Mindset of policymakers matters: cases of climate coalition formation

Amin Mirabdollah
KU Leuven

Sareh Vosooghi
KU Leuven

April 2024

Introduction

- Signatories of climate coalitions promise to reduce emissions jointly.
- Different climate coalitions have different levels of ambition in emission reduction.
- We model the formation of climate coalitions, and try to predict the number of coalitions and the number of signatories.
- Signatories commit to maximising payoffs of all coalition members in choosing their emission reduction levels.

- Our policymakers are **strategic** (or farsighted):
  - they predict the entire coalition structure
  - they take into account the consequences of their membership decisions on others
- Existing methodology of coalition formation by such strategic agents:
  - algorithms to find the number of coalitions and their signatories iteratively
  - in public-good games: small efficiency loss (Ray and Vohra, 2001, JPE)
  - for **univariate** payoff functions

Contribution

- We generalise coalition formation with public goods to have **multivariate** payoff functions.

- An example is relaxing the fixed parameters that can capture the '**mindset of policymakers**' in climate negotiations.

- Two applications:
  - Dynamic games: climate coalition formation + Integrated Assessment Model (IAM)
    $\rightarrow$ we characterise equilibrium at each value of discount factor
  - Stochastic games: climate coalition formation + unknown decay rate of GHG
    $\rightarrow$ we characterise equilibrium at each value of uncertain decay rate of GHG

Contribution

- We generalise coalition formation with public goods to have **multivariate** payoff functions.

- An example is relaxing the fixed parameters that can capture the '**mindset of policymakers**' in climate negotiations.

- Two applications:
  - Dynamic games: climate coalition formation + Integrated Assessment Model (IAM)
    $\rightarrow$ we characterise equilibrium at each value of discount factor
  - Stochastic games: climate coalition formation + unknown decay rate of GHG
    $\rightarrow$ we characterise equilibrium at each value of uncertain decay rate of GHG

Contribution

- We offer an algorithm to **fully characterise** the equilibrium number of climate coalitions and their number of signatories for **multivariate** payoff functions.
- Our algorithm captures a larger set of equilibria, even for **univariate** payoff functions.
- **Policy** message from the applications:
  - discount factor (or time horizon) of policymakers affect their membership decisions!
  - beliefs of policymakers about uncertain parameters affect their membership decisions!

  Thus, they should be taken into account in the design of climate treaties.

Contribution

- We offer an algorithm to **fully characterise** the equilibrium number of climate coalitions and their number of signatories for **multivariate** payoff functions.
- Our algorithm captures a larger set of equilibria, even for **univariate** payoff functions.
- **Policy** message from the applications:
  - discount factor (or time horizon) of policymakers affect their membership decisions!
  - beliefs of policymakers about uncertain parameters affect their membership decisions!

  Thus, they should be taken into account in the design of climate treaties.

Contribution

- We offer an algorithm to **fully characterise** the equilibrium number of climate coalitions and their number of signatories for **multivariate** payoff functions.
- Our algorithm captures a larger set of equilibria, even for **univariate** payoff functions.
- **Policy** message from the applications:
  - discount factor (or time horizon) of policymakers affect their membership decisions!
  - beliefs of policymakers about uncertain parameters affect their membership decisions!

  Thus, they should be taken into account in the design of climate treaties.

Introduction

Climate coalition formation + unknown decay rate of GHG

- Climate coalition formation
- The economy and climate
- Analysis of Action stage

Membership decisions

- Farsightedness Methodology
- Brute-force observations
- Algorithm

Conclusion

Setup

- Country $i \in I$, and set of countries is $I \equiv \{1, 2, ..., N\}$
- Time is discrete, $t = 0, 1, 2, ...$
- Each country has a planner, who represents it in climate negotiations and can implement desired outcomes in a decentralised economy
- Open membership + binding + irreversible agreements
- Let n be the number of active players in the negotiation room ($n \leq N$).
- Symmetric countries

Timeline

Two-stage climate coalition formation

- Beginning of period *t*: **membership stage**
- From end of period *t* onward: **action stage**
  → coalitional decisions within coalitions (e.g., emission reduction)
  → country-level decisions (if any)
- At the end of each period actions are observed and payoffs are realised.

