LA006: Climate Change

Game theoretic analysis of climate change

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Beyond Nash equilibrium

- Mechanism Design – pollution/carbon trading
- Refinements of Nash equilibrium
  - Perfect equilibrium
  - Evolutionary stability
- The Nash Programme
  - No binding agreements – Nash equilibrium
  - Threatening our way to binding agreements – Nash bargaining
  - Groups formation in a post-threat world: cooperative games (core and value)
- Public goods games

Mechanism design

- This is game theory inverted –
- Regular approach:
  - specify rules of the game (to represent the players' understanding of their interaction)
  - Impose solution concept (to summarise the information, not to predict the outcome!)
- Mechanism design
  - identify desirable outcome (depending on players' fragmented and uncoordinated information and powers of action)
  - Devise rules of a game whose play will lead to this outcome under specified solution concept
- Examples
  - Markets (mechanism includes *property rights*)
  - Auctions (a generalised form of market)
  - Treaties and agreements

Mechanism design, 2

- Tradable pollution rights are property rights to pollute
- Long and chequered history
- *Should* enable creation of an additional market sector:
  - Price of permit should reflect full societal cost of pollution
  - Price becomes part of the cost of polluting activities
  - Manufacturers choose between permits, abatement or reduced production
  - This increases demand for abatement technologies and should stimulate R&D
  - Increases consumer prices of polluting goods
  - Firms best able to purchase permits = those whose output society values the most
- Doesn't work out that way:
  - Rights cannot be perfectly defined, monitored or enforced esp. for global public bads
  - Trading is not universal (multilateral trades involving all participants are infrequent, bilateral and sparse trading networks are the rule)
  - The initial amount of permits is indeterminate – it depends on the effectiveness of alternatives to emission, which in turn depends on the (price) incentives for R&D, which depends on the amount of permits!
  - Market is not competitive; monopolistic distortion in permit market *and* in markets for goods produced using permits

Bad mechanism design LA AQMD

- Initial allocation chosen at random; rights not time-limited
- Bad design
  - Too few permits means price is too high
  - This encourages (esp. small) polluters to run the risk of prosecution rather than invest in permits
  - Monitoring and enforcement are more costly for small (and numerous) firms – probability of detection drops
  - Countervailing objectives: stimulate or sustain SMEs
  - Trading network is sparse: SMEs may not be able to force large firms to sell permits
- Result:
  - Prices rose – faster than rate of interest
  - ‘MDR firms’ arose that consisted of filing cabinets full of permits – and nothing more
  - Resulting scarcity drove prices of permits up, use of permits down

Item to consider: cap and trade

- In the absence of a system, get global Prisoners' Dilemma

	Not Pollute	Pollute
Not Pollute	(3,3)	(0,4)
Pollute	(4,0)	(1,1)

- With C&T, can buy permits to pollute from other countries (4, 0) becomes (2,2)

	Not Pollute	Pollute
Not Pollute	(3,3)	(2,2)
Pollute	(2,2)	(1,1)

- Abatement becomes a dominant strategy

What's wrong?

- As with AQMD, profit from trading leads to inefficiently high prices, maldistribution of production, too little abatement
- Public goods inefficiency is worse than trading inefficiency
- An alternative: voting (Crampton/Stoft or Cave/Salant)
- Basic idea: vote on *common* constraint (e.g. carbon price or level of abatement) – country x is just constrained at level xi
  - Countries that are not constrained at a pair of alternatives will prefer (vote for) the tighter one – it squeezes the economic competition and the polluting neighbours
  - Partial agreement – preferences over binding constraints are not monotonic, but if xi < xj and i prefers looser constraint, so does j; if j prefers tighter constraint, so does I
  - Result: ideal point of median country is selected;
    - this involves more abatement than laissez faire or market
    - Incentives to invest, innovate better aligned with impact on environment

Refinements of Nash equilibrium: perfectness

- Consider a static repeated game of pollution control: the underlying game is (say) prisoners' dilemma – the strategies for each country in each period are: {Not Pollute, Pollute}. Payoffs per period are:

	Not Pollute	Pollute
Not Pollute	(3,3)	(0,4)
Pollute	(4,0)	(1,1)

- Consider the following strategies for a repeated game:
  - If the other countr(ies) have always played Not pollute (since the agreement was signed), then play Not pollute
  - Otherwise, play Pollute
- This 'solves' the dilemma if the discount factor is large enough:
  - The payoff to adhering to the strategy is 3 forever:

$$V^e = 3 + \frac{3}{1+r} + \frac{3}{(1+r)^2} + \cdots; \text{note that } V^e - \frac{V^e}{1+r} = 3, \text{so } V^e = \frac{3(1+r)}{r}$$

  - The payoff to defecting – if everyone else uses this strategy – is 4 followed by 1 forever:
  - $V^d = 4 + \frac{1}{1+r} + \frac{1}{(1+r)^2} + \cdots$; so $V^d = \frac{1+4r}{r}$
- The strategy is an equilibrium if r $\leq$ 2 - if the interest rate is 'small enough'

Really?

