Cahiers de Recherche

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CR n°2015-1

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Nonpoint source pollution: An experimental investigation of the Average Pigouvian Tax

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Abstract

The "Average Pigouvian Tax" (APT) was proposed by Suter et al. (2008) to reduce the financial burden of the standard ambient tax. This instrument consists in a standard ambient tax divided by the number of firms, which requires polluters to cooperate in order to achieve the social optimum. To enable polluters to cooperate, communication is allowed. We introduce different types of communication: cheap talk, exogenous costly communication (communication is imposed), and endogenous costly communication (conducted on a voluntary basis after a vote). Our experiment confirms that the instrument induces polluters to reduce their emissions under cheap talk. However, we find that group emissions are less reduced when communication is costly. This result still holds even when we endogenize communication by introducing a voting phase.

Keywords: nonpoint source pollution, ambient tax, social dilemma, cooperation, cheap talk, costly communication, vote.

JEL classifications: C92, H23, Q53.

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1. Introduction

The efficiency of the ambient taxes (Segerson, 1988) has been experimentally demonstrated (Spraggon, 2002; Poe et al., 2004; Spraggon, 2004; Cochard et al. 2005; Suter et al. 2005; Segerson and Wu, 2006; Vossler et al., 2006; Suter et al., 2008; Suter et al., 2009; Cochard and Rozan, 2010; Spraggon and Oxoby, 2010; Suter et al., 2010; Vossler et al., 2013; Suter and Vossler, 2014). However, dependence on collective pollution levels and potentially very large penalties have justified criticism against ambient taxes (Shortle et al., 1998; Shortle and Horan, 2001). As a consequence, the implementation of the instrument outside of the laboratory is likely to raise social acceptability concerns.

To reduce the financial burdens imposed through taxation, Suter et al. (2008) proposed the "Average Pigouvian Tax" (APT) which is equal to the standard ambient tax divided by the number of firms. Unlike the standard ambient taxes, the specificity of the APT implies that the social optimum is not implemented as a Nash equilibrium of the static game. To achieve of the social optimum, firms are required to behave cooperatively by maximizing the joint profit of the group. Suter et al. (2008) found promising results in their lab experiment. They tested the APT combined with nonbinding costless communication (referred to in the experimental economics literature as "cheap talk") and showed that the instrument successfully achieves high levels of efficiency. Even though the ability to communicate is plausible in practice and encouraged in some cases, communication is likely to be costly in the field. Indeed, communication requires a minimum amount of resources, time, and attention. Examples include the introduction of "coordinated crop rotation" where farmers are encouraged to work together to deal with environmental issues whose resolution requires the commitment of all stakeholders.

The purpose of this study is to test the efficiency of the APT in situations where communication is costly. Two forms of costly communication are tested. Firstly, communication phases are imposed (exogenous costly communication); secondly they are conducted on a voluntary basis through a vote (endogenous costly communication). Several studies have already shown that endogenous institutional settings yield substantial benefits to cooperation, by conferring a feeling of self-determination (Ostrom et al., 1992; Tyran and Feld, 2006; Kroll et al., 2007; Putterman et al., 2011). For example, by comparing a setting in which group members could endogenously determine whether they wanted to supplement a standard voluntary contribution mechanism with the possibility of rewarding or punishing other group members, and a setting in which the same institutions have been determined exogenously by the experimenter, Sutter et al. (2010) found a significantly positive effect on cooperation.

As far as we know, Isaac and Walker (1991) are the only authors who have tested the impact of a costly endogenous communication in a social dilemma game. In their experimental study on voluntary contribution to public goods, subjects were informed at each period that they had the choice to buy or not to buy a "right to communicate". A face-to-face communication was held when the majority of the group bought the right to communicate. The results showed that subjects were able to converge towards perfect cooperation even though they rarely used the communication mechanism, as indeed subjects tended to avoid the cost.

Our experiment shows that the instrument induces polluters to reduce their emissions under cheap talk treatment. It also shows that costly communication reduces group emissions but to a lesser extent. This result is still verified even when we endogenize communication by introducing a voting phase. We also observe that when communication is actually voted, emissions are reduced in similar amounts to those in the cheap talk treatment. Finally, we note that subjects' voting behavior is very sensitive to the cost. A larger cost deteriorates the likelihood of voting for communication. A lower cost not only increases this likelihood, but also prompts the polluter into revealing his type reveals the polluter type: a positive vote for communication induces the individual to reduce his emissions, whereas a negative vote leads him to increase his emissions.

The remainder of this paper is organised as follows: the first section presents the theoretical model for the experimental study. Section 2 describes the experiment. The experimental results are presented in Section 3. The last section concludes the results.

2. Theoretical model

n risk-neutral firms whose production activities generate environmental damages are considered. 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[1] 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 damages caused by their activities and emit until their marginal net benefits equals zero. That level of emission is denoted as x^0. To remedy to this situation, the regulator intervenes with the objective to maximize the social welfare $W(x_1,...,x_n)$, defined as the sum of firms' profits minus the damage. It is given by the following relation:

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

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

$$\pi'(x_i^*) = \delta \, . \; (2)$$

As the model is entirely symmetric, we get 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 the marginal social damage. To realize this goal, the regulator can implement the standard ambient tax that was found to be efficient in various experimental studies (e.g. Spraggon, 2002; Cochard et al. 2005; Suter et al., 2008):[2]

$$T_{pt}(X) = \begin{cases} 0 & if \;\; X \le nx^* \\ t(X - nx^*) & if \;\; X > nx^* \end{cases} . \qquad (3)$$

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[1] 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. Experimental studies should start with a simple environment and incrementally introduce realistic assumptions whose specific effects can be separated.

