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Collective and Random Fining versus Tax/Subsidy Schemes to Regulate Non-Point Pollution: An Experimental Study

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Abstract

In this paper we present results of an experimental study on the performance of three mechanisms which are designed to deal with non-point source pollution: collective fining, random fining, and a tax-subsidy scheme. Our results show that collective and random fining schemes do not induce the subjects to play the efficient equilibrium. Experience from participation in similar treatments further enforces the tendency to under-abate. The tax-subsidy mechanism, by contrast, induces the efficient equilibrium action to be played more frequently than the fining mechanisms, with a slight tendency to over-abate. Experience enforces this tendency. Controlling for the subjects' risk attitude, we find that for risk averse subjects the random fining mechanism outperforms the collective fine.

Keywords: Non-point source pollution, environmental policy, collective fining, random fining, tax-subsidy scheme, experiments.

1 Introduction

It is meanwhile widely acknowledged among economists that pollution control instruments which provide incentives to abate pollution through prices, such as emission taxes, subsidies, and tradable permits, are powerful and efficient tools in order to regulate pollution from point sources.[1] However, the application of these measures requires full information about each polluter's individual emission level, a fact which prevents its application to control pollution from non-point sources. A non-point source pollution problem is characterized by the special feature that a pollution control authority can gather information only about the *ambient* pollution level but not about individual emissions. This may be either the case because it is not technically possible to observe the emissions of each single polluter, or because monitoring them is prohibitively expensive.

The growing importance of non-point pollution sources, for instance the pollution of lakes and water sheds from agriculture, has developed a new theoretical and empirical literature that aims at designing appropriate instruments to deal with these kinds of problems.[2] The feature that the origin of non-point emissions cannot be monitored creates a moral hazard problem among the firms which share the same sink for their emissions. Independently, both Meran and Schwalbe [13] and Segerson [16] were the first to tackle this problem by proposing tax-subsidy schemes where each firm is taxed (subsidized) according to social marginal damage when ambient emissions exceed (fall short of) a level which is considered socially optimal by the regulator. This approach is based on the work of Holmström [8] who addresses the problem of free riding in teams in a more general environment. A main finding of Holmström is that, in the absence of uncertainty, no budget balancing mechanism exists to solve the problem of avoiding individual free riding in teams. Rasmusen [14], however, revises Holmström's results by observing that budget-balancing contracts are feasible in an environment of uncertainty if agents are risk averse.

Xepapadeas [21], applies this approach to the regulation of non-point source

[1]For a survey see [15].

[2]See [17] for an extended survey on the economics of non-point source pollution control.

pollution and proposes a new type of contract between each firm and the regulator characterized by a combination of subsidies and fines. While the subsidies paid to each firm are proportional to the aggregate reduction of emissions, the fine is only charged in case that the ambient pollution level exceeds the aggregate emission standard set by the regulator. In his contribution Xepapadeas studies two different fining regimes: collective and random fining. Under collective fining all the firms are fined whenever the observed ambient pollution level lies above that standard. Under the random fining scheme, by contrast, only one firm is randomly chosen to be punished, irrespective of being responsible for the whole group's deviation from the required standard.

Whereas Xepapadeas claims his mechanism to be budget balancing, Kritikos [10] shows that the random fining budget-balancing contract proposed by Xepapadeas is not incentive compatible when firms are symmetric and face the same probability of being fined. Herriges et al. [7] also note that Xepapadeas' claim contradicts Holmström's result. They state, however, that his mechanism might induce compliance if the firms are sufficiently risk averse.

Nevertheless, when relaxing the requirement of budget balancedness and choosing the fees sufficiently high, both mechanisms suggested by Xepapadeas are theoretically suitable to implement the efficient allocation of abatement efforts in Nash equilibrium. However, besides the efficient allocation, intended by the regulator, there is in general a second, inefficient (symmetric) Nash equilibrium which is characterized by under-abatement. Moreover, there may be many more asymmetric equilibria, characterized by meeting the standard, though through inefficient allocation of abatement efforts. This multiplicity of equilibria, therefore, rules out a clear prediction of the outcome.

Whereas with the collective and random fining mechanisms under-abatement cannot be ruled out as a possible equilibrium outcome, the mechanism suggested by Segerson suffers from triggering over-abatement. This is so because the subjects can derive advantage from the feature that the regulator pays a subsidy proportional to total abatement to everybody. Hence by colluding, firms can collectively achieve more subsidies than in the socially optimal non-cooperative equilibrium. If the regulation game is played repeatedly and if there is some uncertainty, for example about the exact number of periods the game is to last, it is well known that collusive outcomes can even be supported by equilibrium strategies such as trigger strategies or optimal penal codes (see [1], [5], and [11]).

Inspired by the theoretical analysis, several experimental studies have been conducted to test the efficiency of the different forcing contracts in inducing the socially optimum outcome. Spraggon [18] finds that the tax-subsidy mechanism suggested by Segerson turns out to be amazingly efficient in achieving the ambient standard while collective fining performs much worse. Cochard et al. [3], by contrast, use a setting where the polluting firms exercise an endogenous negative externality among each other. Using an extremely high fine the authors find the group fine to perform fairly efficiently within this setting. The tax-subsidy scheme, by contrast, induces considerable over-abatement, that is, firms reduce the aggregate ambient pollution level far beyond the socially optimal one.

Vossler et al. [19] introduce uncertainty about the firms' sale revenues and allow for "cheap talk" prior to playing. In this setting, they also propose a mechanism which combines the tax-subsidy scheme with a fixed penalty. Allowing for non-bidding communication among the firms, they conclude that the efficiency of the fixed penalty is increased while under the tax-subsidy mechanism the collusive outcome is observed.

In a recent paper, Alpízar et al. [2] compare the collective and random fining mechanisms using a non-budget-balancing version of the mechanisms proposed by Xepapadeas. Running the experiments with two different subject pools, Costa Rican students, on the one hand, and CEO's of Costa Rican coffee mills, on the other, they find that, firstly, both fining schemes perform relatively well in achieving the optimal pollution level when applied to groups of two. Secondly, no significant differences among fining regimes can be observed in that case. Thirdly, the pool of subjects does matter: while over-abatement was observed with the managers, the students tended to under-abate.

In this paper we present an extension of the study by Alpízar et al. First, we increase the number of subjects that share the same resource (here, the sink for pollution) from 2 to 5. Doing so we introduce uncertainty about the decisions of the other subjects. Secondly, we compare the non-budget balancing versions of the collective and random fining mechanisms to the tax-subsidy instrument. The hypothesis to be tested is that the behavior of a risk neutral subject should not be affected by a change in the fining system since expected gains are identical, and as the main novelty with respect to the previous experiments, we control for the risk attitude of the subjects who participate in the experiments, and we investigate whether or not there is a systematic relationship between risk attitude and the subjects' performance in different treatments. Thirdly, we analyze how the size of the fine affects the instruments' efficiency.

We find that the tax-subsidy instrument outperforms both the collective and the random fining scheme with respect to efficiency. Whereas in both fining mechanisms we observe frequent play of the inefficient symmetric equilibrium and also some out of equilibrium play, mostly inducing under-abatement, we observe a tendency to over-abatement with the tax subsidy scheme. The latter finding, resulting from collusion, is in line with the findings of Cochard et al., but contrasts from Spraggon. Moreover, we find that experience from participation in one of the other treatments studied here enforces under-abatement in the fining games while it increases the tendency to over-abatement in the tax-subsidy scheme.

Raising the size of the fine in the fining games, we would expect compliance to increase. Surprisingly, we found this to be true only in the collective fining mechanism when applied to inexperienced subjects.

Finally, we found that risk attitude has an impact on performance for certain ranges of risk aversion. Whereas the behavior observed under the two mechanisms is the same for risk neutral subjects, risk averse players increase their abatement when the group fine is substituted by the random fine. Surprisingly, highly risk averse subjects show identical behavior to the risk neutral ones when switching from the collective to the random fining mechanisms. Moreover, risk averse subjects are less affected by experience in similar control mechanisms.

