ECON4910 Environmental economics, Spring 2015

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Lecture 12: International environmental agreements

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Please bring lecture note to lecture.

Reading:
Perman et al. (2011): Sections 9.1-9.3
Barrett (2005)
Hoel: "Game theory…", included in this lecture note: pp. 1-21

Outline of lecture:

1) Introduction to the issues
2) 2-country game with binary choice (abate or not)

    Perman 9.1.1

    "Game theory…" pp. 1-5

3) The general case of several countries with continuous choice of abatement/emissions
    a. Non-cooperative and cooperative outcomes

        Perman section 9.1.4.1 and 9.1.4.2

        Barrett section 5

        "Game theory…" pp. 6 - 14

    b. Coalition stability

        Perman section 9.2.4

        Barrett section 6-8

        "Game theory…" pp. 15 - 24

Game theory, international environmental problems, and international climate agreements

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- concepts of game theory
- a simple pollution/abatement game
- extensions of the simple game
- carbon leakage
- types of international climate agreements
- free riding and stable coalitions
- endogenous technology

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Concepts of game theory

– players
– strategies
– payoffs

A game is characterized by how the *payoff* of each *player* depends on the *strategies* of all of the players

In a *Nash equilibrium* each player's strategy is a *best response* to the strategies chosen by all of the other players

2

A simple pollution/abatement game

Simplifications used throughout my lectures:

– ignore dynamic aspects of climate problem

– ignore uncertainty

– each country acts selfishly

Simplifications used first, modified later:

– only two countries

– identical countries

– binary choice (2 strategies): **A**bate or **D**on't abate

3

country 1: *A* or *D*

country 2. *a* or *d*

	a	*d*
A	(0,0)	(-1,1)
D	(1,-1)	$(-L,-L)$

Case 1: $0<L<1$; *Prisoner's dilemma*

D and *d* are *dominant strategies*, and (*D,d*) constitute a unique *Nash equilibrium*

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country 1: *A* or *D*

country 2. *a* or *d*

	a	*d*
A	(0,0)	(-1,1)
D	(1,-1)	(-*L*,-*L*)

Case 2: $L>1$; *Game of chicken*

No dominant strategies, (*A,d*) and (*D,a*) are both Nash equilibria

A more general pollution/abatement game

N countries; payoff of country j:

$$\pi_j = I_j - c(a_j) - D(e)$$

where
I_j = GDP, assumed exogenous
E_j = business as usual (BAU) emissions (assumed exogenous)
e_j = actual emissions ($\le E_j$)
$a_j = E_j - e_j$ = abatement, $a_j \in [0, E_j]$;
$e = \sum_j e_j = \sum_j \left(E_j - a_j\right)$ = sum of actual emissions

c_j and D_j are increasing and convex, with $c_j'' > 0$ and $D_j'' \ge 0$

The first-best social optimum

A useful reference is the abatement levels $(a_1^0, ..., a_N^0)$ and corresponding sum of emissions e^0 that maximize the sum of payoffs (often called the *social optimum*). It is straightforward to see that these abatement levels must satisfy (assuming an interior solution):

$$c_1'(a_1^0) = ... = c_N'(a_N^0) = \sum_i D_i'(e^0)$$

The first N-1 of these equations are the conditions for *cost-effectiveness*.

The Nash equilibrium

The Nash equilibrium is the abatement levels $(a_1^*, ..., a_N^*)$ and corresponding sum of emissions e^* that maximize the payoff for each country, given the abatement levels chosen by all other countries. It is straightforward to see that these abatement levels must satisfy (assuming an interior solution):

$$c_j'(a_j^*) = D_j'(e^*) \text{ for all } j$$

instead of the values maximizing the sum of payoffs (from previous slide):

$$c_j'(a_j^0) = \sum_i D_i'(e^0) \text{ for all } j$$

Example:
N identical countries each with abatement cost and environmental cost functions given by

$c(a) = \frac{a^2}{2}$ implying $c'(a) = a$

$D(e) = be$ implying $D'(e) = b$

which gives $a^0 = Nb$ and $a^* = b$

Carbon leakage

Two countries (or two groups of countries). Country 1 increases its abatement. What happens to abatement in country 2?

