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Jessica Coria[a], Clara Villegas-Palacio[b], and Juan Camilo Cárdenas[c]

Abstract

In this paper we use laboratory experiments to test the theoretical predictions derived by Villegas-Palacio and Coria (2010) about the effects of the interaction between technology adoption and incomplete enforcement. They show that under Tradable Emissions Permits (TEPs), and in contrast to taxes, the fall in permit price produced by adoption of environmentally friendly technologies reduces the benefits of violating the environmental regulation at the margin and leads firms to improve their compliance behavior. Moreover, when TEPs are used, the regulator can speed up the diffusion of new technologies since the benefits from adopting the new technology increase with the enforcement stringency.

Our experimental results confirm these theoretical predictions. While the aggregate emissions do not statistically differ between the two policy instruments, the fraction of firms violating the regulation and the aggregate extent of violation are lower under TEPs than under emission taxes regardless of the monitoring probability. Hence, in contrast to previous studies, our results indicate that TEPs would appear to be a feasible policy alternative in weak regulatory contexts.

JEL classification**:** C91; L51; Q58

Key words**:** laboratory experiments, emission taxes, auctioned tradable emissions permits, imperfect monitoring, technology adoption, developing countries.

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1 Introduction

Over the last decades, many donors and advisors have promoted the use of market-based instrument (MBIs) as the key to more effective environmental protection in the developing world. Yet, the use remains sporadic in these countries. On the one hand, those arguing in favor of market-based instruments emphasize that they are efficient instruments that relax the trade-off between economic growth and improved environmental quality. Besides, they can be implemented without specific knowledge of the technology of or pollution-reduction costs for polluting sources. On the other hand, those opposed to their use emphasize monitoring and enforcement considerations since institutional and economic factors in developing countries limit regulators' ability to monitor and enforce environmental regulations and hence impede the effectiveness of economic instruments (see Blackman and Harrington 2001, Bell and Rusell 2002, and Coria and Sterner 2010).[1]

The latter seems difficult to rectify at least in the medium term, and it seems to be particularly pervasive in the case of TEPs since, unlike emission taxes, firms are linked together through the functioning of the permit market. Weak monitoring and enforcement does not only have a negative direct effect on compliance, there is also an indirect effect that occurs because changes in enforcement strategy can induce changes in permit prices (Malik 1990 and 1992, Stranlund and Dhanda1999, Stranlund and Chavez 2000, and Murphy and Stranlund 2006).

Against this background, Villegas-Palacio and Coria (2010) compare emission taxes and tradable permits when both monitoring is not strong enough to guarantee perfect compliance and firms can adopt new and more efficient technologies to reduce the costs of compliance with environmental regulations.[2] They show that under TEPs –

[1]Environmental policies introduce important dilemmas of equity and justice as alternative policies imply a different distribution of costs among firms. Though these are very relevant in the context of a developing country, its analysis is beyond the scope of this paper.

[2] Monitoring is defined as the process of verifying firms' status of compliance, and enforcement as the actions undertaken to bring firms to compliance. In developing countries, monitoring seems to dominate and better explain environmental performance (Dasgupta et al. 2001), which might be explained by the fact that regulators interact with firms in more than one context of domain and over many periods.

for a given monitoring probability and in contrast to taxes – technology adoption pushes the permit price down, which reduces the benefits of violating the environmental regulation and ultimately leads both adopters and non-adopters to modify their compliance behavior. Furthermore, regulators might speed up the adoption process through a more stringent enforcement under TEPs, while such an effect is absent in the case of taxes. Overall, this is good news for an enforcement regulator who can achieve a higher reduction in the extent of violation as well as a faster diffusion of new technologies through the use of TEPs.

In this paper, we use laboratory experiments to test the theoretical predictions by Villegas-Palacio and Coria (2010). We use a 2x2 experimental design. The first dimension of variation is the policy instrument chosen to control pollution (uniform emissions taxes vs. auctioned tradable emissions permits). The second dimension is the stringency of monitoring probability. Our results indicate that fewer firms violate the regulation under TEPs than under emission taxes. Furthermore, the extent of the violation is lower under TEPs, while aggregate emissions and adoption rate do not differ statistically. Hence, as pointed out by Villegas-Palacio and Coria (2010), compliance behavior is enhanced under TEPs, suggesting that for many developing countries, TEPs would appear to be a feasible policy alternative even though the regulatory contexts are weak.

Several studies have used laboratory experiments to examine compliance behavior or technology adoption either under uniform taxes or TEPs (see, e.g., Gangadharan et al. 2010, Cason and Gangadharan 2006, Murphy and Stranlund 2006, 2007, and Strandlund et al. 2011)[3]. However, none of the aforementioned studies analyze the interaction between incomplete enforcement and technology adoption, or its effects for the choice of policy instruments in developing countries where regulators have more difficulties

[3] Gangadharan et al. (2005) investigate whether emission markets encourage optimal investments. Cason and Gangadharan (2006) identify interactions between emission shocks, banking, compliance and enforcement in an emissions trading market in the presence of emissions uncertainty. Murphy and Stranlund (2006) study the direct and indirect effects of enforcement on compliance under TEPs. Murphy and Stranlund (2007) analyze the links between violations and increased enforcement stringency for heterogeneous firms. Finally, Stranlund et al. (2011) investigate enforcement and compliance when TEPs allow permit banking.

monitoring and sanctioning due to budget and technology constraints, and where the use of market-based mechanisms continues to grow in the policy debate.

The structure of the paper is as follows. Section 2 presents the hypotheses to be tested. Section 3 provides details about experimental design and procedures. Section 4 presents the results and Section 5 concludes the paper.

2. Hypotheses

We designed a series of laboratory experiments to test hypotheses about compliance behavior and technology adoption when firms are regulated either by uniform environmental taxes or by a system of auctioned TEPs. These hypotheses are derived from the theoretical model by Villegas-Palacio and Coria (2010). In the following paragraphs, we briefly synthesize the model. For further details, we recommend the reader to review their paper.

Villegas-Palacio and Coria (2010) consider a competitive industry consisting of a continuum of firms of mass 1 that are risk-neutral.[4] They are also initially homogeneous in the abatement cost $c(e)$, which is strictly convex and decreasing in emissions. In the absence of environmental regulation, each firm emits a quantity e_0 of a homogeneous pollutant. There is an environmental authority that sets a maximum level of emissions and then chooses a policy instrument to reach this target. Since the regulator cannot observe firms' emissions, costly monitoring is undertaken. The probability of being monitored is known by firms and equals π. Once the regulator monitors a firm, it is able to perfectly determine the firm's compliance status. If the monitoring reveals that the firm is non-compliant, it faces the penalty $\phi(v)$, which is a strictly convex function of the extent of violation v. For zero violation, the penalty is zero $\phi(0) = 0$, yet the marginal penalty is greater than zero, i.e., $\phi'(0) > 0$.

[4]Assuming, instead, that firms are risk averse would not change the results of this paper significantly since under a market-based regulation a firm's choice of emissions is independent of its manager's risk preference, its endowment of permits, and the enforcement strategy it faces (Stranlund 2008).Nevertheless, in the case of imperfect monitoring, the violation of a non-compliant firm will decrease if the manager's utility function exhibits increasing absolute risk aversion. In such case, the demand for emission permits will increase and so will the equilibrium permit price and the rate of adoption.

