Internat. Environmental Agreements: A game theory approach

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Int. Env. Agreements

- Global pollution problem
- Voluntary cooperation; prisoners' dilemma
- Internalizing transboundary externalities versus free-rider incentives
- Examples
  - Montreal Protocol
  - Kyoto Protocol

Main stability concept

- Internal/external stability
  - no incentive to leave the coalition
  - no incentive to join the coalition
- Nash equilibrium of two-stage game
  - first membership, then abatement
  - partial agreement Nash equilibrium
- From cartel theory (d'Aspremont et al 1983)

Other stability concepts

- Core concept cooperative game theory
  - sub-group does not have incentive to leave
  - partial agreement Nash equilibrium (γ-core)
  - grand coalition is in core (after transfers)
- Trigger strategies in repeated games
  - punishment (forever Nash) deters deviations
- Bargaining models

Example

- n countries, size of coalition k
- members abate k
- outsiders abate 1

$$\sum_{j=1}^{n} a_j - 0.5 a_i^2$$

Example continued

- Insider benefits *P* and outsider benefits *Q*

$$P(k) = 0.5k^2 + n - k$$

$$Q(k) = k^2 + n - k - 0.5$$

Example continued

- Internal and external stability

$$Q(k-1) \leq P(k) : 1 \leq k \leq 3$$

$$P(k+1) \leq Q(k) : 2 \leq k$$

Result

- Under internal/external stability, size of the stable coalition is very small, regardless of the number of countries
- Robust for model specifications
  - Finus (2003), Barrett (1994, 2003)
- Kyoto Protocol confirms this, but Montreal Protocol is large!? (Barrett)

Cooperative game theory

- Grand coalition is stable if it is in the core which means that a sub-group (possibly an individual country) does not have incentive to leave, assuming that the other countries respond by switching to partial agreement Nash equilibrium (γ-core)
  - Chander and Tulkens (1995)

Result

- Grand coalition is stable
  - for symmetric countries result is trivial
  - for asymmetric countries transfers exist so that result holds
  - transfers reallocate benefits of cooperation in a clever way
  - Germain, Toint, Tulkens and de Zeeuw (JEDC 2003): stock pollution algorithm

Comparison

- Contradictory conclusions
- Behavioural assumptions differ!
  - coalition stays intact
  - trigger mechanism
- What is realistic?
  - Kyoto Protocol stayed intact after USA did not ratify

Farsightedness

- Deviation may trigger further deviations until new stable coalition is reached
- Reconciles two previous approaches
- Internal/external stability concept too weak
- Core concept (trigger strategies) too strong
- Applications to IEA's
  - Diamantoudi and Sartzetakis (2002)

Result

- Set of stable coalitions
  - internal/external stable coalition is an element
  - net benefit insider of *some* larger coalition is higher than net benefit outsider to this coalition
  - etcetera
- Countries coordinate on largest farsighted stable coalition
- Optimistic view under mild conditions

Dynamic aspects

- Detection of deviation takes time
- Does shift to smaller stable coalition deter deviations?
- Static case: yes (per definition)
- Repeated game: yes, if discount factor high enough
- Difference game: depends (de Zeeuw 2008)

Difference game

- Level of emissions is the state of the system
- Game depends on the state of the system
- The state has changed when deviation is detected: punishment high enough?
- Large stable coalition if and only if damage costs are relatively small as compared to abatement costs

Model

- s: level of emissions; a: abatement

$$s(t+1) = s(t) - \sum_{i=1}^{n} a_i(t), t = 0,1,\ldots., s(0) = s_0$$

$$C_i = \sum_{t=0}^{\infty} \delta^t [\tfrac{1}{2} a_i^2(t) + \tfrac{1}{2} p s^2(t)], i = 1,2,.., n.$$

Solution

- Dynamic programming equations
- Value functions are quadratic forms
- Usual approach:
  - (feedback) Nash equilibrium
  - full-cooperative solution
- Coalition of size *m*, PANE
- Value functions insiders/outsiders: k^c, k^o

Formulas

- Coupled system of equations

$$k^c = p + \frac{\delta k^c (1 + \delta m^2 k^c)}{(1 + \delta(m^2 k^c + (n-m)k^o))^2}$$

$$k^o = p + \frac{\delta k^o (1 + \delta k^o)}{(1 + \delta(m^2 k^c + (n-m)k^o))^2}$$

Deviation

- Dynamic programming with cost-to-go k^{o+} of an outsider to a *smaller* stable coalition
- Value function deviator k^d
  - function of p, m, k^c, k^o, k^{o+}
- Deviation if $k^d < k^c$
- Discount factor high (equal to *1)*
- Numerical analysis

Stability concept

- Build stable set from below
  - Nash equilibrium (*m=1*) is stable
  - check if *m=2* is stable
  - if no, check if *m=3* is stable, etc.
  - if yes, repeat to search larger stable coalition
- Static farsighted stable: compare k^c, k^{o+}
- Dynamic farsighted stable: compare k^c, k^d

Results

- *8* countries
- Cost parameter *p* relatively large
  - static farsighted stable: *6*
  - but not dynamically stable
- Cost parameter *p* very small
  - static farsighted stable: *3*, *6*
  - also dynamically stable!

Evaluation

- Farsightedness makes large stable coalitions possible
- However, if and only if parameter p is very small, coalitions are also dynamically stable
- State changes slowly, so that punishment is still effective
- Characteristics Montreal/Kyoto Protocol?

Conclusion

- International Environmental Agreements
- Stable size
- Size is small (except under strong threats)
- Farsightedness?
  - in dynamic context, size is usually still small
- Role technology?