The remainder of the paper is organized as follows. In section 2 we briefly outline the theoretical background. In section 3 we explain the experimental design, and in section 4 we present our main empirical findings. Finally, in section 5 we draw some conclusions and give perspective for further extensions.

2 Theoretical background

Consider an industry consisting of n firms where each firm $i = \{1, ..., n\}$ is characterized by both, its default profit Π_i^0, incurred without engaging in any abatement activity, and by its abatement technology represented by an abatement cost function $C_i(a_i)$, where by a_i we denote the firm's abatement level. The abatement cost function satisfies the following properties: $C_i(0) = 0$, $C_i' > 0$, and $C_i'' > 0$. Zero abatement leads to a maximal emission level $e_i^{\max}$. Thus, the profit function of each firm can be written as:

$$\Pi_i = \Pi_i^0 - C_i(a_i) \tag{1}$$

Total emissions by industry are then given by $E = \sum_{i=1}^{n}(e_i^{\max} - a_i)$ and are evaluated by a social damage function $D(E)$. For simplicity we assume the damage function to be linear in total emissions. Hence we obtain:

$$D(E) = d\left[\sum_{i=1}^{n}(e_i^{\max} - a_i)\right] \tag{2}$$

where $d > 0$ denotes the marginal social damage. As in Xepapadeas [21] we consider a deterministic relationship between the firms' emissions and the ambient pollution level.

In this partial model the regulator's objective is to maximize social welfare (SW) defined as the sum of the firms' profits minus the social damage from pollution.

$$SW = \sum_{i=1}^{n}\left[\Pi_i^0 - C_i(a_i)\right] - d\sum_{i=1}^{n}(e_i^{\max} - a_i) \tag{3}$$

If firms are symmetric, equation (3) can be rewritten as:

$$SW = n\Pi^0 - \sum_{i=1}^{n} C(a_i) - d\left[ne^{\max} - \sum_{i=1}^{n} a_i\right] \tag{4}$$

The socially optimal allocation is then simply characterized by the following first order condition:

$$C'(a_i) = d \tag{5}$$

By a^* we denote the solution of condition (5) and by $A^* = na^*$ the corresponding aggregate optimal abatement. In the following subsections we describe the different instruments designed to decentralize the abatement decisions, that are subject of our experimental investigation.

2.1 Tax-Subsidy Instrument

The Tax-Subsidy mechanism, suggested by Segerson [16], works as follows. Whenever the aggregate abatement level falls short of (exceeds) the socially optimal aggregate abatement level A^*, the regulator charges all the firms with a tax (pays a subsidy to all the firms) proportional to the difference between optimal and actual abatement. Note that the total tax bill (subsidy payment) is the same for each firm. Thus, with this mechanism a typical firm's profit can be written as:

$$\Pi_i(a_i, \boldsymbol{a}_{-i}) = \Pi^0 - C(a_i) - s\left[A^* - \sum_{i=1}^{n} a_i\right] \tag{6}$$

where by s we denote the tax or subsidy rate and by $\boldsymbol{a}_{-i}$ the vector of decisions of the other firms but i. When implemented as a one-shot or finitely repeated game, the unique Nash equilibrium is characterized by the condition

$$C'(a_i) = s \tag{7}$$

i.e. the firms set an abatement level the marginal cost of which equals the tax or subsidy rate. The Nash strategy is even a dominant strategy which leads to the first best allocation, i.e. $a_i = a^*$, if s equals the social marginal damage d. Note that the mechanism is not collusion proof as stressed by Hansen [6]. Therefore, if firms manage to coordinate on an abatement level higher than socially optimal, they can earn a higher profit than in the one–shot Nash equilibrium.

It is well known that collusive outcomes can be supported by different equilibrium strategies in infinitely repeated games. Most prominent of these are trigger strategies where deviation from the collusive outcome is punished by returning to the one-shot Nash equilibrium play forever. In some games there exist other more severe, but also more complicated penal codes (see [1], [11]) which, however, are not very likely to be coordinated on without allowing for "cheap talk".

2.2 The Collective and the Random Fining Mechanisms

Next we introduce a non-budget-balancing version of Xepapadeas' *collective fining mechanism* which combines a subsidy proportional to total abatement and a penalty in case that actual aggregate abatement falls short of the optimal level. Formally a firm's profit can be written as

$$\Pi_i(a_i, \boldsymbol{a}_{-i}) = \begin{cases} \Pi^0 - C(a_i) + \frac{s}{n}\left[\sum_{i=1}^{n} a_i\right] & \text{if} \quad \sum_{i=1}^{n} a_i \geq A^* \\ \\ \Pi^0 - C(a_i) + \frac{s}{n}\left[\sum_{i=1}^{n} a_i\right] - f & \text{if} \quad \sum_{i=1} a_i < A^* \end{cases} \tag{8}$$

where s/n is the share of the total subsidy rate s paid to firms per unit of pollution abated by the whole industry, and f denotes the individual fine the regulator charges each firm.

The *random fining mechanism*, a non-budget-balancing version of the mechanism proposed by Xepapadeas, is very similar to the collective fining mechanism. The only difference is that in case of non-compliance only one of the firms is picked randomly with probability $1/n$ and is charged a total fine of $F = nf$. Note that the expected profit is the same for both the collective and the random fining mechanisms. Note also that a firm which has abated at least a^* units may happen to be fined if $\sum_{i=1}^{n} a_i < A^*$. Thus a typical firm's profit is now given by:[3]

[3]The version of the random fining mechanism here used is non-budget balancing, since the amount of the fine collected from one of the firms is not redistributed among all the other firms as done in Xepapadeas [21]. In addition to this, the punished firm receives its share of the subsidy s/n. This last modification was introduced for the sake of comparability of the experimental results with those of the collective fining mechanism. Otherwise, the randomly selected firm would face a double punishment: the total fine it has to pay and the share of the subsidy it does not receive.

$$\Pi_i(a_i, \boldsymbol{a}_{-i}) \begin{cases} \Pi^0 - C(a_i) + \frac{s}{n}\sum_{i=1}^n a_i & \text{if } \sum_{i=1}^n a_i \geq A^* \\ \\ \Pi^0 - C(a_i) + \frac{s}{n}\sum_{i=1}^n a_i & \text{if } \sum_{i=1}^n a_i < A^* \quad \text{prob.} = \frac{n-1}{n} \\ \\ \Pi^0 - C(a_i) + \frac{s}{n}\sum_{i=1}^n a_i - F & \text{if } \sum_{i=1}^n a_i < A^* \quad \text{prob.} = \frac{1}{n} \end{cases} \tag{9}$$

From (8) and (9) it is straightforward to see[4] that the efficient outcome $\boldsymbol{a}^* = (a^*, ..., a^*)$ is a Nash equilibrium if the fine is chosen sufficiently high. Consider first the *collective fining mechanism*. We see that the incentive compatibility condition for reaching the efficient outcome

$$\Pi_i(\tilde{a}_i, \boldsymbol{a}_{-i}^*) < \Pi_i(a^*, \boldsymbol{a}_{-i}^*)$$

implies the following condition for the fine:

$$F > n\left[C(a^*) - C(\tilde{a}_i)\right] + s(\tilde{a}_i - a^*) \tag{10}$$

for any $\tilde{a}_i \neq a^*$.

For the *random fining mechanism* we have to consider the *expected profit* $E\Pi_i(\tilde{a}_i, \boldsymbol{a}^*)$ since a firm will be fined with a certain probability lower than 1. Therefore, the incentive compatibility condition is now given by:

$$E\Pi_i(\tilde{a}_i, \boldsymbol{a}^*) < \Pi_i(a^*, \boldsymbol{a}^*)$$

and, for a risk neutral player, this implies that the fine should satisfy condition (10).

