The Global Climate Game

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Me

- Applied microeconomist: environmental/resource economics and public policy
- Expertise: theoretical modeling, applied game theory
  - Also interested in numerical calibrations; hoping to run experiments as well
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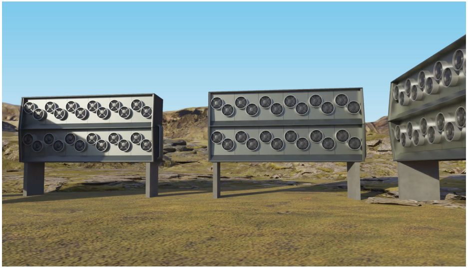
Introduction

Two Technologies

Technology 1: Cheap and dirty



Technology 2: Green but expensive.
"Breakthrough technology"

The Global Climate Game

General Structure

- N players
- Two technologies: green and dirty
- Player i must invest in the dirty $(x_i = 0)$ or the clean $(x_i = 1)$ technology.
- 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: $c^H(m+1)$

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- Cost of green investment: $c^H(m+1)$
- Green (and dirty) 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 adopting the green technology
- If $b < c^H(N) - c^L$, players are strictly better off adopting the dirty technology

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

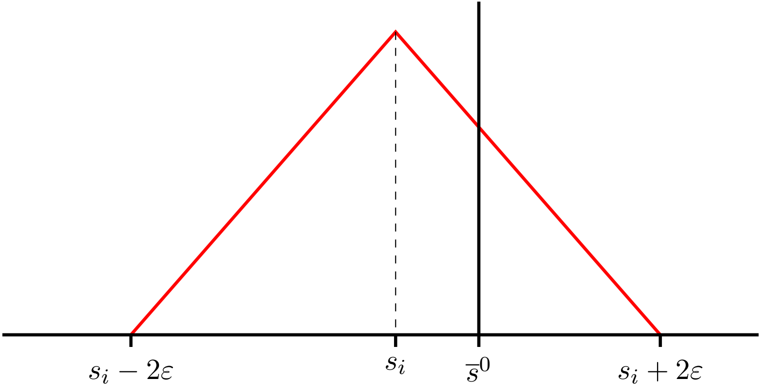
$$s_i = b + \varepsilon_i.$$

- $\varepsilon_i \sim \mathcal{U}(-\varepsilon, \varepsilon)$, 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 lower bound on signals for which $x_i = 1$ is dominant
- 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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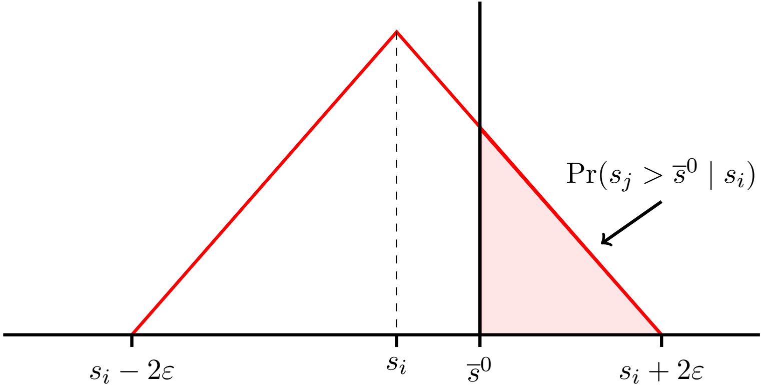

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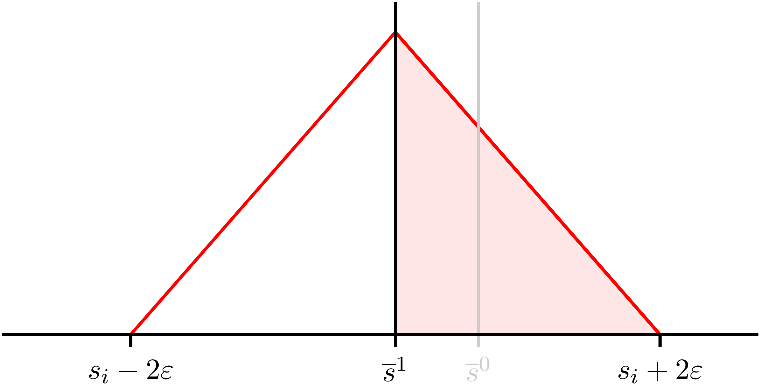

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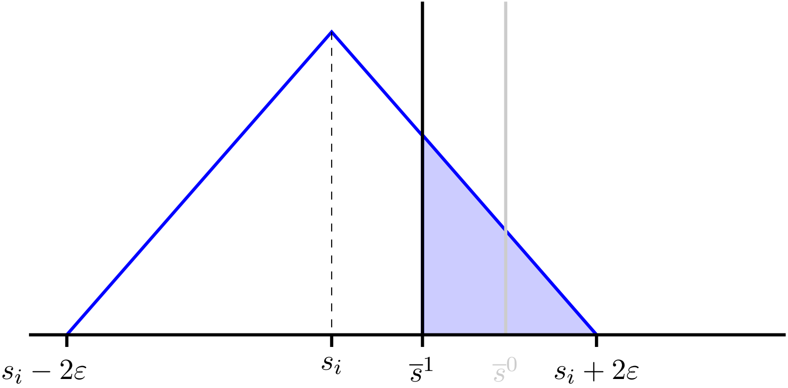