Membership stage

- **Coalition structure** is a partition of set I into coalitions, $\mathbb{M} \equiv \{M_1, M_2, ..., M_k\}$.
- m_j is number of signatories of M_j.
- **Numerical coalition structure (substructure)**, $\mathcal{M} \equiv \{m_1, m_2, ..., m_k\}$.

Timeline

Two-stage climate coalition formation

- ◇ Beginning of period t: **membership stage**
- ◇ From end of period t onward: **action stage**
  $\rightarrow$ coalitional decisions within coalitions (e.g., emission reduction)
  $\rightarrow$ country-level decisions (if any)
- ◇ At the end of each period actions are observed and payoffs are realised.

Membership stage

- **Coalition structure** is a partition of set I into coalitions, $\mathbb{M} \equiv \{M_1, M_2, ..., M_k\}$.
- m_j is number of signatories of M_j.
- **Numerical coalition structure (substructure)**, $\mathcal{M} \equiv \{m_1, m_2, ..., m_k\}$.

Introduction

Climate coalition formation + unknown decay rate of GHG

- Climate coalition formation
- The economy and climate
- Analysis of Action stage

Membership decisions

- Farsightedness Methodology
- Brute-force observations
- Algorithm

Conclusion

The economy and climate

q_{it}: abatement level

Q_t: stock of GHG

β: discount factor

η: mSCC

$1-\phi$: (belief about) decay rate of GHG

Ψ: unabated emission

Country i minimises

$$\sum_{\tau=0}^{\infty} \beta^{\tau} \Pi(q_{it+\tau})$$

where $\quad \Pi_{it} = \frac{q_{it}^2}{2} + \eta Q_t$

$$Q_{t+1} = \phi Q_t + \Psi - \sum_i q_{it}$$

Dutta and Radner (2006, 2009, 2012)

Introduction

Climate coalition formation + unknown decay rate of GHG

- Climate coalition formation
- The economy and climate
- Analysis of Action stage

Membership decisions

- Farsightedness Methodology
- Brute-force observations
- Algorithm

Conclusion

Solution concept

- Pure strategy Markov Perfect equilibrium

  current state: the formed coalitions (if any); number of those negotiating (if any); proposal (if ongoing or signed); Q_t.

- Strategies of country *i*: as P and as R (in period zero); and action stage strategies: $\{q_{1it+\tau}(m, \mathcal{M})\}_{\tau=0}^{\infty}$

Action stage

The m member of coalition M minimise,

$$\sum_{i \in M} \sum_{\tau=0}^{\infty} \beta^t \{\Pi(q_{it+\tau})\}$$

subject to: climate dynamic constraint

Proposition

- Optimal abatement level of $i \in M$ is:

$$q_i(m) = \frac{\beta \eta m}{1 - \beta \phi}$$

- Abatement strategies are **dominant** against what other coalitions choose.

Introduction

Climate coalition formation + unknown decay rate of GHG

- Climate coalition formation
- The economy and climate
- Analysis of Action stage

Membership decisions

- Farsightedness Methodology
- Brute-force observations
- Algorithm

Conclusion

Backward induction to the membership stage

- **Optimum-value function** of $i \in M$ is $V_i(\phi, m, \mathcal{M})$

Value Function

Membership decision of **strategic** countries in the *equilibrium binding agreement* of Ray and Vohra (1999)

$\mathcal{M}^*$ is immune to unilateral and multilateral deviations by

- the deviating group, before signing any agreement,
- the active players in the negotiation room.

