Self-enforcing environmental agreements and international trade

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Motivation

- Carbon emissions generate global climate damage

- Restoring efficiency requires **global** cooperation

  However: *Global* cooperation is unlikely to come soon

- Therefore: Focus on sub-global climate cooperation/coalitions:

  One group of countries (*"climate coalition"*) takes joint action

  All other countries (*"fringe countries"*) act non-cooperatively

Motivation

- A coalition of sovereign countries cannot prevail unless it is stable (or *self-enforcing*) (Barrett 1994)

- A coalition is ***stable***
  (or, equivalently, an international environmental agreement is ***self-enforcing***)

  if no non-member has an incentive to join (external stability)
  and no member has an incentive to defect (internal stability)

- **Objective**: Study determinants of existence, of width and depth of stable climate coalitions

Literature on formation of climate coalitions

- ***Basic model*** of coalition literature consists of identical countries

  Welfare of country *i*:

$$\underbrace{u_i}_{\substack{\text{Total welfare}\\ \text{of country } i}} = \underbrace{V\left(e_i\right)}_{\substack{\text{Welfare from fossil}\\ \text{energy consumption}\\ (V'>0,\ V''<0)}} - D\underbrace{\left(\sum_{j=1}^{j=n} e_j\right)}_{\substack{\text{Climate damage from}\\ \text{world carbon emissions}\\ (D'>0,\ D''>0)}}$$

$$\left\{ \begin{array}{l} e_i = \text{fossil energy consumption} \\ \quad = \text{carbon emissions} \end{array} \right.$$

- Governments fix domestic emissions (= emissions caps)

- No modeling of the economies of individual countries

- No international trade

Literature on coalition formation

- In the basic model of the literature,

  either: Fringe countries and the coalition play **Nash**

  or: Coalition is **Stackelberg** leader and all fringe countries follow

- In our paper: Exclusive focus on Stackelberg approach

- Outcome of Stackelberg approach in the *basic model*:

  Stable coalition consists of at most **4** countries
  if negative emissions are excluded

  (Barrett 1994, Diamantoudi & Sartzetakis 2006, Rubio & Ulph 2006)

Objective of our paper

- **Model** the countries' economies (production, consumption, markets)
- **Allow for** international trade
- **Investigate** the impact of that extension
  on width, depth and stability of coalitions
- **Compare** the results with those of the *basic model*

Preview on main conclusions

- *Good news*: With international trade,
  stable coalitions *may* be much wider than in the *basic model*

- *Bad news I*: With international trade,
  stable coalitions are not deep regardless of how wide they are

