An Experimental Investigation of Economic Incentives in Environmental Conservation and Sustainability

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- 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).

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- Do human decision-makers act as agents in models?

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  - Identifying incentives and corresponding institutions
  - Lag in creating institutions that are necessary for sustainability

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    - motivate applicability of mechanisms via confirmation of response to incentives

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    - heterogeneity in emissions

There are n risk neutral players in the economy.

In period t player i has endowment m and chooses production investment $x_{it} \in [0, m]$, which yields revenue ax_{it}, $a > 1$
Production generates emissions, pollution level Y_t evolves as

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

where, $\gamma \in [0, 1]$ - retention rate of pollution.

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. The game lasts T periods. Player i is maximizing total payoff

$$\Pi_i = \sum_{t=1}^{T} \pi_{it} = mT + (a-1) \sum_{t=1}^{T} x_{it} - b\gamma \sum_{t=1}^{T} \sum_{k=1}^{t-1} \gamma^{t-1-k} X_k.$$

Nash equilibrium

For $a-1>b\gamma/(1-\gamma)$, the dominant strategy of player i is $x_{it}=m$ in all periods. The payoffs are

$$\pi_{it}=am-b\gamma nm\sum_{k=1}^{t-1}\gamma^{t-1-k}=m\left(a-b\gamma n\frac{1-\gamma^{t-1}}{1-\gamma}\right),$$

$$\Pi_i=m\left[\left(a-\frac{b\gamma n}{1-\gamma}\right)T+\frac{b\gamma n(1-\gamma^T)}{(1-\gamma)^2}\right].$$

Pareto optimal outcome

Let $\bar{x}_t$ denote the symmetric P.O. investment in period t. Then the objective function is

$$\bar{\Pi} = mT + \sum_{t=1}^{T} \left(a - 1 - b\gamma n \frac{1-\gamma^{T-t}}{1-\gamma} \right) \bar{x}_t .$$

$\bar{x}_t = m$ whenever the coefficient at it is positive, and 0 whenever it is negative. P.O. profile of investments has the form $(0, \ldots, 0, m \ldots, m)$, where the switching from 0 to m occurs in period t_c, which is the smallest integer exceeding the solution of the equation

$$a - 1 - b\gamma n \frac{1-\gamma^{T-t}}{1-\gamma} = 0.$$

It follows that

$$t^* = T - \frac{1}{\ln \gamma} \ln \left[1 - \frac{(1-\gamma)(a-1)}{b\gamma n} \right].$$

Sustainable outcome

Suppose $x_{it} = \alpha m$. We obtain the "sustainability threshold" value of α corresponding to the long-run payoff of zero.

Each player's payoff is

$$\pi = m\left(1 - \alpha + \alpha a - \alpha b \gamma n \frac{1-\gamma^{t-1}}{1-\gamma}\right).$$

The steady-state payoff of zero corresponds to $\alpha = \alpha_s$, with

$$\alpha_s = \frac{1}{1 - a + b\gamma n/(1-\gamma)}.$$

For $\alpha > \alpha_s$, there is overpollution, and long-run payoffs are negative, whereas for $\alpha \leq \alpha_s$ long-run payoffs are nonnegative.

Suppose

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

where the level of *emissions* $E_t = \sum_{i=1}^{n} q_i x_{it}$; and heterogeneous *impact factors are* q_i. (previously, $q_i = 1$)
Player i's payoff is

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

Further, assume that 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.
The second term can be re-written as

$$\sum_{k=t}^{\infty} \beta^{k-t} \left[m + (a-1)x_{ik} - b\gamma \sum_{l=1}^{t-1} \gamma^{k-1-l} \left(q_i x_{il} + \sum_{j \neq i} q_j x_{jl} \right) \right.$$
$$\left. - b\gamma \sum_{l=t}^{k-1} \gamma^{k-1-l} \left(q_i x_{il} + \sum_{j \neq i} q_j x_{jl} \right) \right].$$

