Facultat de Ciències Jurídiques i Econòmiques

UNIVERSITAT JAUME I

PROBABILITY VS SEVERITY OF PUNISHMENT: THE CASE OF THE NON-POINT SOURCE POLLUTION

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GRADO EN ECONOMÍA

2013/2014

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1. INTRODUCTION

In a world of scarce resources it is a main concern for a regulator how to deal with crime in an optimal way. While we know that increases in the expected penalty facing violators increase the level of compliance, with resource constraints a regulator has to decide in order to create an enforcement strategy whether to enhance the probability of punishment (by investing in monitoring and security) or in the penalty facing violators (years in jail or fines)[1]. To separate the effect of both and to get the optimal combination for the most effective deterrence is a main issue in economics of crime.

A special case is when the regulator deals with non-point pollution problems. These problems arise when it is impossible for the regulator to know the origin of the pollution or it is extremely expensive to monitor for every individual so only the ambient pollution level in known. This could be the case of excess fertilizers, herbicides, toxic chemicals, lakes pollution, atmospheric deposition, hydromodification, etc. In this context, the regulator can choose the best mechanism to avoid pollution and to get the highest possible level of abatement of the firms. The utilization of different mechanisms sets up a good basis for researchers to study the behaviour of firms (choosing their level of abatement) with different combinations of probability of being caught and the severity of punishment when emissions exceed the ambient pollution level set by the regulator.

However, there is not so much empirical evidence or at least it is not conclusive. The main issue about the empirical analyses is the difficulty in obtaining good data. In particular, in most situations, individual data is not available and it can only be collected at the aggregate through various calculations and estimations. Also, as pointed out by Anderson et al (2003), "for many offenses the probability of punishment is computed as the ratio of the number of convictions to the number of reported offenses. Because reporting is costly to the victim, offenses are often underreported and thus there may be systematic measurement error in this variable that can bias estimation" (this bias could be because offenses are generally underreported or because some types of offenses are more reported than others).

Data obtained from experiments can overcome most of these issues. In particular, this paper uses experimental results obtained from Camacho and Requate (2012). Experimental data gives us the opportunity to accurately measure and control the conditions subjects deal with during the experiment. On one side, the experiment controlled for both probability of being caught and the amount fined using different treatments so the expected penalty was the same. On the other side, the experimental data obtained allows us to take into account the risk aversion distribution for all the individuals. It is crucial to take into account the risk preferences of the individuals (firms) because their decision on abatement will be directly linked to it.

[1] As Polinsky and Shavell (2000) explained, public law enforcement is more desirable than private law enforcement in the sense that in some cases victims are not able to identify the violators and also because it is wasteful to catch violators if society has to give rewards to private parties other than victims.

The classic model used in crime literature is the one of Becker (1968), who considers criminals as any other individual so they behave as utility maximizers. Using his economic model of crime, he derives the different roles individuals have. This is: risk-neutral individuals will be not affected by changes in the composition of the expected penalty (neither probability nor size of the fine), risk-averse individuals will comply more with an increase in the size of the fine than with an increase in the probability of being caught, and risk-seeking individuals are deterred more by an increase in the probability of punishment than an increase in the severity of punishment

This paper tries to test the classic Becker´s model of crime for the individuals' behaviour facing different distributions of the expected fine (the probability of punishment and the severity of punishment) depending on their aversion to risk. In this context, it would be easy to see how individuals react to changes in the probability and the size of the fine. To test this, data from the experiment mentioned above concerning non-point pollution problems is used.

The main results obtained from this paper do not seem to fit the Becker´s model perfectly. Most of the predictions from the model regarding risk attitudes and changes in the composition of the expected fine are poorly linked with the result from data and in some cases the effects seem to be completely the opposite.

2. LITERATURE

Albeit much research has been done about law enforcement after the Becker´s article, the effects of probability of punishment and severity of punishment combined are still not clear. One of the main causes of this is the different characteristics of the data used. When we focus on individual-level data, which is the one related with this paper, it is possible to use two different types of sources. On the one hand, if data comes from the criminal justice system it is necessary to deal with problems such as sample selection (criminals who have already committed the crime), like in Grogger (1991). On the other hand it is also possible to run laboratory experiments in order to solve some data issues, controlling the expected penalty to be fixed while changing the magnitudes of probability and severity of punishment and also observing the individual decisions. This last methodology has the inconvenient of abstract some real-world characteristics; in particular, there will also be nonmonetary punishments apart from the expected fine (prison sentences, public shame or consciousness), which will have a huge effect on the decision. Then, it is important not to forget the limitation of both methods.

For studies coming from the crime data, even though they can have different problems as said before, they use to conclude that increases in the probability of punishment has a larger effect for deterrence than an increase in the amount of the fine (An extreme case for this conclusion would be Doob and Webster, 2003). In the same direction, some others like Langlais *(2006)* conclude that "whatever the representation of criminals´ risk preferences under risk, the assumption according to which they are strongly risk averse is not consistent" which would imply that the risk seeking assumption would be better suited for criminals, and then according to the Becker´s model, they would respond more to changes in the probability of punishment.