- *Bad news II*: In autarky,
  stable coalitions are neither wide nor deep

Outline of presentation

1 The problem (done)

2 The model

3 Climate coalition as Stackelberg leader

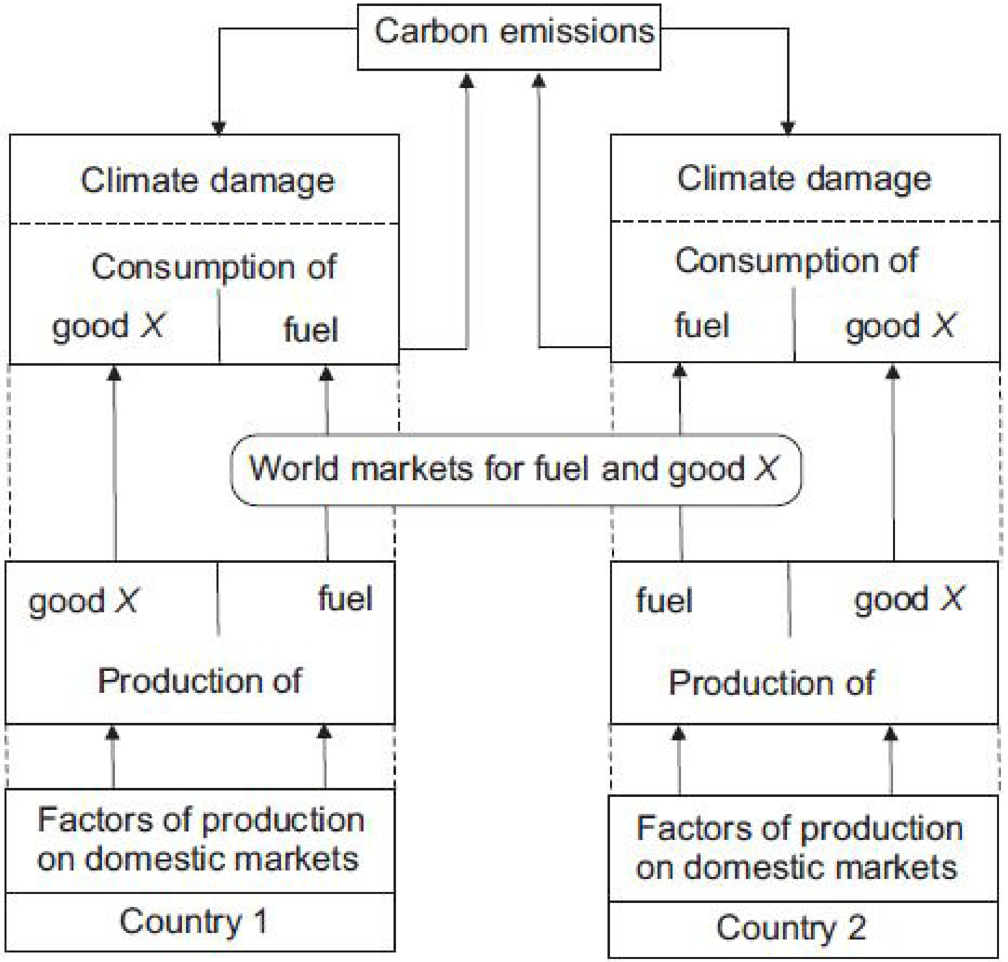
 3.1 Climate coalitions and coalition sizes

 3.2 *Stability of coalitions*

4 On the role of international trade

5 Extensions (work in progress)

The model



Carbon emissions
Climate damage
Consumption of
good X
fuel
Climate damage
Consumption of
fuel
good X
World markets for fuel and good X
good X
fuel
Production of
fuel
good X
Production of
Factors of production
on domestic markets
Country 1
Factors of production
on domestic markets
Country 2

The model

$x_i^s = T\left(e_i^s\right), \quad i = 1, \ldots, n$	Production possibility frontier	(1)
$u_i = V\left(e_i^d\right) + x_i^d - D\left(\sum_j e_j^d\right)$	Utility of representative consumer	(2)
$\sum_j x_j^s = \sum_j x_j^d \quad \text{and} \quad \sum_j e_j^s = \sum_j e_j^d$	World market equilibria for consumer goods and fuel	(3)
$e_i^d = e_i, \quad i = 1, \ldots, n$	Cap e_i on domestic fuel demand (= emissions)	(4)

Parametric version of the functions *T*, *V* and *D*:

$$T\left(e_i^s\right) = \overline{x} - \tfrac{\alpha}{2}\left(e_i^s\right)^2, \qquad V\left(e_i^d\right) = ae_i^d - \tfrac{b}{2}\left(e_i^d\right)^2, \qquad D\left(\sum_j e_j^d\right) = \tfrac{1}{2}\left(\sum_j e_j^d\right)^2$$

The model

- For every given set of binding emissions caps, $(e_1,...,e_n)$, there exists a unique general competitive equilibrium

- In equilibrium, the welfare of an individual country is (shown to be)

$$W^i(e_1,...e_i,...,e_n) := V(e_i) + \underbrace{T\left(\frac{\sum_j e_j}{n}\right) - T'\left(\frac{\sum_j e_j}{n}\right) \cdot \left(\frac{\sum_j e_j}{n} - e_i\right)}_{\textit{Interdependence through international trade}} - \underbrace{D\left(\sum_j e_j\right)}_{\substack{\textit{Interdependence} \\ \textit{through climate} \\ \textit{externality}}}$$

Absence of cooperation (BAU) as a benchmark

- **Standard *n*-country Nash game**

  Country i solves: $\max_{e_i} W^i(e_1,\dots,e_i,\dots,e_n)$ for given $(e_1,\dots,e_{i-1},e_{i+1},\dots,e_n)$