Besides the efficient outcome, the game has a second symmetric equilibrium, characterized by the first order condition of maximizing the individual firm's profit:

$$C'(a_i) = \frac{s}{n} \tag{11}$$

In addition to these symmetric equilibria, there may exist other asymmetric equilibria. Any strategy profile $\boldsymbol{a} = (a_1, ..., a_n)$, satisfying $\sum_{i=1}^n a_i = A^*$, is an equilibrium if the firm which chooses the highest abatement level has no incentive to deviate from this level.

[4]See [2] and [21].

Note that both the collective and the random fining games do not exhibit any collusive outcome which yield higher payoffs than the efficient equilibrium. To see this, observe that the first order condition of joint profit maximization[5] yields the first order condition $C'(a_i) = s$ which is also the equilibrium condition for the efficient and payoff dominant equilibrium. Thus, if players try to coordinate in order to maximize their joint payoff, they should coordinate on the efficient equilibrium.

3 Experimental Design

The experiment was conducted at the experimental laboratory in the University of Kiel (KIEEL). Subjects were volunteers recruited from students of different departments at this university.

In our experimental design we modeled an industry consisting of 5 firms ($n = 5$) with a default profit $\Pi^0 = 200$ and a discrete abatement cost schedule presented in table I.

Abated units	Marginal cost	Total cost
0	0	0
1	20	20
2	40	60
3	60	120
4	80	200

Table I: Abatement cost schedule.

Moreover, the regulator valuates the marginal damage of ambient pollution with $d = 50$, thus choosing an optimal subsidy of $s = 50$. Abatement schedule and marginal damage imply a socially optimal abatement level of $a^* = 2$ for any $i = 1, ..., 5$, leading to an optimal aggregate abatement level of $A^* = 10$.

[5] Joint profits are given by:

$$\sum_{i=1}^{n} \Pi_i = n\Pi^0 - \sum_{i=1}^{n} C(a_i) + s \sum_{i=1}^{n} a_i.$$

In order to measure the sensitivity of the firms' response to the size of the fine, we run different treatments with fines of $f = 60$ and $f = 90$ for the collective fining mechanism, and the corresponding $F = 300$ and $F = 450$) for the random fining mechanism.

Besides the efficient abatement allocation $\boldsymbol{a}^* = (2, ..., 2)$, both the collective and the random fining game have a second symmetric equilibrium with $\boldsymbol{a}^* = (0, ..., 0)$. With our choice of parameters there are no asymmetric equilibria.

Table II summarizes the different treatments including the corresponding fines, taxes and subsidies.

Treatment	Instrument	Fine	Subsidy	Equilibria
Collective 60	Collective fine	60	$10A$	$0, 2^*$
Collective 90	Collective fine	90	$10A$	$0, 2^*$
Random 300	Random fine	300	$10A$	$0, 2^*$
Random 450	Random fine	450	$10A$	$0, 2^*$
Tax-Subsidy	Tax or Subsidy	$50(10 - A)$	$50(A - 10)$	2^*

Table II: Experimental design and symmetric equilibria. The asterisk denotes the socially optimum equilibrium and $A = \sum_{i=1}^{n} a_i$.

The experiment was programmed and conducted with the software z-Tree (Fischbacher [4]). After subjects had arrived at the laboratory, they were randomly assigned to one of the computer terminals. Instructions[6] were given and questions were answered. The subjects were informed that communication was not allowed until the end of the session. Every session involved 10 subjects who participated in two of the treatments, each of which mimicking one of the three mechanisms described in the section above. At the beginning of each treatment, subjects were randomly matched with four other participants. In each treatment three trial rounds were played in order to ensure the correct understanding of the mechanisms. After the trial periods, subjects were again randomly rematched, being informed about

[6]The instructions are available upon request from the authors.

this. During and after the treatments subjects were not informed about whom they were matched with.

Subjects were told to play the role of a firm deciding on the reduction of some pollutant below its default pollution level $e^{\max}$ equal to 4 units. They were also informed about the nature of the special mechanism, each of which allows a maximum level of ambient pollution A^* equal to 10 units. Within this framework in any decision period subjects were asked to simultaneously submit their abatement decision a_i by entering an integer number between 0 and 4 in the respective computer program. After each period, subjects were informed on the screen about total abatement effort of all five members of the group and about their individual payoff.

Each mechanism was administered as a non-cooperative game and was repeated at least 20 periods[7]. After the 20th period a coin was flipped to decide whether or not one further period had to be played[8]. In case of continuation, a coin was flipped again after the additional round, and so on. The subjects were informed from the beginning about this random termination of the treatment.

Subjects were paid in cash at the end of the experiment. To determine their earnings from the experiment, one of the treatments was randomly chosen at the end of the session[9]. Their final payoff consisted then of their cumulated profits in the selected treatment. Earnings during the experiments were designated in experimental currency units (ECUs) and converted into € at the end of the experiment using an exchange rate of 1€=300 ECUs. Six sessions, that lasted about 90 minutes each, were conducted with an average earning of about 15 €.

Note that during the random fining treatment a player's per period payoff becomes negative in case of being fined. Hence it was theoretically possible that the cumulative payoff was negative after the last round. As a matter of fact, this never happened in any session. The subjects were told that in case that the cumulative payoff became negative their final payoff would be zero. We had to do so, because

[7]Except for Collective 60 with inexperienced subjects where only 15 periods were played for sure.

[8]As a result, between 20 and 24 periods were played.

[9]This procedure helps us to avoid any income effect when playing the second treatment.

we had advertised that subjects could earn a positive amount of money. We cannot exclude that the (theoretical) possibility of non-negative final payoffs induced subjects to play more risky once they were fined (because they had less to lose). We could have avoided negative payoffs per round by choosing the default payoff Π^0 sufficiently high. Doing so, however, would have resulted in an implicit restriction on the relative variation of the fine size (increasing Π^0 makes the relative difference between $F = 300$ and $F = 450$ much smaller).

3.1 Risk Attitude Test

At the end of the session, subjects were asked to answer a short questionnaire which, besides some routine questions about age, gender, number of semesters, and subject of their studies, also contained a test which was designed to measure their risk attitude. Inspired by the Multiple Price List procedure used by Laury and Holt [9] to elicit risk attitudes, we presented a menu of choices to the subjects, as illustrated in table 3.1. This test is based on 11 choices between a sure payoff and a lottery.

Situation	Option A	Option B
1	150 ECU	lottery
2	170 ECU	lottery
3	190 ECU	lottery
4	210 ECU	lottery
5	230 ECU	lottery
6	250 ECU	lottery
7	270 ECU	lottery
8	290 ECU	lottery
9	310 ECU	lottery
10	330 ECU	lottery
11	350 ECU	lottery

Table III: Risk attitude test. The lottery option involves a gain of 600 ECU with a 50% probability and zero otherwise.

When presenting the questionnaire, subjects were informed that, depending on their choices, an additional amount of money could be earned. The procedure to determine this payoff was as follows: one of the choice situations was randomly picked with equal probability. Then we used a dice in order to determine the outcome of the lottery if the subject had decided to choose the lottery in that choice situation. On average, subjects got an additional earning of 3 € from the risk test.

From the pattern of choices observed in this questionnaire, a risk attitude coefficient was computed for each of the subjects. This coefficient corresponds to the number of consecutive choices of the lottery (option B) before switching to the sure payoff (option A) and ranks from 0 to 11. In other words, the higher the coefficient, the lower the risk aversion of the subject.

According to the standard theory on individual decision making under risk, a risk neutral subject will always choose the option that gives the highest expected payoff. Therefore, the choice pattern of a risk neutral subject would be 8 consecutive times option B (lottery) until the sure payoff in option A takes the value of 310 ECUs and exceeds the expected payoff of the lottery which is 300 ECUs. As a consequence, the risk coefficient of a risk neutral agent will be between 8 and 9. In the same way, a risk averse subject will show a lower coefficient while a subject considered as risk seeking will be assigned a higher coefficient.

Following this criterion we classify a subject as "highly risk averse" when the number of lottery choices before switching to the sure option is 0, 1, 2, 3, or 4, as "risk averse" when the number of choices is 5, 6, or 7, as "risk neutral" when the number of choices is 8 or 9, and finally as "risk seeking" when the number of choices is 10 or 11.