Farsightedness methodology

- **Ray and Vohra (1999)** The equilibrium $\mathcal{M}^*$ needs to be found **iteratively**: checking iteratively for which group of countries, a grand coalition forms in equilibrium.

  i.e. at stage n of the iteration process, there are n countries negotiating, if $n = 2$, then $\mathcal{M}^* =$? Then if $n = 3$, $\mathcal{M}^* =$? Then, if ... .

  - for example, if at $n = 2$, $\mathcal{M}^* = \{2\}$, then at $n = 3$, compare payoff of $\{3\}$ v.s $\{2, 1\}$ (and ~~$\{1, 1, 1\}$~~).

- **Public-good games: Ray and Vohra (2001)**
  1. In any stage of recursion, to check whether $\{m_1, m_2, ..., m_k\}$ forms versus the grand:

$$V_i(m_1, \mathcal{M}) \quad - \quad V_i(n)$$

  2. The idea of **decomposition** of n using only $\mathcal{M}^*$ of the previous stages

Farsightedness methodology

- **Ray and Vohra (1999)** The equilibrium $\mathcal{M}^*$ needs to be found **iteratively**: checking iteratively for which group of countries, a grand coalition forms in equilibrium.

  i.e. at stage n of the iteration process, there are n countries negotiating, if $n = 2$, then $\mathcal{M}^* =$? Then if $n = 3$, $\mathcal{M}^* =$? Then, if ... .

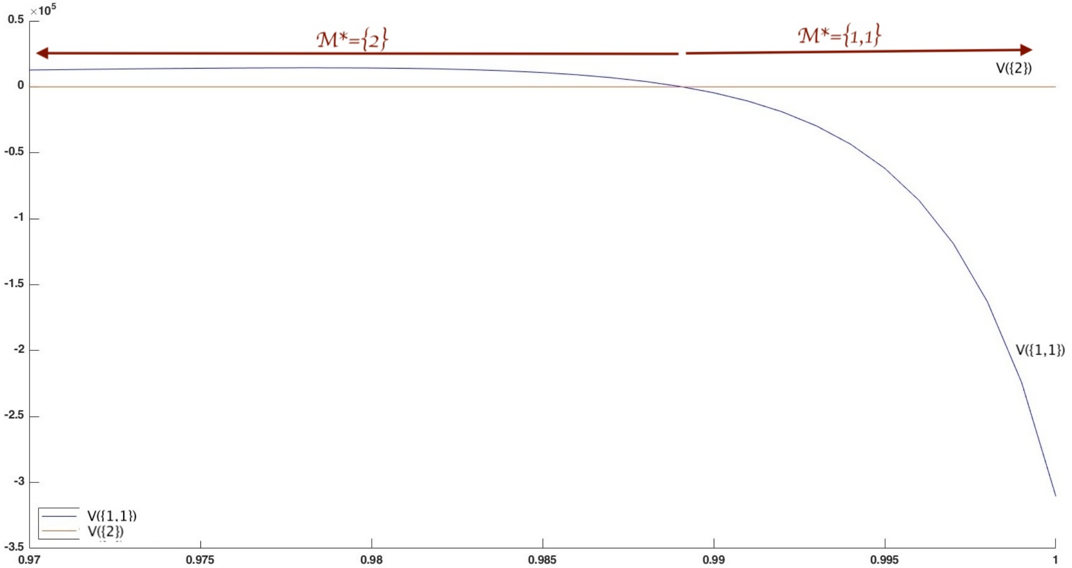
  - for example, if at $n = 2$, $\mathcal{M}^* = \{2\}$, then at $n = 3$, compare payoff of $\{3\}$ v.s $\{2, 1\}$ (and ~~$\{1, 1, 1\}$~~).

