
3		4.31	19.14
4		6.85	35.46
5		9.36	58.16
6		11.87	88.97
7		14.36	130.66
8		16.89	187.25
9		19.40	266.40
10		21.93	381.47

Remark. With transfers, large stable agreements emit less. However, the reduction in aggregate emissions achieved by the enlarged agreements is very small relative to the case without transfers.

The Table presents the global emission levels for the agreements (s^A, s^B) where $s^A \in \{1,2\}$ and $n \in \{10,20,\ldots,100\}$.
We fix the values for the parameters a, γ^A and γ^B such that $a=1$, $\gamma^A = 1.50 * 10^{-5}$ and $\gamma^B = 4.10 * 10^{-10}$.

	Transfers		No Transfers
	Agreement $(1, n)$	Agreement $(2, n)$	Agreement $(2, 0)$
n	E	E	E
10	19.994	19.990	19.996
20	39.976	39.963	39.987
30	59.946	59.917	59.971
40	79.904	79.854	79.950
50	99.850	99.772	99.922
60	119.784	119.673	119.889
70	139.706	139.556	139.849
80	159.616	159.421	159.803
90	179.515	179.268	179.752
100	199.401	199.097	199.694

6. IEAs and trade (symmetric countries)

- We assume open economy, where countries trade with each other a good *e*, that generates pollution at a constant one to one ratio, and pollution is global.

- There are n identical countries, $N=\{1,2,\ldots,n\}$, $n>3$

- The representative consumer's utility in country $i \in N$ is:

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

where e_i^c is total consumption (of the polluting good) in country *i* and K_i is a numeraire good.

- Total consumption in country *i* is:

$$e_i^c = e_i^d + \sum_{j \neq i} e_{ij}^I$$

where e_i^d is the domestically produced part of local consumption and e_{ij}^I is the amount country *i* imports from country *j*.

- Total production in country *i* is:

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

where e_i^d is the domestically produced part of local consumption and e_{ij}^X is the amount country *i* exports to country *j*.

- We assume constant cost of production, common for all countries, which for simplicity we drop to zero

- The damage function for country *i* is,

$$D_i(E) = \tfrac{1}{2} cE^2$$

- Where *E* denotes global emissions, given by,

$$E = \sum_{i=1}^{n} e_i^p$$

- Country i charges a non-negative tariff τ_i per unit of import from any country $j \neq i$.

- The environmental policy in country i is a carbon tax t_i imposed on emissions by the domestic firm due to its production.

- The Timing of the Game
- Three-stage emission game.
  - First stage: Each country decides whether or not to join the agreement.
  - Second stage: Countries choose simultaneously - cooperatively or non-cooperatively - tariff and tax levels.
  - Third stage: Taking countries' decisions as given, firms compete a la Cournot in the product markets.

- We solve the game backwards, starting from firms' profit maximization problem,

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

  from which we derive quantity of outputs (domestic production, consumption, imports and exports for signatory (*s*) and nonsignatory countries).

- Substituting optimal quantities into the welfare functions, we then move to the second stage, in which countries maximize their welfare (aggregate for the coalition members and own for nonsignatories),

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

$$\max_{t_s,\tau_s} sW_s = \frac{1}{2}b\left(e_{ns}^c\right)^2 + p_{ns}\left(e_{ns}^c\right)e_{ns}^d + (n-s-1)p_{ns}\left(e_{ns}^c\right)e_{nsns}^X + s\left(p_s\left(e_s^c\right)-\tau_s\right)e_{nsns}^X + s\tau_{ns}e_{nss}^I - \frac{1}{2}cE^2$$

  from which we derive optimal tax and tariff levels.