4 Results

In the following we will for short refer to as "Collective 60" ("Collective 90") for the collective fining mechanism with a collective fine of $f = 60$ ($f = 90$), and to "Random 300" ("Random 450") for the random mechanism with an individual fine of $F = 300$ ($F = 450$). The tax-subsidy mechanism is simply referred to as "Tax-Subsidy".

Moreover, we will distinguish between *experienced* and *inexperienced* subjects. With *experienced* subjects we refer those which have already participated in one other treatment (mechanism) during one session. *Inexperienced* subjects, by contrast, participated in one of the treatments for the first time, i.e. they do not have experience from any other of our different treatments. No subject played the same treatment more than once.[10] Therefore, subjects could only gather experience from any other of the tested mechanisms.

The presentation of our results is organized as follows: first, we will discuss the efficiency of each tested mechanism to induce the socially desirable outcome and to solve the group moral hazard problem. Secondly, we study the effect of experience in each of the tested instruments. Thirdly, we will compare the collective and random fining mechanisms to test for the hypothesis that the behavior of a risk neutral subject should not be affected by the nature of the fining system (collective vs. random). Finally, we test the sensitivity of the observed results under each of the tested mechanisms with respect to the subjects' risk attitude.

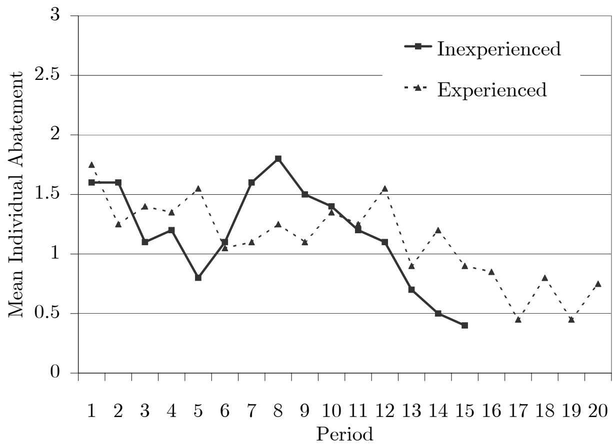
4.1 Efficiency in Inducing the Socially Desirable Outcome

As a first approach to the results, figure 1 shows the average abatement level per period for each of the tested mechanisms. For the Tax-Subsidy we find a rather stable average outcome of 2 units abated whereas for both the collective and the random fining mechanisms we observe frequent outcomes of aggregate under-abatement with a decreasing trend as the number of periods proceeds.[11]

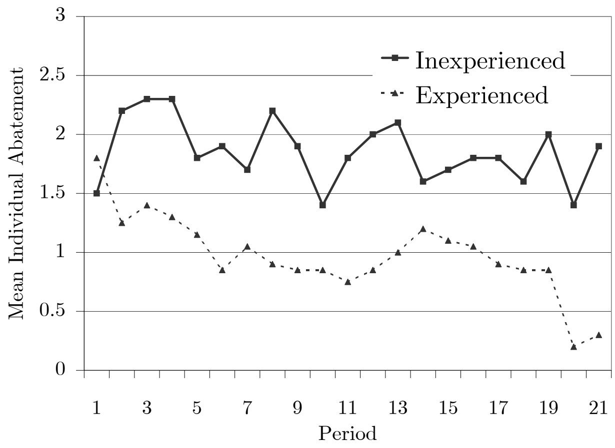
Table IV presents the average individual abatement per treatment for the pooled

[10]Furthermore, each player participated either in Collective 60 or in Collective 90, or either in Random 300 or Random 450.

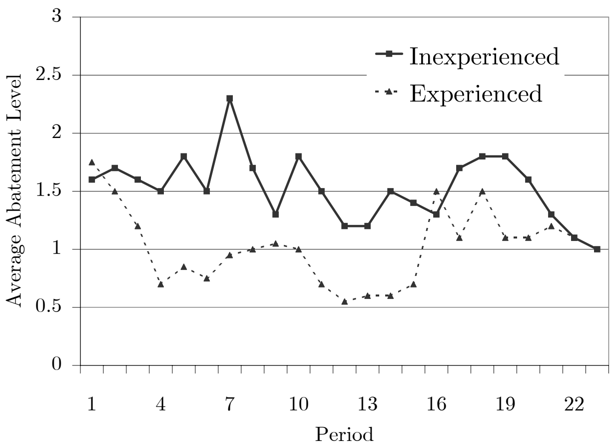
[11]This sort of dynamics is also typical for contributions to a public good under the voluntary contribution mechanism where the starting point is something around 50% of the full contribution (2 units in our setting) followed then by a significant decrease in contribution (abatement level in our case) when the game is repeated. See Ledyard [12] for a survey on the main results in public goods experiments.



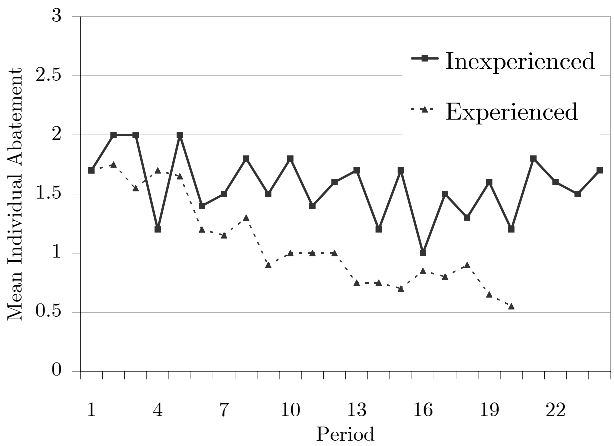
(a) Collective 60



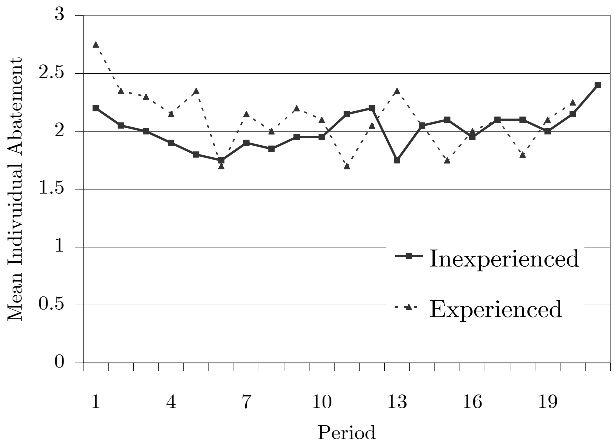
(b) Collective 90



(c) Random 300



(d) Random 450



(e) Tax-Subsidy

Figure 1: Mean individual abatement level per period for each treatment.

data as well as for both inexperienced and experienced subjects aggregated over all periods. Evidence from those aggregate data suggests that the tax-subsidy mechanism works best to induce the socially desirable abatement. However, an average abatement of two units, say, may result from averaging out inefficient individual abatement efforts such as $a_i = 1$ and $a_i = 3$. Hence, in order to obtain a clearer picture about the performance of the mechanisms we have to look at the frequency distributions of choices regarding subjects' abatement level.

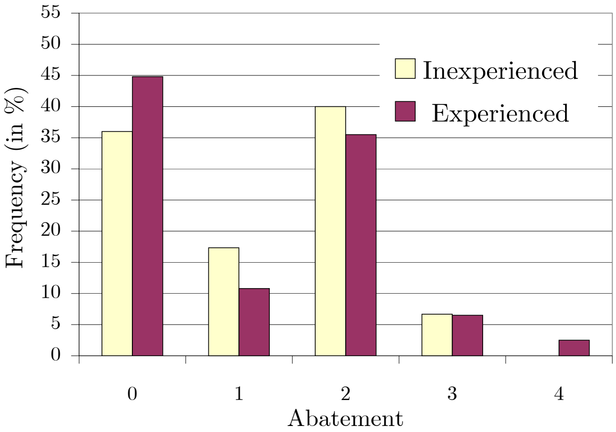
Treatment	Aggregate		Inexperienced		Experienced	
	Mean	S.D.	Mean	S.D.	Mean	S.D.
Collective 60	1.13	1.10	1.17	1.00	1.11	1.13
Collective 90	1.28	1.15	1.85	0.98	0.99	1.11
Random 300	1.19	1.09	1.53	1.12	0.98	1.01
Random 450	1.27	1.09	1.57	1.07	1.09	1.06
Tax-Subsidy	2.06	0.96	2.00	0.93	2.11	1.00

Table IV: Summary statistics on the average individual abatement per treatment.

