International Environmental Agreements

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Course Plan

- 17.1. Introduction
- 24.1. Gordon-Schaefer game
- 31.1. Ruseski game
- 7.2 Fisheries coalition game
- 14.2. Coalitions and stability rules
- 21.2. Dynamic games
- 28.2. exam

Course evaluation

- 60% Final assignment (exam)
- 20% Homework reading and assignments
- 20% Classroom work participation

Learning objectives of the course

The course expected learning outcomes

1. Explain in general terms when game theory is needed in context of environmental and natural resource management
2. Explain underlying economic assumptions in the theory of International Environmental Agreements (IEAs)
3. Apply most relevant GT concepts to describe some of environmental coordination problems, and reflect on main questions, assumptions and conclusions

Context of environmental and natural resource management

Classification of **goods** in Economics

	Excludable	Non-excludable
Rivalrous	Private goods (food, clothing, cars, parking spaces)	Common-pool resources fish stocks, timber, coal)
Non-rivalrous	Club goods (cinemas, private parks, satellite television)	Public goods (free-to-air television, air, national defense)

- natural renewable resources (forest, fisheries)
- natural exhaustible resources (oil, coil, minerals)
- environmental resources (air, water, soil)

Context of environmental and natural resource management

Resource Extraction:overharvesting of natural resource if open access or common pool resource
Pollution is a major environmental issue which results from extraction and usage of natural resources, in part., nonrenewable ones, for production, heating, transportation.
Abatement of pollution requires equipment and the expenditure of resources

Context of environmental and natural resource management

Externality

is market failure which causes deviation from the first-best (Pareto optimal) solution.
When market prices do not truly reflect social costs or benefits, regulatory institutions and regulations are necessary.

Absence of supranational regulating authority, thus improvement can be implemented only through voluntary cooperation

Externalities: positive (reducing pollution) or negative (rivalrous harvesting of migratory fish stocks)

Context of environmental and natural resource management

Ownership

- natural resource (oil, minerals) clearly defined ownership
- common property (open access) then resource is owned by nobody (high-seas fishery)
- very serious problems of pollution do not have a specific ownership
- owned by nobody = owned by the world as a whole
- absence of property rights thus lead to externalities
- air, ocean are common property: everybody can use environment to deposit pollution

Classroom work

- Barrett 2003, Chapter 1 and Chapter 2.
- Montreal protocol (1987), Helsinki Protocol (1985) and Oslo Protocol (1994), North pacific Fur Seal Treaty (1911)
- split in groups (2-4 students each)
- joint discussion

Context of environmental and natural resource management

Characteristics of environmental problems

1. *Interdependence*. Strategic interdependence is when actions of an individual economic agent affect not only welfare of the agent but also of other agents involved. Environmental interdependence is related to environmental externalities
2. *Time*. Damage is caused not by actions but by their long-term implications. Developments in the resource stock or stocks of accumulated pollution happen over time.
3. *Strategic and forward-looking behavior*. Agents take into account present and future consequences of their own own actions and actions of others

Nature of Games

Game theory is a logical analysis of situation of conflict and cooperation.
Definition. A **game** is a situation in which

- at least two *players* (player is an individual, a company, a company, a nation, a biological species)
- each player has a number of possible *strategies* (courses of actions, which they may choose to follow)
- the strategies chosen by players determine the *outcome* of the game
- each outcome corresponds to a collection of numerical *payoff*, one to each player. The payoffs represent the value of the outcome to the different players

Two-player binary choice game

- Country X (row player) and Country Y (a column player) have a binary choice to make
- The game is played just once
- The pair of letters means payoffs (utility) obtained by Country X and Country Y, respectively
- To explore *outcome* of the game, letters should be replaced with numerical values or functions

		Country Y	
		Strategy 1	Strategy 2
Country X	Strategy 1	a,a	b,c
	Strategy 2	c,b	d,d

Two-player binary choice game

Assume, $n = 2$ countries decide to cooperate on emission reduction or to pollute

- Cooperation of n countries generates nB benefits
- Cooperation implies C cost
- Hence if two countries cooperate, their payoff is given by

$$\pi_i = \pi_j = 2B - C$$

- If one country cooperates and the other free-rides, then the co-operator receives

  $$\pi_i = B - C$$

  and the free-rider

  $$\pi_j = B$$

- If both free-ride, then $\pi = 0$.

Two-player binary choice game

		Country Y	
		Pollute	Abate
Country X	Pollute	$0, 0$	$B, B - C$
	Abate	$B - C, B$	$2B - C, 2B - C$

- Full cooperation pays globally and individually if: $2B > C$
- Individual cooperation does not pay: $B < C$

Prisoner's Dilemma

Let $B = 2$, $C = 3$ as in Barrett (2003), Ch. 3

		Country Y	
		Pollute	Abate
Country X	Pollute	0,0	2, -1
	Abate	-1,2	1, 1

Which solution to this game can we suggest?