[2] This version may be referred to as the standard ambient tax in comparison with the ambient "tax/subsidy", which is simply equal to $T_{ts}(X) = t(X - nx^*)$, so that polluters get a subsidy if ambient pollution is below the target (i.e. when $X < nx^*$).

The taxation occurs whenever ambient pollution is greater than the socially optimal pollution level. Therefore, the profit function of a firm *i* which is supposed to follow a Cournot-Nash behaviour when choosing its emission level, becomes:

$$\pi_{pt}(x_i, X) = \begin{cases} \pi(x_i) & if \quad X \leq nx^* \\ \pi(x_i) - t(X - nx^*) & if \quad X > nx^* \end{cases} . \text{ (4)}$$

- If $X \leq nx^*$, a firm maximizes its profit by emitting x_i as close as possible to x^0. Thus in any case, ambient pollution will be driven as high as possible, i.e. $X = nx^*$.
- If $X > nx^*$, the dominant strategy for each firm is to emit until its marginal net benefits equals the marginal tax rate.

$$\pi'_{pt}(x^*) = t . \text{ (5)}$$

To implement the social optimum (2) as a dominant Nash equilibrium, the following relation must be verified:

$$t = \delta . \text{ (6)}$$

At the social optimum, the marginal tax rate should be equal to the marginal environmental damage.

There is no asymmetric equilibrium satisfying the condition $X = nx^*$. At any vector of asymmetric emissions such as $\sum x_i = nx^*$, there is at least one firm *j* which has interest to emit more (on the condition that $x_j < x^*$ due to $\pi'(x_j) > \pi'(x^*) = \delta$), even at the cost of triggering the tax. Thus, any strategy such as $x_i \neq x^*$ is strictly dominated. The game admits a unique Nash equilibrium, so that there is no coordination problem. This is probably one of the reasons why the instrument was found to be very efficient, both in settings allowing communication between participants (e.g. Suter et al. 2008) as well as in settings not allowing communication (e.g. Spraggon, 2002; Suter et al. 2008). However, it seems unlikely that such an instrument would be feasible in practice because all firms bear the full marginal cost of an increase in emission of one of them.

The charges incurred by each polluter can however be limited by relaxing the hypothesis according to which polluters follow a Cournot-Nash behaviour when choosing their emission level. This hypothesis fails to internalize cross-effects among agents. By considering a situation in which a group of polluters might cooperate by coordinating their individual emissions choices in order to maximize joint profits, Millock and Salanié (2005) showed that the optimal policy is to choose a much lower ambient tax than that required in a non-cooperative group. The regulator needs only to consider the regulation of one agent: the polluter group. A tax that is equivalent to the level of the standard tax divided by the number of polluters is imposed on each polluter when the socially optimal target is exceeded. Suter et al. (2008) refer to this tax as the "Average Pigouvian Tax" (APT). It is given by the following relation:

$$T_{apt}(X) = \begin{cases} 0 & if \quad X \leq nx^* \\ \dfrac{\delta}{n}\left(X - nx^*\right) & if \quad X > nx^* \end{cases}. \quad (7)$$

Thus, in equilibrium,

$$\pi'_{apt}(x_i) = \frac{\delta}{n}. \quad (8)$$

The comparison between conditions (2) and (8) shows that social optimum is not implemented as a Nash equilibrium of the static game. However, we can verify that the cooperative strategy (or fully collusive outcome), which we define as the level of emissions that maximizes joint profits, corresponds to the social optimum. Consider the profit sum:

$$\sum_{i=1}^{n} \pi_{apt}(x_i, X) = \begin{cases} \sum_{i=1}^{n} \pi(x_i) & if \quad X \leq nx^*, \\ \sum_{i=1}^{n} \pi(x_i) - \sum_{i=1}^{n} \dfrac{\delta}{n}\left(X - nx^*\right) = \sum_{i=1}^{n} \pi(x_i) - \delta\left(X - nx^*\right) & if \quad X > nx^*. \end{cases} \quad (9)$$

Clearly, maximizing this joint-profit function with respect to vector (x_1, x_2, …, x_n) results in n first-order conditions such that $\pi'(x_i) = \delta$. Thus, if the firms manage to maximize joint profit, then they will comply with the social optimum and the instrument will be efficient.

3. The experiment

We present hereafter the parametrization of the experiment, the different treatments and the practical procedure of the design.

3.1. Theoretical benchmarks

In the experiment, the profit and damage functions are respectively given by:

$$\pi(x) = -2x^2 + 84x + 500, \qquad (10)$$

$$D(X) = 52X. \qquad (11)$$

Hence, the tax rate is equal to 6.5. Given the chosen parameters, each subject has a dominant strategy to invest 19 tokens under the static game. The maximum profit of the entire group (or cooperative strategy) which corresponds to the social optimum is achieved if all subjects invest 8 tokens.

Using backward induction, the unique sub-game perfect Nash equilibrium of the finitely repeated game is to play the non-cooperative strategy in each period for each subject. However, the participants of our experiment are not told the number of periods in advance, which is likely to facilitate the achievement of cooperation as in an infinite horizon game. We consider therefore two main theoretical benchmarks (Table 1): the static Nash equilibrium (or "non-cooperative" strategy) and the social optimum (fully cooperative strategy). It must be noticed that the benchmarks remain identical with or without communication.

Table 1: Theoretical benchmarks

	Non-cooperative benchmark (static Nash equilibrium)	Cooperative benchmark (social optimum)
Individual investment	19	8
Group investments	152	64
Individual payoff	756	1044

The gain at the cooperative outcome for each player is equal to 1044 points. If everyone plays the non-cooperative emission level, the gain will be equal to 756. Therefore, the net gain of cooperation over one period is equal to 288 points.

