Game Theory as a tool for the management of Environmental Problems and Agreements

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Main topics of the talk

- *Game Theory*
- *International Environmental Problems (IEPs)*
- *International Environmental Agreements (IEAs)*

Structure of the talk

- *[Pills of] characterisation*
- *I[E]A*
- *[Few] remarks on coalitions, transfers, issues linkage*
- *IEP*
- *NCGT: models and applications*
- *CGT: examples*

Pills of characterisation

- IA
  - full negotiations
  - (mainly) agreements about "goods"
- IEA
  - self enforcing (lack of international enforcing authority)
  - free-riding
  - (mainly) agreements about "bads"
  - coalitions
- IEP
  - transboundary problems
  - possible international authorities: mediator and or arbitrator
  - contracts and communication, no coalitions (few countries strategically competing), free-riding
  - agreements about "goods" and "bads"

I[E]A

- IA
  - examples
    - International Telecommunication Convention (1965): radio frequencies and geostationary orbit;
    - Law of the Sea (1973): deep ocean bed, divider÷chooser
- IEA
  - examples:
    - Oslo Protocol (1994): sulfur reduction;
    - Montreal Protocol (1987): depletion ozone layer;
    - Kyoto Protocol (1997): reduction greenhouse gases.
  - typologies:
    - global warming, acid rains, high sea fisheries, water management (anyway problems or “bads”)

Some remarks on coalitions 1

- A coalition is any subset S of the set N of players (grand coalition)
  - worth of a coalition
  - stability (internal, external)
  - main cases:
    - single coalition vs. a group of singletons: $c=\{c_s, 1_{n-s}\}$
    - competing coalitions: $c=\{c_1, \ldots c_M\}$
- Operations on coalitions
  - coarsening, concentration
- Ways to form/enlarge coalitions
  - transfers
  - issues linkage

Some remarks on coalitions 2

- Transfers:
  - to form a coalition (ex-ante)
  - to enlarge a coalition (ex-post)
  - to easy an agreement (ex-ante/ex-post)
- Transfers:
  - type of transfers: money (credits, funds for co-operation and development, debts cancellation and so on), in-kind (food, fossil fuels, finished goods and so on) technology and or formation;
  - entity of the transfers;
  - donors and acceptors of the transfers

Some remarks on coalitions 3

- Issue linkage (parallel negotiations), “benefits”:
  - aims at linking two (or more) negotiations so to easy the attainment of a co-operative solution through inter-negotiation compensations;
  - it tries to avoid unilateral losses from one of the negotiators;
  - it tries to face problems form a global point of view.
- Issue linkage, “problems”:
  - stability: still incentives at violation;
  - size and scale: in case of more than 2 countries and more than 2 negotiations, bilateral vs. multilateral, mediators? arbitrators?
  - complexity: linking negotiations makes the whole process more complex, interaction with pre-existing agreements
  - transferability: technology only?

Environmental games

- An environmental game is a three stage game (RGS framework):
  - [constitutional stage (minimum participation rule)];
  - coalition stage (how a coalition forms and if each coutry joins or not);
  - policy stage (each country divides the coalition payoff according to a burden sharing rule) .
- Global Pollution or Global Emission Game

$$C = \{c_1, \ldots, c_M\}$$

$$x^* \in X = \times_{i \in N} X_i$$

$$\forall c_i \in C \ \forall x_{c_i} \in \times_{j \in c_j} X_j \ \sum_{j \in c_i} u_j(x^*_{c_i}, x^*_{N \setminus c_i}) \geq \sum_{j \in c_i} u_j(x_{c_i}, x^*_{N \setminus c_i})$$

$$P(c_i; C) = \sum_{j \in c_i} u_j(x^*)$$

$$\pi_i = \beta(e_i) - \phi(\sum_{j=1}^{N} e_j)$$

IEP

- Example/standard game
  - sharing of a resource, two levels of consumption (correct, too high): Prisoner's Dilemma game;
  - complementary technologies/economies/projects: reassurance game;
  - concurrent technologies/economies/projects: Battle of the Sexes game;
  - sharing of a polluted resource, the other cleans, both benefit (one free rider): chicken game.
- Enforcing co-operation: contract games, communication games, repeated games

NCGT

- We use NCGT to analyse the dynamic of IEPs in the simplest setting: two countries interacting within a static game each one with a very limited set of strategies
- We are going to use standard games to describe some common interaction settings
- Of each setting we are going to show at least one, hopefully realistic, application

