FESC
Florida Energy Systems Consortium

FLORIDA STATE UNIVERSITY

Experimental Investigation of Economic Incentives of Policies, Institutions, and R&D in Environmental Conservation

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Description: The goal of this project is to study the incentive mechanisms of sustainable energy investments and efficiency of institutions combining theoretical and experimental economics methods, with emphasis on direct experimental tests of behavior. We create laboratory interaction environments where human subjects make decisions and earn real money. The key elements of the subjects' decisions are similar to those encountered by decision makers in the field. Thus, by studying experimental subjects' responses to a change in the environment (for example, introduction of a new policy, or discovery of a new technology), we can infer implications of similar changes for the behavior of real decision makers in the field. Our baseline experimental design follows recently developed theoretical models of an economy with climate change (see e.g. Heal and Tarui, 2008, Bretschger and Smulders, 2007, Breton, Sbragia and Zaccour, 2008, Mason, Polasky and Tarui, 2008). It is a global society of decision makers (for example, firms, or local, state, or federal governments) who choose how much of their resources to invest in a production process that generates economic revenue but also leads to pollution. Pollution acts as a "public bad," i.e. it adversely affects the well-being of all decision makers in the society. The environment is dynamic in that pollution accumulates over time. Subjects in our design face the dilemma of continuing to run "business as usual" (i.e. myopically maximizing their payoffs and disregarding the environment) and possibly facing the accumulating costs of environmental damage caused by emissions, or investing in sustainable clean technologies. These decisions are made under several institutional conditions, including a completely decentralized market and a market with regulatory mechanisms such as "cap and trade," taxes on pollution, or government subsidies for adoption of clean technologies. Our ultimate goal is to compare the efficiency across several institutions and provide policy recommendations.

Budget: $43,168.00
Universities: FSU

Progress Summary

Our statement of work includes two major tasks. Task 1, completed by the end of the first year, serves as a foundation for the subsequent comparative study of institutions (Task 2) in year two. Within Task 2, "An experimental investigation of R&D investment in, and adoption of, environmentally friendly technologies under various institutional designs," we use the baseline experimental environment identified in Task 1 and add to it a possibility for economic agents to invest in and use technologies that mitigate the dynamic environmental change.

2010 Annual Report

<u>Report on Deliverables for Task 2 (scope of Task 2 is Year 2 of the project)</u>

1. Analysis of experimental results from Task 1 and design of a baseline treatment for Task 2.

We completed the analysis of data from two experiments conducted within Task 1. The first experiment deals with the role of environmental context and termination uncertainty in games with a dynamic climate change. This resulted in our first paper, currently under review:

Pevnitskaya, S., Ryvkin, D., The effect of context and termination uncertainty in dynamic climate change games.

The second experiment addresses the issue of technological heterogeneity. The paper reporting the results of the second experiment is forthcoming in the series *Research in Experimental Economics*:

Pevnitskaya, S., Ryvkin, D. Behavior in a dynamic environment with costs of climate change and heterogeneous technologies: an experiment. In *Research in Experimental Economics*, Vol. 14 (edited by R.M. Isaac and D. Norton), Emerald, forthcoming.

2. A theoretical model and experimental design of an economic environment with dynamic and uncertain negative externalities

We developed a theoretical model of an environment where agents can invest in clean technology that reduces the amount of pollution their production activity generates.

3. A computer program and instructions for conducting experiments

We worked with Sean Collins, our graduate assistant, on creating a computer program and completed software for two treatments corresponding to two types of access to clean technology – common and private, and open-ended chat communication. Instructions were developed for each of those treatments.

4. A set of experimental sessions exploring the investment and adoption behavior in the absence of institutions and regulation

We conducted 8 sessions with private investment in clean technology. Five of these sessions have been conducted in 2009, and three in the first half of 2010.