A new and more efficient technology arrives and firms must decide whether or not to invest in it. The new technology allows firms to abate emissions at a lower cost given by $\theta c(e)$, where $\theta \in (0{,}1)$ is a parameter that represents the drop in abatement cost due to adoption of the new technology. They assume that buying and installing the new technology implies a fixed cost that differs among firms. Let k_i denote the fixed cost of adoption for firm i, where k_i is uniformly distributed on the interval $(\underline{k}, \overline{k})$, with density function $f(k_i)$ and cumulative distribution function $F(k_i)$. Let μ_{NAi} and μ_{Ai} be firm i's total expected costs of abatement and compliance when using the current abatement technology (non-adoption) and new technology (adoption), respectively. The expected cost savings from adopting are $\mu_{NAi} - \mu_{Ai}$. Any firm whose expected cost saving offset its adoption cost will adopt the new technology. Therefore, the adoption rate – denoted λ – depends on the total expected savings in the costs of abatement and compliance, which are endogenous to the choice of policy instrument, the stringency of the environmental policy, and the enforcement policy.

The interaction between regulator and firms is as follows:

1. The regulator makes a long-term commitment to a policy level and sets and announces her policy choice (either a unitary tax level or the number of emissions permits to be issued). She also chooses a uniform monitoring probability and a monetary sanction scheme, and announces it to the firms.[5]
2. A new technology arrives, and firms have to decide whether to invest in it, their actual emission level, as well as reported emission level if regulated by uniform taxes or number of permits to buy and hold if regulated by TEPs.
3. The regulator monitors the firms according to the announced monitoring probability and then sanctions those found in non-compliance according to the sanctioning scheme.

[5] If the regulator does not adjust the level of the policy in response to arrival of new technology, taxes provide stronger incentives for firms to adopt new technologies than do permits. Instead, if the regulator anticipates new technologies and adjusts the policy levels, taxes and permits are equivalent and they both will induce first-best outcomes if the regulator moves first (Requate and Unold 2003, Coria 2009).

Emissions and violation under taxes and TEPs

In this setting, for the case of uniform taxes the problem of an adopter firm is the following[6]:

$$(1)\quad Min_{e,r}\, \mu_A^{Tax} = \theta c(e) + tr + \pi\phi(e-r),\ s.t. \quad e-r \geq 0.$$

Solving this minimization problem, if the solution is interior, each firm chooses its emission levels such that the marginal abatement cost equals the tax rate. Since there is a uniform tax rate, in equilibrium firms' marginal abatement costs are equal irrespective of their adoption status, i.e., $c'(e_{NA}) = \theta c'(e_A)$. Therefore, adopters' actual levels of emissions are reduced due to the availability of the new technology and are lower than those of non-adopters. In addition, since the tax is exogenous and not influenced by the enforcement strategy, firms' actual emissions do not depend on the parameters of the enforcement problem.

Firms choose to report a level of emissions such that the marginal benefit of non-compliance (given by the tax) equals the marginal expected fine, i.e., $t = \pi\phi(e-r)$. Since both the tax rate and the enforcement policy are the same for adopters and non-adopters, it follows that the extent of violation is the same for both types of firms, i.e., $e_A - r_A = e_{NA} - r_{NA}$. Given that adopters' emissions are lower than non-adopters' emissions, it follows that the emissions reported by adopters are lower than those reported by non-adopters. Moreover, the report levels of adopter and non-adopter firms are decreasing in the tax rate and increasing in the monitoring probability (see Villegas and Coria 2010, page 280).

Hypothesis 1: *With emission taxes, adopters of the new technology have lower emissions and report levels than non-adopters. Moreover, the emission level is*

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[6] The problem of the firms that do not adopt the new abatement technology is analogous to problem (2). The main difference is that the abatement costs for these kinds of firms are given by $c(e)$ instead of $\theta c(e)$.

independent of the monitoring probability but the report level is an increasing function of monitoring probability.

Hypothesis 2*: With emission taxes, the extent of violation is independent of the adoption status and is therefore the same for adopters and non-adopters of the new technology. The extent of violation is a decreasing function of the monitoring probability.*

A firm regulated by TEPs can abate a fraction of its emissions and buy permits to compensate for the remaining fraction. The equilibrium permit price is endogenous to the stringency of the monitoring and enforcement scheme and adoption rate. However, to simplify notation, we denote the equilibrium permit price p instead of $p(\pi, \lambda)$.

Let l denote the quantity of permits held by a firm in equilibrium and l_0 be the number of emissions permits, if any, initially allocated to it. Each permit gives the right to emit one unit of pollution. The problem of the firm in such case is as follows:

$$(2) \quad Min_{e,l} \mu_A^{TEPs} = \theta c(e) + p[l - l_0] + \pi\phi(e - l), \quad s.t. \;\; e - l \geq 0.$$

If the solution to this optimization problem is interior, in equilibrium each firm chooses its emissions such that the marginal abatement cost equals the equilibrium permit price, which is the same for all firms regardless of adoption status. Since adopters' marginal abatement cost function is lower than that of non-adopters, adopters' emission level is lower than that of non-adopters.

In equilibrium, firms hold a quantity of permits such that the marginal benefit of non-compliance (given by the equilibrium permit price) equals the marginal expected fine, i.e., $p = \pi\phi(e - l)$. Since the permit price and the enforcement strategies faced by adopters and non-adopters are the same, we obtain that the difference between actual emissions level and number of permits held in equilibrium, i.e., the extent of violation, is the same for adopters and non-adopters. Therefore, with TEPs, the adopters' actual emissions and the quantity of permits that firms hold in equilibrium are lower than the actual emissions and the quantity of permits held by non-adopters in equilibrium.

In contrast to taxes, though a firm's choice of emissions is not directly affected by the monitoring effort applied to it, it is indirectly affected through the effect of the monitoring probability on the equilibrium permit price. Intuitively, increased monitoring motivates firms to purchase more emissions permits to reduce the magnitude of their violations. This increased demand for permits then puts upward pressure on the equilibrium permit price, inducing firms to reduce their emissions to a larger extent (Stranlund and Dhanda 1999, page 274).

Additionally, the adoption rate reduces the non-compliance incentives via the equilibrium permit price; adoption decreases adopters' demand for permits and consequently the aggregate demand, which reduces the permit price and thus also the marginal benefit of non-compliance. Therefore, unlike taxes, technology adoption does provide incentives to improve compliance when firms are regulated by TEPs. This is an important difference between these two instruments, which relates to the fact that taxes are fixed by the regulator, while the equilibrium permit price varies with the enforcement strategy and the rate of technology adoption (Villegas-Palacio and Coria 2010, page 283).

Hypothesis 3: *With TEPs, adopters of the new technology have a lower emission level and hold a lower quantity of permits than non-adopters. Moreover, the emission level is a decreasing function and the permit holding an increasing function of the monitoring probability.*

Hypothesis 4: *With TEPs, a firm's extent of violation is independent of its adoption status and is therefore the same for adopters and non-adopters of the new technology. The extent of violation is a decreasing function of the monitoring probability.*

Adoption rate

As stated above, the rate of adoption is determined by the difference between the expected costs of abatement and compliance under the current and the new technology. For the case of uniform taxes, this difference is expressed as:

$$(3) \quad \mu_{NA}^{Tax} - \mu_{A}^{Tax} = [c(e_{NA}(t)) - \theta c(e_{A}(t))] + t[e_{NA}(t) - e_{A}(t)].$$

Finally, from the definition of the uniform cumulative distribution of k_i, the adoption rate can be characterized as a fraction of the adoption cost savings $\mu_{NA}^{Tax} - \mu_{A}^{Tax}$, as follows:

$$(4) \quad \lambda^{Tax} = \psi\{c(e_{NA}(t)) - \theta c(e_{A}(t)) + t[e_{NA}(t) - e_{A}(t)]\} - \xi,$$

where $\psi = \frac{1}{\bar{k}-\underline{k}}$ and $\xi = \frac{\underline{k}}{\bar{k}-\underline{k}}$.