Standard one shot static games

- Prisoner's Dilemma games
- Reassurance games
- Battle of the sexes games
- Chicken games
- Games with contracts
- Games with communication

Prisoner's Dilemma games

A vs. B	c	nc
c	1,1	-1,3
nc	3,-1	0,0

Prisoner's Dilemma

$$(nc, c) \succ_A (c, c) \succ_A (nc, nc) \succ_A (c, nc)$$

$$(c, nc) \succ_B (c, c) \succ_B (nc, nc) \succ_B (nc, c)$$

A vs. B	c	nc
c	$B - \frac{C}{2}, B - \frac{C}{2}$	B-C,B
nc	B,B-C	0,0

Prisoner's Dilemma, general form

1. $B < C$
2. $B > \frac{C}{2}$

Prisoner's Dilemma games: application

- co-operative (c) or non co-operative (nc) strategies: correct exploitation (conservation) vs. fast depletion
- $B > b > 0$
- $0 > l > L$
- NE=(nc,nc)
- co-operative (and sustainable) solution:(c,c)

A vs. B	c	nc
c	b,b	L,B
nc	B,L	l,l

Prisoner's Dilemma, depletion vs.conservation game

Prisoner's Dilemma games: solutions?

A vs. B	c	nc
c	$B-\frac{C}{2},B-\frac{C}{2}$	B-C,0
nc	0,B-C	-B,-B

Prisoner's Dilemma, with international punishing authority

A vs. B	c	nc
c	$B-\frac{C}{2}+C',B-\frac{C}{2}+C'$	B-C+C',B
nc	B,B-C+C'	0,0

Prisoner's Dilemma, with international funding authority

1. $B-\frac{C}{2}+C'>B,$
2. $B-C+C'>0,$

$$C'>\frac{C}{2}$$

A reassurance game

A vs. B	c	nc
c	4,4	-8,0
nc	0,-8	0,0

An assurance game

1. (c, c),
2. (nc, nc).

- ex-ante agreements of co-operation are self-reinforcing
- no free-riding
- applications: economical and/or technological complementarity

A vs. B	c	nc
c	$B_A - C_A, B_B - C_B$	$-C_A, 0$
nc	$0, -C_B$	0,0

An assurance game in general form

A battle of the sexes' game

- NE=(P_A,P_A) and (P_B,P_B)
- the choice of the NE depends on the existence of some "convention" between the two countries: rich vs. poor, Stackelberg leader/follower
- applications: energy from distinct sources, countries with distinct availability

A vs. B	P_A	P_B
P_A	$B_A^A - \frac{C}{2}, B_A^B - \frac{C}{2}$	$B_A^A - C, B_B^B - C$
P_B	$B_B^A - C, B_A^B - C$	$B_B^A - \frac{C}{2}, B_B^B - \frac{C}{2}$

A battle of the sexes game

1. $C > B_A^A > B_A^B > C/2$,
2. $C > B_B^B > B_B^A > C/2$.

1. $2C > B_A^A + B_A^B > C$,
2. $2C > B_B^B + B_B^A > C$.

Chicken games

- each country pushes the other to act
- free-rider
- application: sharing of a polluted resource (lake, river), cleaning actions

A vs. B	c	nc
c	$B-\frac{C}{2}, B-\frac{C}{2}$	$B-C, B$
nc	B, $B-C$	0,0

First case of chicken game

$B = B_A = B_B > C$

1. (nc, c);
2. (c, nc).

A vs. B	c	nc
c	$B-\frac{C}{2}, B-\frac{C}{2}$	$B-C$,B
nc	B, $B-C$	D,D

Another case of chicken game

1. $D > B - C$;
2. $D < B - C$.

Pathways toward co-operation

- games with contracts
- games with communication
- repeated games

Games with contracts

- players independently sign a contract (there can be more than one)
- self enforcing co-operative equilibria
- use of correlated strategies
- presence of a trustworthy mediator

A vs. B	x_2	y_2
x_1	2,2	0,6
y_1	6,0	1,1

A Prisoner's Dilemma game

A vs. B	x_2	y_2	s_2
x_1	2,2	0,6	0,6
y_1	6,0	1,1	1,1
s_1	6,0	1,1	2,2

Binding contracts in a strategic form game

$\frac{1}{2}[x_1, y_2] + \frac{1}{2}[x_2, y_1]$

1. $(\hat{s}_1, \hat{s}_2)$,
2. (s_1, s_2)

