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RESEARCH ARTICLE

Is the “average Pigouvian tax” robust to the size of the group of polluters?

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Abstract

We study the “average Pigouvian tax” (APT), an ambient-based policy instrument that requires polluters to cooperate to achieve the social optimum. In this paper, we are interested in the group size variation and its effect of the APT efficiency. Indeed, in the field, the implementation of the instrument will face group sizes that can vary from a few to a large number of farmers. We find that increasing the size of the group reduces cooperation among subjects, thereby reducing the efficiency of the instrument. We also show that when the sucker’s cost is lowered, the instrument can converge towards the social optimum.

Keywords Nonpoint source pollution · Ambient-based taxes · Cooperation · Size effect · sucker’s payoff

JEL classifications C92 · H23 · Q53

Introduction

The regulation of nonpoint source water pollution is impeded by informational problems due to the regulator’s inability to observe the polluters’ individual emissions. The aggregate concentration of pollution is the only easily measured parameter. To overcome the asymmetry of information between the regulator and polluters, Segerson (1988) developed “ambient-based” instruments that assign liabilities to polluters based on aggregate pollution. The efficiency of ambient-based instruments has been experimentally demonstrated (see, for instance, Spraggon, 2002; Cochard et al., 2005; Suter

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et al., 2009; Cochard & Rozan, 2010; Spraggon, 2013; Willinger et al., 2014). However, their implementation in the field will likely raise social acceptability concerns due to the large income transfers that they may involve.

As an extension of their investigation, Suter et al. (2008) introduced the average Pigouvian tax (APT), a new variant of the instrument that takes advantage of the power of cooperation to reduce the total amount of the charges. Indeed, when a group of polluters fully cooperates to reach the social optimum, their maximization problem becomes similar to that of the regulator. In this case, the regulator can treat the polluter group as a unique agent. The APT is then equal to the standard ambient tax divided by the number of firms among the group of polluters. The efficiency of this tax scheme requires that polluters maximize the joint group payoffs to implement the social optimum, in contrast to the standard ambient tax, where firms are supposed to behave noncooperatively. The authors found in their laboratory experiment under nonbinding costless communication (cheap talk) that the resulting group emissions are not significantly different from the social optimum. In addition, they observe that the APT yields successfully high levels of welfare efficiency, equivalent to the level under the standard ambient tax.

Although these preliminary results are very encouraging for the regulation of nonpoint source pollution, definitive conclusions through robustness tests are required before implementation in the field. Sarr et al. (2018) investigated the effect of communication on the performance of the APT. They confirmed the potential of the instrument provided that communication is not too costly. The paper supports the idea that the variables known to affect cooperation in a collective action, such as communication, are likely to affect the performance of the APT instrument.

In this paper, we are interested in the group size variation in a collective action and its effect of the APT efficiency. Indeed, in the field, the implementation of the instrument will face group sizes that can vary from a few to a large number of farmers. An experimental laboratory analysis will not mimic field conditions but can enlighten us on the robustness of the performance of the instrument.

The impact of group size on cooperation has been investigated in the context of continuous (Isaac & Walker, 1988; Isaac et al., 1994; Goeree et al., 2002; Carpenter, 2007; Weimann et al., 2012; Nosenzo et al., 2015) or step level public good settings (Croson & Marks, 2000). Most studies showed that cooperation increases with the group size because the social benefits are larger. But, in n-prisoner dilemma or oligopoly experiments, findings suggest the opposite, which is when group size increases cooperation decreases. This is due to the increased difficulty to coordinate with the increased number of players.[1] We are however unaware of studies examining the group size issue in the context of nonpoint pollution regulation (which implies a non-linear profit function combined with a step level taxation).

In the context of nonpoint pollution regulation, we expect that the group size will also play a negative role on cooperation because of the fear of being the sucker of the game. Indeed, Ahn et al. (2001) showed that there are two drivers for defection in cooperation: greed and fear. Greed determines the free riding strategy which is an opportunistic behavior

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[1] Seminal studies like Olson (1965), Marwell and Schmit (1972), and Kim and Walker (1984) gave other explanations for low cooperation levels when collective action involve large number of persons. Olson (1965) stresses the higher social pressure when groups are smaller. Marwell and Schmit (1972) underline the importance of the conditional cooperators role and their proportion in large groups (the “bad apple” hypothesis). Kim and Walker (1984) focus on the perception of free riders which may be more important in small groups.

for defection. Fear impacts defection because subjects dislike being the sucker of the game. The fear of being the sucker of the game is a non-opportunistic behavior. It results from the uncertainty on others' strategic behavior.