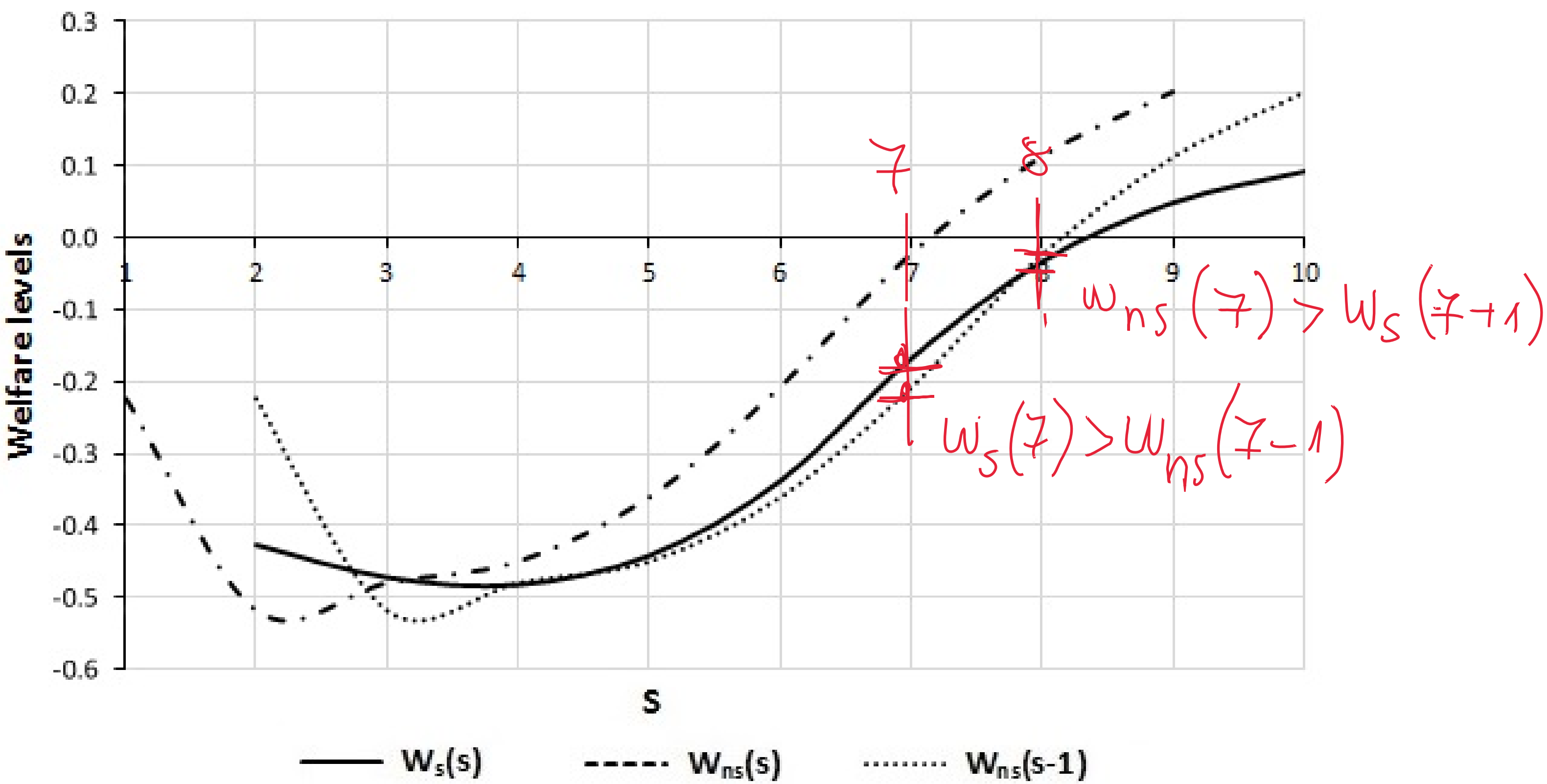
- To define the stable size of the coalition we use the stability conditions,