5. A set of experimental sessions exploring the effect of several regulatory institutions on the investment and adoption behavior

Two of the three sessions with private access to clean technology conducted in 2010 included the communication option. Communication allowed subjects to form endogenous nonbinding agreements and institutions. We also conducted 9 sessions with common access to clean technology, three of which included the possibility for communication. The 2x2 experimental design thus included the private/common type of access to clean technology as an exogenous institution, and absence/presence of communication as a major mechanism of endogenous formation of institutions.

6. Analysis of experimental results and conclusions about the role and efficiency of different institutional designs

This deliverable is scheduled to be underway by the end of Year 2. We are currently in the process of analyzing data and writing a manuscript that reports our findings from the last set of experiments.

We are happy to report that we are ahead of our proposed timetable and are close to completing all the deliverables planned for the second year. We also recently submitted an NSF grant proposal using the results of this project as evidence of prior research. This grant proposal will be part of our next report as its submission took place in August.

Report on Metrics (planned across the two years)

A) Theoretical predictions, experimental designs and research hypotheses

B) Computer programs and experimental instructions ready to conduct sessions

C) Completed experimental sessions

D) Experimental data analyzed

All four are completed for Task 1 as described above

E) Working papers written, circulated and presented

Two working papers have been circulated. Svetlana Pevnitskaya presented our work at Florida State University Experimental Reading group, Louis-André Gérard-Varet conference in public economics and Economic Science Association World Meeting. Our work is also scheduled to be presented at the Southern Economic Association and Chapman University.

F) Papers submitted to journals

Two papers submitted; we plan to submit one more paper by the end of Year 2.

G) Proposals for external funding submitted

Pevnitskaya, S. (PI), & Ryvkin, D.(co-PI) (Aug 2010). *Experimental Study of Games with a Dynamic Public Bad and Applications to Environmental Policy*. Submitted to National Science Foundation (NSF). (2011-2013). $187,844.00. Under review.

Delivering on IESES and FSU strategic imperatives

This project delivers on Objective 2 of IESES – "Assist Florida's governing bodies in the successful development and implementation of a comprehensive, long-term, environmentally compatible, sustainable, and efficient energy strategic plan for the state that overcomes existing legal and policy impediments to a sustainable energy economy." Low investment in, a slow adoption of, sustainable technologies is one of the key impediments to a sustainable energy economy, which we believe is rooted in the fundamental "public bad" property of environmental damage. The design of appropriate policies and institutions to overcome this problem is the primary goal of our project.

Potential to further IESES and FSU strategic priorities

According to IESES Vision Statement, "[IESES] is a public resource, which performs scholarly basic research and analysis in […] the social dimensions of the sustainable energy economy." Our project conforms to this vision by studying the fundamental aspects of economic behavior of agents in dynamic environments and particularly in an environment with energy and climate challenges. as well as by generating policy recommendations on the basis of experimental assessment of efficiency of institutions. Our research also falls within Thrust 6 of Florida Energy Systems Consortium – "Energy Systems and Their Environmental and Economic Impacts." The results provide the State of Florida with policy recommendations on incentive mechanisms for sustainable energy investment and reduction of environmental damage.

Description of Projects:

We present the results of three experimental studies carried out by the PIs within a two-year project "An Experimental Investigation of Economic Incentives of Policies, Institutions and R&D in Environmental Conservation, Sustainability and Renewable Energy" funded by IESES. The first two studies are already completed and resulted in two manuscripts, one accepted for publication and the other currently in circulation. For the third study, the experimental sessions have been conducted, and manuscript preparation is now underway.

A. The effects of context and termination uncertainty

Pevnitskaya and Ryvkin (2010a) reported the results of an experimental study of behavior in an environment involving a dynamic public bad. The focus of the study was to explore how behavior is affected by (i) formulating the instructions in a meaningful environmental context, as opposed to neutral context, and (ii) having subjects play the dynamic game with a fixed and known number of periods T as opposed to the same game with an uncertain number of periods determined by the termination probability $\beta=1/T$.