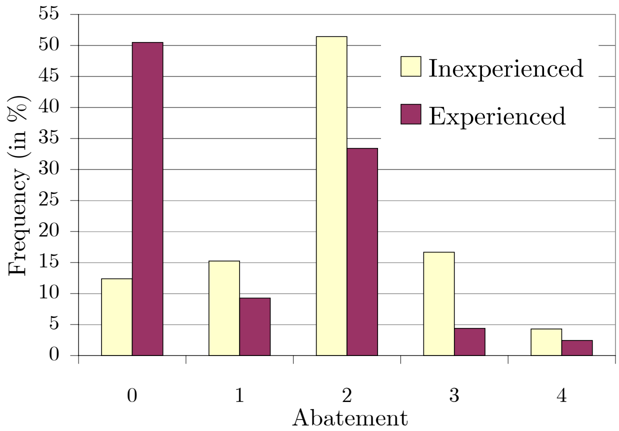
Let us start to discuss the results for the collective and random fining mechanisms. From figure 2 we observe that, in all treatments, inexperienced subjects decided to abate 2 units (the efficient effort) at a frequency between 40% and 53%.

For experienced subjects, the distribution of decisions becomes bimodal with two peaks at 0 and 2 units of abatement. Now approximately 50% of the decisions coincide with the inefficient equilibrium outcome, $a_i = 0$, and only between 30% and 40% of individual decisions remain at the socially optimal level of 2 units. In fact, if we compare the distribution of decisions for inexperienced versus experienced subjects by using a Kolmogorov-Smirnov (KS) test, it turns out that differences are statistically significant for all tested mechanisms but Collective 60.

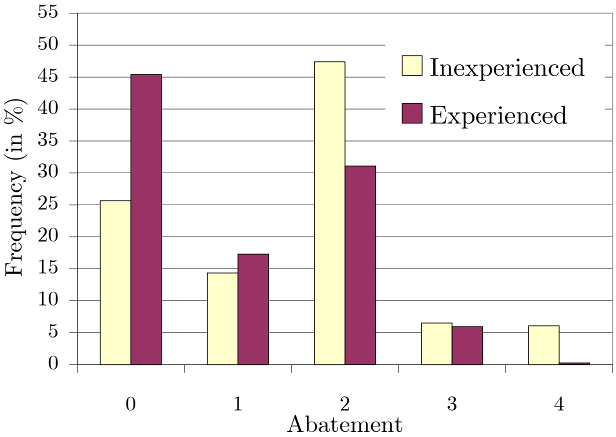
Regarding the tax-subsidy mechanism we observe that inexperienced subjects chose the socially optimal level at a frequency of 50%. Experienced subjects, by contrast, chose the efficient level only at a frequency of 41.8% whereas they picked



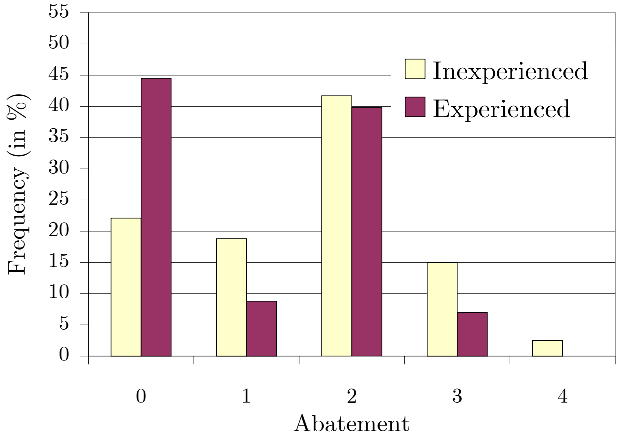
(a) Collective 60



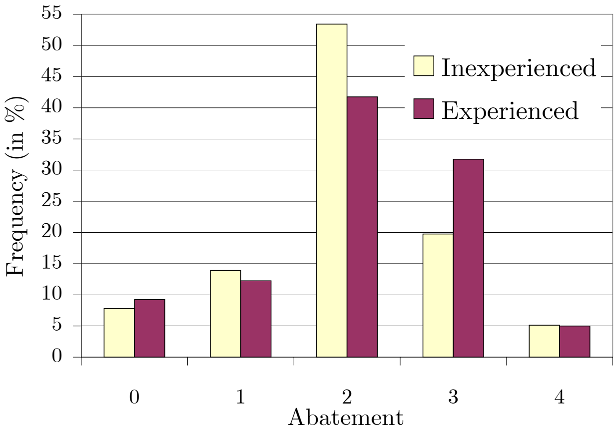
(b) Collective 90



(c) Random 300



(d) Random 450



(e) Tax-Subsidy

Figure 2: Frequency distribution of individual abatement levels per treatment.

3 units in 31.8% of all cases (against a 14.1% with inexperienced subjects), 1 unit in 12.3%, and 0 units in 9.3% of the cases [see also Figure 2(e)]. Employing a KS test, we can confirm that the difference in distributions between inexperience and experience conditions is statistically significant ($\alpha = 0.007$). Note that whereas under-abatement, i.e. playing $a_i = 1$ or even $a_i = 0$, is not quite rational given the incentives of the tax-subsidy mechanism, over-abatement can be well explained as a trial to coordinate on the collusive outcome.

4.2 Efficiency Comparison

In order to fully compare the outcomes of our different mechanisms with respect to efficiency, and also to compare our results to those of other studies which analyze the performance of similar control mechanisms, we compute the relative efficiency of each of the tested instruments.

Following Spraggon [18], we define (relative) efficiency as the ratio of the welfare difference between observed welfare ($SW_{Observed}$), resulting from application of the respective instrument, and welfare under *laissez faire*, ($SW_{No\,regulation}$), on the one hand, and the welfare difference between the social optimal outcome ($SW_{Optimum}$)and *laissez faire*, on the other:

$$E = \frac{SW_{Observed} - SW_{No\,regulation}}{SW_{Optimum} - SW_{No\,regulation}} \times 100 \qquad (12)$$

Note that given our setting, efficiency cannot be negative[12] and therefore will range between 0 and 100.

Table V shows that the tax-subsidy mechanism outperforms both the group fine and the random fine game. An exception from this is the findings by Cochard et al. [3] who, however, use a fine 8 times higher as necessary to make the firm indifferent between compliance and non-compliance. Under this setting, they obtain an efficiency of 60% under the collective fine, being more efficient than the tax-

[12] In Cochard et al. [3] it is possible for the control instrument to induce negative efficiency values. This results from their special setting where the subjects' decisions generate externalities on the other members of the group.

Instrument	Efficiency (in %)							
	Our results		Alpízar et al.[1]		Spraggon[2]		Cochard et al.[3]	Vossler et al.[4]
	Inexp.	Exp.	Inexp.	Exp.	Inexp.	Exp.	(Inexp.)	(Inexp.)
Collective 60	58	68	62	48				42
Collective 90	76	44			54	78	60	
Random 300	63	49	59	58				
Random 450	67	52						
Tax-Subsidy	79	75			98	96	-41	56

[1] Alpízar, Requate and Schramm (2004).

[2] Spraggon (2002).

[3] Cochard, Willinger and Xepapadeas (2002).

[4] Vossler, Poe, Segerson and Schulze (2002).