- **Results:** Uniform emission caps: $e_i = e_o$ for all i

  Emission caps too large (i.e. too little mitigation)

  No trade

Climate coalition and fringe

- Two groups of countries: $C := \{1, 2, ..., m\}$ with ***C*** for ***<u>C</u>oalition***
  $F := \{m+1, ..., n\}$ with ***F*** for ***<u>F</u>ringe***
  $m \in \{1, 2, ..., n\}$ = exogenous coalition size

- **Coalition:** *Payoff* $= \sum_{j \in C} W^j$
  Strategy $= s_c := m e_c$ (with $e_i = e_c$ for all $i \in C$)

- **Fringe countries**: *Payoff* $= W^i$ (same as in BAU)
  Strategy $= e_f$ (with $e_i = e_f$ for all $i \in F$)

Fringe countries as Nash players

- Fringe behavior: Each fringe country plays Nash against the coalition and against all fellow fringe countries

- The reaction function of an individual fringe country can be converted into an ‘aggregate reaction function’ R such that

  $s_f = R(s_c, m)$ with $s_f := (n-m)e_f$, $s_c := me_c$ and with slope $R_{s_c} \in \left]-1, 0\right[$

  R looks like a reaction function for the entire group of fringe countries

  But important: All fringe countries continue acting non-cooperatively!

Welfare functions of *individual* countries

- **Fringe countries**

$$W^f\left(s_c, s_f, m\right) := V\left(\frac{s_f}{n-m}\right) + T\left(\frac{s_c + s_f}{n}\right) - T'\left(\frac{s_c + s_f}{n}\right) \cdot \left(\frac{s_c + s_f}{n} - \frac{s_f}{n-m}\right) - D\left(s_c + s_f\right)$$

- **Coalition countries**

$$W^c\left(s_c, s_f, m\right) := V\left(\frac{s_c}{m}\right) + T\left(\frac{s_c + s_f}{n}\right) - T'\left(\frac{s_c + s_f}{n}\right) \cdot \left(\frac{s_c + s_f}{n} - \frac{s_c}{m}\right) - D\left(s_c + s_f\right)$$

- Recall: Every tuple $\left(s_c, s_f\right)$ maps into a competitive general equilibrium

Stackelberg equilibrium

- Coalition of given size m chooses its strategy s_c first
  Fringe responds with the 'aggregate strategy' $s_f = R(s_c, m)$

- **Stackelberg equilibrium =** pair of strategies $\left(s_c^*, s_f^*\right)$
  such that $s_c^* = \arg\max_{s_c} mW^c\left[s_c, R\left(s_c, m\right), m\right]$ and $s_f^* = R(s_c^*, m)$

- There is a unique Stackelberg equilibrium for every given coalition size m

Welfare of coalition country in Stackelberg equilibrium

- Stackelberg equilibrium = pair of strategies $\left(s_c^*, s_f^*\right)$

- Equilibrium welfare:

$$W^c\left(s_c^*, s_f^*, m\right) := V\left(\frac{s_c^*}{m}\right) + T\left(\frac{s_c^* + s_f^*}{n}\right) - T'\left(\frac{s_c^* + s_f^*}{n}\right) \cdot \left(\frac{s_c^* + s_f^*}{n} - \frac{s_c^*}{m}\right) - D\left(s_c^* + s_f^*\right)$$

Stackelberg equilibria for alternative (given) coalition sizes

- Formalization:

$$e_c^* = \mathcal{E}^c(m); \quad e_f^* = \mathcal{E}^f(m); \quad s_c^* = m\,\mathcal{E}^c(m); \quad s_f^* = (n\text{-}m)\,\mathcal{E}^f(m)$$

$$\mathcal{W}^c(m) := \mathcal{W}^j\left[m\mathcal{E}^c(m), (n\text{-}m)\mathcal{E}^f(m), m\right] \quad \text{for } j \in C$$

$$\mathcal{W}^f(m) := \mathcal{W}^j\left[m\mathcal{E}^c(m), (n\text{-}m)\mathcal{E}^f(m), m\right] \quad \text{for } j \in F$$