3.2. Experimental treatments

The five treatments of this experiment are shown in Table 2. Each participant takes part in only one of them (between-subject design).

Table 2: Experimental design

Treatments	Description	Number of groups	Number of sessions
NC (No Communication)	No cheap talk throughout the experiment.	4	2
CT (Cheap Talk)	Cheap talk at the end of each four periods (before the 5th, 9th, 13th, 17th and 21st periods).	8	4
ECC (Exogenous Costly Communication)	Same as treatment CT except that communication is costly. The communication cost (200 points) is deducted from the gain of the period that immediately follows the communication phase.	4	2
HCV (High Cost Vote)	A communication phase is held after a vote when the majority approves it. The cost (of communication) to each voter is high (200 points). Those voting against the communication do not bear this cost but the discussion is open to them.	4	2
LCV (Low Cost Vote)	Same as treatment HCV except that the cost of voting is low (10 points).	4	2

In the NC treatment, considered as the baseline treatment, there is no communication throughout the game.

In all other treatments, we introduce the opportunity of communication.[3] Hereafter we refer to a "communication phase" as a phase in which subjects can communicate with written messages that transit through the computer network. All messages are public (no bilateral communication).

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[3] Bochet et al. (2006), by comparing three forms of communication as incentives to increase contributions in public goods games, found that verbal communication through a chat room was almost as efficient as face-to-face communication to induce cooperation.

Subjects can discuss abatement strategies in response to the ambient mechanism imposed on them. The communication phases are limited to three minutes. These communication phases take place before the 5th, 9th, 13th, 17th and 21st periods.

In the CT treatment**,** the communication phase is free. All subjects are involved in the communication phase.

In the ECC treatment, the communication phase is subject to a fee of 200. All subjects are involved in the communication phase and are obliged to pay the fee. This is why we denote this treatment as "Exogenous Costly Communication".

In the LCV and HCV treatments, the communication phase is subject to a vote. Hereafter we refer to "voting phase" as the phase when subjects are invited to vote for or against the holding of a communication phase. The following question is asked to each member of the group in the voting phase: "would you like to discuss with other members of your group?" When the majority (at least five subjects) of the group responds "yes", a communication phase begins. Otherwise, no communication takes place. When the discussion is approved by the majority, only those who wanted to communicate by answering "yes" bear the cost of the discussion but all group members can participate in the communication phase. When the majority for a discussion is not reached, no one is charged. Hence, we focus on a situation in which it is not communicating in itself which is costly, but the organization of communication phases (informing others, organizing meetings, etc.).

In addition, we consider a high and a low cost level. The cost is low in the LCV treatment (cost of 10, i.e. about 3% of the net gain of full cooperation) and high in the HCV treatment (cost of 200, i.e. about 70% of the net gain of full cooperation). The communication cost is deducted from the gain of the period that directly follows the communication phases.

3.3. Practical procedures

The experiment was carried out at the BETA laboratory of experimental economics at the University of Strasbourg (FRANCE) in 2011. 192 students of different majors were randomly selected from a pool of about 1000 subjects. Each session involved 16 subjects. At the beginning of the experiment, subjects were randomly affected to groups in a partner design (the composition of the groups remains the same throughout the experiment). The program of this experiment has been designed by Kene Boun My with the web platform EconPlay (www.econplay.fr). All interactions were fully anonymous.

Upon arriving in the laboratory, subjects were given a copy of the instructions (Appendix 1). A monitor read aloud the instructions to make them 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.

Subjects played the role of polluting firms but the framing of the experiment was as neutral as possible in order to limit uncontrolled psychological effects. Thus there was no use of words such as "pollution". Emissions were represented by the amount 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. 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. The game was repeated over a sequence of 24 periods. To avoid potential end-game effects, participants were not told in advance the number of periods. Earned points were accumulated and converted into euros at the end of the experiment using an announced exchange rate. Each session lasted about 1 hour and 15 minutes and subjects earned on average 23 euros.

4. Results

Table 3 reports group average emissions per treatment. It shows that in all treatments average emissions lie between the social optimum and the static Nash equilibrium. The highest average emissions are observed in the no communication treatment (112.8) and the lowest ones in the cheap talk treatment (88.95).