For experiments literature there are not many studies. One of the latest is the one from Lana Friesen (2012). In this paper, laboratory experiments are run to find the opposite result from empirical data: an increase in the severity of punishment is a more effective deterrent than an equivalent increase in the probability of punishment. This paper also found an interesting gender effect: on average, females were 13% more likely to comply than males, supporting the evidence in literature that men are more likely cheat and engage in dishonest behaviour than women.

Anderson and Stafford (2003) analyse the effect of punishment in inducing regulatory compliance. They find that compliance increases with the expected punishment costs no matter if it is a one-time mechanism or a repeated treatment and also that the amount fined has a large effect for deterrence than the probability of being punished.

Some papers have shown the importance of the role of the regulator. Shimshack and Ward (2003) study the impact of enforcement efforts on environmental compliance. They find that the impact of a fine for water pollution reduces in two-thirds the violation for the whole state, so “the deterrence impact on other plants in a state is almost as strong as the impact of the sanctioned plant”. Then if we just focus on the effect for the sanctioned plant we could be underestimating it for the whole group of firms.

Polinsky and Shavell (2006) discuss the importance of having a public regulator and creating a public enforcement of law. When victims know the identity of the injurer (this is the case of contractual obligations or accidents) it would be efficient for society if this victims use their information for their own law enforcement. However, in the case when victims do not know the identity of the one who committed the crime (this is the case of environmental regulation), society would do better if trusting with a public agent for investigating the case.

Xepapadeas (1991) develops a framework for designing incentive systems that could be applied in non-monitoring situations. These systems consist in contracts between the regulator (who could be a pollution control agency) and the firms and they include a mix of fines and subsidies for inducing discharges to get the optimal environmental policy. In particular he develops the two mechanisms used in this paper, the collective and the random fining scheme. In the first one, all firms in the sector are punished when the ambient pollution level exceeds the one set by the regulator while in the random mechanism a random firm is punished when the sector exceeds the pollution level. In Xepapadeas (1995), he found that under uncertainty, the best policy for the regulator to get the optimal situation in non-point pollution cases would be to use a combination between Pigouvian taxes and ambient taxes. The main goal of this treatment would be to gradually change from a non-point pollution case to a point source case (and make it easy to deal with) by imposing the Pigouvian taxes on the pollution revealed by the firm and in exchange for decreasing the ambient tax.

Other papers, such as Garoupa (1998) found some interesting further results when testing the Becker´s model. This particular paper ended up with the conclusion that: “Becker´s argument is not robust when alternative specifications of behaviour under uncertainty are considered”. Bruner (2009) uses the case of context-free lottery choices and analyses the responses to different combination of probability and size of the rewards to find out that the behaviour of the subjects is consistent with the the expected utility theory. Because the Becker´s theoretical model is directly linked with the expected utility theory, we can consider Brunner (2009) as an explicit test of the Becker´s prediction.

3. THEORETICAL MODEL

The hypotheses tested in this paper are derived from the classic Becker´s model in crime literature. In this model, individuals receive an income called *y* and they can pay an amount *c* to comply with the existing regulation, then yielding to an expected utility function if they comply:

$$\text{EU(comply)} = \text{U(y-c)} \tag{1}$$

However, if individuals choose not to comply, they can be caught with probability *p* (0<*p*<1) and therefore being punished with a fine *F*. The expected utility function if the individual does not comply is:

$$\text{EU(violate)} = \text{pU}\big(\text{y-F}\big) + \big(\text{1-p}\big)\text{U(y)} \tag{2}$$

Then the individual just balances the expected profits from both possibilities (comply or violate) and chooses the best. The effects of both the probability and the expected fine will depend on the risk preferences of the individual.

If we get the elasticity of the probability (μp) and the elasticity of the fine (μF) from the equation (2) we get:

$$\mu\text{p} = \frac{\text{dEU}}{\text{dp}}\frac{\text{p}}{\text{EU}} = \text{-}\left(\frac{\text{p}}{\text{EU}}\right)\left[\text{U}\big(\text{y-F}\big)\text{-U(y)}\right] \tag{3}$$

$$\mu\text{F} = \frac{\text{dEU}}{\text{dF}}\frac{F}{EU} = \left(\frac{F}{EU}\right)pU'(y-F) \tag{4}$$

When μp>μF we have that the individual is risk seeking and then, a change in the probability of being fined (*p*) will have a larger effect than the amount fined (*F*). In the other case, when μF>μp then the individual reacts more to a change in the severity of punishment than in the probability of being punished so it is a risk averse individual. When one elasticity is equal to the other we have a risk neutral individual, who is affected by equal to relative changes both in the severity or the probability of punishment.

As we are using data from the laboratory experiments run by Camacho and Requate (2012), we use the same theoretical background for considering the optimal decisions. Then we have a regulator which tries to maximise a social welfare function:

$$SW = n\Pi^0 - \sum_{i=1}^{n} C(a_i) - d[ne^{max} - \sum_{i=1}^{n} a_i] \quad \textbf{(5)}$$

Where n is the number of firms in the economy, which level of emission would be e^{max} if there is no regulation. Π^0 is the default profit of the individual firm . Then we use a_i to measure the level of abatement chosen by each firm and therefore $C(a_i)$ will measure the cost of the abatement. The firm´s profit function can be written as $\Pi_i = \Pi^0 - C(a_i)$.