From $c_2'(a_2) = D_2'(E_1 + E_2 - a_1 - a_2)$

we get

$$\frac{da_2}{da_1} = \frac{-D_2''}{c_2'' + D_2''} \in (-1, 0]$$

Note: zero carbon leakage if $D(e) = be$

Other reasons for carbon leakage:
- lower international prices of fossil fuels
- higher international prices of traded energy-intensive goods

Empirical estimates:
- most studies: between 5 and 25 percent; some studies: much higher
- smaller for large countries (or groups of countries)?
- may depend on type of climate policy (e.g. uniform versus differentiated domestic taxes)

Types of international climate agreements

a) On emission levels
b) On coordinated policy
c) On coordinated R&D efforts to reduce BAU emissions and/or reduce abatement costs

Shall focus on (a):
– without any possibility of quota trading
– with free international quota trading

Without quota trading the condition for cost-effectiveness
$c_1'(a_1) = ... = c_N'(a_N)$
will generally not be satisfied

Quota trade. Let

$\overline{e}_j$ = emission ceiling for country j

p = quota price (same for all countries, determined in international market)

County j: Minimize $c_j(E_j - e_j) + p \cdot \left[e_j - \overline{e}_j \right]$

Gives $c_j'(a_j) = p$ for all j,

and quota price p is determined by

$$\sum_j e_j(p) = \sum_j \overline{e}_j$$

To summarize:

– cost-effectiveness is achieved through quota trading

– overall level of emissions may be set so the social optimum is achieved

– allocation of initial emission quotas determines how gains from cooperation are distributed among countries

BUT:

Even if all countries are better off with agreement than without, each country may be even better off if it does not cooperate, but the other countries do. I.e. free rider incentive!

Free riding and stable coalitions

A coalition is stable if no country or group of countries has an incentive to leave the coalition (and no country or group of countries has an incentive to leave the coalition)

What happens if one or several counties leave a potential coalition?

a) gamma-core (Tulkens): cooperation breaks down, end result is Nash equilibrium
b) two-stage non-cooperative game theory, (Carraro & Siniscalco, Barrett, and others): remaining countries continue to cooperate

We shall demonstrate:

Under (a) the “grand coalition” (coalition of all countries) is stable for a suitable distribution of initial quotas

Under (b) the maximal stable coalition is typically very small (only 3-4 countries if identical countries)

Shall restrict ourselves to the case of identical countries

Coalition of k countries ($1<k\leq N$).

Non-cooperative game between coalition and the N-k remaining countries. Superscripts c and n for coalition members and non-members.

Nash equilibrium given by abatement levels for coalition members and non-members:

$$c'(a^c) = kD'\left(E - \left[ka^c + (N-k)a^n\right]\right)$$

$$c'(a^n) = D'\left(E - \left[ka^c + (N-k)a^n\right]\right)$$

These equilibrium abatement levels give the equilibrium payoffs $\pi^c(k)$ and $\pi^n(k)$.

Gamma-core

Can show that $\pi^c(k)$ is increasing in k. This implies that the grand coalition is stable: No group of $k<N$ countries can improve these countries' payoffs by leaving the grand coalition and forming a sub-coalition.

Chander and Tulkens have extended this to the case of heterogeneous countries for an appropriate structure of transfers between countries.

Two-stage non-cooperative game

Stage 1: cooperate or not
Stage 2: choose emission levels (analysed previously)

Stage 1: Define $\Phi(k) = \pi^c(k) - \pi^n(k-1)$

A coalition of k counties is an equilibrium if

$\Phi(k) \geq 0$ (for $k>1$) "Internal stability"

$\Phi(k+1) \leq 0$ (for $k<N$) "External stability"

Can show: k will typically be small (2-4)

Example: cost functions as in previous example

$$a^c(k) = kb$$
$$a^n(k) = b$$
$$e(k) = E - \left[k(kb) + (N-k)b\right] = (E - Nb) + bk(1-k)$$
$$\pi^c(k) = I - \frac{1}{2}(kb)^2 - b\left[(E-Nb) + bk(1-k)\right] = const. + \frac{b^2}{2}(k^2 - 2k)$$
$$\pi^n(k) = I - \frac{1}{2}(b)^2 - b\left[(E-Nb) + bk(1-k)\right] = const. + \frac{b^2}{2}(k^2 - k - 1)$$

$$\Phi(k) = \frac{b^2}{2}\left[4k - k^2 - 3\right]$$

so

$\Phi(1) = 0$
$\Phi(2) = 1$
$\Phi(3) = 0$
$\Phi(k) < 0$ for $k>3$

so coalitions of size 2 and 3 are stable.

Note: Nash equilibrium is not unique; even for a given coalitions size the equilibrium does not tell us which countries will be members. Note in particular that $\pi^c(k) > \pi^n(k)$, so better to be outside than inside coalition! (Game of chicken)

Extensions/modifications

- policy costs of free riding (Hoel & Schneider)
- farsightedness
- credible threats to deter free riding

Endogenous technology

- Technology development may reduce BAU emissions and/or abatement costs
- Technology development often classified as caused by "Learning by doing (LbD) or by "Research and Development" (R&D)
- Both LbD and R&D may depend on climate policies and on design of international agreement

Shall focus on R&D and consider two issues:
- carbon leakage
- design of an international climate agreement

Carbon leakage with exogenous technology:
Reduced emissions in country A => increased emissions in country B due to
- increasing marginal environmental costs
- lower international prices of fossil fuels
- higher international prices of traded energy-intensive goods