In our group size variation context, when the number of players increases, strategic uncertainty also increases and consequently we can expect that the fear of being the sucker of the game will be larger. Furthermore, when adding the taxation context of the nonpoint pollution, which is a negative frame in comparison to a public good experiment, we expect that the fear of being the sucker of the game will play an even more important role than in a public good experiment. This is due to the negative externality and the cold prickle effect to avoid paying the tax in comparison to the warm glow effect and positive externality of public goods (Andreoni 1995). As the efficiency of the APT instrument relies on the polluters' ability to cooperate, and in particular on the size of the group, it is therefore likely that the performance of controlling emissions will be affected by the number of regulated polluters. We expect therefore that the fear of being the sucker of the game will increase in large groups and therefore lowers the efficiency of the APT.

In this study, we consider a small group and a large group. We find that increasing the size of the group reduces cooperation among subjects, thereby reducing the efficiency of the instrument. We also show that when the sucker's cost is lowered, the instrument can converge towards the social optimum. The paper is organized as follows. In "Theoretical model," we introduce the model of the APT. "Experimental design and procedures" presents the experimental design and procedures. "Results" is devoted to the results and "Conclusion" concludes.

Theoretical model

We consider n risk-neutral firms whose production activities generate environmental damage. Firm i's ($i = 1,..., n$) emission of pollution is denoted as x_i. For simplicity, firm i's profit function $\pi(x_i)$ is defined with respect to its emissions and is assumed to be twice differentiable, strictly increasing, at a strictly decreasing rate. Ambient pollution is equal to total polluters' emissions $X = \sum_{i=1}^{n} x_i$. We assume that ambient pollution is not affected by random natural factors[2] and that the total damage D is a linear function of the ambient pollution level X: $D(X) = \delta X$ with $\delta > 0$.

Without any regulatory policy (i.e., under "laissez-faire"), the firms ignore the damage caused by their activities and emit until their marginal net benefits equal zero. That level of emissions is denoted as x_i^0. To remedy this situation, the regulator intervenes with the objective of maximizing social welfare $W(x_1, \ldots, x_n)$, defined as the sum of firms' profits minus the damage. It is given by the following relation:

$$W(x_1, \ldots, x_n) = \sum_{i=1}^{n} \pi(x_i) - \delta \sum_{i=1}^{n} x_i. \tag{1}$$

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[2] While the introduction of "natural uncertainty" would be more realistic, it would complicate subjects' behavior in the experiment, and could therefore lead to more errors. As our experiment is an initial exploratory step examining the size effect, it should start with a simple environment and incrementally introduce realistic assumptions which specific effects can be separated.

The level of emissions by each firm x_i^* that maximizes social welfare is determined by solving the following first order condition (FOC) for all i:

$$\pi'\left(x_i^*\right) = \delta. \tag{2}$$

As the model is entirely symmetric, we obtain for all i, $x_i^* = x^*$. Moreover, $x^* < x^0$ due to the strict concavity of the profit function.

Achieving the social optimum requires that each firm equalizes its marginal profit to marginal social damage. To realize this goal, the regulator can apply the standard ambient tax that implements the social optimum as a Nash equilibrium and that was found to be efficient in various experimental studies (e.g., Spraggon, 2002; Cochard et al. 2005; Suter et al., 2008):

$$T_{at}(X) = \begin{cases} 0 & \text{if } X < nx^* \\ \delta\left(X - nx^*\right) & \text{if } X \geq nx^* \end{cases}. \tag{3}$$

This policy scheme may, however, be considered very unfair because every firm bears the social marginal cost of an increase in emissions by any one firm. It seems unlikely that such collective penalties would be politically feasible.