It follows from this equation that the social welfare is seen as the sum of profits from all firms $n\Pi^0 - \sum_{i=1}^{n} C(a_i)$ minus the social damage caused by firm´s pollution $D(E) = d[ne^{max} - \sum_{i=1}^{n} a_i]$, where d>0 denotes the marginal social damage and we expect this damage function to be linear in total emissions.

Furthermore, it is possible to obtain the socially optimal allocation by the first order condition:

$$C'(a_i) = d \quad \textbf{(6)}$$

From this condition, we can derive a^* as the solution and the corresponding abatement level. Then if we multiply this abatement level by the number of firms we obtain the total optimal abatement level: $A^* = na^*$. It is important, for further results, to point out that the abatement cost function has the properties: $C' > 0, C'' > 0$; so total costs of abatement will be exponentially increasing (see table 1).

3.1 Mechanisms

It is of a main concern to define as well the different treatments used by the regulator for getting the higher possible social utility function:

Collective fining: this mechanism combines two different effects. First, there is a subsidy proportional to total abatement of all firms. Second, there is a penalty which affects all firms equally when the level of abatement from all individuals falls short of the level set by the regulator. Then, the probability of being punished (p) in this case would be 1.

Random fining: in this treatment, when the aggregate abatement level of all firms falls short of the level set by the regulator, only one of the firms will be randomly selected and punished. Here, the probability of being punished in the case that abatement is not socially enough would be 1/n, where n is the number of firms in the sector. It is important to point out that the mechanism used in this paper is what is called a non-budget-balancing one. This is, the fine paid by the firm selected randomly has no redistribution among the other participating firms.

There is a third mechanism called tax subsidy, which we are not using for our main purposes but we will briefly refer to it further on. This treatment was proposed by

Segerson (1988). In this case, when the total abatement level is not enough, all firms are charged with a fine proportional to the difference between the optimal and the actual level of abatement.

4. EXPERIMENT

The experiment gathered volunteers (mostly students) from different departments and was run at the University of Kiel. It was carried out using the Z-Tree software. All subjects were randomly assigned to one computer and after the explanation, 6 sessions were run with 10 subjects each, divided into 2 groups, so in each group 5 firms composed the industry. The maximum emission level e^{max} was 4 units and the subjects (firms) were told to decide whether to reduce this level and how many units. They were also told that the regulator tries to induce a maximum ambient pollution level of $A^* = 10$. In this industry, firms (subjects) choose their level of abatement (a^*) in order to maximise their benefits, where $a_i = 0,1,2,3,4$. We have 5 firms in the industry so $n = 5$ and each firm have a default profit $\Pi^0 = 200ECU$. There is no possibility for either collusion or any kind of cooperative game because subjects are not allowed to talk to each other. The marginal damage of ambient pollution is measured by the regulator as $d = 50$. The discrete abatement costs can be presented in a table as follows:

Table 1: Abatement costs

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

When each period finishes, subjects are told the total abatement effort and their individual benefits. There are a total of 20 periods and at the end of the last period, a coin is flipped to decide if there should be one extra period. The same is done for the next period and so on. Two mechanisms were conducted in each session and before each treatment, the subjects were randomly assigned to four other participants. Finally, the payoff for each subject consisted in the profits they accumulated during the treatment. These payoffs could not be negative, and this could have important implications for the results as will be explained further on.

For our purposes, different treatments were conducted with different fines, F=60 and F=90 for collective mechanism (from now on collective60 and collective90 respectively), and F=300 and F=450 for the random mechanism (random300 and random 450). It is important to point out that for both collective 60 and random300 the expected penalty is exactly the same (60 with probability 1 or 300 with probability 1/5), and the same happens for collective 90 and random450. This allows us to compare these different mechanisms in order to see the effect of p and F for the same expected penalty.

Were the subjects had already finished the sessions they fulfilled a questionnaire in order to measure their risk attitude. The test consisted in 11 choices between a sure payoff and a lottery, which had an expected value of 300 ECU. Subjects were informed that they could earn additional money with the questionnaire. To determine the payoff, one of the choice situations was selected randomly. If the individual chose a lottery in that situation, then a dice was used. Each subject is then classified depending on his or her risk attitude. For risk neutrals the choice pattern would be to have 8 lotteries starting from the top. Risk averse individuals will choose the lottery option less than 8 times, while highly risk averse individuals are those choosing between 0 and 3 lotteries and risk seeking will choose lottery more than 8 times. We do not expect that fulfilling the questionnaire after the experiment will affect their risk attitude (most of literature has agreed in considering risk attitudes to be consistent through time).

Table 2: Risk attitude test

Situation	Sure payoff	Lottery
1	150 ECU	EV(300)
2	170 ECU	EV(300)
3	190 ECU	EV(300)
4	210 ECU	EV(300)
5	230 ECU	EV(300)
6	250 ECU	EV(300)
7	270 ECU	EV(300)
8	290 ECU	EV(300)
9	310 ECU	EV(300)
10	330 ECU	EV(300)
11	350 ECU	EV(300)

4.1 Equilibrium

In the equilibrium for our experiment, the optimal aggregate abatement level is A*=10 as we said before. Because n=5, this leads to a social optimum abatement level per firm of a*=2. The optimal subsidy is set to be s=50 (equals to the marginal damage of ambient pollution).