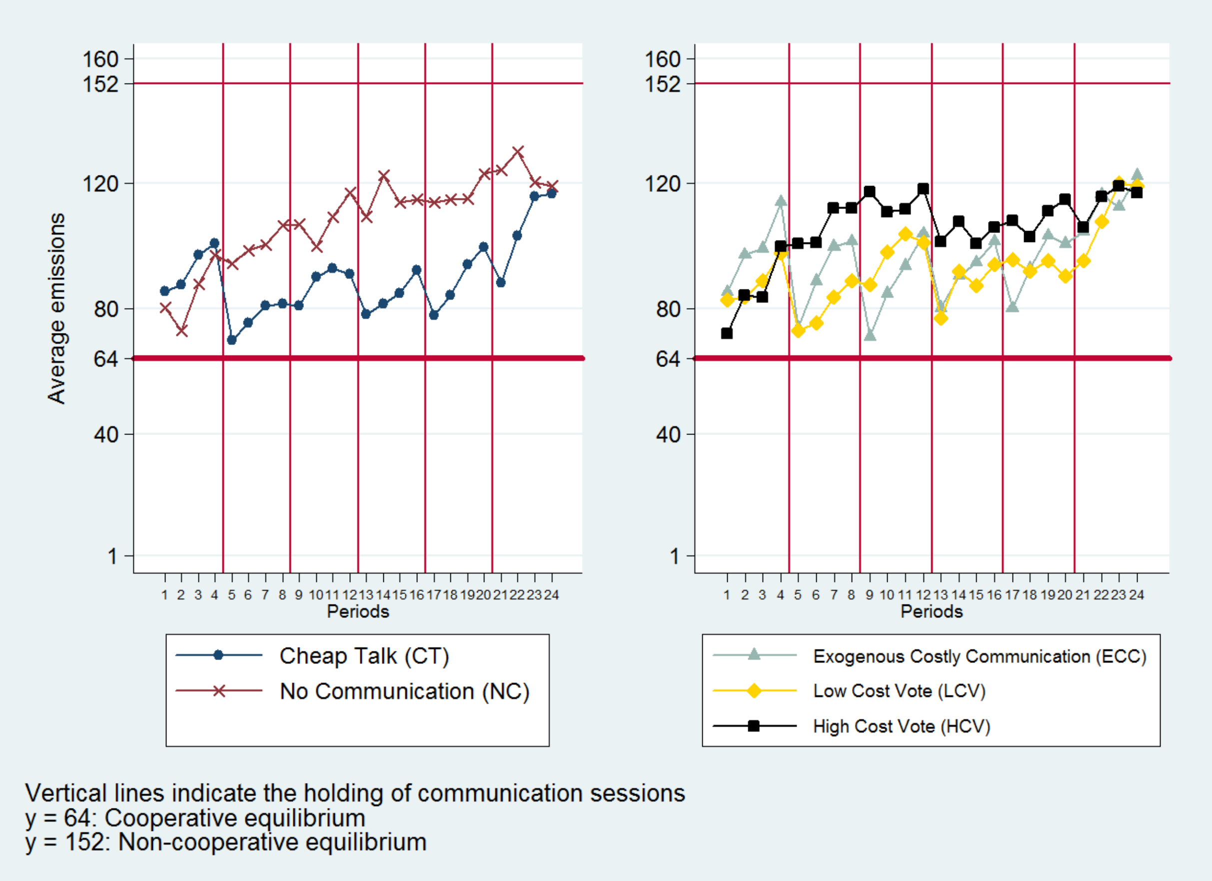
Table 3: Average group emissions per treatment

Treatments	Theoretical benchmarks		Average emissions (S.D)
	Social optimum	Static Nash Equilibrium	
NC	64	152	112.8 (9.28)
CT	64	152	88.95 (12.11)
ECC	64	152	95.85 (13.29)
LCV	64	152	93.82 (12.20)
HCV	64	152	109.78 (6.05)

Note: Standard Deviations are in parentheses.

Figure 1 displays for each treatment the group average emissions per period. It clearly shows that in the no communication treatment average emissions are higher than in the cheap talk treatment. The introduction of costly communication also results in a reduction of emissions, but the effect is smaller than under cheap talk.

Figure 1: Average group emissions per treatment



Vertical lines indicate the holding of communication sessions
y = 64: Cooperative equilibrium
y = 152: Non-cooperative equilibrium

Hereafter, Results 1, 2 and 3 analyse the level of group emissions with respect to the cost (high or low) and the procedure of implementation (exogenous or endogenous). Result 4 addresses the relation between the vote and the emission decisions of a subject, and shows that the vote can be a predictor of the emission decisions when the cost of communication is relatively low. Periods 1 to 4 are excluded from all the analyses since the first communication phase takes place between periods 4 and 5.

Result 1: Costly communication reduces group emissions but to a lesser extent than cheap talk.

Table 3 shows that emissions are closer to the social optimum in CT than in the baseline treatment, NC (88.95 against 112.80). When applying two-tailed Mann–Whitney tests on average emissions per group, we reject the null hypothesis of no difference between NC and CT treatments at the 5% level (p-value = 0.014, n = 8, m = 4). This finding confirms that cheap talk can help in disseminating information on strategies that are optimal for the group (Ostrom, 1998).

The left side of Figure 1, which displays the evolution of emissions over periods in CT and in NC, gives the graphical evidence of the positive impact of cheap talk on cooperation. It reveals also that this impact tends to be more pronounced in the periods that immediately follow communication phases. The emissions decline after communication but then tend to increase again over time. This is in line with the result according to which cooperation decreases several periods after that communication is removed (Frolich and Oppenheimer, 1998). However, the right side of Figure 1 reveals that costly communication has a lower impact on cooperation. Two-sided Mann Whitney tests conclude that average emissions per group in HCV, LCV and ECC are not significantly different from those noted in NC.

We conducted an econometric analysis to estimate the average emissions at the group level in each treatment. Methods for pooled time-series cross-sectional data are used. Each group is considered as a cross-sectional unit observed over a 20-period time horizon. The framework for this analysis is the following model:

$$E_{it} = \alpha_0 + \alpha_1 CT_{it} + \alpha_2 ECC_{it} + \alpha_3 LCV_{it} + \alpha_4 HCV_{it} + \alpha_5 t + \mu_i + \varepsilon_{it}, \qquad (12)$$

where the dependent variable, E_{it}, is the emissions of group $i = 1,\ldots, 24$ at period $t = 5,\ldots, 24$; CT_{it}, ECC_{it}, LCV_{it} and HCV_{it} are dummy treatment-specific indicators and the baseline treatment NC is the reference treatment. $\mu_i \to N(0,\sigma^2_{\mu_i})$ is an individual-specific random effect and $\varepsilon_{it} \to N(0,\sigma^2_{\varepsilon})$ is a mean zero error term. The model is estimated by using the Generalized Least Squares (GLS). The robustness of the results is tested by: first, running estimations based on robust standard errors in order to take into account possible heteroscedasticity and autocorrelation problems (estimating the variance-covariance matrix estimator with the Huber/White/sandwich, Bootstrap methods); second, by running the regression on individual data clustered by groups. The model estimation results are reported in Table 4.