Table V: Efficiency comparison.

subsidy mechanism (with an efficiency of -41%). By contrast, Spraggon [18] uses a fine 2.13 times the maximum deviating net gain (thus comparable to our Collective 90 treatment) and for inexperienced (experienced) subjects obtains an efficiency of 54% (78%) under the group fine mechanism against an efficiency of 98% (96%) for the tax-subsidy. Vossler et al. [19] find that allowing for "cheap talk" increases the efficiency of the group fine from 42% to 72%, whereas "cheap talk" reduces efficiency from 56% to -174% in the tax-subsidy mechanism since subjects seem to coordinate on the collusive outcome. We summarize these findings in the following result:

Result 1: The tax-subsidy mechanism performs better than the collective and random fining instrument in inducing the socially optimal outcome.

4.3 Treatment Effect and the Dynamics of Abatement Decisions

Table VI presents the result of a panel regression estimate (random effects GLS estimation) to analyze individual data as well as dynamics over time. Given that we collected observations for each subject during a certain number of periods, the panel estimation allows us to explicitly estimate specific effects which are common to an individual across periods, but might differ across subjects.

In order to account for treatment effects, we used the data of individual abatement for Collective 60 as baseline and studied how a change in the control mechanism affects abatement decisions. For this purpose, we included dummies for each tested mechanism in the regression.

In addition to the treatment effects we included also the regressors "experience" and "period" to account for the effect of experience and repetition, respectively. Finally, we included a regressor which indicates whether or not the own abatement effort exceeds the mean abatement of other group members in the previous period. We did so because the aggregate abatement effort was the only information available to the subjects at the end of each period, and because we wanted to find out how subjects react on this information. This variable is written as "$a_{it-1} > Average_{t-1}$".

Its value is equal to the difference $|a_{it-1} - Average_{t-1}|$ if a_{it-1} exceeds the average abatement of the other members of the group ($Average_{t-1}$) and is zero otherwise. In a similar way, we define "$a_{it-1} < Average_{t-1}$" for negative deviations.

Variable	Coef.	S.E.	$p > \|z\|$
Constant	1.5617	0.0792	0.000
Collective 90	0.2286	0.0665	0.001
Random 300	-0.0328	0.0608	0.589
Random 450	0.3563	0.0611	0.000
Tax-Subsidy	1.0161	0.0574	0.000
Experience	-0.3175	0.0349	0.000
Period	-0.0260	0.0027	0.000
$a_{it-1} > Average_{t-1}$	0.0516	0.0237	0.030
$a_{it-1} < Average_{t-1}$	-0.0660	0.0249	0.008
N		3220	
T		22	
R^2		0.1485	
$\hat{\rho}$		0.1598	

Table VI: Random Effects GLS Regression.

It is natural to conjecture that under the collective and the random fining mechanisms higher fees induce higher levels of abatement. In order to test this hypothesis, we tested a fine 1.5 (2.25) times the minimum amount that satisfies condition (10) by imposing an individual fine of 60 ECUs (90 ECUs) whenever the aggregate abatement falls short of 10 units. If we assume that in the absence of regulation firms choose an abatement level of 0 units, a Wilcoxon test shows that a group fine of 60 ECUs increases abatement with respect to the *laissez faire* situation since the mean abatement level of 1.13 units for Collective 60 is significantly higher than 0. Moreover, from table VI we can conclude that our hypothesis regarding an increase in the fine is correct since the coefficient for Collective 90 is significant and positive.

Another interesting result comes from the comparison of the collective and random fining mechanisms. Interestingly, the results are related to the fine size. Although the two mechanisms perform equivalently with a low fine - this can be seen form the coefficient of Random 300 which is not significant - they induce different outcomes when we use a higher fine. Thus, the null hypothesis that the coefficients for Collective 90 and Random 450 are equal can be rejected using a Chi-square test ($\alpha = 0.029$). This means that, with a high fine, the random fining mechanism increases abatement when compared to the collective fine.

To finish with the treatment effects, note that, as expected, abatement effort under the tax-subsidy mechanism is significantly higher than under both the collective and the random fining mechanisms.

Turning our attention now to the dynamics of the outcomes, we observe that experience and repetition significantly reduce abatement. Concerning the use of the information about the deviations from the group average, both coefficients for positive and negative deviations are significant. This means that if a subject over-abated with respect to the other members of the group ($a_{it-1} > Average_{t-1}$), the estimated coefficient indicates that he/she increases his/her contribution in the next period. However, when he/she under-abated ($a_{it-1} < Average_{t-1}$) in the past period, the negative sign of the respective coefficient indicates a decrease in his/her contribution. The reaction on past over-abatement could be explained by the existence of subjects who do not want to be fined and decide to increase abatement, or who want to signal the possibility of collusion in the case of tax-subsidy. By contrast, a decrease in abatement effort given past under-abatement compared to the group average could be explained by the rationale that given the group average is below 2 anyway, further reduction of abatement saves costs whereas the chance to induce the efficient outcome by raising abatement is low.

4.4 A closer Look at Experience

The significance of the coefficient for experience in Table VI clearly shows that experience plays an important role on abatement decisions. In order to study how experience affects the differences among treatments and dynamics, table VII reports the results of panel regressions for inexperienced and experienced subjects.

We observe that in the case of inexperienced subjects our results are similar to

Variable	Inexperienced subjects			Experienced subjects		
	Coef.	S.E.	$p > \|z\|$	Coef.	S.E.	$p > \|z\|$
Constant	1.2489	0.1829	0.000	1.6383	0.1125	0.000
Collective 90	0.6952	0.2489	0.005	-0.2259	0.1620	0.163
Random 300	0.4151	0.2485	0.095	-0.3877	0.1143	0.001
Random 450	0.4572	0.2484	0.066	-0.0963	0.1627	0.554
Tax-Subsidy	0.8644	0.2164	0.000	1.0289	0.0823	0.000
Period	-0.0100	0.0039	0.012	-0.0388	0.0034	0.000
$a_{it-1} > Average_{t-1}$	0.0656	0.0415	0.114	0.0226	0.0287	0.430
$a_{it-1} < Average_{t-1}$	-0.0459	0.0368	0.213	-0.0773	0.0327	0.018
N		1240			1980	
T		22			21	
R^2		0.0886			0.1810	
$\hat{\rho}$		0.2558			0.2584	

Table VII: Random Effects GLS Regression, inexperienced and experienced subjects.

those of the pooled sample reported in table VI. The main difference we find is a higher coefficient for Collective 90, which means that an increase in the fine raises abatement significantly when applied to inexperienced subjects. However, once subjects gain experience, this effect disappears. I.e. with experience, an increase in the fine has no effect on the abatement decisions. Moreover, when the random fining is applied with a low fine, this significantly reduces abatement decisions compared to the collective fine, as we can see from the negative coefficient for Random 300. Therefore we obtain as second result:

Result 2: An increase in the fine induces a higher abatement level only when applied to inexperienced subjects.

Table IV confirms that subjects' decisions under both, collective and random fining suffer from under-abatement since the observed average individual abatement level lies below the social optimum of 2 units per subject. By performing a Wilcoxon test we can reject the null hypothesis that the observed average individual abatement is equal to 2. This holds for all treatments and for both, inexperienced and experienced subjects. Moreover a Mann-Whitney (MW) test shows that the difference between the mean abatement of inexperienced and experienced subjects is statistically significant for all treatments ($\alpha = 0.00$), but Collective 60 ($\alpha = 0.92$).

Concerning the effect of experience when the tax-subsidy mechanism is applied, we observe from table VII that the abatement level is significantly higher when compared to the collective and random fining for both, inexperienced and experienced subjects. Whereas experience reduced abatement in all other treatments, comparing the coefficients for Tax-Subsidy a Chi-square test ($\alpha = 0.004$) shows that experience raises abatement under the tax-subsidy mechanism. Moreover, using a Wilcoxon test we cannot reject the hypothesis at a 10% significance level ($\alpha = 0.08$) that the tax-subsidy mechanism with experienced subjects suffers from over-abatement. All these findings are summarized in the following result:

Result 3: Experience in different control instruments tends to induce over-abatement under the tax-subsidy mechanism and under-abatement under both the collective and the random fining mechanisms.

