The Global Climate Game

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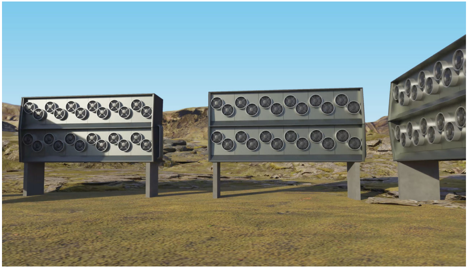
About Me

- Applied microeconomist
- Specialization: environmental/resource economics and public policy
- Methods: theoretical modeling, applied game theory
    - Did numerical calibrations; hope to run experiments as well

The Global Climate Game

Two Technologies

Technology 1: Cheap and dirty



Technology 2: Green but expensive

This paper

- First application of global games to environmental economics
- Resolves complications caused by equilibrium multiplicity
- Novel policy: network subsidies
- Sharp predictions on games of institutional choice

General Structure

- N players
- Two technologies: green and dirty
- Player i must invest dirty ($x_i = 0$) or green ($x_i = 1$)
- Marginal environmental benefit of green investment: b
- Total green investment/green network size: $m = \sum_{j \neq i} x_j$
- Cost of dirty investment: c^L
- Cost of green investment decreases in m: $c^H(m + 1)$

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- Technological investments are **strategic complements**

Payoffs

$$\pi_i(x_i \mid m, b) = \begin{cases} b \cdot m - c^L & \text{if} \quad x_i = 0 \\ b \cdot (m+1) - c^H(m+1) & \text{if} \quad x_i = 1 \end{cases}$$

Observe:

- Gain from investing green, rather than dirty, is *increasing* in b
- Gain from investing green, rather than dirty, is *increasing* in m
- If $b > c^H(1) - c^L$, players are strictly better off investing green
- If $b < c^H(N) - c^L$, players are strictly better off investing dirty

Strategic complements

- Network effects (Katz & Shapiro, 1985; Li et al., 2017)
- Technological/knowledge spillovers (Fischer & Newell, 2008; Hoel & De Zeeuw, 2010; Aghion & Jaravel, 2015; Harstad, 2016)
- Tipping points (Barrett & Dannenberg, 2012)
- Breakthrough technologies (Barrett, 2006; Hoel & De Zeeuw, 2010)
- Climate clubs (Nordhaus, 2015)
- (Social) norms (Allcott, 2011; Kuhn et al., 2011; Nyborg, 2018; Kverndokk et al., 2020)
- Cost sharing (De Coninck et al., 2008)
- Reciprocity

Problem

- Strategic complementarities $\rightarrow$ multiple strict equilibria
  - Barrett (2006), Hoel & De Zeeuw (2010), Harstad (2012, 2016), Barrett & Dannenberg (2012, 2017); Mielke & Steudle (2018)
  - Proposition in paper
- Solutions // complications
  - Equilibrium refinements // cannot eliminate strict equilibria
  - Hand-pick particular equilibrium // ad hoc
  - Run experiments // how to generalize?
- My proposal: **consider uncertainty**

Uncertainty and Signals

- Assume that b is not observed
- $b \sim \mathcal{U}(\underline{B}, \overline{B})$, where $\underline{B} < c^H(N) - c^L$ and $\overline{B} > c^H(1) - c^L$
- Player i: private noisy signal s_i of b

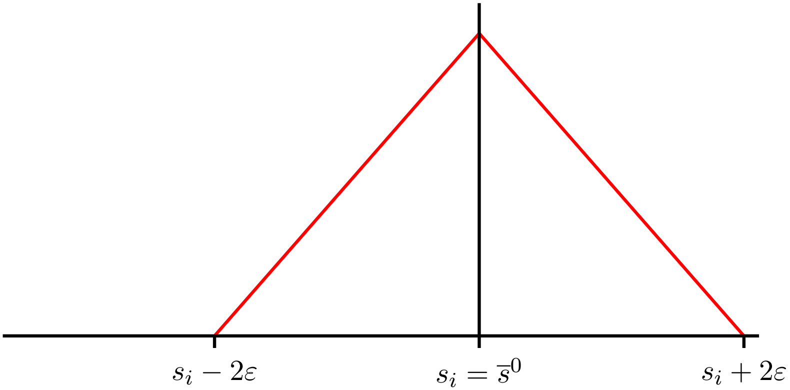
$$s_i = b + \varepsilon_i$$

- $\varepsilon_i \sim \mathcal{U}(-\varepsilon, \varepsilon)$, i.i.d.
- Information structure is common knowledge
- **Global game** (Carlsson & Van Damme, 1993; Morris & Shin, 1998; Frankel et al., 2007)