Additional effect with endogenous technology:
- reduced emissions in country A => improved technology in country A and B
- improved technology in country B => reduced emissions in country B

Sketch of a model (Golombek and Hoel):

For each country:

$c(a,y)$	abatement costs	$c_y < 0$ and $c_{ay} < 0$
a	abatement	
$y = x + \gamma \Sigma x^*$	technology level	
x	R&D expenditures	

Model applied to carbon leakage
(when carbon leakage is zero if technology is exogenous):

Increased concern for the environment in country A =>
- lower emissions and increased R&D in country A
- lower R&D and *unchanged* emissions in country B

BUT *lower* emissions in country B if
- no R&D in country B initially, or
- technology spillovers are non-linear

Model applied to international agreements:

Without any agreement:

Nash equilibrium gives
- too little abatement
- too little R&D

Ideal agreement (first-best social optimum) should encourage both abatement and R&D

Agreement only on emissions (and not on R&D):

Stage 1: Emission levels, i.e. abatement levels, determined in agreement
Stage 2: Each country chooses its own R&D level non-cooperatively

Assume identical countries.

In stage 2 each country takes the abatement level a as given and R&D expenditures x are determined non-cooperatively, i.e. each country chooses its R&D to maximize its own payoff

$$\pi = I - c(a, x + exogenous) - x - D(exogenous)$$

giving x as an increasing function of a, and thus

$$y = x(a) + \gamma(N-1)x(a) = y(a)$$

In stage 1 a is chosen to maximize the common payoff

$$\pi = I - c\left(a, y(a)\right) - x(a) - D\left(N(E-a)\right)$$

It can be shown that the (second-best) optimal abatement level a^0 satisfies

$$c_a\left(a^0, y(a^0)\right) > ND'\left(N(E-a^0)\right)$$

i.e. "more abatement" than in the first-best social optimum

A technology based climate agreement

- what exactly is such an agreement?
  - an agreement leading to more abatement cost reducing R&D than countries otherwise would have carried out
  - could either focus directly on R&D investments or on policies stimulating R&D
- is such an agreement feasible?
  - difficult to monitor such an agreement
  - perhaps more difficult to directly monitor magnitude of R&D investments than policies that stimulate R&D

A technology based climate agreement (cont.)

- is a technology agreement less vulnerable to free riding than a "conventional" agreement?
  - free rider incentive if potential free rider can obtain benefits without paying costs
  - likely to be similar in technology agreement as in conventional agreement (Barrett, 2006)
  - Buchner and Carraro (2005): technology spillovers only to coalition members

A technology based climate agreement (cont.)

- does a technology agreement have other advantages compared with a "conventional" agreement?
  - conventional agreement: some sectors typically bear a disproportionately high share of costs
  - technology agreement: costs more evenly distributed, and benefits to some sectors

Background/references:

S. Barrett (2006), “Climate treaties and “breakthrough” technologies. *American Economic Review* 96 (2), pp. 22-25.

B. Buchner and C. Carraro (2005): “Economic and environmental effectiveness of a technology-based climate protocol”. *Climate Policy 4,* 229-248.

R. Golombek and M. Hoel: “Unilateral Emission Reductions and Cross-Country Technology Spillovers”, *Advances in Economic Analysis & Policy*: Vol. 4: No. 2, Article 3 (2004). (http://www.bepress.com/bejeap/advances/vol4/iss2/art3)
[Also printed as chapter 8 in D. Fullerton (ed.): The Economics of Pollution Havens, Edward Elgar, 2006.] Sections 4 and 6 may be skipped.

R. Golombek and M. Hoel: “The Kyoto agreement and technology spillovers”. Memorandum from the Department of Economics, no 5/2005. (http://www.oekonomi.uio.no/memo/memopdf/memo0505.pdf)

M. Hoel (1997), "How Should International Greenhouse Gas Agreements Be Designed?", in P. Dasgupta ,K.-G. Maler and A. Vercelli (eds.): *The Economics of Transnational Commons* , Clarendon Press, Oxford ; pp. 172-191. Section 7 may be skipped.

M. Hoel and K. Schneider, 1997, "Incentives to participate in an international environmental agreement", *Environmental and Resource Economics* 9, pp.153-170. Sections 1-3.

R. Perman, Y. Ma, J. McGilvray and M. Common: *Natural Resource and Environmental Economics*, Pearson, 3rd edition, 2003. Chapter 10 (“International environmental problems”)

Jean Tirole: *The theory of industrial organization*, MIT Press, 1988.
Chapter 11 (“Noncooperative game theory. A user’s manual”), in particular sections 11.1-11.3

H. Tulkens (1998), “Cooperation versus free-riding in international environmental affairs: two approaches”, in N. Hanley and H. Folmer (eds.): Game Theory and the Environment, Edward Elgar, pp. 30-44.