A vs. B	x_2	y_2	s_2	$\hat{s}_2$
x_1	2,2	0,6	0,6	0,6
y_1	6,0	1,1	1,1	1,1
s_1	6,0	1,1	2,2	1,1
$\hat{s}_1$	6,0	1,1	1,1	3,3

Use of two contracts

Games with contracts: problems and limitations

- role of mediator, observability of the strategies
- (case of n >2) free-riders (inner and outer)
- (case of n >2) subcoalitions' deviations
- unobservable strategies
- inadequate and/or ineffective punishments, hard to detect violations
- inalienable rights are involved in the strategies

Games with communication

- players have the strategies specified by the structure of the game
- and a set of implicit communication options
- presence of a trustworthy mediator that recommends each player a strategy

A vs. B	x_2	y_2
x_1	5,1	0,0
y_1	4,4	1,5

An example of game in strategic form

$$0.5[x_1, x_2] + 0.5[y_1, y_2]$$

$$\frac{1}{3}[x_1, x_2] + \frac{1}{3}[y_1, y_2] + \frac{1}{3}[y_1, x_2]$$

Games with communication: an example

A vs. B	x_2	y_2
x_1	5,1	0,0
y_1	4,4	1,5

$$
\begin{cases}
max\ 6\mu(x_1,x_2) + 0\mu(x_1,y_2) + 8\mu(y_1,x_2) + 6\mu(y_1,y_2) \\
s.t. \\
(5-4)\mu(x_1,x_2) + (0-1)\mu(x_1,y_2) \geq 0 \\
(4-5)\mu(y_1,x_2) + (1-0)\mu(y_1,y_2) \geq 0 \\
(1-0)\mu(x_1,x_2) + (4-5)\mu(y_1,x_2) \geq 0 \\
(0-1)\mu(x_1,y_2) + (5-4)\mu(y_1,y_2) \geq 0 \\
\mu(x_1,x_2) + \mu(x_1,y_2) + \mu(y_1,x_2) + \mu(y_1,y_2) = 1 \\
\mu(x_1,x_2) \geq 0 \\
\mu(x_1,y_2) \geq 0 \\
\mu(y_1,x_2) \geq 0 \\
\mu(y_1,y_2) \geq 0
\end{cases}
$$

$$
\mu(x_1,x_2) = \mu(y_1,y_2) = \mu(y_1,x_2) = \frac{1}{3} \quad \mu(x_1,y_2) = 0
$$

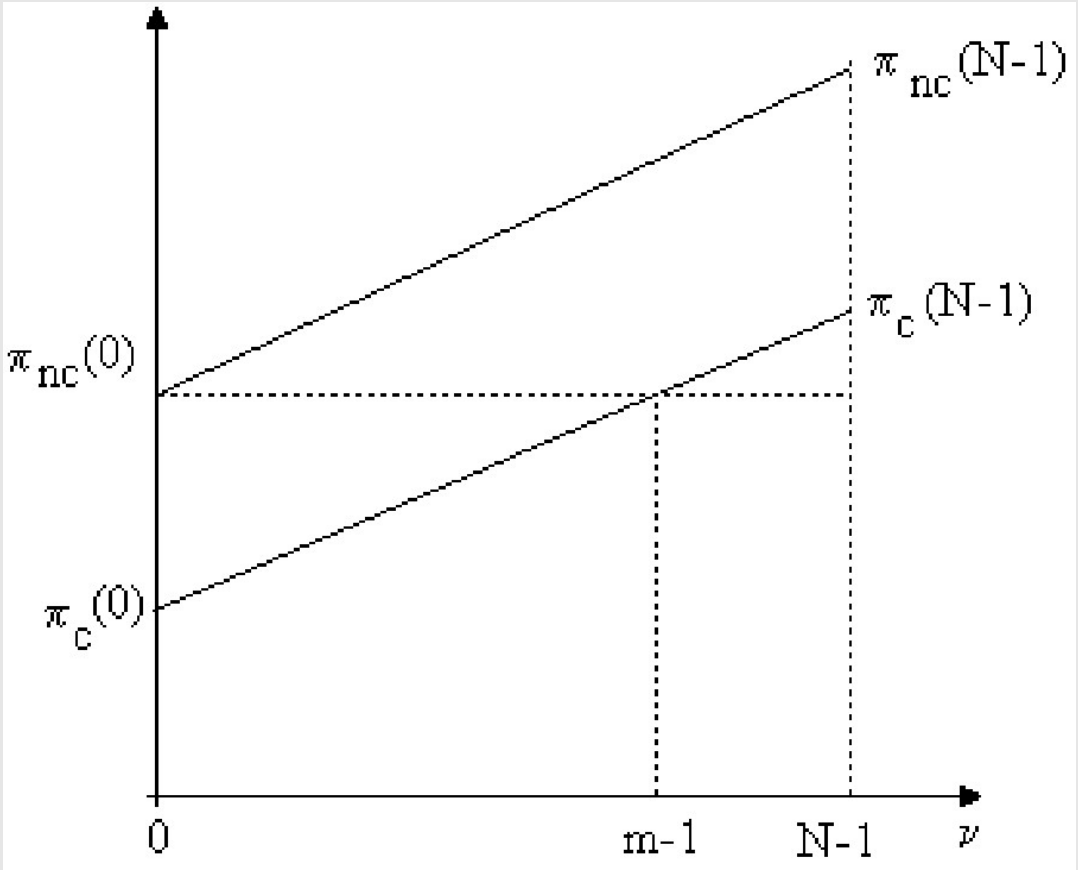
$$
\frac{1}{3}[x_1,x_2] + \frac{1}{3}[y_1,y_2] + \frac{1}{3}[y_1,x_2]
$$