The following theoretical model was used. There are n identical risk-neutral players indexed by i. In period t player i has endowment m of a consumption good that can either be consumed directly or used as production input. Let $x_{it} \in [0,m]$ denote the production input chosen by player i in period t. Production technology has constant returns to scale, and the production revenue is ax_{it}, with $a>1$. Production generates "emissions" proportional to the level of output. Without loss of generality, it is assumed that the amount of emissions generated in period t by processing input x_{it} is equal to x_{it}. Emissions of all players are added to the overall level of pollution evolving as $Y_t=\gamma Y_{t-1} + \sum_i x_{it}$, with initial condition $Y_0=0$.

The payoff of player i in period t is $\pi_{it} = m - x_{it} + ax_{it} - b\gamma Y_{t-1}$. The overall payoff is the player's cumulative payoff at the moment of game termination (either random or deterministic). For theoretical predictions, the authors used two benchmark solution concepts: Nash equilibrium (NE) and Social Optimum (SO). The NE was refined to the subgame-perfect NE in fixed-end treatments, and to the Markov perfect NE in the uncertain-end treatment, to avoid the multiplicity of equilibria arising in the dynamic game. The SO was defined as the strategy profile maximizing the (expected) sum of all players' cumulative payoffs.

The experiment consisted of three treatments. In the fixed-end treatment with neutral context (FE), subjects played the game in fixed groups if n=2 players for T=20 periods. In the fixed-end treatment with contexts (FE-C), subjects played the same game but the instructions were formulated using words "pollution," "environmental damage," etc., to explain how the game worked. In the uncertain-end treatment (UE), subjects only new that in each period there is a 5% chance that the game will end. Additionally, in all treatments subjects played the whole game twice, starting the second sequence of decisions from scratch (they did not know in advance that there will be a second sequence).

Figure 1 shows the experimentally observed production inputs in each treatment, together with the theoretical predictions. For the effect of context, it was found that

(a) Production inputs are lower in the presence of context than without it. Pollution levels are lower and long-run payoffs are higher in the treatment with context.
(b) With experience, the difference between production inputs without context and with context is not statistically significant. There are no significant differences in the pollution levels and payoffs. There is, however, a systematic difference in the end-game effect, and production inputs in the treatment with context are significantly lower in the final rounds.
(c) Experience substitutes for context, with the exception of a few final round decisions.

Unlike previous studies of indefinitely repeated games (e.g., Dal Bo 1995, Camera and Casari 2009), the authors did not find a significant effect of termination uncertainty on behavior, with the exception of the end-game effect in the fixed-end treatments.

The substitution between environmental context and experience is similar to the findings of Cooper and Kagel (2003, 2009).

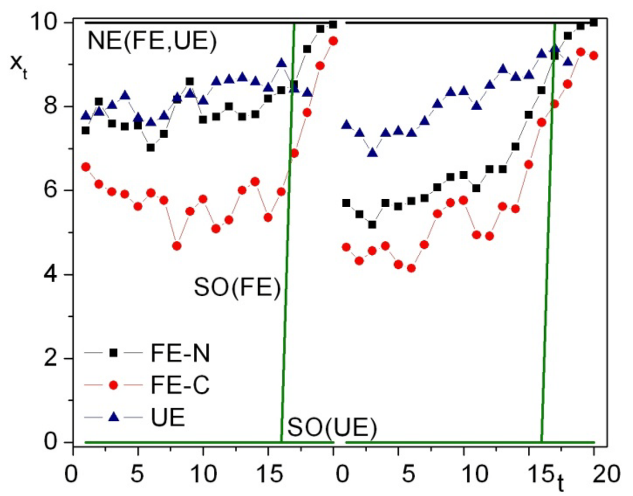

Figure 1. Mean per capita production inputs, by period. The solid lines show the Nash equilibrium (NE) and socially optimal (SO) levels.