Nash equilibrium

The optimum is reached at either $x_{ik} = m$ or $x_{ik} = 0$ for all $k \geq t$, depending in q_i. For $q_i > q_{cN}$, $x_{ik} = 0$, whereas for $q_i < q_{cN}$, $x_{ik} = m$. Here,

$$q_{cN} = \frac{a-1}{b}\left(\frac{1}{\beta\gamma} - 1\right).$$

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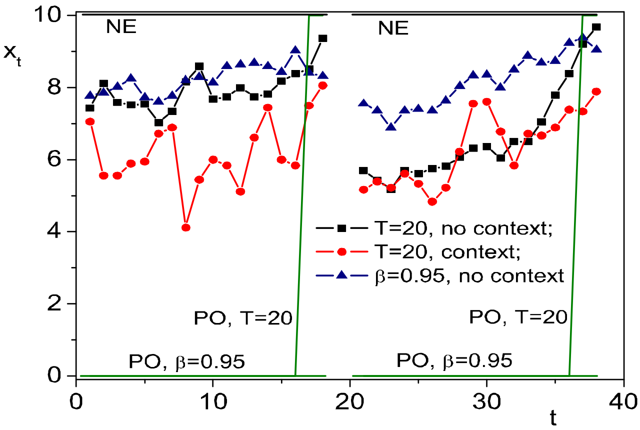
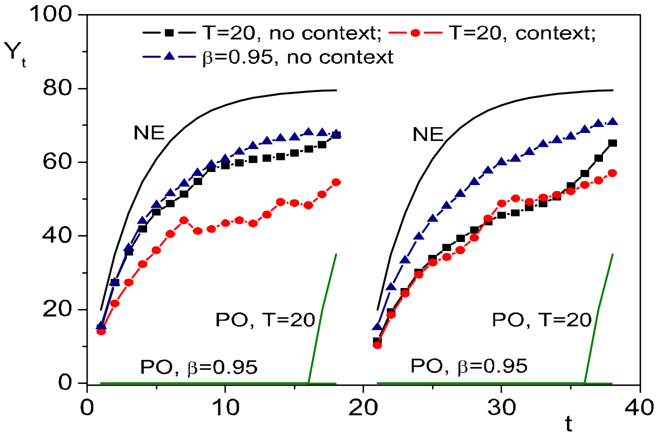
T1: certain end	2 (44)
T2: certain end, context	1 (18)
T3: uncertain, q=1	2 (44)
T4: uncertain, q=1, 1.25	2 (44)
T5: uncertain, q=1, 0.75	2 (42)

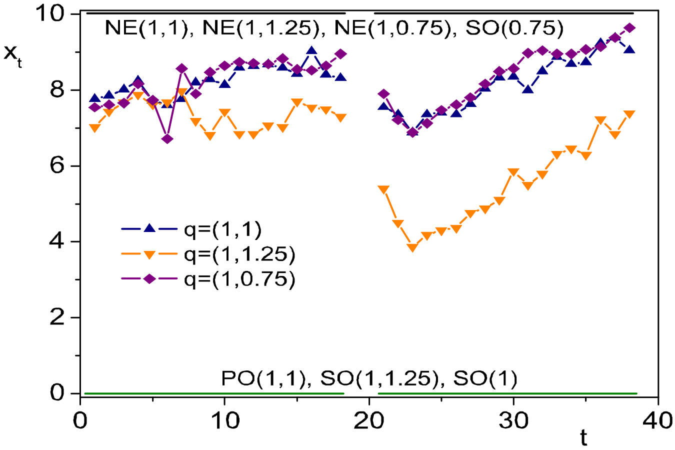
Production investment (treatments 1-3)



Pollution (treatments 1-3)



Production investment (treatments 3-5)