5. HYPOTHESIS TO TEST

The main goal of this paper is to use experimental data obtained from non-point source pollution situation in order to test the well-functioning of the Becker´s model in describing the behaviour of all individuals (firms) in the sector and then compare the effects of the certainty of punishment and the severity of it. For this purpose, we can use the different treatments in which the individuals participated during the experiment. Each treatment has a different combination of the expected fine.

-From collective60 to random300: the probability of being caught in the collective mechanism is p=1 and the fine is 60. When we change from collective to random mechanism the probability of detection decreases to p=1/n together with an increase in the size of the fine (keeping the expected fine constant). When this change happens, we expect risk averse individuals (firms) to increase their abatement levels according to the Becker´s model, and risk seeking individuals to decrease their level of abatement.

-From collective90 to random450: again we expect the same result as before: as we decrease the probability of being caught risk seeking individuals should abate less and risk averse individuals, who are more affected by the increase in the fine than by the change in the probability, will abate more.

-Increase in the expected fine: a straightforward result would be that when we increase the expected fine (collective60 to collective 90 or random90 to random450) the abatement level should increase.

From the equilibrium above we can say that the compliance decision of the firms (c) is a*=2. Then, if the compliance cost exceeds the expected penalty (c >pF) all risk neutral and risk seeking individuals will not comply. In the same way, when the expected penalty is greater than the compliance costs (c <pF) both risk averse and risk neutral individuals would always comply. From table 1, we can see that the cost of comply is 60 so we can formulate the following hypothesis:

-When we have c <pF, as in the case of random450, where the expected penalty is 90, we expect that an increase in p and a decrease in F (so pF unchanged) will result in a weak increase in the average level of compliance, because risk averters and risk neutral will continue to comply while some risk seeking will switch from violation to compliance due to the higher effect of the probability than the severity of punishment. Then changing from random450 to collective90 should produce a higher level of compliance.

-When we have c =pF, as in the case of random350, with an expected penalty of 60, the total effect of changing the treatment can be predicted by focusing on the number of individuals of each class. If there are more risk averters in the experiments and increase in the probability (changing from random350 to collective60) will cause more aggregate abatement level.

6. RESULTS

This section gives an insight of the different effects each treatment has on the subjects´ abatement decision regarding their risk attitude and also provides an overview of all the experimental data. All subjects participated in only one session, but in each session two different treatments were included. This is important because the experience of the subjects will be included in the regressions for further discussion. Experienced subjects are those who have already participated in one treatment (if it is their first treatment they will be considered as inexperienced subjects).

In the first case, we analyse the effect of changing the treatment for the same expected fine. Table 3 shows the average individual abatement depending on their risk attitude and the treatment set:

Table 3: Abatement decision means per treatment and risk attitude

Treatment	High risk averse	Risk averse	Risk neutral	Risk seeking	Aggregate Mean
Collective60	0.987	1.092	1.176	1.31	1.129
Random300	0.988	1.359	1.287	0.522	1.193
Collective90	1.758	1.223	1.272	0.762	1.282
Random450	1.295	1.245	1.257	1.345	1.272

It is important to underline some of the data in the table. Firstly, the lowest abatement decision mean corresponds to those risk seeking individuals participating in random300. This is an obvious result, because this treatment has a lower expected fine than both collective90 and random450 and also because the abatement decision for risk seeking individuals is affected more by the probability of being caught, which is greater in collective60 than the size of the fine. However, we also see that risk seeking subjects abate more when random450 respect to collective90, which would contradict the expected results derived from the Becker´s model. It seems as well contradictory that risk averse individuals tend to abate more in random300 than in random450 and also that risk seeking abate more in collective60 than in collective90. In the case of high risk averters, it does not make much sense that changing from collective60 to random300 has no effect in the average abatement decision and the result is even contradictory when we change from collective90 to random450.

The first hypotheses tested in this paper are the ones regarding the aggregate abatement level depending on the cost of compliance.

When c<pF: In the case when the expected penalty is greater than the cost of compliance, as in collective90 and random450, we expect the average level of compliance to increase when we rise the probability of being caught (this is, from random to collective).

When c=pF: This is the case of random300 and collective60, and the effect would depend on the risk attitude of most individuals.

The aggregate mean of each treatment can be used in order to see the effect of changing the treatment for the different expected fines. These data can be found in Table 3 above.

The first insight seems to show that changing from collective to random mechanism or vice versa does not have much effect in the average level of compliance. The first prediction (when c<pF) seems to occur even though the effect is not very significant: increasing the probability and reducing the fine so keeping the expected fine constant in 90 would only increase the average level of abatement in 0.01. In the other case, when c=pF, the result of the change in the treatment is consistent with the idea supported by literature that there are more risk averse individuals than risk seeking ones (as showed in table 4), so an increase in the size of the fine will cause most of individuals (risk averters plus highly risk averters) to abate more, although this effect is not very significant.