- **Public-good games: Ray and Vohra (2001)**
  1. In any stage of recursion, to check whether $\{m_1, m_2, ..., m_k\}$ forms versus the grand:

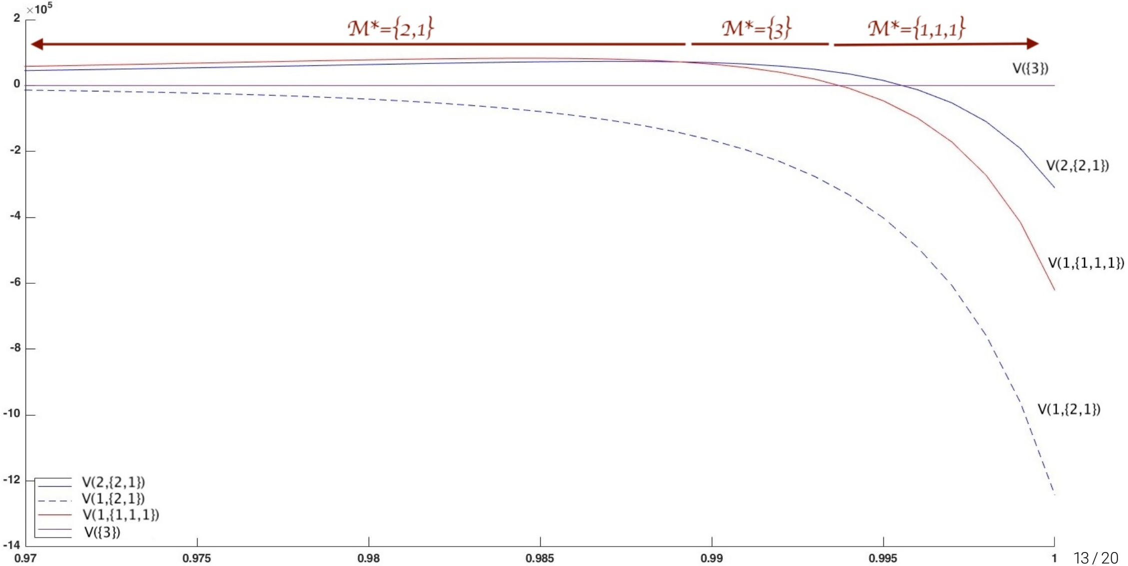
$$V_i(m_1, \mathcal{M}) \quad - \quad V_i(n)$$

