THE AUSTRALIAN NATIONAL UNIVERSITY

Climate Change and Game Theory

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Climate Change and Game Theory:
a Mathematical Survey

Peter John Wood *

May 5, 2010

Abstract

This survey paper examines the problem of achieving global cooperation to reduce greenhouse gas emissions. Contributions to this problem are reviewed from non-cooperative game theory, cooperative game theory, and implementation theory.

Solutions to games where players have a continuous choice about how much to pollute, games where players make decisions about treaty participation, and games where players make decisions about treaty ratification, are examined. The implications of linking cooperation on climate change with cooperation on other issues, such as trade, is examined. Cooperative and non-cooperative approaches to coalition formation are investigated in order to examine the behaviour of coalitions cooperating on climate change.

One way to achieve cooperation is to design a game, known as a mechanism, whose equilibrium corresponds to an optimal outcome. This paper examines some mechanisms that are based on conditional commitments, and could lead to substantial cooperation.

Outline

We will review how game theory can be applied to climate change mitigation, then discuss policy implications.

- Non-cooperative Game Theory
- Coalitions
- Implementation Theory
- Policy Implications

The Problem

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- We need to find mechanisms that facilitate cooperation, such as international negotiations
- Game theory can help up understand strategic behaviour in this situation, and find mechanisms to address this problem

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  - 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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		Player 2	
		Abate	*Pollute*
Player 1	*Abate*	$(-1, -1)$	$(-10, 0)$
	Pollute	$(0, -10)$	$(-9, -9)$

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- The Nash equilibrium has each player continuing to pollute

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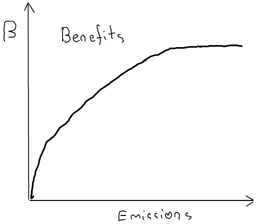
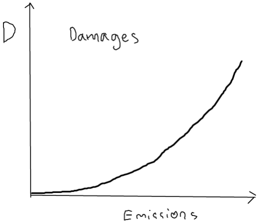
- Each player i represents a country that is choosing its level of greenhouse gas emissions e_i
- Each player has an emissions *benefit function* β_i satisfying $\beta_i' > 0$ and $\beta_i'' \leq 0$; and an emissions *damage function* D_i satisfying $D_i' > 0$ and $D_i'' \geq 0$.





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- The Nash equilibrium involves significantly less emission reductions and less net benefits than the socially optimal outcome – but does involve some emission reductions

Noncooperative Game Theory – Extensive Form Games

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- The subgame perfect equilibrium can be calculated by *backwards induction*

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  - 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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- 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 it will not

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- Chander and Tulkens (1997) used cooperative game theory to investigate the stability of a *grand coalition* of all players, by investigating the situation where if any coalition breaks away from the grand coalition, then the grand coalition will dissolve into non-cooperative singletons
- They found that a grand coalition would be stable

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- It is possible to link issues by adding the associated payoffs together
- Possible issues include trade, and technology cooperation

Non-cooperative Approaches to Coalition Formation

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- For Stage 1, there are a large variety of coalition formation processes

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- The sequential move unanimity game (based on an exogenous ordering of players)

Implementation Theory

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- 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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- The social optimum is *implemented by a mechanism* via a *solution concept* if the solution concept corresponds to the same outcome as the socially optimal outcome

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- 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

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  - **Stage 2** Countries choose their direct abatement level, a_i
- The total abatement of each country is given by

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

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- 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
- This game requires that countries can *commit* to their matching rates
- Helps explain the significance of conditional targets.

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  - Another way that countries can make a commitment is by putting it in their domestic legislation

Thankyou