As far as the dynamics is concerned, the effect of repetition is significantly higher in the cases where subjects are experienced (Chi-square test, $\alpha = 0.000$).

Regarding the deviations from the group average in the past period, once subjects gain experience, positive deviations (over-abatement) are no more significant, while those subjects who abated below the group average keep on decreasing their abatement level.

4.5 Sensitivity to Assumptions about the Risk Attitude

Experimental studies often do not provide data on subjects' risk attitude since many experimental researchers simply assume subjects to be risk neutral when facing the low-payoff usually offered in the lab. However, it has been shown by Holt and Laury [9] that even with a payoff of only several dollars, usually used as reward in laboratory experiments, most subjects proved to be risk averse and only very few proved to be risk seeking.

With respect to the theoretical literature on non-point source pollution, Herriges et al. [7] show that, in a budget-balancing mechanism, the random fining will only induce compliance if subjects are risk averse. Nevertheless, the measurement of subjects' risk attitude has been ignored in experimental studies on these mechanisms.

As described above, we performed a risk test with each subject. Out of 60 subjects that participated in the different sessions, 12 (20.7%) were classified as highly risk averse (HRA), 20 (34.5%) as risk averse (RA) and 22 (36.1%) as risk neutral (RN). Finally, only 4 subjects revealed to be risk seeking.[13]

Table VIII presents the average individual abatement per treatment when we divide subjects into three categories depending on their risk coefficient as explained in section 3.1.

Treatment	Risk Attitude		
	Highly Risk Averse	Risk Averse	Risk Neutral
Collective 60	0.99	1.09	1.18
Collective 90	1.76	1.22	1.27
Random 300	0.99	1.36	1.29
Random 450	1.30	1.25	1.26
Tax-Subsidy	1.88	1.99	2.25

Table VIII: Summary statistics on the average individual abatement per treatment and risk attitude.

The results of table VIII show that whereas some findings are robust with respect to the risk attitude of the subjects, others are not. In order to test for differences due to treatment effects, table IX presents the results of a random effects panel regression estimate of the model first presented in table VI in section 4.3. However, we now divided the subjects pool into three categories depending on their risk coefficient.

[13]Two subjects answered in an inconsistent way, therefore, we did not include their data in the analysis. Moreover, given the small sample of risk seeking subjects, we excluded this category from our analysis.

Variable	Highly Risk Averse			Risk Averse			Risk Neutral		
	Coef.	S.E.	$p > \|z\|$	Coef.	S.E.	$p > \|z\|$	Coef.	S.E.	$p > \|z\|$
Constant	1.5217	0.1604	0.000	1.3649	0.1532	0.000	1.5997	0.1353	0.000
Collective 90	0.4515	0.1711	0.008	0.3820	0.1247	0.002	0.3279	0.1057	0.002
Random 300	0.0347	0.1093	0.751	0.1329	0.1201	0.268	0.0040	0.1018	0.969
Random 450	0.6068	0.1876	0.001	0.7150	0.1235	0.000	0.4227	0.0973	0.000
Tax-Subsidy	1.1500	0.1112	0.000	1.1026	0.1185	0.000	1.1265	0.0973	0.000
Experience	-0.4435	0.0838	0.000	-0.1874	0.0651	0.004	-0.4094	0.0569	0.000
Period	-0.0320	0.0063	0.000	-0.0277	0.0048	0.000	-0.02849	.0040	0.000
$a_{it-1} > Average_{t-1}$	0.0738	0.0564	0.191	0.0247	0.0447	0.580	0.1065	0.0365	0.004
$a_{it-1} < Average_{t-1}$	-0.0745	0.0591	0.208	0.0869	0.0441	0.048	0.0670	0.0374	0.073
N		617			1080			1223	
T		22			22			22	
R^2		0.1977			0.0959			0.2164	
$\hat{\rho}$		0.1764			0.1566			0.2000	

Table IX: Random Effects GLS Regression per risk attitude.

Using again the data from Collective 60 as baseline, table IX confirms result 2 regarding the effect of increasing the fine. Moreover, this effect turns out to be robust with respect to the subjects' degree of risk aversion since the estimated coefficients for Collective 90 and Random 450 are again significant and positive for all three groups.

Let us now compare the performance of the collective and random fining mechanisms. Table IX shows that, independently of the degree of risk aversion, the coefficient for the corresponding random fining treatment Random 300 is not significant. However, this is not the case when a higher fine is used. We observe that the "risk averse" subjects abate significantly more under random (Random 450) than under collective (Collective 90) fining. For the "risk neutral" subjects no difference in performance between collective and random fining can be observed. This is perfectly in line with the predictions of economic theory. Surprisingly, however, this holds also for the group of "highly risk averse" subjects.

Result 4: When a high fine is used, the performance of the collective and random fining mechanisms is the same for risk neutral as for highly risk averse subjects. However, for risk averse subjects the random fining outperforms the collective fining.

As far as the tax-subsidy mechanism is concerned, its performance is not significantly affected by different risk attitudes of the subjects:

Result 5: The efficiency of the tax-subsidy mechanism to control non-point source pollution is robust against different degrees of risk aversion.

Regarding the dynamics, as asserted in result 3, previous experience in control mechanisms reduces abatement. Interestingly, the effect of experience on risk averse subjects is significantly lower when compared to the performance of the other two groups. Moreover, a decrease in the abatement due to the effect of repetition is once again significant and independent of subjects' risk aversion.

Finally, the estimates for the last two variables included in table IX show that only risk averse and risk neutral subjects react to feedback about the group aggregate abatement in the previous period.

5 Conclusions

We have presented the results on pollution control instruments designed to deal with non-point source pollution. In particular we tested a tax-subsidy mechanism, suggested by Segerson [16], and a non-budget balancing version of the collective and a random fining mechanisms suggested by Xepapadeas [21].

From our results we can conclude that the tax-subsidy mechanism seems to be more suitable to induce the subjects to choose the socially optimal abatement level. Both, collective and random fining schemes, by contrast, suffer from serious under-abatement, a feature which is exacerbated over time and through players' experience.

When controlling for the effect of different fine sizes, we surprisingly found that only under the collective fining mechanism when applied to inexperienced subjects a higher fine induced higher levels of compliance.

An important novelty of this paper compared to previous studies is that we controlled for the subjects' risk aversion using a simple risk test carried out at the end of each experimental session. We divided the subjects' data into three different groups (highly risk averse, risk averse and risk neutral) in order to study different hypotheses on the role of risk aversion on subjects' behavior. As a result, we obtain that the efficiency of the tax-subsidy mechanism is not affected by agents' risk attitude. It has an impact, however, on the performance of the the collective and random fines. Our results confirm the hypothesis that the behavior of risk neutral subjects in not affected by a change in the fining mechanism, since the expected gains are identical. Risk averse subjects by contrast abate more under the random than under the collective fining. This result confirms the results of Herriges et al. [7] according to which a random fine would induce compliance in the presence of sufficiently risk averse subjects. For highly risk averse subjects, however, this difference surprisingly disappears.

Finally, as possible extensions, it would be interesting to also test for the effects of group size. Weersink et al. [20] suggest that the ambient taxes perform better when applied to a small group of polluters. Moreover, Alpízar et al. [2] found higher compliance for collective and random fining games when conducting the experiments for groups of 2.

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Instructions

[For the convenience of the referees, not to be published]

General Instructions

You are taking part in an economic experiment on decision making. The experiment consists of two different sub-experiments (treatments). Each treatment lasts over several rounds in each of which you can earn some money. Your payoff does not only depend on your own decision but also on the decisions of other players. During the experiment your payoff will be measured in experimental currency units (ECUs). At the end of the experiment your payoff will be converted into € at an exchange rate of 300:1, i.e. 300ECUs=1€.

At the end of the experiment one of the treatments, to be randomly chosen, will determine your final payoff. Each of you will be rewarded individually and without being observed by other subjects which have taken part in the experiment.