- It makes intuitive sense that a strategy of unrelenting punishment will deter defection if
  - The future matters enough (r is small)
  - All players value the future equally
  - The punishment is credible
- The latter is the object of ‘perfect equilibrium’ –intuitively, the idea that any threatened punishment will actually be carried out.
  - In the prisoners’ dilemma, this is easy to see: the punishment is a Nash equilibrium
  - In other games, this logic might not be compelling: unending punishment is **very** costly, and not collectively rational
  - Consider a game with profitable punishment (e.g. trade sanctions):

	Not Pollute	Pollute	Punish
Not Pollute	(3,3)	(0,4)	(-1,5)
Pollute	(4,0)	(1,1)	(-1,5)
Punish	(5,-1)	(5,-1)	(-5,-5)

  - As before, play Not Pollute if no one has ever defected
  - If player I has defected, play ‘Punish’ for just long enough to deter initial defection: t periods where the present value of defection: 4, -1,…-1 (t times), 3, … (return to cooperation) is just less than never defecting (3 forever) (formulas a bit messy)
  - But this isn’t enough; need to threaten the ‘punishing’ player with punishment if they don’t lift the sanctions.
  - If the punishment itself was costly, would need to punish the non-defecting player for failure to punish.

Results and practical implications

- Folk Theorems: if players care enough about the future, almost anything *can* be an equilibrium, a large subset can be a perfect equilibrium
- May need to adjust payoffs to get a good equilibrium, or to adjust discount rates (e.g. by long-term cooperation agreements)
- May need to commit to irrationality to get rid of bad equilibria

The value of a short memory

	Not Pollute	Pollute
Not Pollute	(3,3)	(0,4)
Pollute	(4,0)	(1,1)

- Consider the repeated Prisoner’s Dilemma if players can only remember what the opponent did the previous round. Clearly cannot ‘punish forever’
- There are 8 pure strategies: 2 choices each for the first day (when there is no history); 2 choices if the opponent played ‘Not pollute’ last time; and 2 choices if the opponent played ‘Pollute’ last time.
- The strategy ‘Pollute forever’ (P, P, P) is a Nash equilibrium in this 8 x 8 game; indeed, it weakly dominates many other strategies (it is never worse, and sometimes better).
- A player unsure of his opponent’s rationality and control will never use a weakly dominated strategy – if this is *common knowledge* we can successively eliminate weakly dominated strategies (as bad strategies disappear, new dominance relations appear)
- After (P, P, P) has killed off many other strategies, we are left with only 2 (shown with their long-run average payoffs) – and now Tit for Tat drives out the old Nash equilibrium

	Tit for tat (N, N, P)	Pollute forever (P, P, P)
Tit for tat (N, N, P)	(3,3)	(1,1)
Pollute forever (P, P, P)	(1,1)	(1,1)

Refinements of Nash equilibrium: Evolutionary stability

- In a symmetric game with two players, a strategy S is *evolutionarily stable* if for all alternative strategies T:
  - $U_1(S,S) > U_1(T,S)$ **or**
  - $U_1(S,S) = U_1(T,S)$ **and** $U_1(S,T) > U_1(T,T)$
- That is, either S is the only best reply to T or T is equally good but will not succeed in taking over from S.
- This is obviously stronger than Nash $[U_1(S,S) \geq U_1(T,S)]$

  - In the pollute thy neighbour game Clean, Clean and Dirty, Dirty and both

	Clean	Dirty
Clean	4,4	0,4
Dirty	4,0	4,4
Pollute thy neighbour		

	Invest in R&D	Do not invest
Invest in R&D	0,0	-1,1
Do not invest	1,-1	-10,-10
Chicken (Hawk-Dove)		

  - In the pollute thy neighbour game Clean, Clean and Dirty, Dirty and both Nash, but only Dirty, Dirty is evolutionarily stable
  - In the game of Chicken, neither strategy is evolutionarily stable (there are no symmetric equilibria)

A further alternative: dynamic stability

- There are two approaches to the ‘evolution of conventions’ (e.g. regarding climate change).
- Choosing strategies in a ‘social’ setting – trying to cohere with your neighbours
- Epidemiological approach – ‘catching’ good or bad attitudes from contacts ($B<1$; $A < 3$)

	Good	Bad
Good	(3,3)	(B,A)
Bad	(A,B)	(1,1)

The Nash Programme

- No binding agreements – Nash equilibrium
- Threatening our way to binding agreements – Nash bargaining
- Groups formation in a post-threat world: cooperative games (core and value)

Bargaining

- In the bargaining problem, players try to choose an *agreement* (a member of a set A); if they fail, they will get *disagreement* (or threat) payoffs d.
- This provides a way of analysing *climate change negotiations*, though it is oversimplified in some respects (e.g. monitoring and enforcement, ability of negotiators to commit or speak for their ‘hinterlands’, issue linkage)
- It can also be used to model *tradable pollution permits* (or carbon trading), though ideally, this should be modelled as a cooperative or market game
- The bargaining model can be used where underlying assumptions do not hold (markets are not competitive, trading takes time/is sequential, traders do not have perfect information, trade is multilateral, rights are clearly defined and enforceable and transactions costs are negligible)

Th Nash bargaining solution

- Axioms:
  - Individual rationality (agreement better than disagreement)
  - Independence of equivalent representations (monotone changes in utility)
  - Symmetry (names don't matter – no bargaining power)
  - Independence of irrelevant alternatives (adding a new agreement either results in that one being chosen or does not affect the result)
- Result: unique selection of the outcome that maximises the product of the bargainers' gains compared to the threat point