The manifestation of environmental preferences in the laboratory means that subjects receive utility from taking a pro-environmental action even if this action has no real impact in the field (unlike in the study of Abbink and Hennig-Schmidt 2006 who report no effect of context in a bribery experiment). When subjects have environmentally friendly preferences they are willing to forgo profits to manifest a pro-environmental action. This finding is in line with the recent results on the effect of "green" advertisement on consumer behavior (see, e.g., Cason and Gangadharan 2002, Vermier and Verbeke 2006, Hartmann and Apaolaza-Ibanez 2010), and the effect of status quo or framing (e.g., Andreoni 1995). Our results on the impact of environmental context contribute to the literature on the effects of framing in economics experiments. In our setting, framing the experiment in environmental terms facilitates understanding of the game and also invokes subjects' environmental preferences. Such preferences, formed naturally outside the lab, assign a "moral" connotation to the public bad, and thus promote cooperation.

B. The impact of technological heterogeneity

Pevnitskaya and Ryvkin (2010b) use a setting similar to Pevnitskaya and Ryvkin (2010a) to study the impact of heterogeneity in players' production technologies in an environment with a dynamic public bad. The basic model is similar to the one presented above, with the following modification. The overall level of pollution evolves as $Y_t=\gamma Y_{t-1} + E_t$, where $E_t = \sum_i q_i x_{it}$ is the level of "emissions" in period t. Thus, emissions are formed by the production inputs of all players multiplied by the corresponding pollution propensities or "impact factors" q_i that can be heterogeneous across players.

The experiment consisted of three treatments differing by the configuration of impact factors (q_1,q_2) in the groups of two players: homogeneous baseline, (1,1); heterogeneous with high pollution propensity, (1,1.25); and heterogeneous with low pollution propensity, (1,0.75). All treatments used the uncertain termination rule and neutral context. As in the previous study, subjects played the game twice restarting the second sequence from scratch, to test for the effect of experience.

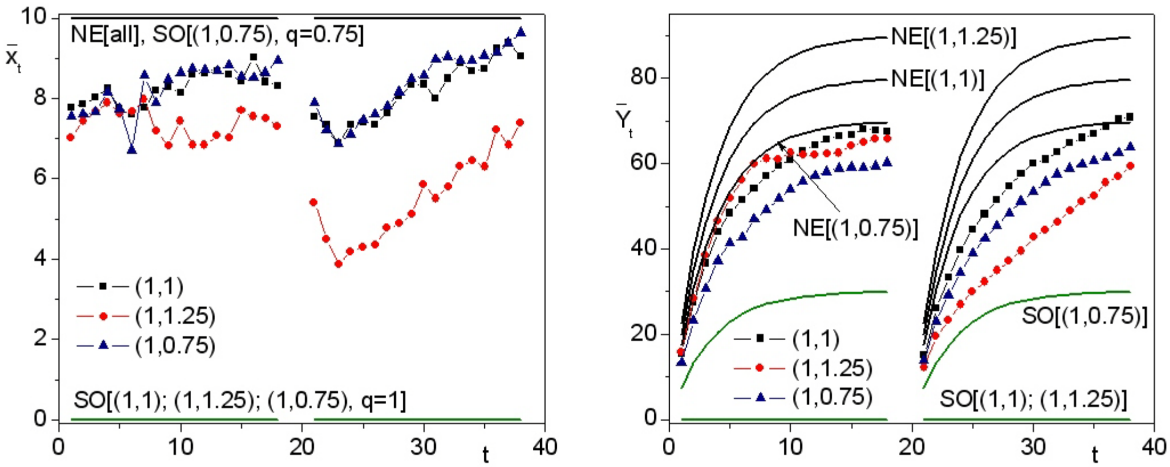

Figure 2. *Left*: Mean per capita production inputs and theoretical predictions (NE and SO). *Right*: mean group level of pollution and theoretical predictions (NE and SO).

Figure 2 shows the observed per capita production inputs as function of time in each of the three treatments. The following results were established.

(a) There are no differences in behavior between player types in the heterogeneous treatments (hence, the results for treatments (1,1.25) and (1,0.75) are pooled in Figure 2).

