Behavior in a Dynamic Environment with Costs of Climate Change and Heterogeneous Technologies: an Experiment

Svetlana Pevnitskaya and Dmitry Ryvkin

Florida State University
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New features of the environment
Pollution, depletion of resources and climate change lead to environmental damage and costs
  - externality problems
  - dynamic

Insufficient response to institutional arrangements
The current climate situation is likely matching or exceeding the worst-case scenarios predicted by the Intergovernmental Panel on Climate Change (IPCC), which issued warnings in 2007.

New features of the environment
  - Slow reversibility: National Oceanic and Atmospheric Administration (NOAA) determined that it would take more than 1,000 years to undo changes in temperature, sea level and rainfall after CO2 emissions had been completely stopped (NOAA, 2009)
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Technological heterogeneity is one of the challenges

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heterogeneous technologies
Model

There are $n$ risk neutral players.
In period $t$ player $i$ has endowment $m$ and chooses production allocation $x_{it} \in [0, m]$, which yields revenue $ax_{it}$, $a > 1$.

Production by $i$ in period $t$ generates emissions $e_{it} = q_i x_{it}$; with technology $q_i \geq 0$; (if $q_i = 0 \Rightarrow$ clean technology; baseline here $q_i = 1$)
Total level of emissions in period $t$, $E_t = \sum_{i=1}^{n} q_i x_{it}$ leads to pollution.

Pollution level at the end of period $t$, $Y_t$, evolves as

$$Y_t = \gamma Y_{t-1} + E_t; \quad Y_0 = 0.$$

where, $\gamma \in [0, 1]$ - retention rate of pollution.
Baseline.
Player $i$’s payoff in period $t$ is

$$\pi_{it} = m - x_{it} + ax_{it} - b\gamma Y_{t-1}. $$

$b > 0$ is the cost of unit of pollution.

$$\pi_{it} = m + (a - 1)x_{it} - b\gamma \sum_{k=1}^{t-1} \gamma^{t-1-k} E_k. $$

where $E_t = \sum_{i=1}^{n} q_i x_{it}$. 
In each period there is a continuation probability $\beta \in (0, 1)$. The expected payoff of player $i$ in period $t$ is

$$\Pi_{it} = \tilde{\Pi}_{i,t-1} + \sum_{k=t}^{\infty} \beta^{k-t} \pi_{ik}.$$ 

where, $\tilde{\Pi}_{i,t-1}$ is the payoff player $i$ has accumulated by the beginning of period $t$. 
Benchmark solution concepts:
Markov perfect Nash Equilibrium (NE) and social optimum (SO)

**Proposition 1.** The NE profile of inputs for a player with emission factor $q_i$ is to choose $x_{it} = 0, \forall t$, if $q_i > \bar{q}_N$; choose $x_{it} = m, \forall t$, if $q_i < \bar{q}_N$; and choose $\forall x_{it} \in [0, m], \forall t$, if $q_i = \bar{q}_N$. Here,

$$\bar{q}_N = \frac{a - 1}{b} \left( \frac{1}{\beta \gamma} - 1 \right). \quad (1)$$

**Proposition 2.** The SO profile of inputs for a player with emission factor $q_i$ is to choose $x_{it} = 0, \forall t$, if $q_i > \bar{q}_S$; choose $x_{it} = m, \forall t$, if $q_i < \bar{q}_S$; and choose $\forall x_{it} \in [0, m], \forall t$, if $q_i = \bar{q}_S$. Here,

$$\bar{q}_S = \frac{a - 1}{bn} \left( \frac{1}{\beta \gamma} - 1 \right). \quad (2)$$
Experiment Design

- \( n = 2, \ m = 10, \ a = 5, \ b = 1, \ \gamma = 0.75, \ \beta = 0.95 \)
Experiment Design

- \( n = 2, m = 10, a = 5, b = 1, \gamma = 0.75, \beta = 0.95 \)

<table>
<thead>
<tr>
<th>Treatments ((q_1, q_2))</th>
<th>(1,1)</th>
<th>(1,1.25)</th>
<th>(1,0.75)</th>
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<tbody>
<tr>
<td>Sessions</td>
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<td>22</td>
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Table: Experimental design and theoretical predictions for input levels \((x_{1t}, x_{2t})\), by treatment.
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**Table:** Experimental design and theoretical predictions for input levels \((x_{1t}, x_{2t})\), by treatment.

- Look at:
  - Production decision, \(x_t\)
  - Pollution, \(Y_t\)
  - Payoffs, \(\tilde{\Pi}_t\)
Theoretical predictions

$NE([1], \ SO([1,0.75], q=0.75])$

$SO([1,1), (1,1.25), (1,0.75), q=1)]$

$NE([1,1.25])$

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$SO([1,1); (1,1.25)]$

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**Result 1:** There are no differences in behavior across types within the same treatment.

**Result 2:** Production input levels are lower than the NE but higher than the SO in all treatments. In treatment $(1, 1.25)$, the input levels are lowest starting from period 7 of part 1; furthermore, in part 2 they are approximately halfway between the SO and NE levels (lowest).
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**Result 3:** Pollution is between the NE and SO levels in all treatments.

In part 1, the levels of pollution are the same for treatments \((1,1)\) and \((1,1.25)\) and lower for treatment \((1,0.75)\).

With experience, in part 2, treatment \((1,1.25)\) has the lowest pollution due to strong adjustment of production behavior.
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\[ \bar{\Pi}_t \]

SO\([(1,1); (1,1.25)]

SO\([(1,0.75)]

NE\([(1,0.75)]

NE\([(1,1)]

NE\([(1,1.25)]

(1,1)

(1,1.25)

(1,0.75)
Result 4: In part 1, the ranking of payoffs is consistent with the NE, while subjects’ payoffs are higher than the NE in all treatments. In part 2, payoffs in treatment (1, 1.25) reached the same payoff level as (1, 1).
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- Treatment variable: configurations of technological heterogeneity \((1, 1.25), (1, 1), (1, 0.75)\).
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Markov perfect NE and social optimum solution benchmarks
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- Treatment variable: configurations of technological heterogeneity \((1, 1.25), (1, 1), (1, 0.75)\).

- Markov perfect NE and social optimum solution benchmarks.

- Production and pollution are below NE but above SO levels in all treatments.

- No difference in behavior across types. Developing countries would likely not curb emissions at the expense of production.
Sustainability is reached in (1, 0.75) in part 1 and in (1, 1.25) and (1, 0.75) in part 2.
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- Treatment $(1, 1.25)$ corresponds with greatest adjustment
- Under unfavorable conditions countries are more likely to curb emissions and reach sustainability but only with experience.
- Regulation may be more necessary in the presence of moderate damage.