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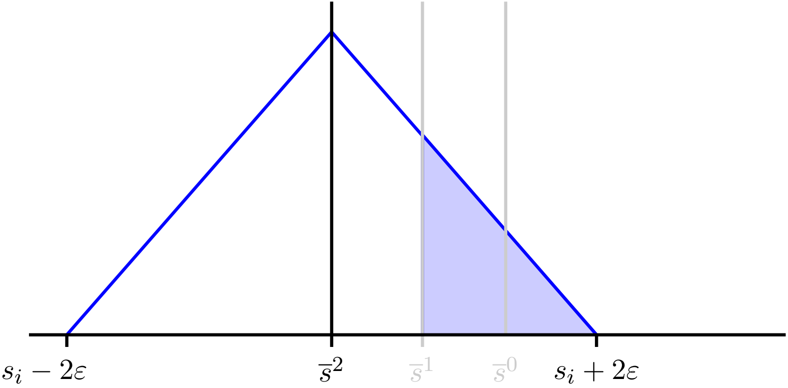

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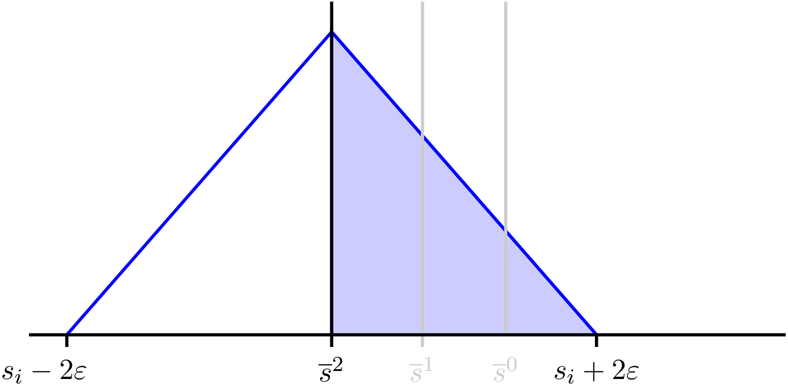
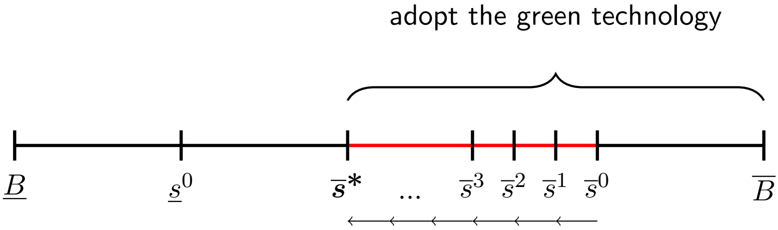


Induction and Convergence



Unique Equilibrium

Proposition 1

The global climate game has a unique equilibrium. There exists a unique threshold b^* 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:

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

Inefficiency

Corollary 1

For all $b \in \left(\frac{c^H(N)-c^L}{N}, b^*\right)$*, 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 solution: **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 $b > \frac{c^H(N)-c^L}{N}$ (and ε small)
- Implies that $m = N-1$ for all $b > \frac{c^H(N)-c^L}{N}$.
- Hence, $t^*(m) = t^*(N-1) = c^H(N) - c^H(N) = 0$.
- Well-designed network subsidy is effective and cheap.
- Does *not* induce multiple equilibria

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.*

Institutional Choice

A Game of Games

- "*In some important multiplayer situations, such as efforts to supply a global public good, players can choose the game they want to play* (Barrett & Dannenberg, 2017)."
- Two-stage game:

  Stage 1: vote on game to be played in stage 2. Criterion: minimum participation, simple majority, qualified majority, unanimity,...

  Stage 2: play the game voted upon in stage 1.
- Literature: Barrett & Dannenberg (2017); Dal Bó, Dal Bó, & Eyster (2018); Dannenberg & Gaulier, (2019).
- Strategic complementarities endogenous?

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.

IEAs: An Example

- Countries choose to sign an IEA targeting technologies
- But before that, they can forge an international R&D platform
- Cost sharing, technological spillovers, dissemination of information and knowledge, etc.
- Turns ratification stage in a coordination game (Barrett, 2006; Hoel & De Zeeuw, 2010; Hong & Karp, 2012; Battaglini & Harstad, 2016)

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 $d \leq d^*$. In the second stage, 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 increasing 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

Future work

1. Theoretical: two-sided green markets
2. Experimental: test network subsidies in the lab
3. Experimental: test (comparative statics of) two-stage game in the lab
4. Numerical/empirical: estimate potential cost-saving from using network subsidies instead in green markets, e.g. electric vehicles, photovoltaics, ...
    - 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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