Table 4: Risk attitude per individuals

Risk attitude	Number of individuals	Percentage
Highly risk averse	617	19.16%
Risk averse	1,080	33.54%
Risk neutral	1,223	37.98%
Risk seeking	300	9.32%

Another straightforward result is that, when we increase the expected fine, such that from collective60 to collective 90 or from random300 to random450, we expect the average level of abatement to increase. Table 3 above showed that this is not true for all individuals´ risk attitudes: risk averse and risk neutral individuals abate more when random 300 than random450 and risk seeking individuals abate more in collective60 than in collective90. It does not seem to have much sense that individuals abate more when the expected fine is lower and the effect is difficult to explain. It could be the case that when participating in random450 some individuals got punished randomly and they considered it unfair, and then deciding not abate anymore or maybe because they think it is unlikely that they are punished again. In the case of risk seeking individuals, we know that they are affected mostly by the probability of punishment and not so much about the size, so it would be normal not to expect a huge change from collective60 to collective90, when probability in both cases keeps constant to 1, but there is no sense that risk seeking individuals abate more when collective60, where the expected fine is lower.

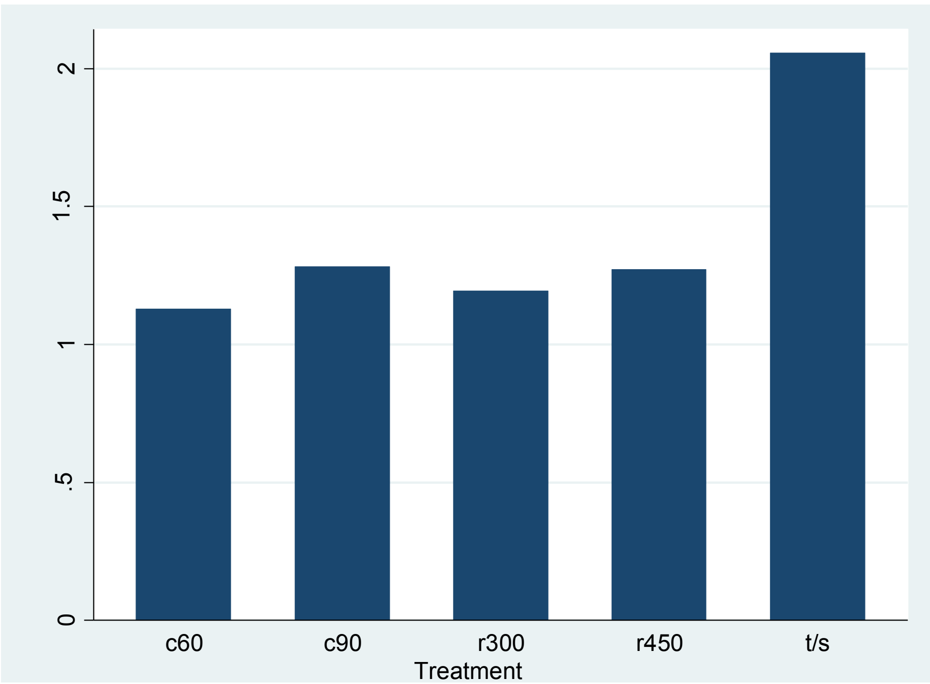
Despite these controversial results, table 3 shows that when we increase the expected fine, the overall abatement level increases, which is an intuitive result.

6.1 Certainty vs severity of punishment

A main issue to discuss would be the comparison between both the probability and the severity of punishment. As we explained before, although the large quantity of papers published since the Becker´s article, there is still not a consensus about the effect of both measures.

In this paper, we have considered these effects by taking into account the risk attitudes of individuals, so we could test the main hypothesis derived from the Becker´s model, but we can also compare the effectiveness of both certainty and severity of punishment overall by comparing different treatments. On the one hand, we have the collective mechanism which has a certainty or probability of punishment equals to 1 and a small punishment. On the other hand, the random mechanism has a smaller certainty but a higher severity in the punishment. Then, if we present both mechanisms together with the two different expected fines we have from our data, it would be possible to see which mechanism induces a higher level of abatement and compare the effects of certainty and severity overall. Graph 1 is directly linked with Table 8 and represents the mean abatement decision for each treatment.