$$w_s(s^*) \geq w_{ns}(s^*-1) \text{ and } w_{ns}(s^*) \geq w_s(s^*+1)$$

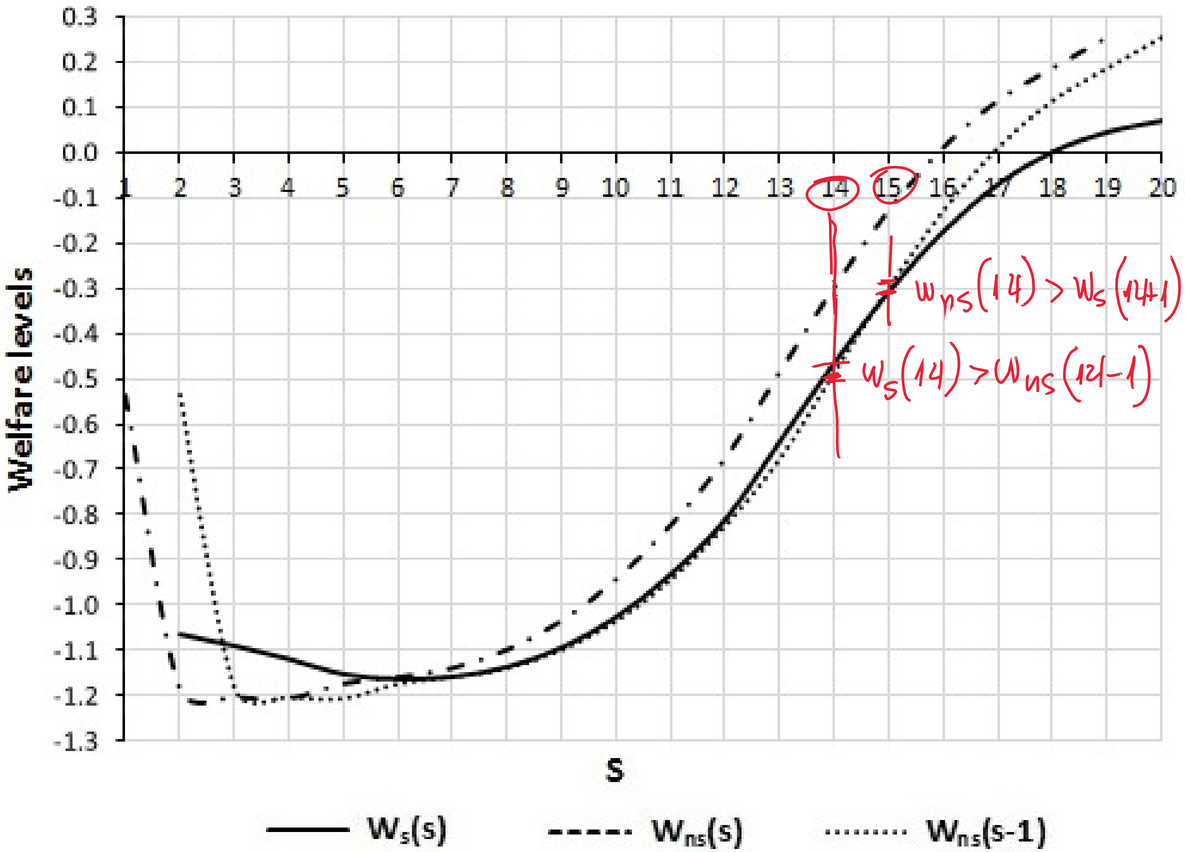
or, $w_s(s^*) \geq w_{ns}(s^*-1)$, $w_{ns}(s^*) < w_s(s^*+1)$ and $\underbrace{w_s(s^*) > w_s(s^*+1)}_{\text{Admissibility condition}}$

- That is, even if external stability is violated and non-signatories wish to join, signatories oppose to the enlargement.
- The admissibility condition ensures that existing members will admit a new member only if they become better off by expanding the coalition.
- Solving analytically for the stability conditions under the two policies, i.e. tariffs and emission taxes, has proven impossible thus far. Thus, we resort to numerical analysis.

- Stable Agreements for n=10
  - Trade between signatories and non-signatories takes place for coalitions $s=\{2,3\}$.
  - Signatories export while non-signatories import.
  - A stable agreement is achieved at $s^*=7$, according to Definition, part (i).
  - There exists also a small coalition at $s^*=3$, according to Definition, part (i).
  - The coalitions with sizes $s=4$, 5 and $s=6$ are not stable



- Stable Agreements for n=20
  - Trade between signatories and non-signatories takes place for coalitions *s={2,3,4,5}*
  - Signatories export while non-signatories import
  - A stable agreement is achieved at $s^*=14$, according to Definition, part (i)
  - There exists also a small coalition at $s^*=6$, according to Definition, part (i)



IEAs and trade

- Results:

Regardless of stability, the formation of an agreement improves welfare relative to the basic model of the IEAs' literature.

The size of a stable coalition increases when trade policies are included in the formation of an environmental agreement. The analysis also illustrates that emissions are significantly lower and welfare higher at the stable coalition\ when compared to the corresponding outcomes of the IEA model.

7. Conclusions

- Introducing heterogeneity in environmental damages does not increase the size of the coalition. On the contrary, if heterogeneity is strong enough, a smaller stable coalition results relative to the homogeneous case.
- Introducing asymmetry into a stable under symmetry agreement can disturb stability.
- Moreover, when stable coalitions exist their size is small and, when the asymmetry is strong enough, they cannot include both types of countries.

- We find that transfers can increase the size of the coalition, but only by increasing the number of signatories from the type of countries that suffer less damages.
- These countries are drawn into the coalition by the transfers offered, but their contribution in emission reductions is minimal. Overall the emission reduction, and thus the welfare improvement, is very small through the use of transfers

- Results when linked to trade agreements, are optimistic
- The formation of an environmental agreement can be more successful when environmental policies are linked with trade policies.
- Stable agreements are larger and more effective in reducing global emissions and improving welfare.
- Moreover, findings show that the size of a stable agreement increases in the number of countries affected by the externalities.