Note that since neither the emission level nor the tax rate is a function of monitoring probability or of the sanction structure, the enforcement strategy does not affect the rate of adoption.

Hypothesis 5: *When emission taxes are used, the adoption rate does not depend on the enforcement strategy but is determined only by the tax rate.*

As with the case of taxes, the rate of adoption under TEPs is determined by the difference between the expected costs of abatement and compliance under the current and the new technology; and it can be characterized as follows:

$$(5) \quad \lambda^{TEPs} = \psi\{c(e_{NA}(p)) - \theta c(e_{A}(p)) + p[l_{NA}(p,\pi) - l_{A}(p,\pi)]\} - \xi.$$

Note that since the permit price and adopters' and non-adopters' demand for permits are increasing functions of the monitoring probability, the rate of technology adoption depends on this parameter as well.

Hypothesis 6: *When TEPs are used, the adoption rate is an increasing function of the monitoring probability.*

Hypothesis 5 and 6 represent another important difference between taxes and TEPs. In contrast to taxes, the rate of technology adoption is an increasing function of monitoring probability when the regulation takes the form of TEPs. This result has interesting implications for the comparison of the adoption incentives provided by these two policy instruments. Since firms with higher costs of adoption can free ride on the decreased permit price caused by other firms' adoption, the private gains from adopting the technology under permits are reduced and so is the rate of adoption. However, hypothesis 6 implies that by increasing the monitoring probability, the regulator can offset the permit price depreciation while encouraging firms to reduce the extent of violation. Therefore, under permits, a more stringent enforcement strategy may increase the rate of adoption of new technology while still providing firms with larger incentives to increase compliance than taxes. This is good news for the regulators since by choosing TEPs, the continuous development of cleaner technologies may imply a larger rate of compliance with environmental regulations (Villegas-Palacio and Coria 2010, page 285).

3. Experimental design and procedures

3.1 Experimental design

Section II introduced six hypotheses regarding the relationship between imperfect enforcement and technology adoption. To test these hypotheses we conducted a series of laboratory experiments in a between-subjects 2x2 design with 4 treatments as shown in Table 1. The first dimension of variation is the policy instrument chosen to control pollution (uniform emissions taxes vs. auctioned tradable emissions permits). The second dimension is the stringency of monitoring probability. Our experiments are framed in the context of a firm (represented by a subject) that is regulated by either environmental taxes or auctioned TEPs.[7]

All treatments consisted of only one round. Each treatment had three experimental sessions with 18 subjects in each, all in all 211participants. Each subject represented a firm with an initial endowment of E=20,000 tokens, representing their profits before decisions were made.[8]

Table 1: Experimental design

Monitoring probability	**Regulatory policy instrument**	
	Uniform taxes	**Auctioned TEPs**
Low (π = 0.4)	Treatment 1	Treatment 3
High (π = 0.9)	Treatment 2	Treatment 4

In line with the model presented in the previous section, we assume that as a result of its production and before any abatement process, each firm has an initial level of emissions e_0 of 10 units. The firm has a current abatement technology represented by the marginal abatement cost function $c_0'(e_0 - e) = 400[e_0 - e]$. A new and more efficient abatement technology is available and represented by the abatement cost function $c_1'(e_0 - e) = 160[e_0 - e]$. Each subject was randomly assigned a fixed cost of adoption ranging uniformly in the range [10, 2500]. A firm that is regulated by uniform taxes, i.e., treatments 1 and 2, has to make the following decisions:

[7]There is no consensus on whether experiments should be framed in a particular context to avoid this influencing the results (see Murphy and Cárdenas 2004). However, we frame our experiment in the context of compliance to environmental regulations since we want to capture the effect of intrinsic motivations to comply with regulations and to adopt new technologies, which could potentially be affected by attitudes with respect to the environment. We do not consider this a problem given our between subjects design and that participants were randomly assigned to each treatment.

[8] Each token was converted into 1.5 Colombian pesos (COP).

(1) The adoption decision: whether the firm will operate with the current abatement technology or buy and install a new and more efficient abatement technology.

(2) The actual emissions decision: how many units of the initial emission level it will abate, which determines the actual emission level e.

(3) The reported emissions decision: how many units of the actual emission level the firm will self-report to the authority. The unitary tax is 500 tokens. Note that there are no benefits of reporting more emissions than the actual level, since then the firm would have to pay the tax per unit of excess emissions. Instead, the firm might want to underreport in order to reduce the tax payment. Hence, $r \in [0, e]$.

At the end of the round, the authority conducted an auditory procedure with a known monitoring probability to verify that the reported emission level coincided with the actual emission level. Since the monitoring probability is one of our treatment variables, it varies across treatment, as described in Table 1. In the first treatment, only 7 out of 18 participants were monitored (i.e., 40% of the subjects). In the second treatment, 90% of the participants were monitored. The difference between the two monitoring probabilities should reflect the stringency of the enforcement schemes observed in developing and developed countries. While direct and continuous monitoring of emissions has been an important factor in the success of environmental programs in developed countries (Stranlund et al. 2002), the enforcement design used in less developed countries has not induced a high level of compliance (Coria and Sterner 2010).

When caught in violation, the firm was sanctioned according to a penalty schedule given by$\phi = 100v^2 + 250v$. The convexity of this penalty schedule, together with the convexity of the abatement cost function, guarantees that the second order conditions of the minimization problems in equations (1) and (2) are satisfied.

As with taxes, a firm regulated by TEPs, i.e., treatments 3 and 4, has to make (1) *the adoption decision* and (2) *the actual emissions decision*. However, instead of reporting emissions, the firm must decide (3) *how many permits to buy to compensate its emissions*. The unitary permit price is endogenously determined by the number of firms that adopt the new technology. As with uniform taxes, the number of permits that the firm buys should be in the interval $[0, e]$. As in the first two treatments, at the end of the round the authority conducted an auditory procedure with a known monitoring probability to verify that the reported emission level coincided with the number of permits held by the firm in equilibrium. The monitoring probability and the penalty schedule are as in treatments 1 and 2.

3.2 Experimental procedure

Participants were recruited at the Universidad Nacional de Colombia from the business management and administration engineering undergraduate programs. This allows us to derive conclusions from a group of people that are representative of the future managers and engineers in polluting industries or in regulatory agencies in the public sector, and that are not too far from making these kinds of decisions in reality. Subjects were paid an initial COP 5,000 show-up fee (about USD 2.7) for participating in the experiment and showing up on time. Their additional earnings from their decisions ranged from COP 11,000 to COP 30,000 with an average of COP 23,800 (USD 12.87) and a standard deviation of around COP 3,800. At the time, the daily minimum wage in the country was around USD 9.9.

The experiment was run in a computer lab with each terminal providing an Excel worksheet specially designed to allow the subjects to perform calculations of additional earnings for all possible combinations of adoption decisions, actual emission level and reported emissions (in the case of taxes)/demand for permits (in the case of TEPs). Each session lasted around 90 minutes. At the beginning of the session, each participant was randomly assigned an identification number that determined her fixed adoption cost. They were also handed the instructions, which were read aloud by the experimenter. The instructions for treatments 1 and 2 are presented in Appendix A. To make the participants familiar with the experimental protocol, a set of control questions was included in the instructions. In order to answer the control questions, the participants needed to operate the same Excel worksheet that was used in the experiment but with a different set of parameters. The answers to the control questions were not considered in the analysis.[9] After all the participants had completed the training and all questions had been answered, the experiment began.

[9] All of our participants answered the control questions correctly, indicating a good understanding of the instructions and Excel worksheet.