Each treatment lasts at least 20 rounds. At the end of round 20, we will flip a coin. If the coin show "tails", the experiment will be terminated. If the coin show "heads", the experiment will be continued for one more round. At the end of that round a coin will be flipped again to determine whether or not a further round is played, and so on.

At the beginning of each treatment you will be randomly matched with 4 other subjects. During one treatment you will stay within the same group. However, neither during nor after the experiment you will know the identity of the other persons within your group. Before each treatment starts, you will be again randomly rematched.

The economic background and the rules of the experiment:

Consider an industry consisting of 5 firms. Imagine you are the manager of one of those firms. Each member of the group you are matched with, manages one of the other 4 firms. Each firm produces some good with identical technologies. Production causes pollution which will be released into a lake. A regulatory authority is not able to monitor the emissions of each individual firm but can only monitor the ambient emission level of the lake. The authority tolerates an ambient emission level of 10 units (independently of which firm has emitted how much).

If a firm does not take abatement measures, it will emit 4 units into the lake. The firm can, however, abate all the pollution (4 units), abate partially (3 units, 2 units, or 1 unit), or not abate at all (0 units). Abatement, however, is costly. Both, the abatement costs and the marginal abatement costs, are displayed in the following table: (see table I).

Explanation: The marginal abatement cost denotes the additional cost of abating one additional unit. For example, if you want to increase your abatement from 3 to 4 units, this will cost you additional 80 ECUs. Your total abatement cost of abating 4 units is then 20 + 40 + 60 + 80 = 200 ECUs.

In each round of the experiment you and the managers of the other 4 firms must decide simultaneously and independently of each other how many units you want to abate. You have the choice to abate 0, 1, 2, 3, or 4 units.

After you have made your choices, the authority measures the ambient pollution level of the lake and takes different measures, in the following treatments.

Collective Fine

Collective 60

After you have made your choices, the authority measures the ambient pollution level of the lake and takes the following measure:

1. The authority pays a subsidy of 50 ECUs for each abated unit to the whole industry. Each firm receives 20% of the total subsidy to the industry, i.e. your subsidy amounts to 10 × (sum of the total amount of abated units).

2. If the total abatement of all 5 firms is less than 10 units (i.e. more than 10 units are emitted into the lake), each firm must pay a fine of 60 ECUs.

Note again that the regulator cannot observe the individual emissions. At the end of each round you will be informed about the total abatement effort (and thus the total emissions released into the lake).

Your payoff per round is determined as follows:

If all five firms have abated at least 10 units (i.e. no more than 10 units have been emitted into the lake), your profit will be:

$$200 \text{ - (your abatement cost) + (your subsidy).}$$

If all five firms have abated less than 10 units (i.e. more than 10 units have been emitted into the lake), your profit will be:

$$200 \text{ - (your abatement cost) + (your subsidy) - 60.}$$

Example 1:

You abate 3 units in one round, the other 4 firms abate a total of 11 units in the same round. In this case, your abatement cost amounts to 120 ECUs. The regulator pays a total subsidy of $50 \times 14 = 700$ ECUs. Your share of the subsidy is then given by $10 \times 14 = 140$ ECUs.

Your payoff in this round is then: 200 - 120 + 140 = 220

Example 2:

You abate 2 units in one round, the other 4 firms abate a total of 7 units in the same round. In this case, your abatement cost amounts to 60 ECUs. The regulator pays a total subsidy of $50 \times 9 = 450$ ECUs. Your share of the subsidy is then given by $10 \times 9 = 90$ ECUs. The regulator fines each firm by 60 ECUs since only 9 units have been abated and thus 11 units have been emitted into the lake.

Your payoff in this round is then: 200 - 60 + 90 - 60 = 170

If anything is still unclear please feel free to ask before the experiment starts. During the experiment no communication is allowed.

Collective 90

As for Collective 90, but the fine amounts now 90 ECUs instead of 60 ECUs.

Random Fine

Random 300

After you have made your choices, the authority measures the ambient pollution level of the lake and takes the following measure:

1. The authority pays a subsidy of 50 ECUs for each abated unit to the whole industry. Each firm receives 20% of the total subsidy to the industry, i.e. your subsidy amounts to 10 × (sum of the total amount of abated units).

2. If the total abatement of all 5 firms is less than 10 units (i.e. more than 10 units are emitted into the lake), the regulator picks one firm randomly and fines this firm by 300 ECUs.

Note again that the regulator cannot observe the individual emissions. At the end of each round you will be informed about the total abatement effort (and thus the total emissions into he lake).

Your payoff per round is determined as follows:

If all 5 firms have abated at least 10 units (i.e. no more than 10 units have been emitted into the lake, your profit will be:

$$200 \text{ - (your abatement cost) + (your subsidy).}$$

If all five firms have abated less than 10 units (i.e. more than 10 units have been emitted into the lake) and the regulator picks you for fining, your profit will be:

$$200 \text{ - (your abatement cost) + (your subsidy) - 300.}$$

If all five firms have abated less than 10 units (i.e. more than 10 units have been emitted into the lake) and the regulator does not pick you for fining, your profit will be:

$$200 \text{ - (your abatement cost) + (your subsidy).}$$

Example 1:

You abate 3 units in one round, the other 4 firms abate a total of 11 units in the same round. In this case, your abatement cost amounts to 120 ECUs. The regulator pays a total subsidy of $50 \times 14 = 700$ ECUs. Your share of the subsidy is then given by $10 \times 14 = 140$ ECUs.

Your payoff in this round is then: 200 - 120 + 140 = 220

Example 2:

You abate 4 units in one round, the other 4 firms abate a total of 5 units in the same round. In this case, your abatement cost amounts to 200 ECUs. The regulator pays a total subsidy of $50 \times 9 = 450$ ECUs. Your share of the subsidy is then given by $10 \times 9 = 90$ ECUs. The regulator picks now one firm randomly and fines it by 300 ECUs since only 9 units have been abated and thus 11 units have been emitted into the lake.

If your firm is picked for fining, your payoff in this round will be:

200 - 200 + 90 - 300 = -210

If your firm is not picked for fining, your payoff in this round will be:

200 - 200 + 90 = 90

Note that it can happen that your payoff in one round will be negative. It can also happen that the accumulative payoff at the end of treatment is negative. If this is the case your total payoff will be set equal to zero.

If anything is still unclear please feel free to ask before the experiment starts. During the experiment no communication is allowed.

Random 450

As for Random 300, but the fine amounts now 450 ECUs instead of 300 ECUs.

Tax-Subsidy

After you have made your choices, the authority measures the ambient pollution level of the lake and takes the following measure:

1. If a total of less than 10 units have been emitted into the lake (i.e. more than 10 units have been abated by all five firms), the regulator pays a subsidy of 50 ECUs per abated unit exceeding the level of 10 to each firm.

2. If a total of more than 10 units have been emitted into the lake (i.e. less than 10 units have been abated by all five firms), the regulator charges a tax of 50 ECUs per unit abated too little to each firm.

3. If exactly 10 units have been emitted into the lake, neither a subsidy is payed, nor a tax is charged.

Your payoff per round is determined as follows:

$$200 \text{ - (your abatement cost)} + 50 \times \text{(sum of the abated units minus 10)}$$

Example 1:

You abate 3 units in one round. Your abatement cost amount to 120 ECUs. The other 4 firms abate a total of 8 units in the same round. Hence a total of 11 units have been abated, one more than demanded. The regulator pays a subsidy of 50 × (11-10) = 50 ECUs to each firm.

Your payoff will then be: 200 - 120 + 50 = 130

Example 2:

You abate 2 units in one round. Your abatement cost amount to 60 ECU. The other 4 firms abate a total of 6 units in the same round. Hence a total of 8 units have been abated, two less than demanded. The regulator charges each firm a tax of 50 × (10-8) = 100 ECUs.

Your payoff will then be: 200 - 60 - 100 = 40

If anything is still unclear please feel free to ask before the experiment starts. During the experiment no communication is allowed.