(b) 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.

(c) 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.

(d) 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) reach the same level as (1, 1).

We find that production and pollution are below the NE but above the SO levels in all treatments. This finding indicates that pollution-mitigating institutions are necessary to solve the social dilemma between local economic growth and global environmental sustainability. We do not observe any differences in behavior between subject types in heterogeneous treatments (Previous studies of public good games with heterogeneity found differences in behavior between player types. For example, Croson and Marks 1999 report the results of an experiment involving a provision-point public good game with heterogeneous public good valuations and find that, generally, contributions are heterogeneous; our heterogeneous setting, however, can be reduced neither to heterogeneous valuations nor to heterogeneous MPCRs.) This confirms concerns that developing countries would likely not curb emissions at the expense of production and suggests that in the absence of enforcement mechanisms countries with different pollution abatement technologies would not adjust their production according to the environmental damage they generate, and the more polluting countries may follow with pollution reduction only if the less polluting countries lead.

This result is in line with some of the observed behavior of developing countries. Thus, the overall level of technological development, as reflected by the average emission factor, is more important to curb pollution levels than the development of individual members.

The results indicate that under relatively low cost of pollution heterogeneous countries are less likely to achieve sustainability without external enforcement than under more severe costs of pollution and climate change. Such behavioral response is consistent with previous studies of learning in the presence of losses. For example, Bereby-Meyer and Erev (1998) and Erev et al. (1999) find that negative payoffs lead to faster learning in the individual and strategic decision tasks respectively. Bereby-Meyer and Grosskopf (2008) find that negative payoff experiences lead to faster learning to avoid the winner's curse in the "Acquiring a company" game. Cachon and Camerer (1996) report that subjects learn to better coordinate on Pareto-superior equilibria if Pareto-dominated equilibria result in losses.

We conclude that under unfavorable conditions countries are more likely to curb emissions and reach sustainability, and the effect is significant with experience. This result is somewhat unfortunate, because, in light of the new findings about the irreversibility of climate change (Solomon et al. 2010), experience and second trial may not be available in the field. At the same time, our results indicate that, somewhat counter-intuitively, environmental regulation is more necessary in the presence of a moderate damage than in the presence of a more obvious damage. In the latter case, the results of continuing "business as usual" are too obvious to ignore, while in the former case the relatively slow and subtle build-up of pollution costs may be insufficient to cause adjustments in behavior. The results also indicate that subjects substantially adjust their behavior only when they are faced with negative payoffs, which is not a practical or acceptable solution in the field in a sense of requiring a threat of extinction to induce dramatic adjustments without external enforcement institutions.

C. Investment in clean technologies

This project uses the same basic framework as the two projects described above, to study the effect of investment in clean technology on decisions and outcomes in an environment with a dynamic public bad. The model public bad generation and dynamics is similar to the ones described above, with the following modification. In each period t, each player i allocates her endowment m between three options: keep (m-x_{it}-r_{it}), invest in production (x_{it}), and invest in impact reduction (r_{it}). Investment in production yields revenue ax_{it}, as before. Investment in impact reduction represents a "clean technology investment" that reduces the player's impact factor.

We consider two different types of investment in clean technology, in addition to the baseline where no investment in impact reduction is possible. In the "private" investment treatments, player i's investment in impact reduction only affects the impact factor of player i: $\hat{q}_{it} = \max\{0, q_i - \alpha r_{it}\}$. Here, q_i is the initial impact factor of player i (without investment), α>0 is the investment efficiency parameter. In the "common" investment treatments, player i's investment in impact reduction affects all players' impact factors: $\tilde{q}_t = \max\{0, q - \rho \sum_i r_{it}\}$. Here, q is the common impact factor of all players prior to investment, and ρ>0 is another efficiency parameter.

The private investment treatments model a situation when a clean technology is only available to the investor. The common investment treatments model a situation when a clean technology created by one agent is available to all participating agents. To exclude the obvious efficiency gain in the latter case, parameters have been chosen so that $\rho=\alpha/n$. In this case, it can be shown that the Markov perfect equilibrium and the socially optimal allocations are the same across the two treatments.