Game-theoretic solution

To predict an outcome, we need to consider how countries are handling strategic interdependency:

- individual rationality: dominant strategy equilibrium (DSE) and Nash equilibrium (NE)
- group rationality: Pareto optimal solution

Dominance

Definition

A strategy S **dominates** a strategy T if every outcome in S is at least as good as the corresponding outcome in T, and at least one outcome in S is strictly better than the corresponding outcome in T.

Remark: You can either say S dominates T, or T is dominated by S.

Definition

Dominance Principle: A rational player should never play a dominated strategy.

Nash Equilibrium

Definition

The situation (s_1^*, s_2^*), $s_1^* \in S_1$, $s_2^* \in S_2$, is called Nash Equilibrium (NE) if the following inequalities hold

$$\pi_1(s_1^*, s_2^*) \geq \pi_1(s_1, s_2^*), \ \forall \ s_1 \in S_1$$

$$\pi_2(s_1^*, s_2^*) \geq \pi_2(s_1^*, s_2), \ \forall \ s_2 \in S_2$$

Important feature: any deviation from Nash equilibrium made by a player cannot increase the player's payoff.

Pareto Optimality

Definition

An outcome of a game is non-Pareto-optimal if there is another outcome which would give both players higher payoffs, or would give one player the same payoff but the other player a higher payoff.

An outcome is called **Pareto optimal** if there is no such other outcome.

Prisoner's Dilemma

- DSE
- NE

		Country Y	
		Pollute	Abate
Country X	Pollute	0,0	2, -1
	Abate	-1,2	1,1

Is cooperation possible?

Classroom work

- Barrett 2003, Chapter 3
- Theory and experiments: cooperation vs. free-riding
- split in groups (2-4 students each)
- joint discussion

Prisoner's Dilemma

How to transform the game to make (*Abate*, *Abate*) a stable solution?

- binding agreement
- penalties

Prisoner's Dilemma transformed

Fine of '-2' units for playing unilaterally 'Pollute'

		Country Y	
		Pollute	Abate
Country X	Pollute	0,0	0, 1
	Abate	1,0	1,1

How does the outcome of the game change? Does it deter free-riding? Is cooperation self-enforcing?

Altruism and Side Payments effects

Game 1

Country X \ Country Y	Pollute	Abate
Pollute	0,0	-1, -1
Abate	-1, -1	1,1

Game 2

Country X \ Country Y	Pollute	Abate
Pollute	0,0	2, -1
Abate	-1, 2	3 ,1

N-person games. Example

Let $N = 10$ identical countries

Abating effort cost $C = 7$ and confer benefits $B = 7$

N-person games

Let $N \geq 2$
Barrett 1997

Let K be number of cooperators who contribute to public good. Then players' payoffs are

$$\pi_p = a + bK, \text{ if country pollutes}$$

$$\pi_a = c + dK, \text{ if abates}$$

Cooperation size is determined by K

The structure of the payoff is critical in determining whether cooperation can be sustained

N-person games. Example

$$a = 0, b = 5, c = -7, d = 5$$

		Number of abating countries other than i									
		0	1	2	3	4	5	6	7	8	9
Country i	Pollute	0	5	10	15	20	25	30	35	40	45
	Abate	-2	3	8	13	18	23	28	33	38	43

- Prisoner's dilemma revisited
- What is non-cooperative solution?
- Is cooperative solution stable?

N-person games. Example

Find non-cooperative and cooperative solutions to the game if

$$a = 12, b = 3, c = -7, d = 7$$

What is the minimum participation requirement to induce cooperation?

		Number of abating countries other than *i*									
		0	1	2	3	4	5	6	7	8	9
Country i	Pollute	12	15	18	21	24	27	30	33	36	39
	Abate	0	7	14	21	28	35	42	49	56	63

N-person games. Example

Find solution to the game if

$$a = 0, b = 5, c = 3, d = 3$$

What is the size of cooperation?

		Number of abating countries other than i									
		0	1	2	3	4	5	6	7	8	9
Country i	Pollute	0	5	10	15	20	25	30	35	40	45
	Abate	6	9	12	15	18	21	24	27	30	33

Basic Game-theoretic conclusions

Two main reason for using game theory

- Positive: Explain some observes real-world behavior
- Normative: How to reach certain desirable outcome

Summary of the simple model of the lecture

- Environmental problems can 'solve themselves' if they are privately beneficial for all the countries
- Environmental problems can be socially optimal but not privately optimal - very hard to solve
- Sometimes there are several equilibria and countries must to coordinate to pick the right ones