The social acceptability of the instrument might, however, be improved by lowering the level of the tax rate. In this situation, the Nash equilibrium is no longer socially optimal, but firms have the opportunity to increase their profits by reaching a collusive outcome in which they reduce their emissions to maximize joint profits, as shown by Millock & Salanié (2005). Assuming that firms are able to cooperate in this way, the regulator only needs to consider the regulation of one agent: the polluter group. A tax equal to the level of the pure tax divided by the number of polluters is then efficient. Suter et al. (2008) refer to this tax as the “average Pigouvian tax” (APT). It is given by the following relation:

$$T_{apt}(X) = \begin{cases} 0 & \text{if } X < nx^* \\ \dfrac{\delta}{n}\left(X - nx^*\right) & \text{if } X \geq nx^* \end{cases}. \tag{4}$$

Thus, if firms manage to achieve full cooperation, they will comply with the social optimum, and the instrument will be efficient.

Experimental design and procedures

We investigate the effect of group size on the efficiency of the APT. The difficulty in the field is the ability to determine what is a “small” or a “large” group of polluters. We implemented a “small group” (SG) treatment involving 4 polluter groups and a “large group” (LG) treatment involving 8 polluter groups. One might consider that an 8-person group is not large enough to be behaviorally distinct from a 4-person group. However, the reasoning underlying the study is that if a significant change occurs between a group of 4 and 8 members, there is a good reason to think that the same significant variation occurs in the real world where the differences between groups are, a priori, more important. Table 1 presents the experimental design parameters for

Table 1 Experimental design parameters

	Treatments		
	SG	*LG*	*LG2*
Number of groups	8	8	8
Size of the groups (n)	4	8	8
Polluter i's profit function (π_i)	$-2x_i^2+84x_i+500$		$-2x_i^2+84x_i+290$
Marginal damage (δ)	52		32
APT rate (δ/n)	13	6.5	4

treatments SG and LG and also for an additional treatment (LG2) that will be discussed below.

As we vary the size of the group, the fear of being the sucker of the game will also be impacted. The relative cost of being the sucker can be measured by computing the sucker's payoff. We define the sucker's payoff as the polluter's payoff when she chooses the socially optimal level of emission while every other group member chooses the Nash level of emission. Table 2 shows the Nash equilibria, social optimum, and sucker's payoffs. The relative cost of being the sucker will be higher in LG than in SG: the sucker's payoff equals 543.5 (−32.2% relative to the Nash equilibrium[3]) in LG and 654 (−22.5%) in SG.

To further investigate the effect of the cost of being the sucker, we carried out a third treatment, LG2, which is characterized by large groups of polluters but a lower relative cost of being the sucker. To do so, we consider a situation in which the marginal environmental damage is lower, implying that the marginal tax is also lower.[4] The cost of being the "sucker" will be lower in LG2 than in LG: the sucker's payoff 848 (−10.4%) in LG2.

Table 2 shows that in each treatment, there is a unique Nash equilibrium in the stage game (Nash equilibrium). As in any social dilemma game, subjects can increase their payoffs by cooperating to maximize the joint payoff. This is the cooperative outcome, which also corresponds to the social optimum. Using backward induction, the unique subgame-perfect equilibrium of the finitely repeated game is for each polluter to play the static Nash equilibrium strategy in each period. We therefore consider three main theoretical benchmarks: the Nash equilibrium (or "noncooperative" outcome), the social optimum (fully cooperative outcome), and the sucker situation.

The experiment was carried out at the BETA laboratory of experimental economics at the University of Strasbourg (FRANCE). A total of 160 students of different majors were randomly selected from a pool of approximately 1000 subjects. At the beginning of the experiment, subjects were randomly assigned to groups in a partner design (the composition of the groups remained the same throughout the experiment). The program used in this experiment was designed by Kene Boun My with the web platform

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[3] $-32.2\% = \frac{543.5-802}{802}$.

[4] We move from LG to LG2 by decreasing the marginal damage from 52 to 32, which results in a tax rate of 4, a socially optimal level of emissions of 13 and a Nash equilibrium level of emissions of 20. The (before-tax) profit function is the same as in the previous treatments except for the constant term, which is varied in order to equalize after-tax earnings at the social optimum. The individual profit function is $2x^2 + 84x + 290$.