In addition to manipulating the type of access to clean technology, we also changed the number of players (groups of n=2 and n=4 have been studied) and allowed subjects to communicate through unrestricted chat (only groups with n=4 participated in the chat treatment; subject had 60 seconds to chat after each round). The complete taxonomy of treatments and sessions is shown in Table 1.

Treatments	*n*=2, no chat	*n*=4, no chat	*n*=4, chat
No investment in *q*	2 (44)	2 (44)	x
Private investment in *q*	2 (44)	3 (52)	2 (36)
Common investment in *q*	2 (36)	3 (48)	2 (40)

Table 1. The number of sessions and subjects (in parentheses) for each treatment.

Figure 3 presents the experimental results for the treatments with *n*=2. The upper left graph in Figure 3 shows the dependence of average per capita production input as a function of time for each of the three treatments with *n*=2, as well as the theoretical predictions of the Markov perfect equilibrium (NE) and social optimum (SO). As seen from the Figure, production in the treatments with investment in clean technology is lower than in the baseline treatment where such investment is impossible. Moreover, production in the treatment with common access to clean technology is generally lower than in the treatment with private access, although the difference is not statistically significant in all periods. The upper right panel in Figure 3 shows the average investment in clean technology. It is not statistically different between the two treatments in most time periods, and there is no obvious ranking of treatments by the level of average investment.

