Theory

Until Caffera and Chavez (2010), the literature had not given an answer to the question of the relative cost - effectiveness of a system of tradable emission permits versus a system of emission standards when not only the abatement costs of the firms but also the enforcement costs of the regulator are included in the equation. These authors extend the literature in several ways. First, they extend the work of Arguedas (2008) to derive the condition under which a regulator can reduce the social costs of an emissions control program based on emission standards by inducing perfect compliance. This condition is conceptually identical to that derived by Stranlund (2007) for the case of tradable permits. This allows to conclude that whether it is cost-effective or not to induce perfect compliance in an emissions control program does not depend on the regulatory instrument used (emission standards or transferable permits), but on the relative marginal costs of monitoring emissions vs. punishing non-compliance.

Second, Caffera and Chavez (2010) derived the conditions characterizing how the regulator has to set the monitoring probability and the emission standard for every firm when it is not cost effective to induce perfect compliance and it wants to cap the aggregate emissions of a pollutant to a certain level minimizing the social costs of the program. The latter include: (a) the firms' costs of reducing emissions, (b) the regulator's costs of monitoring the firms' emissions, and (c) the costs incurred by the regulator when sanctioning those who do not comply, after being discovered.

Third, Caffera and Chavez (2010) compared the social costs of such a program to the social costs of a program that is also based on emission standards that induces the same level of aggregate emissions but it is perfectly enforced (characterized by Malik 1992). The result is that the latter is always cheaper than the former.

Fourth, Caffera and Chavez (2010) compare the total social cost of an optimally designed program based on emission standards (a program that induces perfect compliance) with the costs of an optimally designed program based on tradable permits. The characterization of the latter is in Stranlund (2007) and involves fully enforcing the program (issuing a number of permits equal to the cap and making every firm to emit a level of emissions equal to the number of permits holding). The result of the comparison is that an emissions control program based on emission standards is always cheaper in social terms to a program based on tradable permits, except when the costs of inspection do not vary between firms and when the fine for non compliance is linear (a fixed amount per ton in excess of those permitted).

Finally, Caffera and Chavez (2010) also compare the total social costs of a program optimally designed based on the emission standards with that of an optimally designed program based on tradable permits, when it is optimal to induce violations. The comparison shows that the conditions under which tradable permits are equally costly in expected terms to a program based on emission standards are even more special in this case.

These results seem to contradict the classic recommendation by environmental economists, which states that tradable permits are cost-effective instruments for pollution control. Nevertheless, this recommendation is based only on abatement costs, which tradable permits certainly minimize. What the results above show is that when the enforcement costs are brought into the picture, tradable permits can minimize the total costs of an emission control program only if the costs of monitoring emissions do not differ between polluters or when the penalty for not complying is linear. Moreover,

the superiority of emission standards that seems to come out from the above results depend on the information that the regulator has on the abatement costs of the firms. To put it clearly, in order to implement the cost-minimizing program based on emission standards the regulator has to know the abatement costs of the regulated firms. This is hardly the case in the real world. Precisely, Caffera and Chávez (2010) end their paper arguing that when the regulator has imperfect information on the abatement costs of the firms it is only with tradable permits and a linear penalty structure that the regulator can surmount the informational problem and minimize the social costs of capping emissions of a pollutant to a given cap

Experiments

Surprisingly, the number of experimental works that analyze the behavior of polluting firms under different environmental policy instruments and different enforcement designs is limited. Cason and Gangadharan (2006) analyzed the efficiency of tradable permits markets when the emissions are subject to random shocks, the enforcement is imperfect, and the firms can save permits between periods. More related to this project, Anderson and Stafford (2006) present a class experiment where students act as polluting firms that choose whether to comply or not with an environmental regulation that states that they must remove the pollution of their effluent before discharging it to a river at a given fixed cost. The experiment tests the effect of increasing the probability of being monitored versus the effect of increasing the fine, keeping constant the expected fine, on the decision of the students. The results indicate that increasing the fine has a greater effect on behavior than increasing the inspection probability; a result that suggests that individuals are risk averse (Becker, 1968).