Games with communication: remarks

- revelation principle: communication systems with a mediator as a universal model
- trustworthy mediator: identification
- confidentiality: private information if becomes public can "defeat" a correlated strategy
- sub-coalitions?

Repeated games: a case study 1

- We examine a repeated Prisoner's Dilemma game with N players
- For each player: profits from co-operation ($\pi_c(\nu)$) and no co-operation ($\pi_{nc}(\nu)$) with 0, m-1, N-1 other players



$$\pi_c(\nu) \qquad \pi_{nc}(\nu)$$

$$\pi_{nc}(\nu) > \pi_c(\nu)$$

$$\pi_c(N-1) > \pi_{nc}(0)$$

$$\pi_{nc}(0) < \pi_c(N-1)$$

$$\pi_{nc}(0) = \pi_c(m-1)$$

Repeated games: a case study 2

- Coalition involves m+1 countries on N (N-m-1 free-riders)
- m (and so the size of the coalition) is lower the steeper is π_c and the higher is $\pi_c(0)$

$$\sum_{i=0}^{\infty} \delta^i \pi_c(m) = \sum_{i=0}^{\infty} (\frac{1}{1+r})^i \pi_c(m) = \pi_c(m) \frac{1+r}{r}$$

$$\pi_{nc}(m) + \sum_{i=1}^{\infty} \delta^i \pi_{nc}(0) = \pi_{nc}(m) + \pi_{nc}(0)(\sum_{i=0}^{\infty} \delta^i - 1)$$

$$\pi_{nc}(m) + \pi_{nc}(0) \frac{1}{r}$$

$$r < \frac{\pi_c(m) - \pi_{nc}(0)}{\pi_{nc}(m) - \pi_c(m)}$$

Co-operation and GT

- We present here two examples :
  - a group S of n countries that co-operate to minimise a pollution problem;
  - a couple of countries that reach co-operation through parallel negotiations (issues linkage).
- Afterward we discuss some problems that can make co-operation difficult and possible incentives to co-operation (transfers)

Minimising global pollution: a case study1

- The setting:
  - set S of n polluting countries,
  - country i: e_i, $m_i X$
  - $X=\Sigma_i e_i \quad M=\Sigma_i m_i \quad m_1 \geq m_2 \geq \ldots m_n$
  - $B'(e_i) > 0 \; B''(e_i) < 0$ benefit function for country i
  - $C'(e_i) > 0 \; C''(e_i) > 0$ cost function for country i