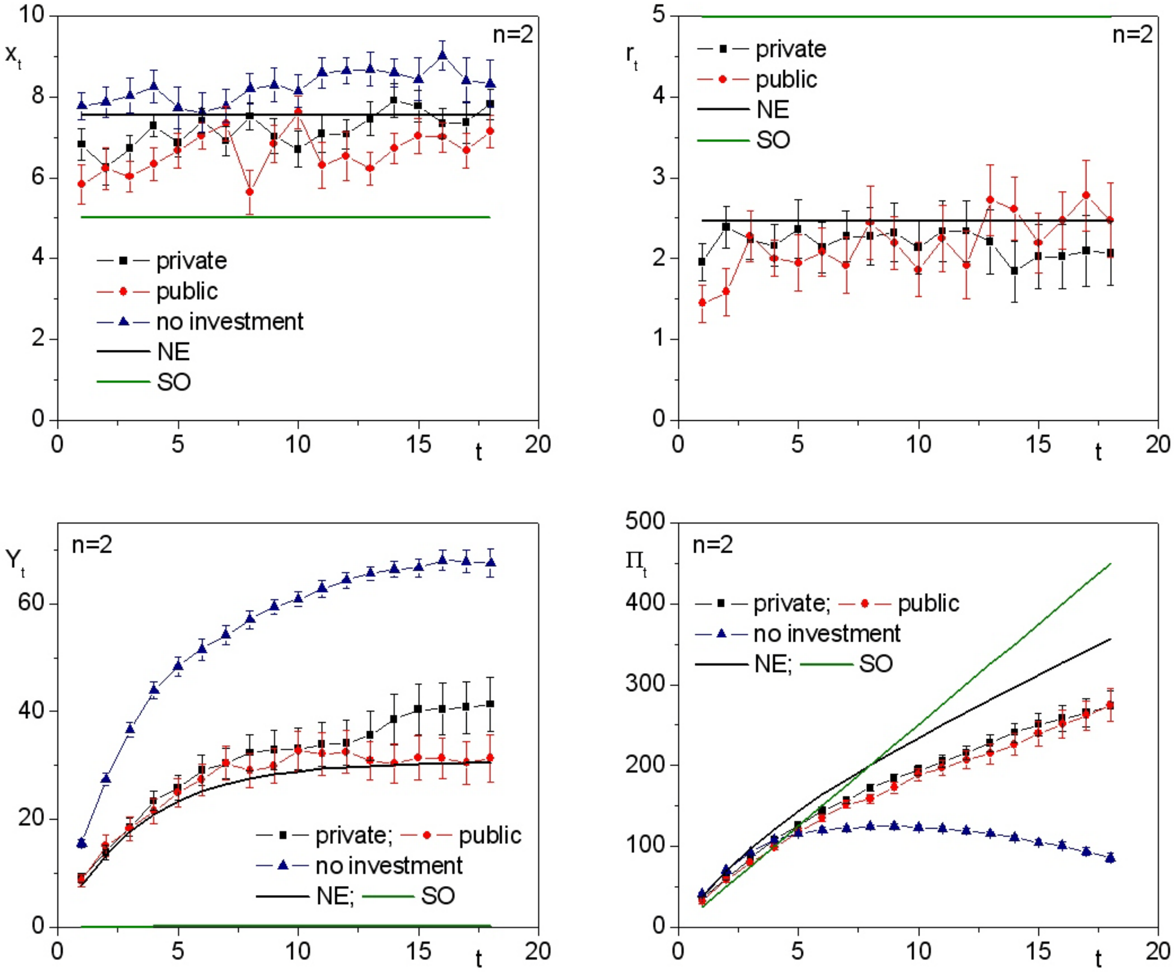

Figure 3. The average production input (x_t), investment in impact reduction (r_t), pollution level (Y_t), and cumulative payoffs (Π_t) in treatments with group size *n*=2, with group-level error bars. The solid curves

show the theoretical predictions based on the Markov perfect equilibrium (NE) and social optimum (SO) solution concepts.

The lower left graph in Figure 3 shows the average amount of pollution (the public bad) generated by a group. As expected, the treatment without investment in clean technology generates the highest level of pollution. There is no statistical difference in the levels of pollution between the two treatments with investment in earlier periods; however, in later periods the treatment with common access to clean technology generates less pollution. Interestingly, the level of pollution in that treatment follows closely the NE prediction.

The lower right graph in Figure 3 shows the average cumulative payoffs in the three treatments. Payoffs in the treatment without investment in clean technology are the lowest and do not satisfy the sustainability criterion (non-decreasing long-run payoffs). In the other two treatments, sustainability is reached, and there is no statistical difference between payoffs in the two treatments.