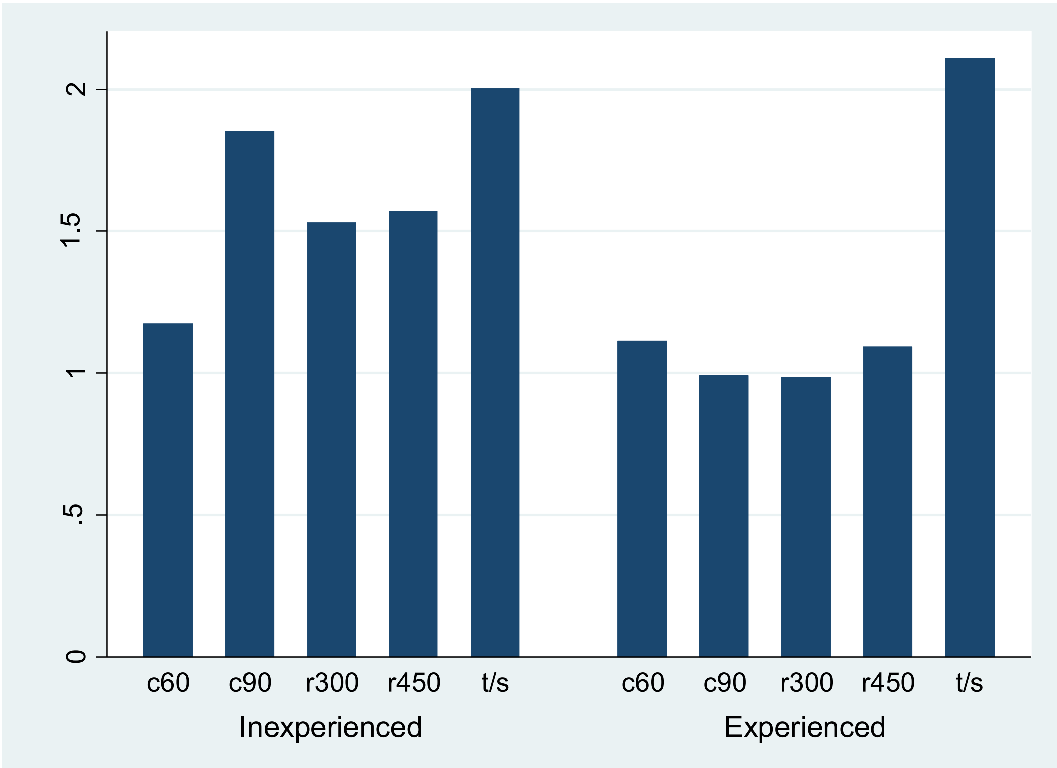
Graph 1: Abatement decision per treatment



As we see clearly from the graph, there is no much difference in the average abatement decision between collective60 and random300 or between collective90 and random450. Then, it seems difficult to judge the effect of both certainty and severity of punishment. We can conclude that from the point of view of the regulator, at least for the case of non-point pollution problems it is not so important how he combines the probability of being punished and the fine in order to get the highest social abatement. From our data, which seems more important is, firstly, the expected fine. Although the level of abatement does not raise a lot when we increase the expected fine from 60 to 90, it has some small positive effect which must be taken into account. Secondly, the most important decision for the regulator should involve the tax-subsidy mechanism. From the graph we can conclude that the tax-subsidy mechanism leads to the higher social abatement, which is near 2 (the individual optimum abatement level) and in some cases could almost double the social abatement level of other mechanisms.

Another interesting result arises when we differentiate between experienced and inexperienced subjects. Graph 2 shows the different abatement levels derived from both cases. This paper already demonstrated that experience has a negative effect on the abatement decision and this happens for all treatments except for the Tax-subsidy mechanism, where the abatement level even increases with experience. This leads us to think that the tax-subsidy mechanism, where firms are charged the difference between the optimal and the actual level of abatement is the best choice for a regulator who tries to get a high level of abatement.

Graph 2: Mean abatement decision with experience



6.2 From collective60 to random300

In order to empirically test our hypothesis of individual decision regarding their risk attitude and the treatment used, this paper uses a random effects tobit regression where the limits of the dependent variable *decision* will be 0 and 4 and collective60 and risk aversion are used as baseline. The independent variables will be a group of binary variables which represent the combination of other treatments and risk attitudes. In particular, variables such as "High Risk averse, Risk averse or Risk seeking" will take value 1 when subjects are classified in the correspondent risk attitude and 0 otherwise (the same goes for the treatments). We include as well in the regression the tax-subsidy treatment which was explained above and some other variables for analysing further effects such as:

-Period: this variable represents the period number taking account of the time trend in the decision process. It basically describes the effect of repetition on the subject´s abatement effort. For both random300 and random450 there is data for 24 periods (even though there are only 20 for experiences in random450). For collective90 and tax-subsidy there are 21 periods and for collective60 there is data for 15 periods for inexperienced subjects and 20 periods for experienced.

-Experience: as previously explained, this binary variable takes value 1 when the subject has already participated in one treatment.

-Fine_1: this variable will be used for some further discussion at the end. It shows the effect of a fine charged in the previous period (obviously, it goes from 0 to 450) and how the individual reacts to this punishment. This paper differentiates the effect of the fine between the different treatments in order to check if exists some difference due to the structure of the expected fine.

Now, it is important to test our first hypothesis from the theoretical model. We expect risk averse individuals to increase their level of abatement and risk seeking individuals to decrease it when we move from collective60 to random350. Table 4 shows the results of the tobit regression taking collective60 and risk averse as baseline.