Table 2 Theoretical benchmarks

	Noncooperative outcome (Nash equilibrium)			Cooperative outcome (social optimum)			Sucker situation		
Treatments	*SG*	*LG*	*LG2*	*SG*	*LG*	*LG2*	*SG*	*LG*	*LG2*
Individual emissions	18	19	20	8	8	13	8	8	13
Others' emissions	18	19	20	8	8	13	18	19	20
Total emissions	72	152	160	32	64	104	62	141	153
Payoff	844	802	946	1044	1044	1044	654	543.5	848

Note: The threshold level of taxation is equal to the socially optimal level of group emissions nx^*

EconPlay (www.econplay.fr). All interactions were fully anonymous. Upon arriving in the laboratory, subjects were given a copy of the instructions (see online Appendix 1). A monitor read aloud the instructions to ensure that they were common knowledge and informed the participants that before starting the experiment, they would be asked to answer a questionnaire to verify their understanding of the instructions. Once the questionnaire was filled out and corrected if necessary, one trial period was played before the start of the real game.

The experiment was completely decontextualized. The subjects were informed that there would be "at least 22 periods."[5] Subjects could communicate every four periods (i.e., before periods 5, 9, 13, 17, 21). Emissions were represented by the number of invested tokens. In each period, subjects could invest any integer number of tokens between 0 and 20. A "decision sheet" showing the earnings from investment for each of the 20 available choices was indicated in the instructions (see online Appendix 1). Subjects knew that they faced the same investment function and that their payoff depended on "their own investment" and on the "investment of the group." After each period, subjects were informed of the sum of the invested tokens by the other members of their group. If the total number of tokens invested by the group is larger than the socially optimal emission level (e.g., 64 for treatment LG), all subjects lose the tax rate (e.g., 6.5 for LG) times the difference between the total number of tokens invested by their group and the socially optimal emission level. Earned points were accumulated and converted into euros at the end of the experiment using an announced exchange rate. Each session lasted approximately one hour and a half, and subjects earned an average of 26 euros.

Results

In the following analysis, we focus on periods 5 to 20 because communication starts just before period 5, and we are not interested in a possible end-game effect. Table 3 indicates the average emissions and the compliance rate, i.e., the percentage of times

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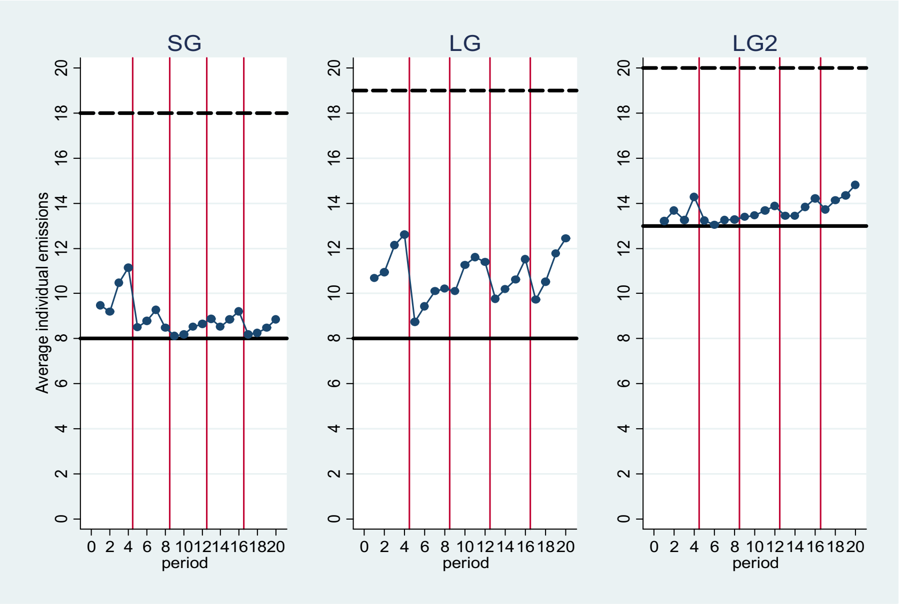
[5] We did not inform the subjects of the exact number of periods because we were more interested in the long-run efficiency of the instrument. In practice, the game was repeated over a sequence of 24 periods.

Table 3 Average individual emissions levels and compliance rates from periods 5 to 20

Treatments	Number of individual observations (16 periods, 8 groups)	Individual Nash equilibrium emission level	Individual socially optimal emission level	Average individual emissions (S.D.)	Compliance rate
SG	512	18	8	8.61 (2.55)	78.71%
LG	1024	19	8	10.58 (4.90)	59.86%
LG2	1024	20	13	13.70 (2.15)	84.90%

that individuals reach the social optimum. It appears that emissions are much closer to the social optimum in treatments SG and LG2 than in treatment LG. Furthermore, the compliance rate was 78.7% in the SG treatment and 84.9% in the LG2 treatment, both largely above the compliance rate of 59.9% in the LG treatment.

