
Svetlana Pevnitskaya

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Mathematical Modeling

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Any policy adoption relies on specific quantitative goals it is trying to achieve and/or specific incentive structure of proposed mechanism (rebates, audit, loans, etc.).
Mathematical Modeling
quantitative evaluation
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- complementary to surveys
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Mathematical Modeling

- A set of formal assumptions is made to characterize agent's preferences and decision-making process.
- Agent's optimization problem is set for a specific mechanism.
- Adopting a specific solution concept (for example, Nash Equilibrium or Socially Optimal outcome), agent's choices are obtained.
- Based on results, an analysis of general mechanism performance, efficiency, etc., can be characterized.
- Design of optimal mechanisms and policies aimed to promote pro-environmental decisions is more robust if it is supported by formal theoretical framework with quantitative predictions.
- Mathematical modeling allows to determine the effect of such policies or incentive schemes.

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Introduction

Theory

Mathematical Modeling

- Sometimes assumptions simplify decision-making conditions (information, etc.)
- Complementary to field/survey studies that identify barriers, etc., and allow for more accurate assumptions
- Analysis of performance of specific programs (for example audit, rebate, loan) often reduced to monetary incentives alone
- How to isolate the effect of the mechanism/program itself from monetary incentives within the mechanism.

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There are systematic behavioral patterns that affect decision making

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- Adoption of pro-environmental technologies may be limited due to status quo bias
- Typically involves high upfront investment with the potential of better payoffs in the future (over the course of lifecycle), or/and more desirable properties.
Experimental Economics

- Do human decision-makers act as agents in models?
- Actual human behavior typically deviates from predicted by the model in a systematic way, often resulting in insufficient response to institutional arrangements.
- Observed decision-making process exhibits behavioral patterns that are not consistent with assumptions of the model. In some cases, this leads to significant errors in evaluating the effect.
- Possible reasons for deviations: bounded rationality, comprehension of dynamic effects, risk aversion, inaccurate anticipated benefit like increased comfort.
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Mathematical Modeling and Experimental Economics in Studying...
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Economics
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- In Social Dillemas there is typically underprovision of a good that benefits everyone compared to efficient level (or overprovision of a bad, like pollution).
- Examples: unsufficient conservation (of energy or resources) based on private decisions; society benefits from more efficient building structure, longer life cycle, but private investor does not have incentives to adopt it.
A New Experimental Mechanism to Investigate Polarized Demands for Public Goods
(Isaac, Norton and Pevnitskaya, 2015)
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Another example from the energy sector is the NIMBY (not-in-my-backyard) problem (siting of alternative energy facilities such as biomass, wind, solar, and geothermal power).
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Another example from the energy sector is the NIMBY (not-in-my-backyard) problem (siting of alternative energy facilities such as biomass, wind, solar, and geothermal power).

We propose a Generalized Voluntary Contributions Mechanism (GVCM) to study the decisions and possibility of reaching efficient outcome in such cases.
Dynamic Public Bad (PB)
Model (Pevnitskaya and Ryvkin, 2011)

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 private revenue $a x_{it},$ $a > 1.$

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.

Total level of emissions in period $t,$

$$E_t = \sum_{i=1}^{n} q_i x_{it}$$

which leads to accumulation of PB (pollution).
The level of PB (pollution) 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.
**Decision-maker’s objective.**

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 public bad.

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

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 $t$. 
Investment in clean technology (private access) (Pevnitskaya and Ryvkin, 2015).

In addition to production allocation, \( x \), each player \( i \) can invest amount, \( r_{it} \), to reduce \( q_i \) to a new post-investment technology in period \( t \), \( \hat{q}_{it} \leq q_i \):

\[
\hat{q}_{it} = \max\{0, q_i - \alpha r_{it}\}
\]

\( \alpha \) is the effectiveness of private investment in clean technology (abatement).

The resulting payoff in period \( t \) is

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

where \( E_k = \sum_{j=1}^{n} \hat{q}_{jk} x_{jk} \)
Investment in clean technology (public access) (Pevnitskaya and Ryvkin, 2015)

In addition to production allocation, each player can invest some amount, $r_{it}$, to reduce $q_{jt} = q_t$, in period $t$ to

$$\tilde{q}_t = \max\{0, q - \rho \sum_{k=1}^{t-1} r_{it}\}$$

$\rho$ is the effectiveness of public investment in clean technology (abatement).

The resulting payoff in period $t$ is

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

where $E_k = \sum_{j=1}^{n} \tilde{q}_k x_{jk}$

Solution concepts: NE, SO
Solution concepts:
Nash equilibrium
Socially optimal outcome
Sustainable outcome
Target pollution rate
Experiment Design

- $n = 4$, $m = 10$, $a = 5$, $b = 1$, $\gamma = 0.75$, $\beta = 0.95$
Experiment Design

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- Sessions (subjects)
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- Look at:
  - Production decision, $x_t$
  - Investment in clean technology, $r_{it}$
  - Pollution, $Y_t$
  - Payoffs, $\Pi_t$
Production allocation, $n=4$

- private
- common
- no inv.
- NE
- SO

- $n=4$

$t$ range from 0 to 20.
Investment in clean technology, n=4

The effect of access to clean technology and communication on pollution reduction: an experiment
Public Bad, n=4
The effect of access to clean technology and communication on pollution reduction: an experiment.

Payoffs, $n=4$
New Directions

We assumed that a building is a consumer of energy, buying energy on the market. The government can create policies aimed at more efficient consumption.

New technologies allow the building to also produce energy and be completely off the grid, or have periods when the building can transmit (supply) energy into the grid. This makes it important to consider new energy pricing schemes to integrate decentralized power generation into the grid and energy market.

Now policies can involve real time pricing that allows more efficient houses to generate income based on new green technologies.