  2. The idea of **decomposition** of n using only $\mathcal{M}^*$ of the previous stages

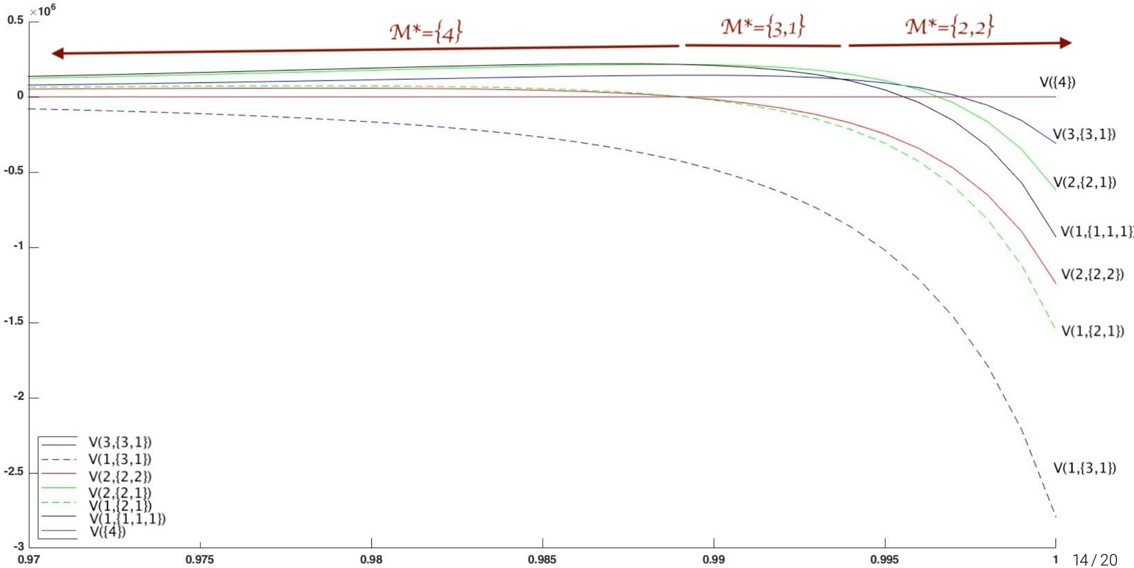
Brute-force observations: $n = 2$



Brute-force observations: $n = 3$



Brute-force observations: $n = 4$



Observations from the brute-force approach

- **Observation 1**: for each $n > 1$, the equilibrium coalition structure depends on decay rate, ϕ.
- **Observation 2**: coalitions of equal size can emerge in equilibrium, e.g., $\mathcal{M}^* = \{2, 2\}$ for $n = 4$ (even by collapsing ϕ).

Observations from the brute-force approach

- **Observation 1**: for each $n > 1$, the equilibrium coalition structure depends on decay rate, ϕ.
- **Observation 2**: coalitions of equal size can emerge in equilibrium, e.g., $\mathcal{M}^* = \{2, 2\}$ for $n = 4$ (even by collapsing ϕ).

Introduction

Climate coalition formation + unknown decay rate of GHG

- Climate coalition formation
- The economy and climate
- Analysis of Action stage

Membership decisions

- Farsightedness Methodology
- Brute-force observations
- Algorithm

Conclusion

Algorithm

- As N increases, applying a brute-force approach (e.g. farsighted algorithms of Ray and Vohra, 1999) to check all possible payoffs across ϕ, can be tedious and computationally demanding.
- We need an approach to **reduce the number of possibilities.**
- The algorithm should rely on a iteration process too, but each step in the iteration process **depends on** ϕ.
- In a public-good game, the smallest coalitions have the highest payoffs. But we can't compare only the *decomposition* of n (from previous stages) with the grand's payoff, as coalition structures with **repeated elements** should be checked too.
- By dependence of payoffs on ϕ, multiplicity of equilibria can happen only at thresholds, where we break the ties in favour of the largest coalition. Otherwise, $\mathcal{M}^*$ is **unique**.

Algorithm

- As ***N*** increases, applying a brute-force approach (e.g. farsighted algorithms of Ray and Vohra, 1999) to check all possible payoffs across ϕ, can be tedious and computationally demanding.
- We need an approach to **reduce the number of possibilities.**
- The algorithm should rely on a iteration process too, but each step in the iteration process **depends on** ϕ.
- In a public-good game, the smallest coalitions have the highest payoffs. But we can't compare only the *decomposition* of ***n*** (from previous stages) with the grand's payoff, as coalition structures with **repeated elements** should be checked too.
- By dependence of payoffs on ϕ, multiplicity of equilibria can happen only at thresholds, where we break the ties in favour of the largest coalition. Otherwise, $\mathcal{M}^*$ is **unique**.

Algorithm

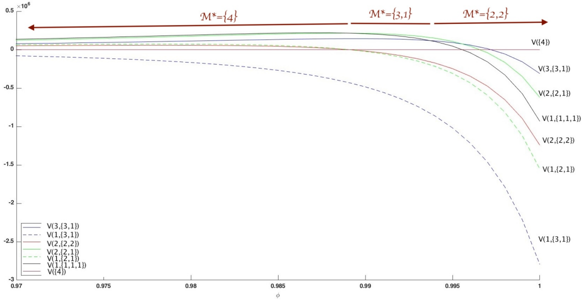
(I) For $n = 1$, $\mathcal{M}^* = \{1\}$ at any ϕ.

