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Climate Change and Game Theory

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The Problem

- Global cooperation to reduce greenhouse gas emissions is difficult, because there are significant free-rider incentives
- We need to find mechanisms that facilitate cooperation between states
- Game theory can help up understand strategic behaviour in this situation, and find mechanisms to address this problem

- Many of these mechanisms are likely to be associated with international treaty-making

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Game Theory

- Non-cooperative Game Theory
  - Helps us to understand the behaviour of players who are aiming to maximise their utility
  - Two types of game:
    - Normal Form Games – often represented by 'payoff matrices'
    - Extensive Form Games – analyse dynamic behaviour
- Implementation Theory
  - Analyses how to design a non-cooperative game whose solution corresponds to a socially optimal outcome
- Cooperative Game Theory
  - Analyses the formation of coalitions, where players behave cooperatively within the coalition, and non-cooperatively towards other coalitions

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Normal Form Games

- Specify
  - The set of players
  - A set of strategy combinations, each strategy combination assigns a strategy to each player
  - A set of payoffs received by each player for each possible strategy combination
- The key solution concept is the *Nash equilibrium*
- The Nash equilibrium is a strategy combination where no single player can improve their payoff by playing a different strategy when the other players are playing their Nash equilibrium strategy

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Example: The Prisoner's Dilemma

- A normal form game
- The payoffs for an example of a prisoner's dilemma can be expressed using the following table:

	Abate	Pollute
Abate	10, 10	0, 11
Pollute	11, 0	1, 1

- The Nash equilibrium has each player continuing to pollute

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Example: Normal Form Climate Change Game

- A continuous 'prisoner's dilemma'
- Each player represents a country that is choosing its level of greenhouse gas emissions
- Each player receives benefits from its pollution, and damages from everyone's pollution
- Let the utility of player *i* be given by

$$\pi_i = B_i(e_i) - D_i(\Sigma_j e_j)$$

where the emissions *benefit function* B_i satisfies $B_i' > 0$ and $B_i'' \leq 0$ and the emissions *damage function* D_i satisfies $D_i' > 0$ and $D_i'' \geq 0$.

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Example: Normal Form Climate Change Game

- Recalling that

$$\pi_i = B_i(e_i) - D_i(\Sigma_j\, e_j)$$

we can calculate the Nash equilibrium by maximising each π_i subject to the constraint that the other π_i's are also maximised

- The social optimum can be calculated by maximising $\Sigma_i \pi_i$
- The Nash equilibrium involves significantly less emission reductions and less net benefits than the socially optimal outcome
- But it does involve some emission reductions

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Extensive Form Games

- An explicit description of the sequential structure of the decision problems faced by the players in a strategic situation
- Key solution concept is the *subgame perfect equilibrium*
- A subgame perfect equilibrium is a strategy combination which is also a Nash equilibrium for every subgame of the entire game
- For finite horizon extensive form games, the subgame perfect equilibrium can be calculated by *backwards induction*, this involves working backwards from the last stage of the game

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Example: A Treaty Ratification Game

- Extensive form game with two stages. The players consist of countries
  - Stage 1: the countries negotiate a treaty
  - Stage 2: each country decides whether to ratify the treaty

- In order to ratify a treaty, the United States requires 67 out of 100 Senate votes, making ratification difficult
- Backwards induction suggests that negotiators will take into account that a treaty will have to be sufficiently aligned with the domestic interests of the United States, in order for it to be ratified by the United States.

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Example: A Treaty Participation Game

- Players again consist of countries, negotiating a climate change agreement
  - Stage 1: all players choose whether to be a signatory or non-signatory to an agreement
  - Stage 2: signatories collectively choose their emissions, with the objective of maximising their collective payoff
  - Stage 3: non-signatories individually choose their emissions, with the objective of maximising their individual payoff
- Subgame perfect equilibrium can be found with backwards induction
- For 2 players, the game will lead to a socially optimal outcome, but for more players this is unlikely

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Implementation Theory

- How can we design games whose solutions correspond to cooperative outcomes?
- We are dealing with an international problem, and there is no world government. So we are particularly interested in games which do not require strong institutions.