Table 4: Regression explaining group emissions by all treatment variables

Variables	Coefficients (S.E)
Intercept	93.33*** (9.71)
CT	-23.85** (11.68)
ECC	-16.95 (13.48)
LCV	-18.97 (13.48)
HCV	-3.01 (13.48)
t	1.34*** (0.12)
N obs.	480
Overall R^2	0.22

Note: *** Denotes that parameter estimate is statistically significant at the 1% level, ** at the 5% level. Standard errors are in parentheses. Various robustness tests were carried out and confirmed these results.

CT is the only treatment in which emissions significantly differ from those observed in the baseline treatment (NC). On average, a group reduces its emissions by about 24 units when the ability to communicate freely is granted in comparison to a situation where this possibility does not exist. In a “meta-analysis” of experiments conducted on social dilemma games from 1958 to 1992, Sally (1995) found that communication increases cooperation by approximately 30% compared to a situation in which it is not implemented. In a more recent study Balliet (2010) confirmed this result by finding a significant positive relationship between cheap talk and cooperation in social dilemma games. Several explanations for the effect of communication include a better understanding of the game, increasing expectations of cooperation, enhancing group identity, and generating norms of cooperation (e.g. Chaudhuri, 2011). In contrast to treatment CT, emissions in ECC, LCV, and HCV do not significantly differ from those obtained in NC. Finally, we observe that emissions in all treatments are significantly increasing, indicating that the performance of the instrument decreases over time. This is in line with the deterioration of cooperation in social dilemma games.

Result 2: For a given cost, endogenizing communication has no significant impact on group emissions.

We run a regression in order to compare the exogenous communication (ECC) and the endogenous communication treatments which has the same cost (HCV). The framework for this analysis is the following model:

$$E_{it} = \alpha_0 + \alpha_1 HCV_{it} + \alpha_2 t + \mu_i + \varepsilon_{it}, \qquad (13)$$

where the dependent variable, E_{it}, is the emissions of group $i = 1, \ldots, 8$ at period $t = 5, \ldots, 24$; HCV_{it} is treatment-specific indicators equal to 0 in the exogenous communication treatment (ECC) and 1 in the endogenous communication treatment (HCV). $\mu_i \rightarrow N(0, \sigma^2_{\mu_i})$ is an individual-specific random effect and $\varepsilon_{it} \rightarrow N(0, \sigma^2_{\varepsilon})$ is a mean zero error term. The model is estimated by using the Generalized Least Squares (GLS) and the same robustness tests as in Result 1 are carried out. The results are reported in Table 5. It shows no significant difference between these two treatments, indicating that for a given cost, endogenizing communication has no impact on group emissions.

Table 5: Regression explaining group emissions by same cost communication treatments (ECC and HCV)

Variables	Coefficients (S.E)
Intercept	82.16*** (10.08)
HCV	13.94 (13.34)
t	0.94*** (0.24)
N obs.	160
Overall R^2	0.12

Note: *** denotes that parameter estimate is statistically significant at the 1% level, ** at the 5% level. Standard errors are in parentheses. Various robustness tests were carried out and confirmed these results.

Result 3.1: When communication is endogenous, a lower cost has no significant impact on group emissions.

Here we restrict ourselves to the treatments HCV and LCV by considering the model (3):

$$E_{it} = \alpha_0 + \alpha_1 HCV_{it} + \alpha_2 t + \mu_i + \varepsilon_{it}, \qquad (14)$$

where the dependent variable, E_{it}, is the emissions of group $i = 1,...., 8$ at period $t = 5,..., 24$, HCV_{it} is equal to 1 in HCV and 0 in LCV. The model is estimated by using the Generalized Least Squares (GLS) and the same robustness tests as in Result 1 are carried out. The results are reported in Table 6. They reveal that the cost of communication (variable HCV) has no significant effect in itself.

Table 6: Regression explaining group emissions by cost in endogenous communication treatments (LCV and HCV)

Variables	Coefficients (S.E)
Intercept	80.30*** (10.11)
HCV	15.96 (13.45)
t	0.93*** (0.24)
N obs.	160
Overall R²	0.14

Note: LCV is the reference treatment. *** denotes that parameter estimate is statistically significant at the 1% level. Standard errors are in parentheses. Various robustness tests were carried out and confirmed these results.

Result 3.2: When communication is endogenous and a communication phase is actually voted in the group, group emissions are as reduced as under cheap talk.

We consider model (1) in which we add two interaction terms between variables LCV_{it} and HCV_{it} and variable Com_{it}, which is equal to 1 when the group actually communicates and 0 otherwise:

$$\begin{aligned} E_{it} = \alpha_0 + \alpha_1 CT_{it} + \alpha_2 ECC_{it} + \alpha_3 LCV_{it} + \alpha_4 HCV_{it} + \alpha_5 HCV_{it} * Com_{it} \\ + \alpha_6 LCV_{it} * Com_{it} + \alpha_7 t + \mu_i + \varepsilon_{it}. \end{aligned} \tag{15}$$

The model is estimated by using the Generalized Least Squares (GLS) and the same robustness tests as in Result 1 are carried out. The results are presented in Table 7. LCV and HCV are not found to be significant. This shows that group emissions are not significantly reduced with respect to treatment NC when communication is not favored by vote in the group. In contrast, the interaction terms are significant, showing that whenever communication is actually favored by voted, group emissions do decrease with respect to the case where communication is not favored by voted. The global effects on group emissions in groups that communicate compared to the NC treatment are given by LCV+LCV*Com and HCV+HCV*Com, which are respectively -26.92** (13.55) and -30.21* (15.74), which should be compared to the effect of CT, -23.85** (11.58). This proves that in groups that actually communicate, group emissions are as reduced as in the Cheap Talk treatment, despite the cost of communication. Although the effect of HCV*Com appears to be very large, one should keep in mind that in this treatment, communication is favored by vote only once in one group. This result should therefore be taken with precaution.