Minimising global pollution: a case study2

- The problem for country i:

$$W_i(e_i, e_{-i}) = B(e_i) - m_i X \; X = e_i + e_{-i}$$ welfare country i

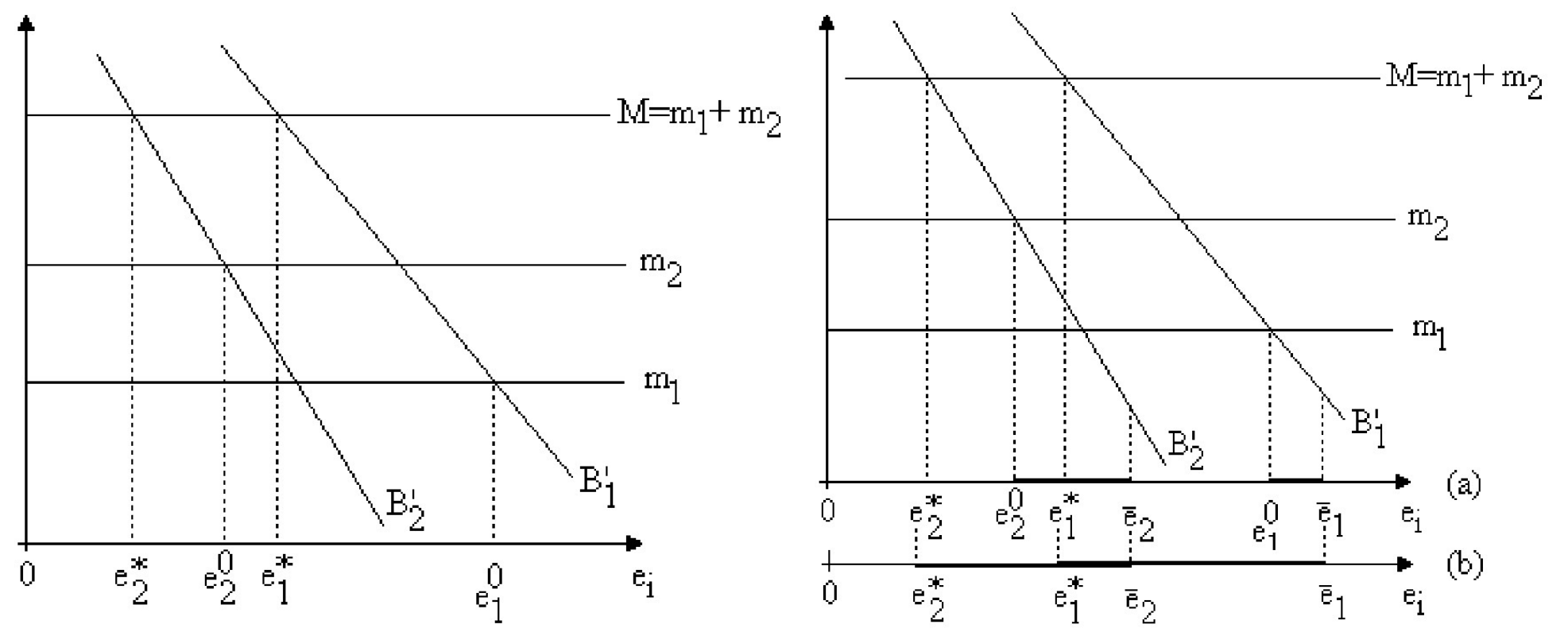
$$\frac{dW_i(e_i, e_{-i})}{de_i} = 0$$ optimisation problem

$$B_i'(e_i^0) = m_i$$ optimum condition

$$\sum_i W_i(e_i, e_{-i}) = \sum_i (B(e_i) - m_i X)$$ global welfare

$$B'(e_i^*) = \sum_j m_j = M$$ optimum condition

Minimising global pollution: case of two countries



$$X^* = e_1^* + e_2^* < X^0 = e_1^0 + e_2^0$$

Issues linkage 1

- The setting:
  - two countries A and B
  - two parallel negotiations: an environmental negotiation for the reduction of greenhouse gases and an economical negotiation for the adhesion to a free trade agreement or to a technology transfer agreement
  - every negotiation separately as a non co-operative NE, the switching to a co-operative solution causes a loss to one of the two countries
  - also the compound game has a non co-operative NE but the switching to a co-operative solution can occur without any loss for both countries so that no transfer is needed (and co-operation is easier)

Issues linkage 2

- The separate games

A vs. B	c	nc
c	b_1, c_2	d_1, a_2
nc	a_1, d_2	c_1, b_2

Environmental negotiation game

$$a_1 > b_1 > c_1 > d_1$$
$$a_2 > b_2 > c_2 > d_2$$
$$nc \succ_1 c \quad nc \succ_2 c$$