(II) at each stage $n > 1$ of the recursion,

- write down the family of all possible $\mathcal{M}$,
- partition ϕ based on its thresholds at stage $n - 1$, and at each partition, eliminate all known unstable $\mathcal{M}$ based on all previous rounds of recursion,
- among the remaining $\mathcal{M}$, compare payoff of one country in the smallest (if any) coalition of each $\mathcal{M}$, and find $\mathcal{M}$ with the maximum payoff.

(III) stop at $n = N$.

The application example ($n = 4$):



Algorithm

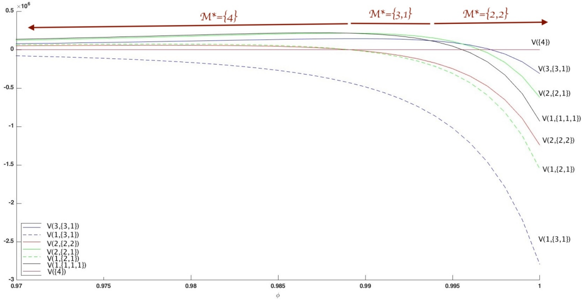
(I) For $n = 1$, $\mathcal{M}^* = \{1\}$ at any ϕ.

(II) at each stage $n > 1$ of the recursion,

- write down the family of all possible $\mathcal{M}$,
- partition ϕ based on its thresholds at stage $n - 1$, and at each partition, eliminate all known unstable $\mathcal{M}$ based on all previous rounds of recursion,
- among the remaining $\mathcal{M}$, compare payoff of one country in the smallest (if any) coalition of each $\mathcal{M}$, and find $\mathcal{M}$ with the maximum payoff.

(III) stop at $n = N$.

The application example ($n = 4$):



$$\mathcal{F} = \{ \{4\}, \{3, 1\}, \{2, 1, 1\}, \{1, 1, 1, 1\} \}$$

Algorithm

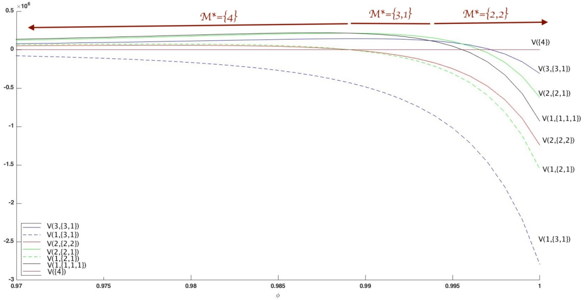
(I) For $n = 1$, $\mathcal{M}^* = \{1\}$ at any ϕ.

(II) at each stage $n > 1$ of the recursion,

- write down the family of all possible $\mathcal{M}$,
- partition ϕ based on its thresholds at stage $n - 1$, and at each partition, eliminate all known unstable $\mathcal{M}$ based on all previous rounds of recursion,
- among the remaining $\mathcal{M}$, compare payoff of one country in the smallest (if any) coalition of each $\mathcal{M}$, and find $\mathcal{M}$ with the maximum payoff.

(III) stop at $n = N$.

The application example ($n = 4$):



Algorithm

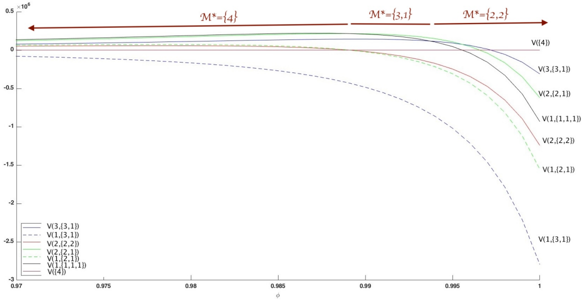
(I) For $n = 1$, $\mathcal{M}^* = \{1\}$ at any ϕ.