Table 7: Regression explaining group emissions by treatment and communication phase variables

Variables	Coefficients (S.E)
Intercept	95.07*** (9.64)
CT	-23.85** (11.58)
ECC	-16.95 (13.37)
LCV	-13.68 (13.45)
LCV * Com	-13.24*** (3.71)
HCV	-1.58 (13.38)
HCV * Com	-28.63*** (8.74)
t	1.22*** (0.13)
N obs.	480
Overall R^2	0.25

Note: LCV is the reference treatment. *** denotes that parameter estimate is statistically significant at the 1% level. Standard errors are in parentheses. Various robustness tests were carried out and confirmed these results.

In a nutshell, endogenous costly communication has no significant impact on group emissions (Result 1). However, whenever communication actually takes place, endogenous costly communication significantly reduces group emissions (Result 3.2). Next we solve the puzzle by examining the impact of the cost on the probability of voting for a communication phase.

Result 4.1: A higher cost of communication deteriorates the individual probability to vote for a communication phase.

Tables 8 and 9 indicate respectively the number of subjects who voted for communication in HCV and LCV. Subjects communicate more in LCV than in HCV. 8 communication phases took place in LCV against only 1 in HCV (out of 20 opportunities to communicate, *i.e.* 4 groups * 5 voting phases). The low number of communication phases observed in LCV and HCV is consistent with the studies on costly endogenous communication. Indeed, Isaac and Walker (1991) showed that subjects rarely vote for communication. They suggest that the refusal to communicate could be due to a relatively high cost.[4] Similarly, Kriss et al. (2011) investigated the impact of costly communication in a coordination game, and found that subjects choose not to communicate due to the free-riding on the communication cost even for low costs. Substantial efforts are undertaken in order to avoid incurring the communication costs.

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[4] In their study, another explanation could be due to the fact that the cost of communication is not refunded if communication is not favored by vote.

Table 8: Number of subjects who voted for a communication phase in the HCV treatment

Vote before period Groups	5th	9th	13th	17th	21st
Group 1	2	4	5*	0	0
Group 2	2	1	1	1	2
Group 3	2	1	1	2	2
Group 4	4	2	3	4	2

Table 9: Number of subjects who voted for a communication phase in the LCV treatment

Vote before period Groups	5th	9th	13th	17th	21st
Group 1	5*	5*	1	3	4
Group 2	5*	4	5*	2	2
Group 3	5*	4	5*	0	1
Group 4	5*	3	6*	2	3

(*): The vote led to a communication phase.

In order to substantiate the previous descriptive analysis, we estimate the determinants of subjects' vote for the communication phase. As previously, the observations can be treated as cross-sectional time series (or panel) data. However, this time, we work at the subject level and consider only the 5 voting phases (that is, just before periods 5, 9, 13, 17 and 21). There are 64 subjects (2 treatments (LCV and HCV) * 4 groups * 8 subjects). Assume that subject i's (i = 1, . . . , 64) probability of voting for the communication phase in periods t (= 5, 9, 13, 17, 21) is given by:

$$y_{it}^{*} = \alpha' x_{it} + \mu_i + \varepsilon_{it}, \qquad (16)$$

where y_{it}^{*} is a latent variable representing subject i's utility level at period t, x_{it} is a (k × 1) vector of k explanatory variables, α is the (k × 1) regression vector to be estimated, μ_{it} and ε_{it} have the same role as in the previous models. We assume that if y_{it}^{*} ≤ 0, then the subject votes against the communication phase and if y_{it}^{*} > 0, then the subject votes for it. We define the binary observed variable y_{it}, which is equal to 0 when y_{it}^{*} ≤ 0 and to 1 if y_{it}^{*} > 0. The model assumes that prob(y_{it}=0 / x_{it}) = prob(y_{it}^{*}≤0 / x_{it}) = F($-\alpha' x_{it}$) and p(y_{it}=1 / x_{it}) = p(y_{it}^{*}>0 / x_{it}) = 1−F($-\alpha' x_{it}$), where F(.) is the cumulative normal distribution. We consider the following panel probit model with random effects:

$$y_{it}^{*} = \alpha_0 + \alpha_1 HCV_{it} + \alpha_2 E_{i-1,t-1} + \alpha_3 t + \mu_i + \varepsilon_{it}, \qquad (17)$$

where $E_{i-1,t-1}$ is the sum of the emissions of the other group members in the period just before the voting phase, which is likely to have an impact on voting behavior. We carried out robustness tests (Bootstrap, Jackknife), and also checked that a logit and a hierarchical model specifications yield similar results. The results of the maximum likelihood estimation of are displayed in Table 10.

Table 10: Regression explaining the individual probability of voting for a communication phase

	Coefficients (S.E)
Intercept	-1.72*** (0.60)
HCV	-1.14*** (0.36)
Emissions of others in t-1	0.03*** (0.01)
t	-0.06*** (0.02)
Log likelihood	-167.27
N.obs	320

Note: LCV is the reference treatment. *** denotes that parameter estimate is statistically significant at the 1% level. Standard errors are in parentheses. Various robustness tests were carried out and confirmed these results.