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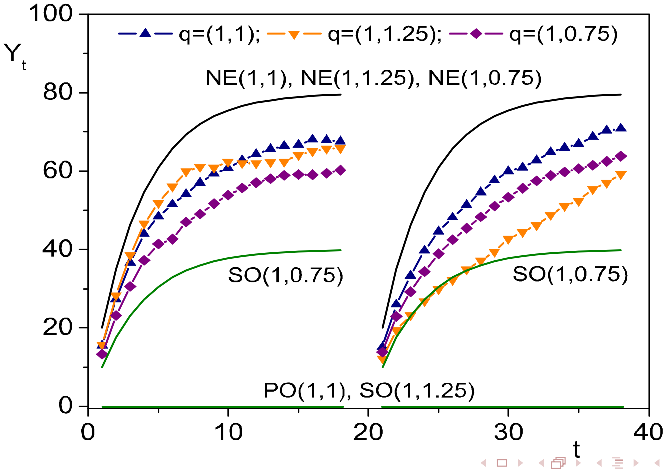
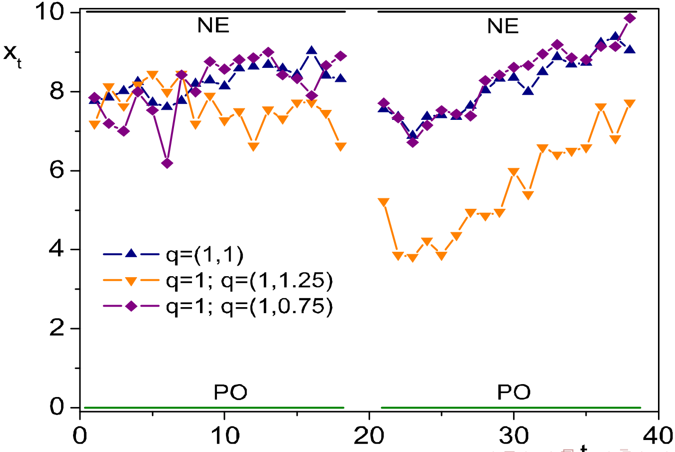
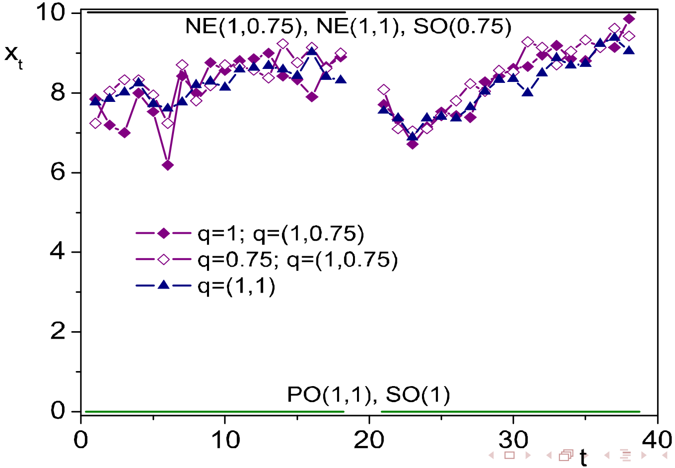


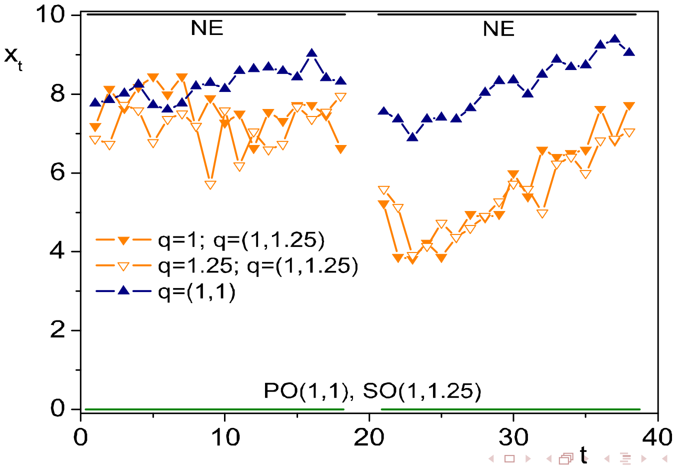
Production investment (treatments 3-5, q=1)