Dominant Strategies

- For very high s_i, player i adopts the green technology even if $m = 0$
- Let $\overline{s}^0$ be the initial signal such that player i is indifferent between dirty and green investment for $m = 0$
- When $s_i > \overline{s}^0$, adopting the green technology is a *dominant strategy*

Posterior distribution on s_j, given s_i



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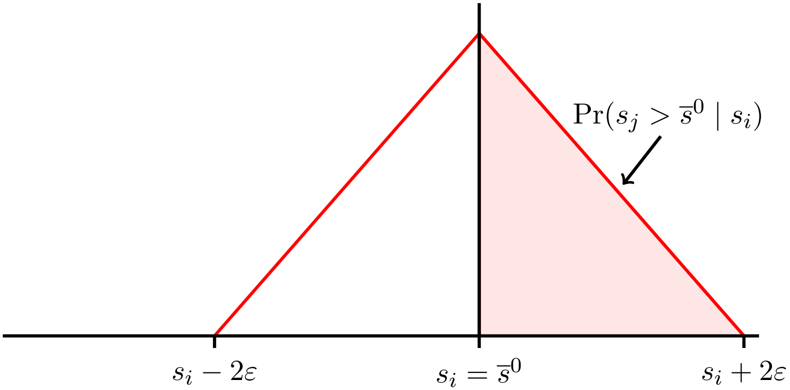

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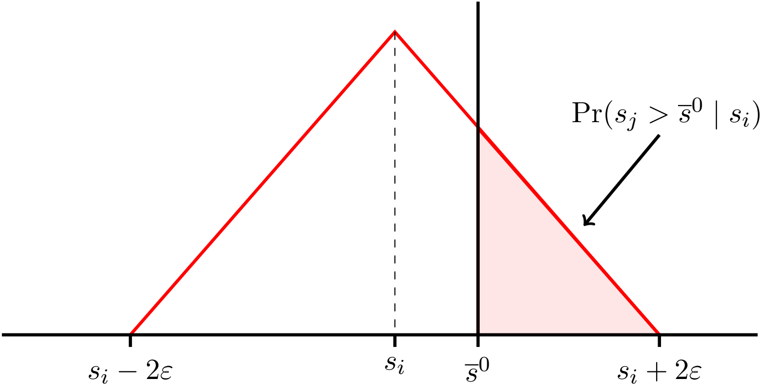

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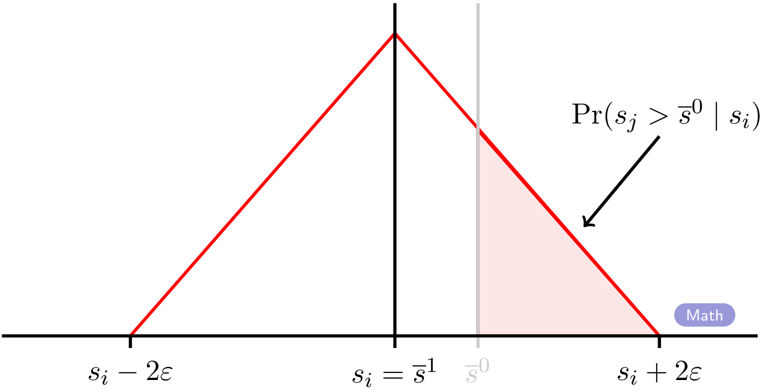

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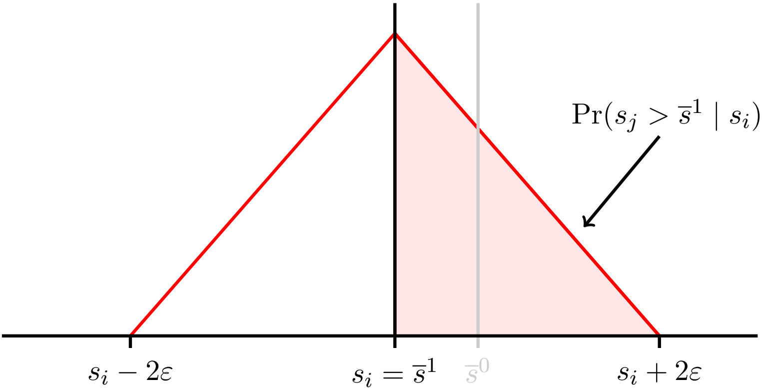
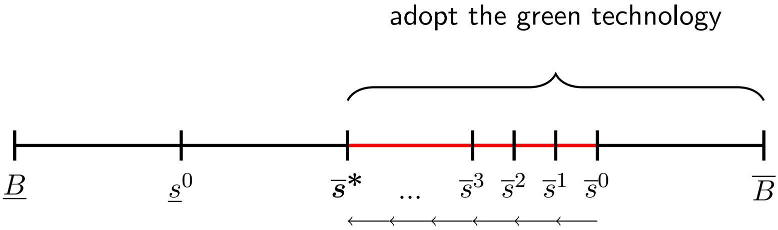