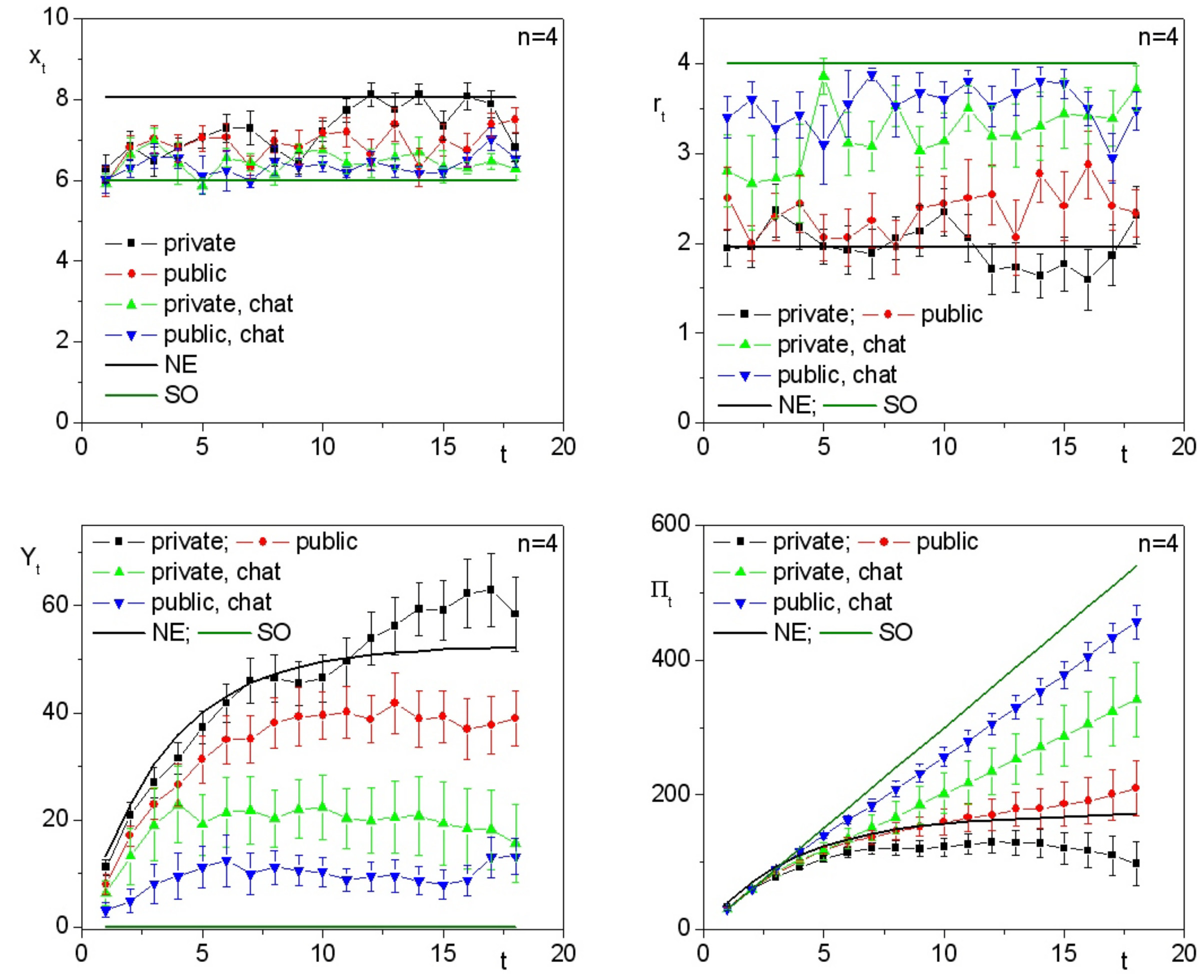

Figure 4. The average production input (x_t), investment in impact reduction (r_t), pollution level (Y_t), and cumulative payoffs (Π_t) in treatments with group size *n*=4, with group-level error bars. The solid curves show the theoretical predictions based on the Markov perfect equilibrium (NE) and social optimum (SO) solution concepts.

The results for treatments with *n*=4 are shown in Figure 4. Each graph in Figure 4 shows four experimental curves corresponding to the 2x2 taxonomy of treatments with private/common access to clean technology and no chat/chat. As seen from the upper left graph in Figure 4, the highest production inputs are observed in the treatment with private access and no chat (although the difference is only significant in a few later rounds), while there is no statistical difference between average production inputs in the three other treatments. In terms of investment in clean technology (the upper right graph), the treatments with chat produce more investment than the treatments without chat. Common access tends to produce more investment than private access, although the difference is not statistically significant in all rounds. The ranking of treatments by the level of pollution (the lower left graph in Figure 4) has the same features: the treatment with private access/no chat produces the highest level of pollution, followed by common access/no chat, then by private/no chat and common/chat, although the difference between the latter two treatments disappears in later rounds. The lower right graph in Figure 4 shows the cumulative payoffs. The ranking of treatments by payoff levels follows the identified pattern, with statistically significant differences between all four treatments. Sustainability is not reached in the treatment with private access/no chat, and reached in all other treatments.

To summarize the findings:

(a) Common access to clean technology leads to higher investment in clean technology, lower levels of pollution and dominating payoffs. The effect does not disappear (and, in fact, is enhanced) with an increase in group size.

(b) Common access leads to behavior that is the closest to the socially optimal outcome. The effect is enhanced with an increase in group size and in the presence of chat.

(c) The results suggest the effectiveness of policies promoting R&D collaboration and technology sharing in dynamic public bad problems, for example, in combating environmental damage and climate change.