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

Svetlana Pevnitskaya and Dmitry Ryvkin

Florida State University

- Pollution, depletion of resources and climate change lead to environmental damage and costs

- Pollution, depletion of resources and climate change lead to environmental damage and costs
  - externality problems

- Pollution, depletion of resources and climate change lead to environmental damage and costs
  - externality problems
  - dynamic

- Pollution, depletion of resources and climate change lead to environmental damage and costs
  - externality problems
  - dynamic
- Insufficient response to institutional arrangements

- 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.

- 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

- 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 reversability: 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)

- Some regional institutions have been relatively successful

- Some regional institutions have been relatively successful
  - European Union Emission Trading System

- Some regional institutions have been relatively successful
  - European Union Emission Trading System
  - Clean Air Act (US)

- Some regional institutions have been relatively successful
  - European Union Emission Trading System
  - Clean Air Act (US)
- Insufficient results of international agreements (for example Kyoto treaty)

- Some regional institutions have been relatively successful
  - European Union Emission Trading System
  - Clean Air Act (US)
- Insufficient results of international agreements (for example Kyoto treaty)
- One of the reasons is the conflict between developed and developing nations (the latter having limited access to clean technologies and unwilling to jeopardize their economic growth).

- Some regional institutions have been relatively successful
  - European Union Emission Trading System
  - Clean Air Act (US)
- Insufficient results of international agreements (for example Kyoto treaty)
- One of the reasons is the conflict between developed and developing nations (the latter having limited access to clean technologies and unwilling to jeopardize their economic growth).
- Technological heterogeneity is one of the challenges

- Theoretical models of pollution and environmental damage (Heal and Tarui, 2008, Bretschger and Smulders, 2007, Breton, Sbragia and Zaccour, 2008, Mason, Polasky and Tarui, 2008, Dutta and Radner, 2004, Pindyck, 2009, etc.).

- Theoretical models of pollution and environmental damage (Heal and Tarui, 2008, Bretschger and Smulders, 2007, Breton, Sbragia and Zaccour, 2008, Mason, Polasky and Tarui, 2008, Dutta and Radner, 2004, Pindyck, 2009, etc.).
- Do human decision-makers act as agents in models?

- Theoretical models of pollution and environmental damage (Heal and Tarui, 2008, Bretschger and Smulders, 2007, Breton, Sbragia and Zaccour, 2008, Mason, Polasky and Tarui, 2008, Dutta and Radner, 2004, Pindyck, 2009, etc.).
- Do human decision-makers act as agents in models?
- **In this study** we use laboratory experiments to study decisions

- Theoretical models of pollution and environmental damage (Heal and Tarui, 2008, Bretschger and Smulders, 2007, Breton, Sbragia and Zaccour, 2008, Mason, Polasky and Tarui, 2008, Dutta and Radner, 2004, Pindyck, 2009, etc.).
- Do human decision-makers act as agents in models?
- **In this study** we use laboratory experiments to study decisions
- in an environment with costs of pollution and climate change (dynamic public bad) and

- Theoretical models of pollution and environmental damage (Heal and Tarui, 2008, Bretschger and Smulders, 2007, Breton, Sbragia and Zaccour, 2008, Mason, Polasky and Tarui, 2008, Dutta and Radner, 2004, Pindyck, 2009, etc.).
- Do human decision-makers act as agents in models?
- **In this study** we use laboratory experiments to study decisions
- in an environment with costs of pollution and climate change (dynamic public bad) and
- 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

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

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,

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

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,

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

Experiment Design

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

Experiment Design

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

Treatments (q_1, q_2)	(1,1)	(1,1.25)	(1,0.75)
Sessions	2	2	2
Subjects	44	44	42
Groups	22	22	21
NE (x_{1t}, x_{2t})	(m, m)	(m, m)	(m, m)
SO (x_{1t}, x_{2t})	$(0, 0)$	$(0, 0)$	$(0, m)$

Table: Experimental design and theoretical predictions for input levels (x_{1t}, x_{2t}), by treatment.

Experiment Design

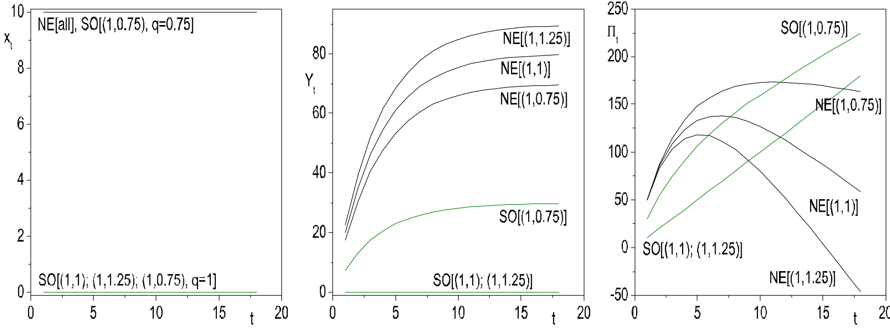
- $n = 2$, $m = 10$, $a = 5$, $b = 1$, $\gamma = 0.75$, $\beta = 0.95$
-