$\mathcal{E}^c(m), \mathcal{W}^c(m)$ etc. are the values of e_c, w_c etc. in the Stackelberg equilibrium with coalition of size $m \in [1, n]$

Coincidence of Stackelberg equilibrium and BAU

- **Result:**

  The Stackelberg equilibrium with coalition of size $m \in [1, n]$ *coincides with the BAU equilibrium, if and only if* $m = \tilde{m} := \dfrac{(\alpha + b + n) n^2}{\alpha(2n-1) + (1+b) n^2} > 1$

Remark:

For analytical convenience we take the interval $[1, n]$ to be the domain of coalition sizes

Comparison of Stackelberg equilibria with BAU equilibrium

Analytical results:

Consider the transition from BAU to Stackelberg equilibrium.

(i) $\mathcal{E}^c(m) \gtreqless e_o \Leftrightarrow m \lesseqgtr \tilde{m},$

(ii) $[m\mathcal{E}^c(m) + (n - m)\,\mathcal{E}^f(m)] \gtreqless ne_o \Leftrightarrow m \lesseqgtr \tilde{m},$

(iii) $\begin{Bmatrix} \mathcal{W}^c(m) > W_o > \mathcal{W}^f(m) \\ \mathcal{W}^c(m) = W_o = \mathcal{W}^f(m) \\ \mathcal{W}^f(m) > \mathcal{W}^c(m) > W_o \end{Bmatrix} \Leftrightarrow m \begin{Bmatrix} < \\ - \\ > \end{Bmatrix} \tilde{m}$