Figure 1 depicts the evolution of the average individual emissions over periods. The average individual emissions are above the social optimum in the three treatments. However, in every period, the difference between average individual emissions and the socially optimal level of emissions is greater in treatment LG than in treatment SG and LG2.



Note:

- Dashed straight line = Nash equilibrium emissions level (noncooperative level)
- Solid straight line = social optimum (cooperative emissions level)
- Vertical lines = communication phase
- Periods 1–4 are excluded from all econometric analyses, since the first communication phase occurs between periods 4 and 5.

Fig. 1 Average individual emissions over time, per treatment

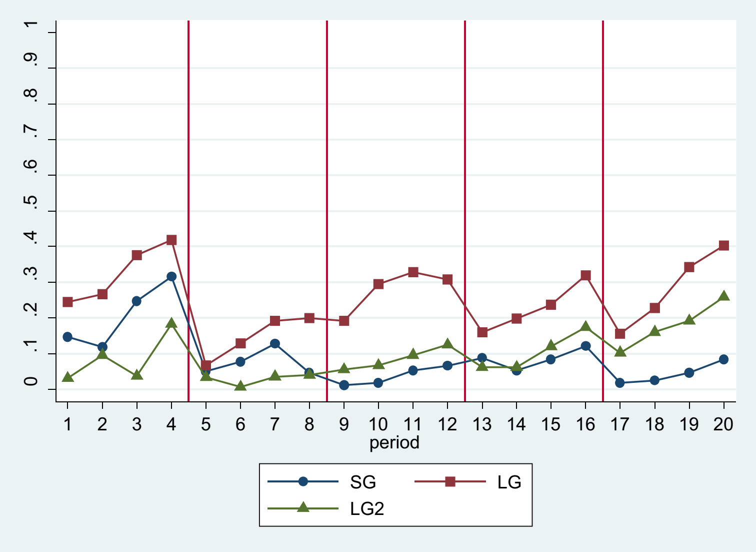
However, because the gap between the Nash equilibrium and the socially optimal emissions level differs across treatments, one could argue that a direct comparison is not valid. To take this into account, we define a normalized indicator of emissions equal to the difference between individual emissions and the socially optimal level of emissions divided by the difference between emissions at the equilibrium and the socially optimal level of emissions. Figure 2 displays thus the normalized levels of emissions; we observe the same tendencies as before.

To assess the significance of differences between treatments, we use methods for pooled time-series cross-sectional data. Each subject is considered to be a cross-sectional unit observed over periods. The following model is estimated:

$$Nd_{it} = \alpha_0 + \alpha_1 LG_i + \alpha_2 LG2_i + \alpha_3 t + \mu_i + \varepsilon_{it}, \tag{5}$$

where the dependent variable, Nd_{it}, denotes the normalized difference between individual emissions and the socially optimal level of emissions, $i = 1, \ldots, 160$ at period $t = 5, \ldots, 20$; LG and LG2 are a treatment-specific indicator equal to 1 in treatment LG (resp. LG2) and 0 otherwise; $\mu_i \rightarrow N\left(0, \sigma_\mu^2\right)$ is an individual-specific random effect, and $\varepsilon_{it} \rightarrow N\left(0, \sigma_\varepsilon^2\right)$ is a mean zero error term. The model is estimated using generalized least squares (GLS) clustered by groups. The coefficients from the model are reported in Table 4.

The output of the regression shows that the deviation from the social optimum observed in LG is significantly larger at the 1% level from that



Note:

- Normalized individual emissions = 0 means that emissions are at the socially optimal level;
- Normalized individual emissions = 1 means that emissions are at the Nash equilibrium emissions level.
- Vertical lines = communication phase.
- Periods 1–4 are excluded from all econometric analyses, since the first communication phase occurs between periods 4 and 5.