All participants had 20 minutes to make their decisions. Once all participants had made their decisions, the completed experimental cards were collected by the experimenter and the monitoring stage followed. To select the firms that were going to be monitored, the experimenter had cards with all the participants' numbers in a bag. In front of the participants, the experimenter randomly selected and read aloud the numbers of the participants to be monitored.

After the monitoring stage had been completed, the final questionnaire was handed out to the participants. Given that our experimental design included a stochastic regulatory process, the first part of the questionnaire aimed at measuring risk preferences. To this end we had an incentivized risk experiment adapted from the risk experiment by Holt and Laury (2002). Subjects were faced with a menu of 10 paired lottery choices; in each case they had to choose between two lotteries, A and B. The payment for lottery A was constant, riskless and equal to USD 2.77[10]; lottery B was risky, but offered twice as much as lottery A. In the first paired lottery, the probability of the high payoff under lottery B was 9/10. In the second, it was equal to 8/10, and it decreased systematically though the sequence of paired lotteries. When the probability of the high payoff outcome decreases to a certain point, a person should cross over to lottery A. Hence, the crossover point from the risky to the riskless lottery can be used to infer the degree of risk aversion. Clearly, the lower the probability of the high payoff at which subjects switch to lottery A, the lower the risk aversion since subjects demand a lower expected compensation in order to turn down to the risky alternative.

Subjects were told from the beginning that at the moment of payment one of the choice sets was going to be randomly selected for the payment using a dice such that all choice sets had the same probability of being chosen. If the participant had chosen alternative B in the selected choice, a second dice was used to play the lottery according to the indicated probabilities.

Once all participants had handed in the final questionnaire, subjects were privately paid (in cash) the show-up fee, the earnings from the experiment, and the earnings from the risk experiment.

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[10]Exchange rate 1,800 COP per USD.

4. Results

First, we will present some descriptive statistics of the socio-economic characteristics of our participants and non-parametric tests of our hypotheses. We will then analyze the influence of some behavioral variables.

4.1. Descriptive statistics and non-parametric tests of hypotheses

Table 2 presents the average and standard deviation of some demographic characteristics, i.e., gender, age, monthly expenses (as a proxy for income), and risk attitudes, of the participants in each treatment. For the variable risk attitudes we use the results of the incentivized risk experiment described in the previous section. Based on the Wilcoxon-Mann-Whitney test, we cannot reject the null hypothesis that gender, monthly expenses, risk attitudes, and age composition are equal between the comparable treatments (i.e., T_1 vs. T_2, T_1 vs. T_3, T_2 vs. T_4, and T_3 vs. T_4).

Table 2: Socio-demographic characteristics

Treatment	$\mathbf{T_1}$	$\mathbf{T_2}$	$\mathbf{T_3}$	$\mathbf{T_4}$
N	54	52	53	53
Gender (% males)	0.57 (0.5)	0.6 (0.5)	0.57 (0.50)	0.60 (0.49)
Age	21.77 (2.51)	21.19 (2.33)	21.45 (2.94)	21.01 (2.23)
Monthly expenses (US $)	214.36 (81.78)	179.78 (50.12)	207.02 (103.59)	202.82 (70.31)
Risk attitudes	54.62 (15.50)	55.96 (15.50)	53.08 (14.89)	57.92 (17.14)

Standard deviations in parentheses

Table 3 presents the descriptive statistics of the actual and reported emission levels and of violation for adopters and non-adopters in all treatments (Appendix B presents the level predicted by the theoretical model for each of these variables given our set of parameters).

Table 3: Summary statistics for actual/reported emissions and violation.

	Actual emissions		*Reported emissions*		*Firms violating (%)*		*Violation*	
	Adopters	*Non-adopters*	*Adopters*	*Non-adopters*	*Adopters*	*Non-adopters*	*Adopters*	*Non-adopters*
Emission taxes								
Treatment 1	6.25 (1.52)	8.2 (1.18)	3.83 (1.9)	4.47 (1.54)	71.43	94.74	2.43 (2.2)	3.73 (1.66)
Treatment 2	6.30 (1.04)	8.35 (1.23)	5.07 (1.72)	6.31 (2.59)	53.85	73.08	1.23 (1.39)	2,03 (2.41)
Auctioned TEPs								
Treatment 3	6.18 (1.41)	8.77 (1.28)	5.44 (1.65)	6.23 (3.05)	40.74	61.54	0.81 (1.11)	2.53 (2.9)
Treatment 4	6.18 (1.75)	7.85 (2.33)	6.22 (1.62)	7.7 (1.93)	12.5	19.05	0.15 (0.45)	0.38 (0.97)

Standard deviations in parentheses

As expected, we observe that adopters emit less than non-adopters in all treatments. They also report less than non-adopters. With respect to the extent of violation, we observe that as theory predicts, the higher the monitoring probability, the lower the fraction of firms violating the regulation and the lower the average violation.

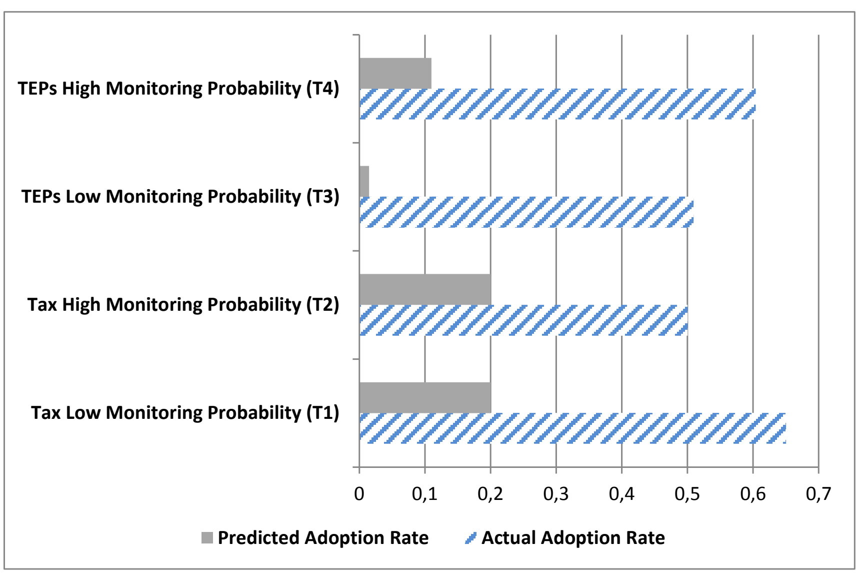
In the case of taxes, the results support Hypothesis 1 as adopters have significantly lower emissions and report less than do non-adopters of the new technology. However, Hypothesis 2 only holds when the monitoring probability is high (see Appendix C for Mann-Whitney statistical tests of Hypotheses 1 and 2). If the monitoring probability is low (treatment 1), adopters violate significantly less than non-adopters. This result indicates that there could be some behavioral characteristics of adopters related to decision making under risk and uncertainty (not captured by the theoretical model) that also affect the compliance decision and that become relatively more relevant when the enforcement is less stringent. We explore this issue in the econometric analysis in Section 4.3.

In contrast to the case of uniform taxes, the theoretical prediction for TEPs is that firms' actual emission levels decrease with the monitoring probability since the permit price increases. However, we do not find evidence to support such a hypothesis as adopters' and non-adopters' emission levels are not statistically affected by the probability of being monitored. Nevertheless, as expected, we observe that adopters emit significantly less than non-adopters in both treatments, yet hold significantly fewer permits than non-adopters only for high monitoring probabilities.