We observe that HCV is significantly negative, indicating that the cost of communication deteriorates subjects' willingness to vote for it. This provides an explanation for the bad performance of endogenous costly communication with respect to cheap talk. Because of the cost, communication phases are rare. As a result, subjects' ability to cooperate is reduced. This can be because subjects have fewer opportunities to coordinate, or alternatively, the unwillingness to communicate of other group members can also be interpreted as an unwillingness to cooperate. It should be noticed that the probability of voting for a communication phase is also positively related to the sum of other subjects' emissions in the period before. So, subjects are all the more ready to provide efforts to communicate as group emissions become larger. Finally, we note that the probability of voting for communication decreases over time. Thus, all other things being equal, subjects would be decreasingly willing to vote for communication. It may be because their group already cooperates, or because their interest has flagged.

Result 4.2: When the cost of communication is low, the vote reveals the type of the polluter. A positive vote for communication reduces the individual emissions level while a negative vote increases emissions.

We restrict our analysis to treatment LCV because the communication phase was adopted only once in one group in treatment HCV. So, there are 32 subjects (4 groups * 8 subjects). Consider the following model:

$$e_{it} = \alpha_0 + \alpha_1 Vote_{it} + \alpha_2 Com_{it} + \alpha_3 E_{i-1,t-1} + \alpha_4 t + \mu_i + \varepsilon_{it}\text{,} \qquad (18)$$

where e_{it} subject i's $i = 1,...., 32$ emissions at period $t = 5,..., 24$; $Vote_{it}$ equals 1 if the subject voted for the communication phase in the last voting phase (that is, just before periods 5, 9, 13, 17 and 21); Com_{it} is equal to 1 when a communication phase actually took place in the group in the last voting phase, and 0 otherwise; $E_{i-1,t-1}$ is the other group members' sum of emissions in the period before (one should keep in mind that variables $Vote_{it}$ and Com_{it} vary every 4 periods whereas variables $E_{i-1,t-1}$ and t vary at every period). The model is estimated by using the Generalized Least Squares (GLS) and the same robustness tests as before are carried out. We first consider the model without variable Com_{it}, and then with this variable. The results are presented in Table 11.

Table 11: Regression explaining individual emissions in the LCV treatment

	Coefficients (S.E)	
	without Com	with Com
Intercept	5.05*** (1.17)	7.00*** (1.26)
Vote	-1.25*** (0.31)	-0.82*** (0.27)
Emissions of others in t-1	0.07*** (0.02)	0.06*** (0.1)
t	0.10 (0.06)	0.03 (0.7)
Com		-1.49** (0.72)
N obs.	640	640
Overall R²	0.24	0.24

Note: LCV is the reference treatment. *** denotes that parameter estimate is statistically significant at the 1% level; ** at the 5% level. Standard errors are in parentheses. Various robustness tests were carried out and confirmed these results.

Considering first the results of model without the variable Com, we observe that the subject's vote is negatively related to his emission. Thus, a subject voting for communication emits less in the following periods while a subject voting against communication emits more on average. Therefore, voting for communication can be interpreted as an expression of the willingness to cooperate. This result was not self-evident. Indeed, a subject voting for communication might update his plan once he observes the result of the voting phase. To test the robustness of this result, we run the model with Com, which includes the result of the voting phase. We find that the occurrence of a communication phase has also a negative impact on individual emissions and that the individual vote is still significant. Hence, the fact that the individual vote reveals behavior remains true even after controlling for the output of the voting phase. Finally, it can be noticed that individual emissions are increasing with the sum of others' emissions at the period before, which is a form of reciprocity.

5. Conclusion

We tested the efficiency of the Average Pigovian Tax (APT) first proposed by Suter et al. (2008) to regulate the phenomena of nonpoint source pollution. The choice of this instrument from the set of ambient-based tax mechanisms is justified by the fact that it is less severe and therefore more politically feasible. Contrary to the standard ambient tax, the efficiency of the APT requires cooperation. To facilitate cooperation, Suter et al. (2008) have suggested costless non-binding communication or cheap talk. However, in considering the experimental circumstances in which communication solves cooperation problems, one must remember that the costless communication used in the experiment of Suter et al. (2008) to obtain high rates of efficiency is very unlikely to exist outside the laboratory setting. Thus, in order to mimic that real-world communication often imposes costs on those who are involved in it, we consider in this experiment costly communication.

We confirmed that with cheap talk the instrument induces polluters to reduce their emissions. However, we found that the reduction of group emissions is less important when communication is costly. This result is still verified even when we endogenize communication by introducing a voting phase. In addition, a variation of the cost when communication is endogenous revealed that a drastic drop of the cost does not provoke a significant reduction of group emissions. A more specific analysis of the performance of the APT instrument under endogenous communication reveals that these findings have to be nuanced. First, we observed that in groups where communication is actually voted, emissions are reduced at the same level as under the cheap talk treatment. However, one should keep in mind that communication is in fact rarely voted. Second, we noticed that subjects' voting behavior is very sensitive to the cost. In other words, a larger cost deteriorates the probability of voting for communication. This explains why communication was rarely favored by vote when it was costly. In contrast, a lower cost not only increases the likelihood of voting for communication, but also prompts the polluter into revealing his type a positive vote for communication induces the reduction of an individual's emissions, whereas a negative vote leads him to the increase of his emissions. This result implies that the vote might be an indicator to differentiate between the cooperative agents and the non-cooperative ones.