The important effect for testing the first hypothesis is the one of R300 Risk averse. Even though the effect is positive as we were expecting, the p-value is greater than an hypothetical alpha of $\alpha=0,05$, so it is not statistically significant and we cannot say that changing from collective60 to random300 will make risk averse individuals to abate more. Nevertheless, as we have seen from table 3, the abatement decision mean is greater in random 300 so probably there is some small effect towards the increase predicted by the theory. Furthermore, both Period and Experience have a negative effect, so once subjects have played one treatment and as they make more decisions the abatement decision will tend to reduce, and this effect is statistically significant even for a smaller α (the effect of Experience is clearly described in Graph X). Some further results are also derived from the model, such that when the risk averse individual participate in collective 90 instead of collective 60 the average abatement level rises up 0.378 points and the effect is statistically significant for the α=0,05, which means that as we can expect, for a greater expected fine the abatement decisions from the individuals are greater. This effect is even more remarkable when we consider R450 Risk averse, in which case we expect the increase in the abatement level to come from two different sources: due to an increase in the expected fine and because of the change in the structure (increase in the size of the fine) as predicted by the model. Another remarkable result would be the one from Tax-Subsidy because it has a positive and significant effect (p-value<0.000). In particular, when risk averters participating in collective60 are changed to participate in the Tax Subsidy mechanism we expect an average increase in the abatement decision of 1.479.

Table 4: Random Effects tobit Regression using collective 60 and risk aversion as baseline. Dependent variable: decision.

Variable	Coefficient	p>|z|
Constant	1.269 ***	0.000
Risk neutral	0.183	0.478
Risk seeking	0.347	0.406
R300 Risk averse	0.0564	0.621
R300 Risk neutral	-0.015	0.919
R300 Risk seeking	-0.224	0.581
C90 Risk averse	0.378 **	0.010
C90 Risk neutral	0.407 **	0.010
C90 Risk seeking	-0.270	0.499
R450 Risk averse	1.113 ***	0.000
R450 Risk neutral	0.577 ***	0.000
R450 Risk seeking	-0.401 ***	0.048
Tax-subsidy	1.498 ***	0.000
Period	-0.381 ***	0.000
Experience	-0.563 ***	0.000
Fine_1 Collective 90	0.002	0.149
Fine_1 Random 300	-0.003 ***	0.000
Fine_1 Random 450	-0.001 ***	0.000

It is important to point out as well the different effects the fine has depending on the treatment. In particular, table 4 shows how the only case where Fine_1 has a significant effect is in the random mechanism. While we expect the fine in the current period to have a positive effect on the abatement decision, it is interesting to see how this fine has a negative effect when it occurred in the previous period. The reason for this could be that when the subject is charged a big fine (like the case of the random mechanism) he considers that the probability of being fined again is very small. Then, the individual feels save of being charged in the next period and reduces his level of abatement. In the case of the collective treatment we can expect a positive effect on abatement because this time the fine is not randomly charged, but as we see in the table, it seems not to be significant.

The results derived from the theoretical model also predicted that the level of abatement of risk seeking individuals would be lower when changing from collective60 to random300. We can check this by comparing the two coefficients (one for collective60 when risk seeking and the other for Random300 when risk seeking). The high p-value in the test does not allow us to reject the null hypothesis that both coefficients are equal. Then, we cannot say that the change in the treatment will make risk seeking individuals to abate less. However, the negative effect of the coefficient in R300 Risk seeking is in accordance with the aggregate values obtained in table 3 for risk seeking individuals.

6.3 From collective90 to random450

The second hypothesis this paper tries to test is directly linked with the previous one (we are only changing here the expected fine). Basically, we expect that changing from collective90 to random450 will have a similar effect than the one expected before, this is, that decreasing the probability and rising up the size of the fine (keeping the expected fine constant) will make again risk averters to abate more and risk seeking to abate less. Using the same regression as before and doing a test for C90 Risk Averse and R450 Risk Averse, we see that now the differences are statistically significant and then an increase in the size of the fine makes risk averters to abate more. However, when we focus only in highly risk averse individuals this does not seem to be the case and the effect is completely the opposite: they tend to abate more when collective90 than in random450.

To end up with this section of the results, when we consider the effect of changes in treatments regarding the risk attitude, it is important to see the effect that a change in the mechanism when the expected fine is greater in risk seeking individuals. In order to test this, a similar test than before is used but now for risk seeking individuals in c90 and r450 and no significant differences are found.

6.4 Hypothesis results and limitations

Result 1: On one side, a decrease in the probability of punishment and an increase in the size of the fine do not significantly change the average abatement level of the risk averse individuals (even though there could be a small effect) at least when the expected fine is 60. For an expected fine of 90 it seems to be a significant positive effect but it is not true for highly risk averse, who tend to reduce when changing to the random mechanism. On the other side, for risk seeking individuals we find the expected negative effect in their abatement decision, but again, this effect is not statistically significant.

Result 2: When the abatement cost is lower than the expected fine, increasing the probability of punishment while decreasing the size of the fine makes the total abatement level to increase, due to those risk seeking individuals who are affected by the increase in the probability. But again, this effect is too small for being significant and we cannot make a clear conclusion from it.

Result 3: There are more risk averse individuals than risk seeking and risk neutral ones, as predicted by the literature. This result could explain why the total abatement level increases by 0.064 points when we increase the size of the fine while reducing the probability.