The hypothesis that under TEPs the extent of violation drops when the monitoring probability increases is also confirmed (see Appendix D for Mann-Whitney statistical tests of Hypotheses 3 and 4). Similarly, we find that when the monitoring probability is high, adopters and non-adopters violate to the same extent.

Finally, Figure 1 presents the expected and actual adoption rates in all the treatments. Actual adoption rates are significantly higher than expected across the board. As stated above, this might be due to behavioral variables, in addition to the variables in the theoretical model, increasing the willingness to invest in environmentally friendly technologies. On the other hand, we observe that for both policy instruments, the adoption rate is not affected by monitoring probability. Thus, we cannot reject Hypothesis 5 (p value = 0.13). However, we can reject Hypothesis 6 since under TEPs the rate of adoption when the monitoring probability is low is statistically equivalent to the rate of adoption when the monitoring probability is high (p-value = 0.33).

Figure 1: Observed and expected adoption rates



4.2 Non-parametric tests comparing taxes and TEPs

Table 4 reports the p-values of the Mann-Whitney statistical test to verify whether there are statistically significant differences in the levels of actual emissions, percentage of firms in violation, and the extent of violation between the comparable treatments involving taxes and TEPs (i.e., T_1 vs. T_3 and T_2 vs. T_4). As the rate of adoption differs between treatments, we also report the weighted average of the variables under study.

Note that there are no statistically significant differences in the adopters' and weighted average levels of emissions under taxes and TEPs. However, non-adopters emit less under emission taxes when the monitoring probability is low. Under TEPs though, fewer adopters and non-adopters violate the regulation, and the extent of their violation is significantly lower than under taxes. This holds regardless of monitoring probability.

Table 4: Non-parametric test comparing emissions and violation under emission taxes and TEPs

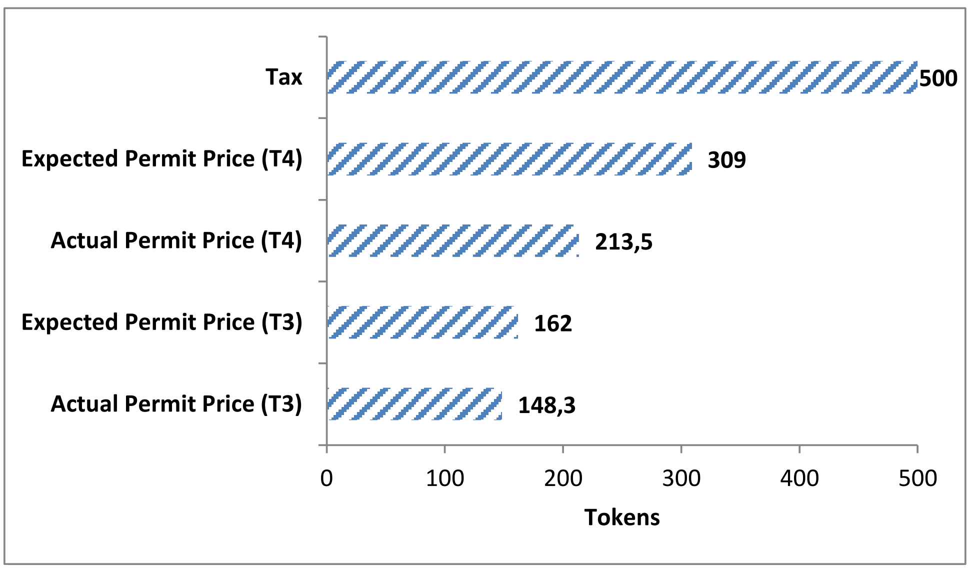
	Actual emissions			*Firms violating (%)*			*Extent of violation*		
	Adopters	***Non adopters***	***Weighted average***	***Adopters***	***Non-adopters***	***Weighted average***	***Adopters***	***Non-adopters***	***Weighted average***
T_1-T_3	0.694	0.084*	0.149	0.016***	0.01***	0.002***	0.002***	0.043**	0.001***
T_2-T_4	0.955	0.930	0.393	0.001***	0.000***	0.000***	0.000***	0.000***	0.000***

(***) statistically significant at 1%. (**) statistically significant at 5%, (*) statistically significant at 10%.

Why do firms, for a given monitoring probability, violate less under TEPs while still emitting the same? This result seems to be driven by the effect of technology adoption on the permit price. Even though for a given monitoring probability there are no statistical differences between the adoption rate induced by uniform taxes and TEPs (p-values 0.148 and 0.287 for T_1-T_3 and T_2-T_4 respectively), the final emission prices, and therefore the marginal benefits of non-compliance, are rather different. Indeed, Figure 2 presents the actual and expected permit prices for treatments 3 and 4. As theory predicts, the permit price is increasing with monitoring probability (p-value =0.000), and it is lower than the emission tax. Actual permit prices are much lower than expected due to the large fraction of firms adopting the technology and hence demanding fewer permits, pushing the permit price down.

Furthermore, even though the rate of adoption under TEPs does not statistically differ between T_3-T_4, the fraction of firms violating and the violation extent do decrease in monitoring probability under TEPs. Hence, our results show that in contrast to taxes, the deterrent effect of the monitoring effort under TEPs is reinforced by the effect of the technology adoption rate on the extent of violations.

Figure 2: Actual / expected prices under different treatments



Finally, although the analysis of the fiscal uses of the tax revenues or proceeds from selling permits is beyond the scope of our paper, it is straightforward to say that governmental revenues would be lower under TEPs due to the lower price per unit of emissions.

4.3 Influence of behavioral variables on our results – some regressions

Here we explore the effects of some socio-demographic and attitudinal variables on actual emissions and reporting and on the adoption decision.

Table 5 presents the results of a probit model for the probability of adopting the new technology. The explanatory variables are monitoring probability, risk attitudes, gender (as a dummy variable that takes the value one for males and zero otherwise), the interaction between risk and gender, and the fixed cost of adoption (randomly assigned to each participant at the beginning of the experiment). We also included a "pro-technology index" that indicates the degree (on a scale from 1 to 10) to which participants agreed with the following statements: "Science and technology are making our lives healthier, easier, and more comfortable" and "Thanks to science and technology the next generations will have more opportunities." The pro-technology index is the average of the participants' answers to these two statements. The higher the value of the index, the more pro-technology the participant is.

Table 5: Probit model of adoption.

Probability of adopting the new technology (marginal effects)	**Uniform taxes**	**Auctioned TEPs**
Monitoring probability	-0.364 (0.093)	0.178 (0.382)
Risk	***-0.015**** ***(0.006)***	0.004 (0.005)
Gender	-0.313 (0.404)	**0.614*** **(0.265)**
Fixed adoption cost (in thousand tokens)	***-0.414******* ***(0.083)***	-0.062 (0.284)
Pro-technology index	-0.008 (-0.027)	-0.032 (-0.029)
Risk*Gender	0.005 (0.008)	**-0.015*** **(0.007)**
N	106	104

Standard deviations in parentheses.
(***) statistically significant at 1%. (**) statistically significant at 5%, (*) statistically significant at 10%.

The results suggest that under uniform taxes, the higher the risk aversion the lower the probability of a firm adopting the new technology. However, this variable does not have a significant effect on the probability of adopting a new technology under TEPs. Analogously, those who have a higher fixed cost of adoption have a lower probability of adopting the new technology under uniform taxes while its effect is not statistically significant under TEPs. Under TEPs, however, gender influences the probability of adopting a new technology as males are more prone to adopt it than females. In addition, under TEPs, the more risk-averse males are less likely to adopt the new technology as indicated by the negative interaction between risk aversion and gender.