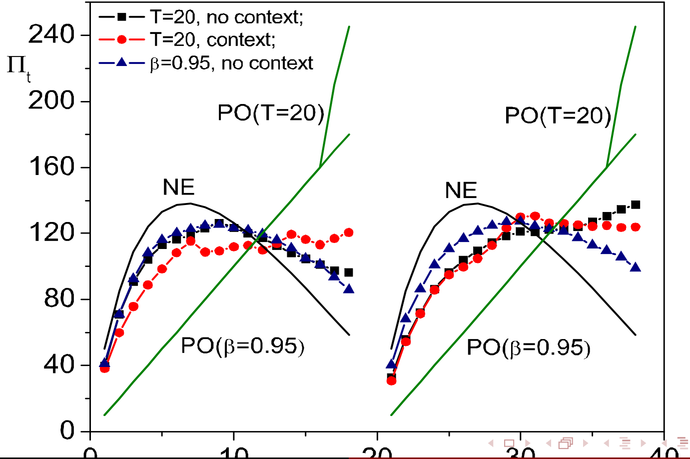
Production investment (treatments 5, 3)



Production investment (treatments 4, 3)



Payoffs (treatments 1,2,3)



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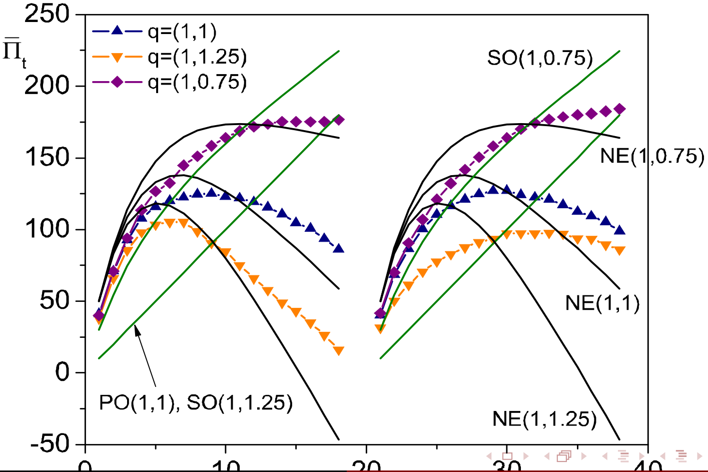

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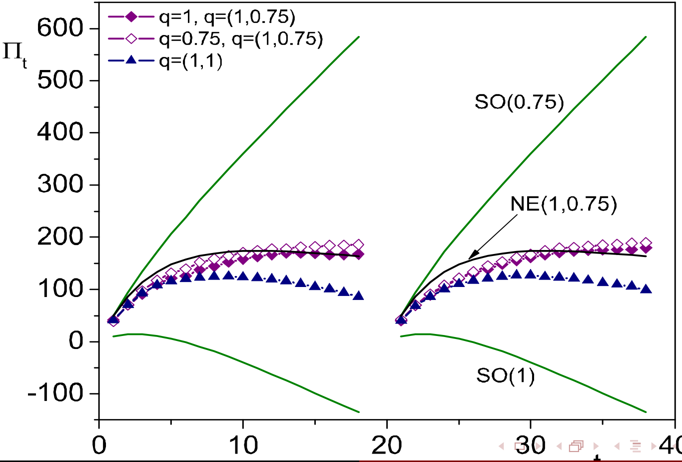

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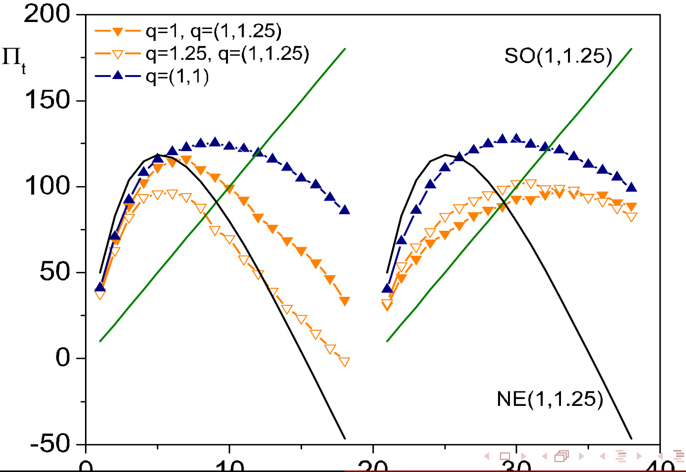

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- Heterogeneity: strongest adjustment in case of (unfavorable) heterogeneity (to the extent of compensating for difference in means).