Result 4: The theoretical Becker´s model does not seem to fit perfectly to the data used in our experiment. In fact, our results are plenty of contradictions where they show not just the poor link with the theory results predicted but even an opposite one. Table 3 is a perfect example of this, where highly risk averse tend to abate less than risk averse or even risk seeking individuals when they participate in random300 rather than collective60, or the case where risk seeking individuals abate more in collective60 than in collective90.

Result 5: It is important to underline some important variables which seem to be very important for the abatement decision. The experience of the subjects, which means that they have already participated in one treatment, affects negatively to their abatement decision, no matter their risk attitude. It is the same for the variable period, which describes the effect of repetition on the subject´s abatement effort and therefore period by period the abatement decision tends to reduce. These two variables seem to work in the same direction and even in the same quantities for both risk averse and risk seeking individuals. Furthermore, the variable Fine_1 only has a significant and negative effect in the case of the random mechanism, probably because the subject has been randomly punished and he thinks that the probability of being punished again is very small (so he abates less).

Result 6: From our analyses it is important not to forget the remarkable effect of the tax-subsidy mechanism. From the perspective of our regressions (using collective as a baseline), tax subsidy has a positive and strong effect, which allows the regulator to get a higher social level of abatement.

It is important to point out the experimental problem we already talked about in a previous section concerning the random fining mechanism. The experiment rules considered that there could not be negative payoffs and, in this case, the final result would be simply zero. In the random fining treatment some individuals could have obtained a negative payoff, so they should have paid this negative amount at the end of the experiment. Because this possibility was not allowed, it could be the case that some individuals, being sure of not losing money at the end, behave in a more risky way, leading to a lower abatement level. If this is the case, maybe the abatement results from the random mechanism for both expected fines could be underestimated. This mechanism can have as well a main problem regarding its implementation. It does not seem fair for a firm to be randomly chosen and charged a huge fine while the other firms do not have to pay anything. The treatments used and the punishment measures have to be rational and believable (a regulator cannot set a fine so big that no one believes he is going to charge it).

It is of a main concern not to forget as well the limitations of the experimental results when advising for a regulator. When we run a laboratory experiment we necessarily create a context for decision-making which is much different from the real context individuals will deal with in the real world. For our case, we are not considering many different kind of punishment which appears beyond the fine. Usually, when individuals (firms) face the justice system, not only the fine causes deterrence when they pollute and there could be as well prison sentences and also the tribunals could shut down the company. We are not considering as well the causes related with externalities caused by the ambient pollution which could affect the production of all firms in the sector in a medium or large term. Another controversial punishment which could appear in these cases would be the one related with public shame and conscience problems regarding the moral of the behaviour, which would make individuals to pollute less if they are aware of the problems linked with contamination. This leads us to the importance of the regulator not only in creating a good fining mechanism but in launching programmes to make companies aware of the problems related with pollution. All these effects, which are not directly considered in the experiment, would make individuals to abate more in a real-world situation, resulting in an underestimation of our abatement results.

7. CONCLUSION

The main goal of this paper was to test the theoretical implications of the Becker´s theoretical model using data from non-point source pollution by comparing different mechanism set by the regulator with different expected fine structures. Therefore we can compare the effects of probability and severity of punishment based on the results.

Firstly, we cannot say that the Becker´s model fits well with our experiment regarding the risk attitudes. In particular, when we increase the size of the fine and decrease the probability, risk averse individuals do not seem to increase their level of abatement (at least not for the case of highly risk averters) and risk seeking individuals do not decrease it significantly. We cannot conclude then that risk averse individuals react more to a change in the size of the fine than to a change in the probability, or that risk seeking react more to a change in the probability of being caught.

Secondly, focusing on the overall results, when the abatement cost is lower than the expected fine, a change from the random to the collective mechanism poorly increases the aggregate abatement level, as predicted by the Becker´s model. On the other side, when the abatement cost equals the expected fine, a change from collective to random mechanism causes a small increase, probably due to the fact that most of individuals are risk averse and are more affected by an increase in the size of the fine (even though this effect could be very small).

Thirdly, we cannot ignore some contradictions with the Becker´s model which do not fit with the individual behaviour we expected. The fact that risk seeking individuals abate more in the random300 treatment than risk averse ones makes no sense if we consider the prediction that risk averters should abate more than risk seeking when the size of the fine increases. But the most controversial result comes with the behaviour of risk seeking individuals, who seem to abate more with a lower expected fine when participating in the collective mechanism.

Furthermore, results showed some variables such as the experience or the effect of repetition of the abatement effort (period) seem to have an important negative effect in the aggregate abatement level and this effect does not change for different risk attitudes. It is important as well to underline that the tax-subsidy mechanism is not affected by the experience and it seems to be the best mechanism if the regulator aims to get the higher optimal level of abatement.

For policy purposes, the structure of the expected fine, combining both the probability and the severity of the punishment seems not to be so important in order to implement the optimal ambient regulation at least for the case of non-point pollution sources, since both collective and random mechanisms have approximately the same aggregate results. Instead, the tax-subsidy mechanism seems to be an optimal decision. However, we cannot ignore the possibility that we are underestimating the random mechanism abatement level by not allowing negative payoffs and probably also the aggregate abatement level by not taking into account the punishments beyond the fine.

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