Table 6 presents the results of a Tobit model for the actual emission levels under uniform taxes and TEPs. As explanatory variables we included adoption status and the responses to a series of attitudinal questions. For instance, we asked subjects how well they were represented by the statement, “For this person, it is very important to take care of nature and the environment.” The participant selected a value from 1 to 6, where the lower the value the stronger the identification with the statement. This last variable is denoted *Importance of environment*. We also asked the participants if they knew about the existence of environmental regulations in Colombia, which we include in the model as a dummy variable.

Table 6: Tobit model of actual emission levels.

Dependent variable: Actual emissions level	**Emission taxes**	**Auctioned TEPs**
Adoption	***-2.090****** ***(0.265)***	***-2.312****** ***(0.369)***
Knowledge of environmental regulations	0.337 (0.345)	***3.22****** ***(0.975)***
Importance of environment	***0.319**** ***(0.147)***	***0.34**** ***(0.18)***
Monthly expenses (UD $)	0.00 (0.000)	0.00 (0.000)
Constant	7.871*** (0.53)	7.67*** (0.67)
N	105	103

Standard deviations in parentheses.
(***) statistically significant at 1%. (**) statistically significant at 5%, (*) statistically significant at 10%.

Our results show that adopters emit less than non-adopters under both policy instruments. Participants who feel strongly that it is important to take care of the environment emit statistically less under both policy instruments. Furthermore, the individuals who claimed to know about the existence of environmental regulations emit more under TEPs than those who did not have such knowledge. This is an indication of the role that intrinsic motivation and knowledge can play for pro-environmental behavior.

Finally, Table 7 reports the results of both a Probit and a Tobit model for the probability of being in non-compliance and for the extent of violation, respectively. We included variables such as treatment (as an indication of monitoring probability), adoption status, and some attitudinal variables, e.g., how guilty they would feel if they would violate the regulation (on a scale from 1 to 5, where the larger the value the lower the guilt), the degree of agreement with the statement, "Environmental regulations should never be violated" (where the larger the value the stronger the agreement), and how well subjects were represented by the statement, "For this person it is very important to always to do the correct thing" (on a scale from 1 to 6, where the lower the value the stronger the identification with the statement).

Our results suggest that under uniform taxes and TEPs, technology adoption and a higher monitoring probability reduce the probability of being in non-compliance. In the case of taxes, those who feel strongly that it is important to take care of the environment are less likely to be in violation, whereas this variable does not have a significant effect in the case of TEPs. However, those who agree with the statement that it is important to always do the correct thing are less likely to violate under TEPs, whereas this variable does not have a significant effect under taxes. Again, these results indicate that intrinsic motivations may affect the decision to comply with a regulation. Intrinsic motivation and the monitoring probability also affect the size of violation. For the case of taxes, the extent of the violation of those who agree that environmental regulations should not be violated is lower; in the case of TEPs those who think that it is important to always do what is correct violate to a lower extent.

Table 7: Probit and Tobit model for probability and extent of violation

	Emission taxes			*Auctioned TEPs*		
	Probit model	**Tobit model**	**Tobit model for v>0**	**Probit model**	**Tobit model**	**Tobit model for v>0**
Treatment	**-0.25** (0.096)**	**-2.16*** (0.528)**	**-1.33** (0.437)**	**-0.44*** (0.10)**	**-4.26*** (0.918)**	**-2.137* (0.81)**
Adoption	**-0.19* (0.089)**	**-1.23* (0.516)**	-0.455 (0.414)	**-0.316** (0.11)**	**-3.464*** (0.878)**	**-2.44** (0.67)**
Guilt	-0.032 (0.056)	-0.249 (0.321)	-0.106 (0.279)	**0.12* (0.06)**	**0.967* (0.46)**	0.05 (0.40)
Environmental regulations should never be violated	-0.068 (0.08)	**-0.743* (0.402)**	**-0.523* (0.314)**	-0.02 (0.717)	-0.198 (0.723)	0.227 (0.50)
It is important to always do the correct thing	-0.015 (0.040)	-0.09 (0.23)	-0.02 (0.21)	**0.12** (0.05)**	**1.199** (0.41)**	**0.943* (0.403)**
Importance of the environment	**0.132* (0.04)**	**0.656* (0.338)**	0.159 (0.273)	0.015 0.792	0.010 (0.982)	-0.05 (0.88)
Monthly expenses	**-0.0006* (0.00)**	**-0.004* (0.002)**	-0.001 (0.002)	0.0006 (0.00)	-0.007 (0.005)	-0.008 (0.005)
Knowledge of environmental regulations	0.122 (0.099)	0.514 (0.674)	-0.08 (0.88)			
Constant		10.26*** (2.519)	8.27*** (2.11)		20.74** (6.27)	14.36** (5.055)
N	103	103	74	98	104	35

Standard deviations in parentheses
(***) statistically significant at 1%. (**) statistically significant at 5%, (*) statistically significant at 10%.

5. Conclusions

Over the years, environmental economists have argued for the use of economic policy instruments for pollution control. Emission taxes and tradable emissions permits have been extensively compared and ranked under several criteria. In a recent theoretical paper, Villegas-Palacio and Coria (2010) study the interaction between incomplete enforcement and technology adoption when firms are regulated under uniform emission taxes and auctioned tradable emissions permits. The present paper constitutes an empirical test of the theoretical predictions derived in their study. Our experimental results confirm most of the theoretical predictions related to actual emission levels, reported emission levels, and number of permits held by firms. Nevertheless, the observed adoption rate is significantly higher than predicted. In contrast to theory, which predicts that the adoption rate is higher under taxes than under TEPs, we find that it is not significantly different between the two policy instruments. At aggregate level, our results suggest that aggregate emissions do not differ significantly between the two policy instruments either. However, the fraction of firms violating the regulation and the aggregate extent of violation are lower under TEPs than under uniform taxes regardless of monitoring probability.

Overall, our results provide support for the use of TEPs. One should also remember that emission taxes imply a need for monitoring and institutions. From our results it is not clear that trading schemes require a more “stringent enforcement” in order to fulfill the same environmental target in the presence of imperfect compliance. Furthermore, the fact that emission prices are endogenous to technological progress and the enforcement strategy allows for an adjustment in the equilibrium permit price needed to induce further compliance and enhance economic efficiency. This effect is absent in the case of emission taxes.

Choosing the adequate policy instrument to regulate pollution requires a strict analysis from the theoretical but also from the empirical point of view. The opportunities for such an analysis in a controlled environment are rather scarce. Economic experiments offer useful tools for understanding the performance of different policy instruments under different conditions. This paper uses such a technique for testing theoretical predictions and comparing uniform taxes and TEPs in the context of imperfect monitoring and technology adoption. A natural further step in this line of research is to replicate these results within actual firms that regularly face a regulatory environment and have to make decisions about pollution and abatement technologies. The growth of field experiments with firms confirms that such a path should offer additional insights (Bandeira et al. 2011). We have here offered a new experimental design that could be taken to the field – either by using experimental subjects as representative of firms or by conducting the experiments within firms with different types of decision makers – to explore the effectiveness of these different regulatory mechanisms in contexts where monitoring and enforcement by the regulator are determinant, as in the case of many developing countries.

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Appendix A: INSTRUCTIONS

You are about to participate in an experiment that tries to recreate a situation in which a group of firms are regulated by an environmental policy and must make some decisions that we will explain later.

You represent a firm that will have the opportunity to earn some profits in an experimental currency called tokens (E$). The quantity of tokens that your firm will earn depends on your decisions. At the end of the session each token will be converted to Colombian pesos and you will be paid in cash the quantity you earned with your decisions. For each token you earn you will receive 1.5 Colombian pesos.