A vs. B	c	nc
c	γ_1, β_2	δ_1, α_2
nc	α_1, δ_2	β_1, γ_2

Economical negotiation game

$$\alpha_1 > \beta_1 > \gamma_1 > \delta_1$$
$$\alpha_2 > \beta_2 > \gamma_2 > \delta_2$$
$$nc \succ_1 c \quad nc \succ_2 c$$

a loss (either $b_2 - c_2$ or $\beta_1 - \gamma_1$)

1. $b_1 + c_2 > c_1 + b_2$,
2. $\gamma_1 + \beta_2 > \beta_1 + \gamma_2$,

Issues linkage 3

- The compound game

$$S_A = S_B = \{nc, nc; nc, c; c, nc; c, c\}$$

A vs. B	nc, nc	nc, c	c, nc	c, c
nc, nc	$c_1 + \beta_1, b_2 + \gamma_2$	$c_1 + \alpha_1, b_2 + \delta_2$	$a_1 + \beta_1, d_2 + \gamma_2$	$a_1 + \alpha_1, d_2 + \delta_2$
nc, c	$c_1 + \delta_1, b_2 + \alpha_2$	$c_1 + \gamma_1, b_2 + \beta_2$	$a_1 + \delta_1\, d_2 + \alpha_2$	$a_1 + \gamma_1, d_2 + \beta_2$
c, nc	$d_1 + \beta_1, a_2 + \gamma_2$	$d_1 + \alpha_1, a_2 + \delta_2$	$b_1 + \beta_1, c_2 + \gamma_2$	$b_1 + \alpha_1, c_2 + \delta_2$
c, c	$d_1 + \delta_1, a_2 + \alpha_2$	$d_1 + \gamma_1, a_2 + \beta_2$	$b_1 + \delta_1, c_2 + \alpha_2$	$b_1 + \gamma_1, c_2 + \beta_2$

Composed game

$$c_1 = b_2 = \beta_1 = \gamma_2 = 0$$

A vs. B	nc, nc	nc, c	c, nc	c, c
nc, nc	$0, 0$	α_1, δ_2	a_1, d_2	$a_1 + \alpha_1, d_2 + \delta_2$
nc, c	δ_1, α_2	γ_1, β_2	$a_1 + \delta_1\, d_2 + \alpha_2$	$a_1 + \gamma_1, d_2 + \beta_2$
c, nc	d_1, a_2	$d_1 + \alpha_1, a_2 + \delta_2$	b_1, c_2	$b_1 + \alpha_1, c_2 + \delta_2$
c, c	$d_1 + \delta_1, a_2 + \alpha_2$	$d_1 + \gamma_1, a_2 + \beta_2$	$b_1 + \delta_1, c_2 + \alpha_2$	$b_1 + \gamma_1, c_2 + \beta_2$

Composed game, reduced table

1. $b_1 = \beta_2$,

2. $c_2 = \gamma_1$,

Co-operation: problems and incentives

- switching from a non co-operative solution to a co-operative one may be impossible if the switching imposes a loss to one of the players;
- a possible solution may consist in a transfer of resources from one player to the other so that no country suffers a loss.

A vs. B	c	nc
c	b_1, c_2	d_1, a_2
nc	a_1, d_2	c_1, b_2

Co-operation is hard

$a_1 > b_1 > c_1 > d_1$

$a_2 > b_2 > c_2 > d_2$

$nc \succ_1 c \quad nc \succ_2 c$

$b_1 + c_2 > c_1 + b_2$

$b_1 - c_1 > b_2 - c_2$

A vs. B	c	nc
c	$b_1 - \epsilon, c_2 + \epsilon$	d_1, a_2
nc	a_1, d_2	c_1, b_2

Incentives to co-operation

1. for country A we have $b_1 - \epsilon > c_1$;
2. for country B we have $c_2 + \epsilon > b_2$.

$a_1 > b_1 - \epsilon > c_1 > d_1$

$a_2 > c_2 + \epsilon > b_2 > d_2$

the only Nash equilibrium at (nc, nc)

Problems with transfers

- what: kinds of transfers (money, in-kind, technology i.e. knowledge)
- when: before or after the agreement
- how much: entity of the transfer, who can decide what quantity is enough for a given agreement

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Concluding remarks

- deeper analysis of the available literature, mainly NCGT
- widen the concept of coalition? non flat structures? graphs?
- conflicting and non disjoint coalitions
- modelling of negotiations not in international contexts but in presence of environmental “local” conflicts

Game Over.....

Thank you for your attention

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