Induction and Convergence



Unique Equilibrium

Proposition 1

The global climate game has a unique equilibrium. There exists a unique threshold $b^* = (\overline{s}^* = \underline{s}^*)$ such that each player i invests in the green technology for all $s_i > b^*$, while s/he invest in the dirty technology for all $s_i < b^*$. When $\varepsilon \to 0$, the threshold b^* is given by:

$$b^* = \sum_{n=0}^{N-1} \binom{N-1}{n} \cdot \frac{c^H(n+1)}{2^{N-1}} - c^L.$$

Inefficiency

Corollary 1

Let $\varepsilon \to 0$. For all $b \in \left(c^H(N) - c^L, b^*\right)$, the equilibrium of the global climate game is inefficient. Players adopt the dirty technology even though payoffs are higher were all to adopt the green technology instead.

Network Subsidies

Taxes and Subsidies

- Policymakers can use taxes or subsidies to stimulate selection of the efficient equilibrium
- Complications:
  1. May need to be very high (Sartzetakis and Tsigaris, 2005; Greaker and Midttømme, 2016; Mielke and Steudle, 2018)
  2. Taxes not always feasible (e.g. in EU)
  3. Subsidies are expensive
  4. Returns multiple equilibria (Angeletos et al., 2006)
- My proposal: **network subsidies**

Network Subsidies

- Let a policymaker offer the following **network subsidy**:

$$t^*(m) = c^H(m+1) - c^H(N)$$

- Decreasing in m: "Insurance against small green network"
- Green technology universally adopted iff $b > c^H(N) - c^L$ (and ε small)
- Implies that $m = N - 1$ for all $b > c^H(N) - c^L$
- Hence, $t^*(m) = t^*(N-1) = c^H(N) - c^H(N) = 0$

Free Lunch

Proposition 2

Let $\varepsilon \to 0$. A network subsidy equal to t^* implements the efficient equilibrium of the underlying game but does not cost the policymaker anything.

- Well-designed network subsidy is effective and cheap
- Does *not* induce multiple equilibria

Institutional Choice

A Game of Games

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- Strategic complementarities endogenous?

IEAs: An Example

- Treaties targeting abatement are prisoners' dilemmas – achieve little (Carraro & Siniscalco, 1993; Barrett, 1994)

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- Focus on *technologies* can turn game in a coordination game (Barrett, 2006; Hoel & De Zeeuw, 2010; Hong & Karp, 2012; Battaglini & Harstad, 2016)
- Cost sharing, technological spillovers, dissemination of information and knowledge, etc.

Timing

1. Players vote on the game played in stage 2. They must choose between *(i)* a prisoners' dilemma in which adopting the dirty technology is a dominant strategy, or *(ii)* a coordination game. If the latter is chosen, all incur a cost d
2. Players receive their signals of b and play the game decided upon in stage 1

Unique Perfect Bayesian Equilibrium

Proposition 3

The two-stage game has a unique perfect Bayesian equilibrium. In the first stage, players choose to play a coordination game in stage 2 if and only if $d \leq d^*$. If the coordination game is chosen, players adopt the green technology if and only if $b > b^*$.

$$d^* = \frac{\overline{B} - b^*}{\overline{B} - \underline{B}} \left[N \cdot \frac{b^* + \overline{B}}{2} + c^L - c^H(N) \right]$$

Climate Clubs

Proposition 4

In the two-stage game, policies that (indirectly) increase c^L provide a twofold stimulus toward adopting the green technology.

1. *They make the voting on a coordination game more likely in stage 1*
2. *Conditional on the coordination game being chosen, they make adoption of the green technology more likely in stage 2*

Conclusions

Extensions

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    - U.S. Federal Tax Credit for Solar Photovoltaics, California's Clean Vehicle Rebate Project, or the U.S. National Plug-In Electric Drive Vehicle Credit, Dutch tax discount on electric vehicles for business drivers

Thank you!

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Characterization of $\overline{s}^1$

$$\underbrace{\sum_{n=0}^{N-1} \binom{N-1}{n} \left[\Pr(s_j > \overline{s}^0 \mid \overline{s}^1)\right]^n \cdot \left[\Pr(s_j < \overline{s}^0 \mid \overline{s}^1)\right]^{N-n-1} \cdot \Delta_i^{\varepsilon}(\overline{s}^1, n)}_{\text{Lowest expected gain from investing in } H \text{, given } \overline{s}^0 \text{ and } \underline{s}^0} = 0,$$

where $\Delta(s_i, m) := \pi_i(1 \mid s_i, m) - \pi_i(0 \mid s_i, m)$ is the expected gain (conditional on s_i and m) from investing green rather than dirty.

Back