Different participants will earn different amounts. It is important that you do not talk or communicate with other participants during this experiment. If you do not follow these rules we will have to ask you to leave the experiment.

We will start by giving you a complete description of the experiment. If you have any questions while we read the instructions please raise your hand. If you have any hesitation after we start the experiment, please raise your hand and a monitor will be with you to help.

ALL YOUR DECISIONS WILL BE COMPLETELY ANONYMOUS

In this experiment you represent a firm that as a consequence of its production process emits a fixed quantity of pollution to the atmosphere; this quantity will be called INITIAL EMISSIONS. Nobody in the experiment, except you, knows your initial emissions. Your firm is regulated by an environmental policy that dictates that for each unit of pollutant that is emitted to the atmosphere you should pay a fixed quantity of money to the authority as a tax.

To pay such taxes you should self-report to the authority the quantity of pollutant you are emitting. Your firm can reduce the quantity of money to pay to the authority through two channels: reducing the initial emissions with the use of pollution control technologies and/or under-reporting to the authority the quantity of pollution you are emitting. The final quantity of pollution you emit after you have controlled part of it by using technologies is called REAL EMISSIONS. The quantity of pollutant you self-report to the authority is called REPORTED EMISSIONS.

With the aim of verifying that the reported emissions coincide with the real emissions, the authority must visit the firms. But given that the authority has limited resources only some firms will be visited. You will know how many firms the authority will visit but you will not know if your firm will be visited or not. If your firm tries to evade taxes – that is, if the reported emissions are lower than the real emissions – your firm will be sanctioned and you will have to pay a fine.

The costs of reducing the initial emissions (called costs of emissions control or abatement costs) depend on the quantity of emissions that your firm decides to reduce and the abatement technology it has. Actually, your firm has an abatement technology that we will call "actual technology" and that you can use to reduce your initial emissions. However, you can buy and install a new abatement technology that is more efficient and that will reduce the abatement costs further.

During the experiment you will have information about:

- Abatement costs using the actual technology.
- Abatement costs using the new technology.
- Costs of buying and installing the new technology. This will be called investment costs.

At the beginning of the experiment you will receive a quantity of tokens as an initial endowment. During the experiment you will have to make decisions about:

- Whether to buy and install the new technology.
- How many units of your initial emissions to reduce.
- How many units of your real emissions to report, that is, your reported emissions.

What you decide determines your earnings, which will be calculated as follows:

Your initial endowment minus:

- Investment costs (only if your firm decides to buy and install the new technology)
- Tax payments (based on your reported emissions)
- Sanctions (only if you evade taxes and are visited by the authority)

= Total earnings

Now we will explain how we will conduct the experiment. All the numbers that you will see now are only examples and do not necessarily coincide with the numbers that you will work with during the experiment.

During the experiment you will use an Excel worksheet. In that worksheet you will have the information about your initial endowment, your investment costs, your initial emissions, and the number of firms that will be visited by the authority. Additionally, using the worksheet you will be able to see how much your earnings would be for different decisions. The worksheet looks as follows. You will be able to write your decisions in the yellow cells.

THANKS FOR PARTICIPATING IN THIS EXPERIMENT

Initial endowment in tokens

Out of the 18 firms participating in this experiment, the number of firms to be visited by the authority is:

The costs of buying and installing the abatement technology range between 30 tokens and 250 tokens.

Initial emissions

Costs of buying and installing the new abatement technology (investment costs) for your firm:

Please write your firm number (your identification number in the experiment)	

DECISIONS

Reduced emissions	
That means that your real emissions are	
How many of these real emissions are you going to report (reported emissions)?	

These are the detailed costs (in tokens) in which you will incur with your decisions		
	If you buy and install the new technology	**If you use the actual technology**
Investment costs		
Abatement costs		
Tax payment		
Sanction if you are visited by the authority and found under-reporting emissions		

EARNINGS

	If you buy and install the new technology		**If you use the actual technology**	
	In tokens	**In Colombian Pesos**	**In tokens**	**In Colombian Pesos**
Your earnings if you ARE NOT VISITED by the authority				
Your earnings if you ARE VISITED by the authority				

As an example we will assume the following:

- Initial endowment: 800 tokens
- Initial emissions: 15 units
- Investment costs: 100 tokens
- Out of the 18 firms participating in this experiment, the number of firms to be monitored is 7
- Assume you reduce 4 units of emissions. That implies that your real emissions are 11 units (15-4=11)
- If you use the actual technology your abatement costs are 48 tokens
- If you use the new technology your abatement costs are 34 tokens
- Out of the 11 units of pollution you report 2 units to the authority

Let's consider different situations to see your earnings with different decisions:

A. If your firm adopts the new technology and is not visited by the authority, your earnings are:

800 tokens (initial endowment) - 100 tokens (investment costs) – 34 tokens (abatement costs) – 100 tokens (tax payment) = 566 tokens

B. If your firm adopts the new technology and is visited by the authority, your earnings are:

800 tokens (initial endowment) - 100 tokens (investment costs) – 34 tokens (abatement costs) – 100 tokens (tax payment) – 406 tokens (fine) = 161 tokens

C. If your firm uses the actual technology and is not visited by the authority, your earnings are:

800 tokens (initial endowment) – 48 tokens (abatement costs) – 100 tokens (tax payment) = 652 tokens

D. If your firm uses the actual technology and is visited by the authority, your earnings are:

800 tokens (initial endowment) – 48 tokens (abatement costs) – 100 tokens (tax payment) - 406 tokens (fine)= 246 tokens

You will not need to make these calculations; you only need to write your decisions about reduced emissions and reported emissions in the yellow cells, and the Excel worksheet will calculate for you. You can see the results in the same worksheet as follows:

EARNINGS	If you buy and install the new technology		If you use the actual technology	
	In tokens	In Colombian Pesos	In tokens	In Colombian Pesos
Your earnings if you ARE NOT VISITED by the authority	566	22 656	652	26 080
Your earnings if you ARE VISITED by the authority	161	6 420	246	9 844

In this example you will earn more money when your firm uses the actual technology and is not monitored by the authority. However, this is not always the case and depends on the specific number you get in the experiment.

Please remember that all the numbers in the examples above are hypothetical and do not necessarily coincide with the numbers you will see in the experiment.

2. Control questions.

Please use the Excel worksheet called "Instructions treatment 1" to answer the following questions. The purpose is to make you familiar with it.

a) Assume you decided to reduce 8 units. Write number 8 in the yellow cell that corresponds to "reduced emissions". Out of the 7 units that correspond to your real emissions you decide to report 5 units. Please write number 5 in the yellow cell that corresponds to "reported emissions". Please look at the table called "earnings" in the same worksheet and answer:

i. How much do you earn in tokens if your firm buys and installs the new technology and is visited by the authority? _____
ii. How much do you earn in tokens if your firm buys and installs the new technology and is not visited by the authority? _____
iii. How much do you earn in tokens if your firm uses the actual technology and is visited by the authority?_____
iv. How much do you earn in tokens if your firm uses the actual technology and is not visited by the authority? _____

b) Now we will assume something different. Change the numbers you have in the yellow cells according to the following. Assume you reduced 5 units of pollution. Out of the 10 units that correspond to your real emissions you decide to report 10 units

v. How much do you earn in tokens if your firm buys and installs the new technology and is visited by the authority? _____
vi. How much do you earn in tokens if your firm buys and installs the new technology and is not visited by the authority? _____
vii. How much do you earn in tokens if your firm uses the actual technology and

is visited by the authority?_____

viii. How much do you earn in tokens if your firm uses the actual technology and is not visited by the authority? _____

3. The experimental card

To report your decisions you will receive an experimental card, like the one shown below, where you will write your decisions.