Numerical results: Example 1 $(n = 10; \tilde{m} = 4.881)$

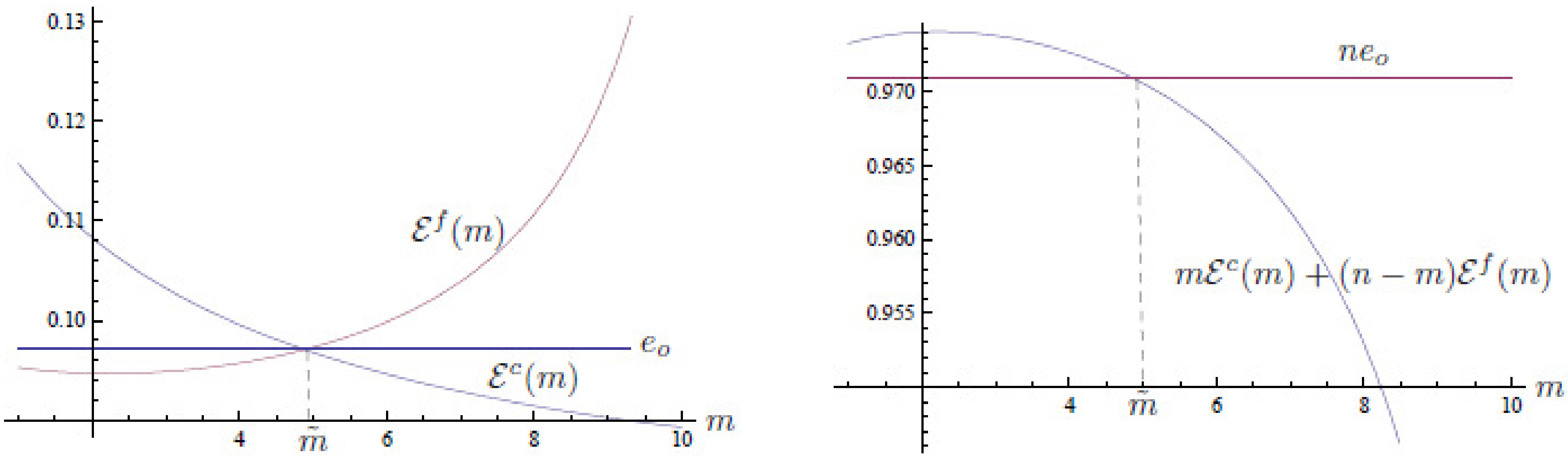


Figure 3: Emissions caps and total emissions in Example 1

Numerical results: Example 1 $(n = 10; \tilde{m} = 4.881)$

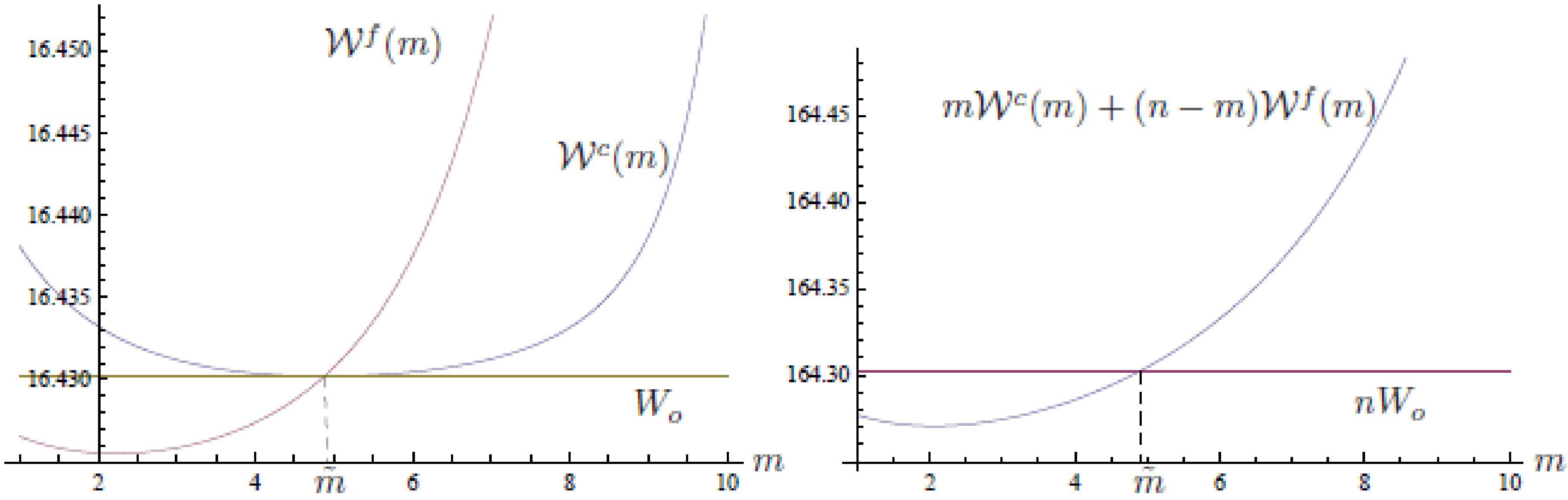


Figure 4: Welfare and aggregate welfare in Example 1

Stability of coalitions

- *Definition:* The coalition of size $m \in \{2,...n\}$ is stable, if

  $[w^c(m) - w^f(m-1)] \geq 0$ (internal stability condition)

  and $[w^f(m) - w^c(m+1)] \geq 0$ (external stability condition)

- **Question:** Do stable coalitions exist ?