To summarize, our study shows that the APT may be an interesting compromise for dealing with the major concerns of nonpoint source pollution. The APT may allow addressing the challenges of pollution reduction and political acceptability raised by the ambient tax mechanisms. We emphasized that the role of communication is crucial in enhancing the performance of the instrument. However, the performance of communication is subject to different variables. Specifically, the regulator should pay attention to the cost borne by polluters to implement communication. Further investigations are required to identify the other potential factors that are likely to impact the ability of polluters to communicate with one another.

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Appendix 1: Instructions

These are the translated instructions for treatment HCV. The instructions for the other treatments are available upon request.

Welcome

Introduction

You will participate in an experiment whose objective is to study individual and group decision-making.

Before starting the experiment, we will ask you some questions to verify your understanding of the instructions. After we finish reading the instructions, you can ask us any question you may have.

16 people, randomly divided into two groups of eight, are involved in this experience. So you are a member of one of these two groups of eight members. During the experience you will interact anonymously with the members of your own group.

The gains you realize depend both on your own decisions and on the decisions taken by the other members of your group. These gains will be recorded in points and converted into euros at the end of the experiment.

This experience consists of at least 22 periods. The following instructions will inform you on how your gain at each period will be calculated. They also will explain the chronology of the experience.

1. Your decision

At the beginning of each period, each member of your group, including yourself, has 20 tokens. Your task consists in investing an integer number of tokens between 0 and 20. Your earnings depend on the number of tokens invested by yourself and the other seven members of the group. It is possible that you will win nothing, and worse even, you can lose points.

The gain (or loss) you realize at each period consists of two parts:

- A gain that depends on your own investment.
- A loss that depends on both your investment and those of the seven other members of your group.

In addition, every 4 periods, you may also bear an extra cost if you vote for having a discussion with the other group members.

1.1. The gain due to your own investment

Each token you invest brings you a certain number of points, as shown in the Table below. It is composed of three columns. They respectively indicate the number of tokens you wish to invest, the additional earnings generated by the investment of your last token and your overall earnings.

- If you invest 0 token, your gain is 500 points
- If you invest 1 point, your gain is 582 points (500 +82)
- If you invest 2 tokens, your gain is 660 points (500 +82 +78)

The same principle is applied up to 20 tokens:

- If you invest 20 tokens, your gain is 1380 points (500 + 78 + 82 ... + 14 +10 +6 = 1380).

Tokens	Earnings (in points)	Additional earnings generated by the last token
0	500	-
1	582	82
2	660	78
3	734	74
4	804	70
5	870	66
6	932	62
7	990	58
8	1044	54
9	1094	50

10	1140	46
11	1182	42
12	1220	38
13	1254	34
14	1284	30
15	1310	26
16	1332	22
17	1350	18
18	1364	14
19	1374	10
20	1380	6

You will notice that the more tokens you invest, the less points each of them generates. The un-invested tokens are lost. You can not reuse them in the following periods.

Example: If you invest 9 tokens in one period, you will not have 31 tokens in the next period but 20.

1.2. The loss due to the group investment (your investment and those of your group-members)

Each member of your group, including yourself, incurs a loss if the total number of invested tokens is greater than 64. If the total number of tokens invested by your group is larger than 64, everyone loses 6.5 times the difference between the total number of tokens invested by your group and 64.

Example: The total number of tokens invested by your group is 100 tokens. This number is greater than 64 so each member of the group, including yourself, loses 234 points ((100-64)*6.5).

In summary, the loss depends on the total number of tokens invested by the group. If it is larger than 64, each member of the group incurs a similar loss. The more the number of tokens invested are further from 64, the greater the loss is.

2. The cost due to your participation in the discussion session

You have the opportunity to communicate with your other group-members before the 5th, 9th, 13th, 17th and 21st periods. At each of these periods, you indicate by a vote whether you want to discuss with them (“yes” or “no”). The question “Would you like to discuss with the other members of your group?” appears on your screen. If the majority of the group (at least 5 “yes”) wishes to discuss, a chat room will appear and all members of the group, including those who responded "no” can then engage in a discussion phase. Otherwise no discussion will take place.

- If you voted “yes”, 200 points will be deducted from your earnings at the end of this period, but only if there is a discussion.
- If you voted “no”, no points will be deducted from your earnings at the end of that period whether or not there is a discussion.

After the vote, you will be informed of the holding or not of a discussion session. However, the voting score (how many “yes”" and “no”) will not be indicated.

During the discussion phases, limited to three minutes, agreements to share gains after the experiment are prohibited. Apart from the discussion time allowed, it is forbidden to communicate during the experiment.

3. Chronology of the experience

In each period, the computer asks you to enter the number of tokens you want to invest. You can enter any integer number between 0 and 20. The other members of your group do the same task on their side, but you do not observe their individual decisions. You will just know the total sum of their individual decisions at the end of a period. Once all members of your group have made their decisions, the computer calculates the gain or loss for that period. Then it provides each participant with the total number of tokens invested by the seven other members of the group and its gain for the period. The next period begins when all members of your group are ready. At any time, you can view the history of experience. It reminds you for each historical period, your decision, the total number of tokens made by the other seven members of the group and your gain.

At the end of the experiment, your gain will be converted into Euros. The conversion rate to be applied is 1000 points equal to € 1.

Before starting the experiment, you will participate in a trial period. The aim is to enable you to familiarize yourself with the user interface of the computer. During this trial period the computer will play the role of the other seven people, assuming that they invest 70 tokens. The earnings received during this period will not be converted into euros.

Cahiers de Recherche

CR n°2015 - 01 : Sarr H., Bchir, M.A., Cochard F., Rozan A. « Nonpoint source pollution: An experimental investigation of the Average Pigouvian Tax »

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