(II) at each stage $n > 1$ of the recursion,

- write down the family of all possible $\mathcal{M}$,
- partition ϕ based on its thresholds at stage $n - 1$, and at each partition, eliminate all known unstable $\mathcal{M}$ based on all previous rounds of recursion,
- among the remaining $\mathcal{M}$, compare payoff of one country in the smallest (if any) coalition of each $\mathcal{M}$, and find $\mathcal{M}$ with the maximum payoff.

(III) stop at $n = N$.

The application example ($n = 4$):



$$\begin{cases} \{1,1,1,1\} or \{4\} or \{2,2\} & \text{if } 0.994 < \phi \\ \{3,1\} or \{4\} or \{2,2\} & \text{if } 0.989 < \phi \leq 0.994 \\ \{4\} or \{2,2\} & \text{if } \phi \leq 0.989 \end{cases}$$

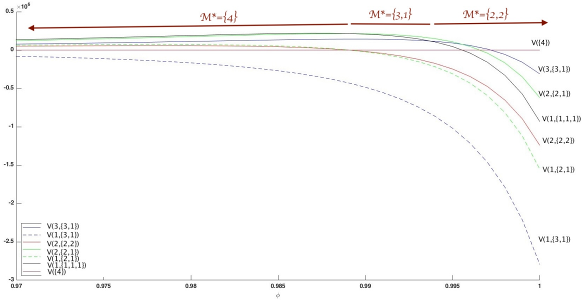
Algorithm

(I) For $n = 1$, $\mathcal{M}^* = \{1\}$ at any ϕ.

(II) at each stage $n > 1$ of the recursion,
- write down the family of all possible $\mathcal{M}$,
- partition ϕ based on its thresholds at stage $n - 1$, and at each partition, eliminate all known unstable $\mathcal{M}$ based on all previous rounds of recursion,
- among the remaining $\mathcal{M}$, compare payoff of one country in the smallest (if any) coalition of each $\mathcal{M}$, and find $\mathcal{M}$ with the maximum payoff.

(III) stop at $n = N$.

The application example ($n = 4$):



$$\mathcal{M}^* = \begin{cases} \{2,2\} & \text{if } 0.994 < \phi \\ \{3,1\} & \text{if } 0.989 < \phi \leq 0.994 \\ \{4\} & \text{if } \phi \leq 0.989 \end{cases}$$

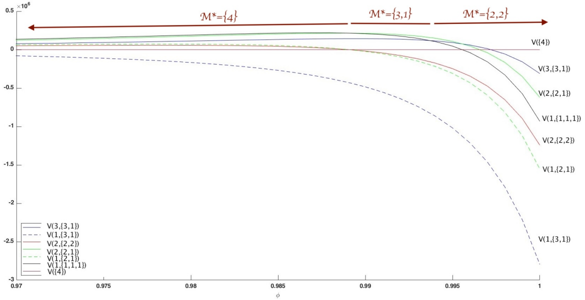
Algorithm

(I) For $n = 1$, $\mathcal{M}^* = \{1\}$ at any ϕ.

(II) at each stage $n > 1$ of the recursion,
- write down the family of all possible $\mathcal{M}$,
- partition ϕ based on its thresholds at stage $n - 1$, and at each partition, eliminate all known unstable $\mathcal{M}$ based on all previous rounds of recursion,
- among the remaining $\mathcal{M}$, compare payoff of one country in the smallest (if any) coalition of each $\mathcal{M}$, and find $\mathcal{M}$ with the maximum payoff.

(III) stop at $n = N$.

The application example ($n = 4$):



More on the elimination step

At stage n and at each partition,

(a) among all possible coalition structures, **eliminate** all unstable $\mathcal{M}$ based on **all** previous rounds of recursion:

- from the previous stages, only $\{\mathcal{M}^*_{n-j}, j\}$ for $j < \frac{n}{2}$, ... , can be potentially self-enforceable.
- This reduces the number of checks.