Experimental card	
Firm number	
Will you buy and install the new technology?	
Reduced emissions	
Reported emissions	

4. How does the experiment work?

a. You will receive the Excel worksheet that you will use during the experiment and that has the information you need to make decisions.
b. Using the Excel worksheet you will have 10 minutes to analyze your decisions.
c. Once you have made your decisions you write them in the experimental card.
d. Once everyone has turned in the experimental cards, the monitor will randomly draw the firms that will be visited by the authority from a bag that has all the firms´ numbers.
e. For those firms that were randomly selected, the authority will verify that the actual emissions coincide with the reported emissions. If the authority finds that the firm is trying to evade taxes the authority imposes a fine.
f. Finally we calculate the earnings of all participants according to your decisions.

ALL YOUR DECISIONS WILL BE ANONYMOUS AND WILL NOT BE DISCLOSED DURING ANY PART OF THE EXPERIMENT. At the end of the experiment you will be paid in cash according to your earnings.

Appendix B: Predicted levels for actual/reported emissions and violation.

	Predicted actual emissions		***Predicted reported emissions***		***Predicted violation***	
	Adopters	***Non-adopters***	***Adopters***	***Non-adopters***	***Adopters***	***Non-adopters***
Emission taxes						
Treatment 1	6.9	8.8	1.9	3.8	5.0	5.0
Treatment 2	6.9	8.8	5.3	7.2	1.6	1.6
Auctioned TEPs						
Treatment 3	8.9	9.6	8.0	8.7	0.9	0.9
Treatment 4	8.0	9.2	7.6	8.8	0.4	0.4

Appendix C: Non-parametric test of Hypotheses 1 and 2

Null hypothesis	Expected result	P-value	Experimental evidence
What is the influence of monitoring effort on emissions under emission taxes?			
Adopters' emissions in Treatment 1 = Adopters' emissions in Treatment 2	Adopters' emissions in Treatment 1 = Adopters' emissions in Treatment 2	0.920	Confirms theoretical prediction
Non-Adopters' emissions in Treatment 1 = Non-adopters' emissions in Treatment 2	Non- adopters' emissions in Treatment 1 = Non-adopters' emissions in Treatment 2	0.660	Confirms theoretical prediction
What is the influence of adoption status on emission under emission taxes?			
Adopters' emissions in Treatment 1= Non-Adopters' emissions in Treatment 1	Adopters' emissions in Treatment 1 < Non-adopters' emissions in Treatment 1	0.000	Confirms theoretical prediction
Adopters' emissions in Treatment 2= Non-adopters' emissions in Treatment 2	Adopters' emissions in Treatment 2 < Non-adopters' emissions in Treatment 2	0.000	Confirms theoretical prediction
What is the influence of monitoring probability on report under emission taxes?			
Adopters' report in Treatment 1 = Adopters' report with Treatment2	Adopters' report in Treatment 1 < Adopters' report in Treatment 2	0.012	Confirms theoretical prediction
Non-Adopters' report in Treatment 1 = Non-adopters' report with Treatment 2	Non-Adopters' report in Treatment 1 < Non-adopters' report in Treatment 2	0.004	Confirms theoretical prediction
What is the influence of adoption status on report under emission taxes?			
Adopters' report in Treatment 1= Non- adopters' report in Treatment 1	Adopters' report in Treatment 1< Non-adopters' report in Treatment 1	0.100	Does not confirm theoretical prediction
Adopters' report in Treatment 2= Non- adopters' report in Treatment 2	Adopters' report in Treatment 2 < Non-adopters' report in Treatment 2	0.025	Confirms theoretical prediction
What is the influence of monitoring effort on violation?			

Adopters' violation in Treatment 1= Adopters' violation in Treatment 2	Adopters' violation in Treatment 1 > Adopters' violation in Treatment 2	0.030	Confirms theoretical prediction
Non- Adopters' violation in Treatment 1 = Non-adopters' violation in Treatment 2	Non-adopters' violation in Treatment 1 > Non-adopters' violation in Treatment 2	0.003	Confirms theoretical prediction
What is the influence of adoption status on violation?			
Adopters' violation in Treatment 1= Non- adopters' violation in Treatment 1	Adopters' violation in Treatment 1= Non-adopters' violation in Treatment 1	0.015	Does not confirm theoretical prediction
Adopters' violation in Treatment 2= Non- adopters' violation in Treatment 2	Adopters' violation in Treatment 2= Non-adopters' violation in Treatment 2	0.225	Confirms theoretical prediction

Appendix D: Non-parametric test of Hypothesis 3 and 4

Null hypothesis	Expected result	P-value	Experimental evidence
What is the influence of monitoring effort on emissions under TEPs?			
Adopters’ emissions in Treatment 3 = Adopters’ emissions with Treatment 4	Adopters’ emissions in Treatment 3< Adopters’ emissions in Treatment 4	0,89	Does not confirm theoretical prediction
Non-Adopters’ emissions in Treatment 3 = Non-adopters’ emissions in Treatment 4	Non- adopters’ emissions in Treatment 3< Non-adopters’ emissions in Treatment 4	0,22	Does not confirm theoretical prediction
What is the influence of adoption status on emission under TEPs?			
Adopters’ emissions in Treatment 3= Non-adopters’ emissions in Treatment 3	Adopters’ emissions in Treatment 3< Non-adopters’ emissions in Treatment 3	0.000	Confirms theoretical prediction
Adopters’ emissions in Treatment 4= Non-adopters’ emissions in Treatment 4	Adopters’ emissions in Treatment 4< Non-adopters’ emissions in Treatment 4	0.0011	Confirms theoretical prediction
What is the influence of monitoring probability on permits holding under TEPs?			
Adopters’ holding in Treatment 3 = Adopters’ holding in Treatment 4	Adopters’ permit holding in Treatment 3<Adopters’ holding in Treatment 4	0.04	Confirms theoretical prediction
Non-Adopters’ holding in Treatment 3 = Non-adopters’ holding in Treatment 4	Non-adopters’ permit holding in Treatment 3 < Non-adopters’ permit holding in Treatment 4	0.13	Does not confirm theoretical prediction
What is the influence of adoption status on permits holding under TEPs?			
Adopters’ permit holding in Treatment 3= Non- adopters’ permit holding in Treatment 3	Adopters’ permit holding in Treatment 3< Non-adopters’ permit holding in Treatment 3	0,11	Does not confirm theoretical prediction
Adopters’ permit holding in Treatment 4= Non- adopters’ permit holding in Treatment 4	Adopters’ permit holding in Treatment 4< Non-adopters’ permit holding in Treatment 4	0,006	Confirms theoretical prediction
What is the influence of monitoring effort on violation under TEPs?			
Adopters’ violation in Treatment 3 = Adopters’ violation in Treatment 4	Adopters’ violation in Treatment 3> Adopters’ violation in Treatment 4	0.008	Confirms theoretical prediction

Non-Adopters’ violation in Treatment 3 = Non-adopters’ violation in Treatment 4	Non-adopters’ violation in Treatment 3> Non-adopters’ violation in Treatment 4	0.0007	Confirms theoretical prediction
What is the influence of adoption status on violation under TEPs?			
Adopters’ violation in Treatment 3= Non- adopters’ violation in Treatment 3	Adopters’ violation in Treatment 3= Non-adopters’ violation in Treatment 3	0,02	Does not confirm theoretical prediction
Adopters’ violation in Treatment 4= Non- adopters’ violation in Treatment 4	Adopters’ violation in Treatment 4 = Non-adopters’ violation in Treatment 4	0,82	Confirms theoretical prediction