Checking Example 1 for stable coalition $(n = 10; \tilde{m} = 4.881; m^* = 5)$

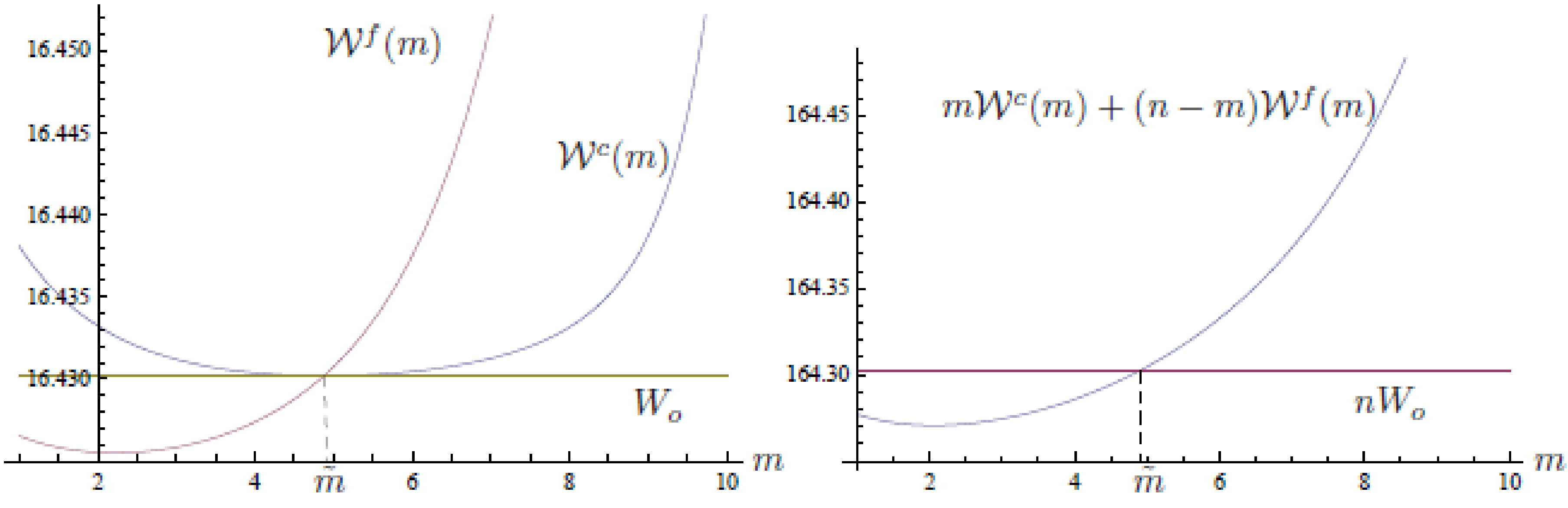
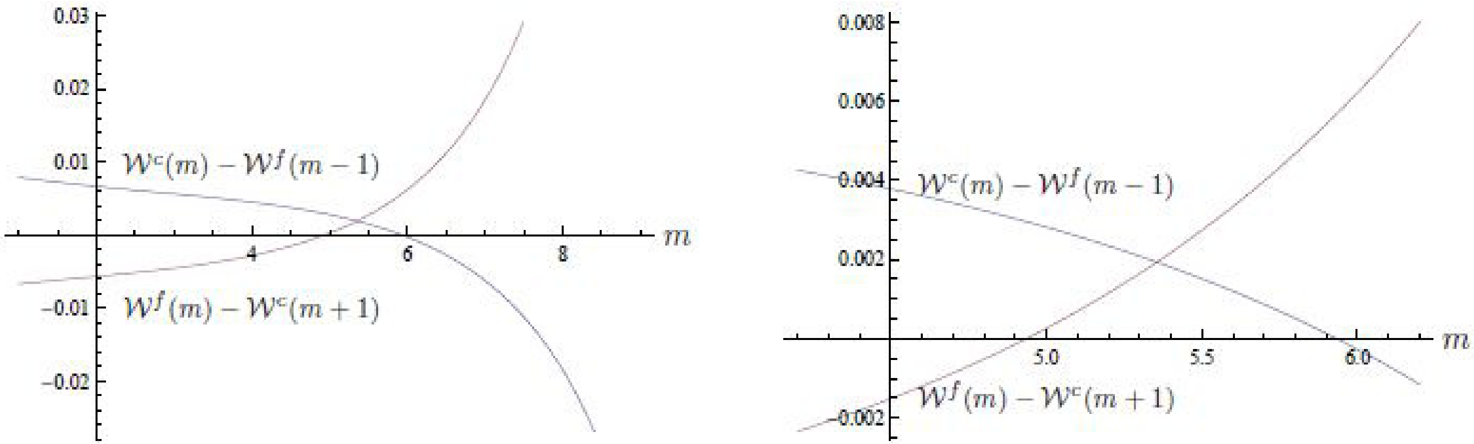


Figure 4: Welfare and aggregate welfare in Example 1

- **Result**: If the coalition of size m^* is stable, then $m^* \geq \tilde{m}$ (= necessary condition for stability)

Checking Example 1 for stable coalition $(n=10; \tilde{m}=4.881; m^*=5)$



- **Question:** Do stable coalitions exist with size $m^* \geq \tilde{m}$?
  Answer: Yes, in all of our numerous examples

A coalition of size $m^* \in \mathbb{N}$ is stable iff both curves are positive at $m=m^*$
Both curves have positive values in a small interval only (see Figure)
The only integer in that interval is $m^* = 5 > \tilde{m} = 4.881$
Example 1: Share of countries in stable coalition = 50% !