Fig. 2 Average normalized individual emissions over time per treatment

Table 4 Result of the regression on the normalized difference between individual emissions and the socially optimal level of emissions, treatments SG, LG, and LG2

Variables	Coefficients (S.E.)
Intercept	−0.060 (0.040)
LG	0.174*** (0.062)
LG2	0.039 (0.048)
t	0.010*** (0.003)
σ_μ	0.235
σ_ϵ	0.272
N. obs	2560
Overall R^2	0.055

Note: *** denotes that the parameter estimate is statistically significant at the 1% level, ** at the 5% level; and * at the 10% level. Robust standard errors in parentheses

observed in SG. Therefore, we confirm that increasing the size of the group reduces the ability of the tax in reducing emissions. We also note that deviations from the social optimum in LG2 are not significantly different from those observed in SG. Emissions are significantly closer to the social optimum in LG2 than in LG (two-sided test on the difference between the coefficients of LG and LG2, $p = 0.0692$).[6] Hence, the reduction of the sucker's cost appears to counterbalance the increase of the group size. Our result therefore provides a possible explanation to the high efficiency rate observed by Suter et al. (2008) in relative large groups. Indeed, although they consider 6 polluter groups, their parametrization induces a very low suckers' cost (approximately −3%).[7]

Finally, it is standard in this literature to examine the level of efficiency that is achieved at each period of time in each group in terms of social welfare.[8] Indeed, it may happen that the mean level of emissions in a group corresponds to the social optimum but that individual emissions do not. In such a case, social welfare will not be maximized. The rate of efficiency is equal to the level of social welfare achieved minus the theoretical level of efficiency in the absence of regulation divided by the socially optimal level minus the theoretical no-regulation level. Thus, the rate equals 100% if the socially optimal vector of emissions is achieved and 0% if the no-regulation vector of emissions is reached. An analysis of efficiency rates (see online Appendix 2) confirms the results obtained by analyzing the emissions. This shows that efficiency in the LG treatment is lower than efficiency the SG treatment and also the LG2 treatment.

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[6] Our findings are robust to a bootstrap OLS regression clustered by groups. They are also robust to the existence of stop and start effects in the periods immediately following a communication phase. We find that there are significant restart effects in periods 5, 13, and 17 but not in period 9. However, they do not affect the significance of the other coefficients of the regression. Results are available upon request.

[7] In Suter et al.'s (2008) study, the sucker's payoff is approximately 699 in comparison to the noncooperative payoff of about 719 (see the online Appendix, "Treatment 7, Average Pigouvian Linear Tax, Threshold = 30, Noncooperative Prediction = 54 (Individual = 9)").

[8] Social welfare is defined as the sum of profits (without taking the tax into account) minus the social damage. The tax is assumed to cancel out at the social level (i.e., the "social cost" of public funds are assumed to be zero).

Conclusion

In this paper, we focused on the robustness of the efficiency of an ambient Pigouvian tax when varying the group size. Given that the efficiency of the APT relies on subjects' ability to cooperate, our study amounts at analyzing whether subjects coordinate successfully in a setting with a nonlinear profit function combined with a step level taxation. Our study shows that increasing the size of the group significantly reduces the efficiency of the APT. This confirms that a larger group induces higher strategic uncertainty, involving a larger fear of being the sucker. However, by considering a framework with a lower marginal damage, we find that the deleterious effect of group size can be mitigated by a lower sucker's cost. Further research may help identify the conditions in which the APT might remain efficient even with large groups. In particular, wealth heterogeneity within polluters may play a determinant role because it may affect the fear of being the sucker.

Obviously, group size in the real world cannot be directly compared to group size in the laboratory. What our study suggests for the APT to be efficient is that either a small cooperative group of polluters or a large group with a low sucker's cost is necessary. Both situations require frequent and efficient opportunities to communicate. These conditions are likely to be met in small watersheds or in strong professional organizations because they involve higher trust levels among polluters. Field experiments will be insightful to explore the efficiency of the instrument in these contexts.

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Author contribution All authors have contributed to all steps of the study: conception of the idea, design of the experiment, analysis of the results and writing of the article.

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Data availability Instructions and supplementary analyses are available online. Data are available upon request.

Code availability Not applicable.

Declarations

Ethics approval Not applicable.

Consent to participate The participants sign a consent form when they register to the Laboratory of Experimental Economics of Strasbourg (LEES).

Consent for publication This article has not been published before; it is not under consideration for publication anywhere else; its publication has been approved by all co-authors as well as by the responsible authorities—tacitly—at the institute where the work has been carried out.

Conflict of interest The authors declare no competing interests.

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