For example, in the application: at $n = 4$ and $0.994 < \phi$, eliminate $\{3, 2\}$ and $\{3, 1, 1\}$, since at $n = 3$ and at that partition of ϕ, $\{3\}$ was not self-enforceable.

(b) In addition, we include coalition (sub)structures with **repeated elements**, in addition to the grand $\{n\}$.

For example, in the application example, at $n = 4$, the new possible structures are $\{2, 2\}$ and $\{4\}$.

More on the elimination step

At stage n and at each partition,

(a) among all possible coalition structures, **eliminate** all unstable $\mathcal{M}$ based on **all** previous rounds of recursion:

- from the previous stages, only $\{\mathcal{M}^*_{n-j}, j\}$ for $j < \frac{n}{2}$, ... , can be potentially self-enforceable.
- This reduces the number of checks.

For example, in the application: at $n = 4$ and $0.994 < \phi$, eliminate $\{3, 2\}$ and $\{3, 1, 1\}$, since at $n = 3$ and at that partition of ϕ, $\{3\}$ was not self-enforceable.

(b) In addition, we include coalition (sub)structures with **repeated elements**, in addition to the grand $\{n\}$.

For example, in the application example, at $n = 4$, the new possible structures are $\{2, 2\}$ and $\{4\}$.

More on the elimination step

At stage n and at each partition,

(a) among all possible coalition structures, **eliminate** all unstable $\mathcal{M}$ based on **all** previous rounds of recursion:

- from the previous stages, only $\{\mathcal{M}^*_{n-j}, j\}$ for $j < \frac{n}{2}$, ... , can be potentially self-enforceable.
- This reduces the number of checks.

For example, in the application: at $n = 4$ and $0.994 < \phi$, eliminate $\{3, 2\}$ and $\{3, 1, 1\}$, since at $n = 3$ and at that partition of ϕ, $\{3\}$ was not self-enforceable.

(b) In addition, we include coalition (sub)structures with **repeated elements**, in addition to the grand $\{n\}$.

For example, in the application example, at $n = 4$, the new possible structures are $\{2, 2\}$ and $\{4\}$.

More on the elimination step

At stage n and at each partition,

(a) among all possible coalition structures, **eliminate** all unstable $\mathcal{M}$ based on **all** previous rounds of recursion:

- from the previous stages, only $\{\mathcal{M}^*_{n-j}, j\}$ for $j < \frac{n}{2}$, ... , can be potentially self-enforceable.
- This reduces the number of checks.

For example, in the application: at $n = 4$ and $0.994 < \phi$, eliminate $\{3, 2\}$ and $\{3, 1, 1\}$, since at $n = 3$ and at that partition of ϕ, $\{3\}$ was not self-enforceable.

(b) In addition, we include coalition (sub)structures with **repeated elements**, in addition to the grand $\{n\}$.

For example, in the application example, at $n = 4$, the new possible structures are $\{2, 2\}$ and $\{4\}$.

$N = 40$ and the application example:

If $\phi = 0.985$ then $\mathcal{M}^* = \{29, 8, 2, 1\}$

If $\phi = 0.995$ then $\mathcal{M}^* = \{20, 20\}$

- At higher natural decay rate of GHG (smaller ϕ), the countries form larger coalitions in equilibrium.

Introduction

Climate coalition formation + unknown decay rate of GHG

- Climate coalition formation
- The economy and climate
- Analysis of Action stage

Membership decisions

- Farsightedness Methodology
- Brute-force observations
- Algorithm

Conclusion

Conclusion

- The design of an architecture for climate treaties should depend on parameters of underlying models, e.g. those related to the policymakers mindset: their discount factor or their belief about decay rate of GHG, etc.
- We generalise coalition formation game with public goods to multivariate payoff functions.
- We offer an algorithm to fully characterise $\mathcal{M}^*$ in coalition formation of climate games by *strategic* agents.
  - Unique prediction of equilibrium climate coalitions
  - Characterising broader set of equilibrium outcomes