Checking Example 1 for stable coalition ($n = 10; \tilde{m} = 4.881; m^* = 5$)

- **Question**: How much larger than $\tilde{m}$ is the stable coalition size m^*?

  Answer: m^* is the smallest or second smallest integer larger than $\tilde{m}$ (in all of our numerous examples)

Intuition: Why is m^* so close to $\tilde{m}$?

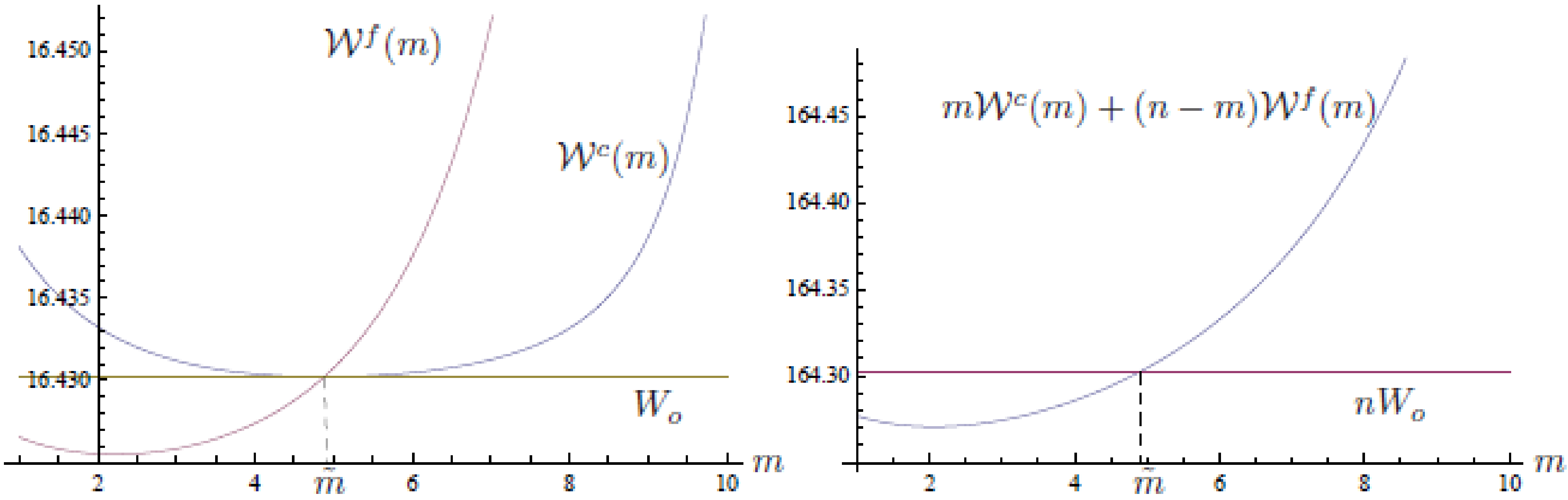


Figure 4: Welfare and aggregate welfare in Example 1

Role of parameter α for coalition stability

- **Question**: What are the determinants of the size of $\tilde{m}$?

  Answer: Essentially, the size of $\tilde{m}$ depends on the parameter α

  Under mild restrictions: $\frac{d\tilde{m}}{d\alpha} > 0$ and $\lim_{\alpha\to\infty} \tilde{m} = \frac{n^2}{2n-1} \approx \frac{n}{2} + \varepsilon$

- Variation of α while all other parameters are as in Example 1

Example 1 ⇓

α	1	10	50	100	500	1000	∞
$\tilde{m}$	1.46	1.75	2.62	3.25	4.57	4.88	5.26
m^*	2	2	3	4	5	5	6

Role of parameter α for coalition stability

Interpretation:

- α is the parameter in the transformation function $T\left(e_i^s\right) = \overline{x} - \frac{\alpha}{2}\left(e_i^s\right)^2$

- Increasing α corresponds to rising marginal extraction costs of fossil fuel

  $\Rightarrow$ The more progressive extraction costs are,

  - the larger the stable coalition,
  - the smaller total equilibrium emissions,
  - the smaller the potential gain from cooperation.