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Example: Provision Point Mechanisms

- Due to Bagnoli and Lipman (1989), Admati and Perry (1991)
- Each player voluntarily commits an amount of their choice to the provision of a public good
- If the total amount of contributions add up to a pre-determined amount (the cost), then the players pay and the good is provided
- If not, then nobody has to pay, and the good is not provided
- The solution of this game has the good being provided if its total value to the players is greater than the cost

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Example: Matching Abatement Commitments

- Due to Boadway, Song and Tremblay (2009)
- Same payoffs as the climate change game
- An extensive form game where each country *i* choose 'matching rates' for the other countries and a level of 'direct abatement'
  - Stage 1: Countries choose matching rates m_{ij}, the rate at which they increase their abatement based on other country *j*'s direct abatement levels
  - Stage 2: Countries choose their direct abatement level, a_i
- The total abatement of each country is the sum of that countries direct abatement with the product of the matching rate and the other countries' direct abatement

$$A_i = a_i + \Sigma_{j \neq i} m_{ij} a_j$$

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Example: Matching Abatement Commitments

- The subgame perfect equilibrium of this game achieves the efficient level of pollution abatement
- If a third stage is added where countries trade permits, marginal abatement costs are equalised leading to more efficiency
- The model can also be extended to more than one time period, with the pollutant being treated as a stock pollutant. In this case, abatement is allocated efficiently between periods

- This game requires that countries can *commit* to their matching rates

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A Deposit Based Compliance Mechanism

- Due to Gerber and Wichardt (2009)
- Same payoffs as the climate change game
- Stage 1: Each player is required to pay a deposit
- Stage 2: Two possibilities:
  - If not all players paid the deposit, they are refunded and the underlying public goods game is played
  - If all players paid the deposit, they are required to make a pre-specified contribution to the public good. If they make the contribution, they get their deposit back.
- Subgame perfect equilibrium is for each player to contribute the specified amount to the public good.
- Players ‘execute their own punishment’

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Cooperative Game Theory

- Cooperative game theory investigates situations where groups of players may enforce cooperative behaviour
- For cooperative games, the outcomes of interest consist of a partition of the players into coalitions, and actions for each coalition
- Players in a coalition behave cooperatively with each other, and non-cooperatively with respect to other players and coalitions

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Transferrable Utility Games and the Core

- *Transferrable utility* games represent games where there can be transfer payments within a coalition
- The *core* of a transferrable utility game is the set of all possible outcomes in which no coalition can break away from a *grand coalition* of all players in such a way that all of its members are better off
- The core tells us about the stability of a grand coalition
- If the core is not empty, cooperation is more feasible

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Example: The γ-Core

- Due to Chander and Tulkens (1997)
- We consider a transferrable utility game based on the climate change game
- We assume that if any coalition breaks away from the grand coalition, then the grand coalition will dissolve into singletons acting non-cooperatively
- Chander and Tulkens show that the γ-core is not empty

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Coalition Externalities

- Interested in the behaviour of multiple coalitions
- If the merging of two coalitions benefits other coalitions, then we say it has a *positive coalition externality*
- If the merging of two coalitions reduces the payoff for other coalitions, then we say it has a *negative coalition externality*
- The climate change game is an example of a positive coalition externality game
- The formation of customs union is an example of a negative coalition externality
- It is easier to form a grand coalition for a negative coalition externality game (Maskin, 2003)

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Issue Linkage and Trade

- It is possible to link issues by adding the associated payoffs together
- If game with positive coalition externalities (e.g. climate change) is linked to a game with negative coalition externalities (e.g. trade), it may be possible to have a larger and more stable coalition than is possible with just the positive coalition externality game
- This could lead to more cooperation, but that would depend in detail on how the issue linkage works

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The UNFCCC Negotiations

- At CoP 15 and subsequent meetings countries will attempt to negotiate commitments that may be stronger and more comprehensive than have so far been negotiated under the Kyoto protocol
- Issues also being negotiated include financing for mitigation and adaptation in developing countries, compliance, the legal framework for a post-2012 agreement and accounting issues

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The UNFCCC Negotiations

- Game theory is relevant to the question of whether trade measures should be linked to compliance
- The mechanisms described before including provision point mechanisms and matching abatement commitment mechanism could help lead to stronger emission reductions. They could also facilitate the provision of finance for mitigation and adaptation.
- Some participants in the negotiations, including Australia and the EU, have signalled that they would be prepared to strengthen their commitments if others do the same. This has similarities to the above mechanisms.