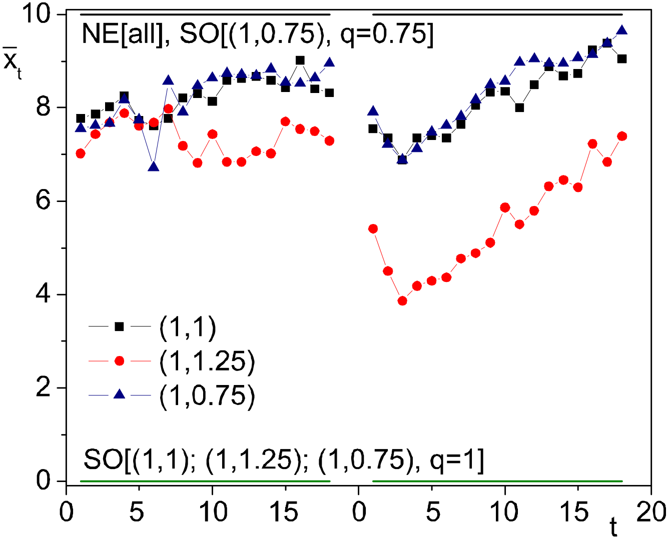
Treatments (q_1, q_2)	(1,1)	(1,1.25)	(1,0.75)
Sessions	2	2	2
Subjects	44	44	42
Groups	22	22	21
NE (x_{1t}, x_{2t})	(m, m)	(m, m)	(m, m)
SO (x_{1t}, x_{2t})	$(0, 0)$	$(0, 0)$	$(0, m)$

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, $\tilde{\Pi}_t$

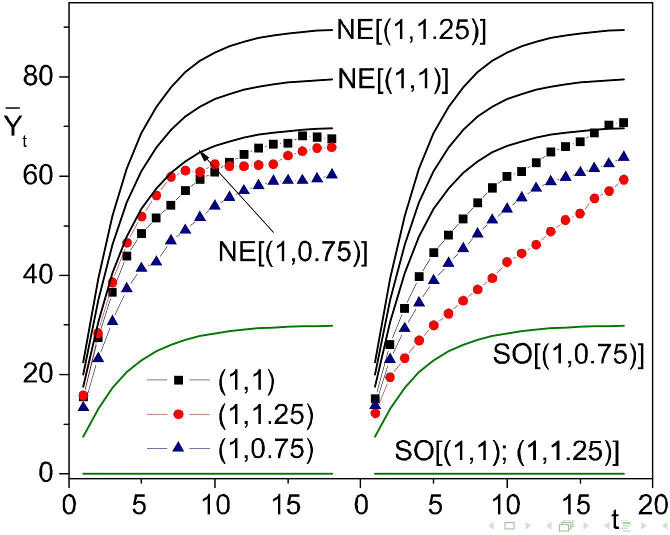
Theoretical predictions



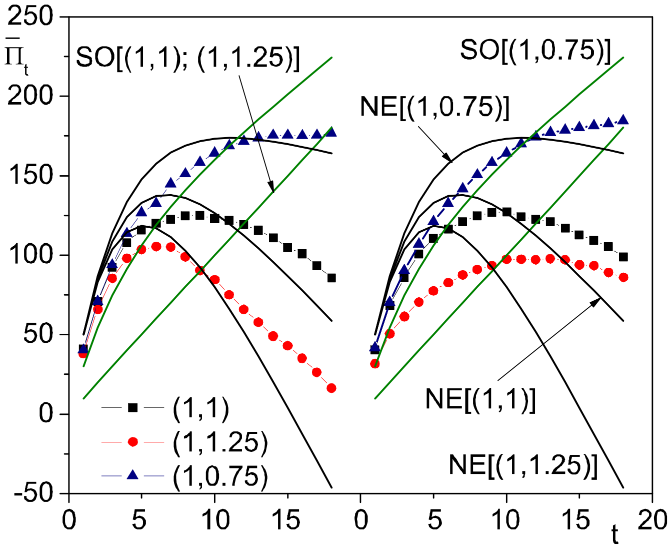

NE[all], SO[(1,0.75), q=0.75]
SO[(1,1); (1,1.25); (1,0.75), q=1]
(1,1)
(1,1.25)
(1,0.75)
x̄t
t
0
2
4
6
8
10
0
5
10
15
0
5
10
15
20

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).


NE[(1,1.25)]
NE[(1,1)]
NE[(1,0.75)]
SO[(1,0.75)]
SO[(1,1); (1,1.25)]
$\bar{Y}_t$
t
(1,1)
(1,1.25)
(1,0.75)
0
20
40
60
80
0
5
10
15
0
5
10
15
20

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.


250
200
150
100
50
0
-50
$\overline{\Pi}_t$
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)
0
5
10
15
0
5
10
15
20
t

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 $(1, 1)$.

- Studied behavior in an environments with a dynamic public bad (costs of pollution) and heterogeneous pollution propensity

- Studied behavior in an environments with a dynamic public bad (costs of pollution) and heterogeneous pollution propensity
- Treatment variable: configurations of technological heterogeneity $(1, 1.25)$, $(1, 1)$, $(1, 0.75)$.

- Studied behavior in an environments with a dynamic public bad (costs of pollution) and heterogeneous pollution propensity
- Treatment variable: configurations of technological heterogeneity $(1, 1.25)$, $(1, 1)$, $(1, 0.75)$.
- Markov perfect NE and social optimum solution benchmarks

- Studied behavior in an environments with a dynamic public bad (costs of pollution) and heterogeneous pollution propensity
- 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

- Studied behavior in an environments with a dynamic public bad (costs of pollution) and heterogeneous pollution propensity
- 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

- Sustainability is reached in $(1, 0.75)$ in part 1 and in $(1, 1.25)$ and $(1, 0.75)$ in part 2
- Treatment $(1, 1.25)$ corresponds with greatest adjustment

- Sustainability is reached in $(1, 0.75)$ in part 1 and in $(1, 1.25)$ and $(1, 0.75)$ in part 2
- 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.

- Sustainability is reached in $(1, 0.75)$ in part 1 and in $(1, 1.25)$ and $(1, 0.75)$ in part 2
- 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.