Messages from Example 1 (and from ***all*** of our numerical examples)

- **Good news**: For any size of n the share of countries in stable coalition *may* be up to 40% - 50%

  $\Rightarrow$ Stark contrast to the basic model
  (Rubio et al. (2006) and Diamantoudi et al. (2006))

- **Bad news:** m^* is the smallest (or second smallest) integer larger than $\tilde{m}$

  $\Rightarrow$ Stable coalition *does* reduce total emissions compared to BAU
  But by a very small amount only …

On the role of international trade

- Comparison of the scenarios of free trade and autarky

- We switch from free trade to autarky by

  replacing the world-market clearing conditions

  $\sum_j x_j^s = \sum_j x_j^d$ and $\sum_j e_j^s = \sum_j e_j^d$

  with the domestic-market clearing conditions

  $x_i^s = x_i^d$ and $e_i^s = e_i^d$ for $i = 1, \ldots, n$ (prices $p_{xi} \equiv 1, p_{ei}, \pi_i$)

Country *i*'s welfare with and without international trade

- Recall: Welfare in case of **free trade**:

$$W^{ti}(e_1,\dots,e_n) := V(e_i) + \underbrace{T\left(\frac{\sum_j e_j}{n}\right) - T'\left(\frac{\sum_j e_j}{n}\right)\cdot\left(\frac{\sum_j e_j}{n} - e_i\right)}_{\textit{Interdependence through international trade}} - \underbrace{D\left(\sum_j e_j\right)}_{\textit{Interdependence through climate externality}}$$

- Welfare in case of **autarky**:

$$W^{ai}(e_1,\dots,e_n) := V(e_i) + T(e_i) - D\left(\sum_j e_j\right) = \underbrace{a e_i - \tfrac{\alpha+b}{2} e_i^2 - \overline{x} - \tfrac{1}{2}\left(\sum_j e_j\right)^2}_{\textit{Parametric version of autarky welfare}}$$

$\Rightarrow$ **The functional form of welfare in autarky is exactly the same as in the *basic model* of the coalition formation literature**

On the role of international trade

- Our model in autarky coincides with the *basic model*

  Hence: The results of Barrett (1994), Diamantoudi et al. (2006) and Rubio & Ulph (2006) apply

  $\Rightarrow$ In autarky, stable coalitions are not wide ($m \le 4$)

- Our new result:

  In all of our numerical examples of the autarky regime stable coalitions are not deep

  (m_a^* is the smallest or second smallest integer m larger than $\tilde{m}_a$)

- **Conclusion:**

  Trade tends to widen but fails to deepen stable coalitions

Concluding remarks

- We have extended the *basic model* of the coalition formation literature by considering production, consumption and international trade

- We have reexamined and characterized coalition stability assuming the coalition acts as a Stackelberg leader

- **Result 1:** In the world economy with stable coalition, total emissions fall short of BAU emissions to a very small extent only
  That is true for the scenarios of autarky *and* free trade

- **Result 2:** Free trade tends to widen stable coalitions but fails to deepen them

Caveat

- Robustness of results is unclear
  because analytical complexity requires resorting
  to simple parametric functions and to numerical calculations

- Our study shares this limitation with much of pertaining literature

Follow-up work (in progress) (I)

- **Coalition as Nash player rather than as Stackelberg leader**

  What is the difference in outcome?

- **Results**:

  - Nash stable coalitions consist of two countries at most

  - World emissions with stable coalitions are only slightly less than in BAU

  - Trade liberalization is bad for the climate, the coalition countries' welfare and for the aggregate welfare of all countries.

Follow-up work (in progress) (II)

- **Impact of tariffs on size and performance of stable coalitions when coalitions are Stackelberg leaders**

- **Results:**

  - Size of stable coalition shrinks when coalitions set tariffs in addition to their cap-and-trade schemes

  - The smaller stable coalitions reduce total emissions more effectively than the larger stable coalitions without tariffs

Thank you for your attention

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