In the experiment of Anderson and Stafford (2006), however, all firms have the same costs of reducing emissions. Nevertheless, the heterogeneity of firms in terms of abatement costs is a central aspect in the relative cost-effectiveness of tradable permits. Murphy and Stranlund (2006) designed and carried out laboratory experiments to analyze the behavior of firms in emission permits markets. In their experimental design, polluting firms differ in firms with "high" marginal abatement costs and firms with "low" marginal abatement costs. In the different treatments of the experiments, these firms face three different levels of expected marginal penalty, two different levels of aggregate emissions cap and two type of initial allocation of permits: uniform and non-uniform. They find evidence of a direct and an indirect effect of an increase in the expected fine on the firms' violations, both through an increase in the probability of monitoring and an increase in the fine. The direct effect is negative: the firms reduce their violations buying more permits. The indirect effect has an opposite sign: a higher expected penalty increases the demand for permits, its price, and by this way increases the incentive to violate. However, the authors show that the latter counter-effect is smaller in absolute magnitude than the direct effect, so the net effect of a more severe control is a decrease in violations.

Using data from the same set of experiments, Stranlund, Murphy and Spraggon (2008) found experimental evidence on the hypothesis of Malik (1990) that competitive markets for tradable permits mechanisms are cost - effective to allocate emissions even in the presence of an emissions control policy that is not able to achieve perfect compliance.

So far, the only work we are aware of that specifically studies the behavior of firms in the context of environmental regulation under different policy instruments (standards and permits transferable) and different enforcement designs is Stranlund and

Murphy (2007). These authors test the differences that according to the theory emission standards and tradable permits have with respect to the incentives to violate and the enforcement design to prevent it. In the case of emission standards, those firms with higher marginal abatement costs and/or facing lower emission standards have more incentive to violate. The regulator must therefore focus their enforcement efforts in these firms. In the case of tradable permits, because all the firms face the same incentive to violate (the permits' price) this is not true. The regulator must monitor all firms with the same frequency. Murphy and Stranlund (2007) found evidence of all these theoretical results.

The project makes a contribution providing experimental evidence on the relative cost-effectiveness of tradable permits as compared to emission standards. This depends on two issues (1) the impact that different structures of the penalty function have on the behavior of firms, and (2) the level of information that the regulator has on the abatement costs of the firms. None of these two aspects has been tested in a laboratory. This project aims to start filling this gap in our knowledge, testing the effect of different combinations of enforcement strategies and instruments on the social costs of programs for controlling emissions.

References

Anderson, L. R. y S. L. Stafford (2006). "Does Crime Pay? A Classroom Demonstration of Monitoring and Enforcement", Southern Economic Journal, 72: 1016 - 1025.
Arguedas C (2008) To comply or not to comply? Pollution standard setting under costly monitoring and sanctioning. Environmental and Resource Economics 41:155-168
Becker GS (1968) Crime and punishment: an economic approach. Journal of Political Economy 76: 169-217
Caffera, M. y C. Chávez (2010). "The Cost-Effective Choice of Policy Instruments to Cap Aggregate Emissions with Costly Enforcement". Submitted to *Environmental and Resource Economics*.
Cason, T. N. y L. Gangadharan (2006). Emissions variability in tradable permits market with imperfect enforcement and banking". Journal of Economic Behavior and
Malik, A. (1990). "Markets for Pollution Control when Firms are Noncompliant", Journal of Environmental Economics and Management 18: 97 - 106.
Murphy, J. J. y J. K. Stranlund (2006). "Direct and marketts effects of enforcing emissions trading programs: An experimental analysis", Journal of Economic Behavior and Organization, 61: 217 - 233.
Murphy, J. J. y J. K. Stranlund (2007). "A laboratory investigation of compliance behavior under tradable emissions rights: Implications for targeted enforcement", Journal of Environmental Economics and Management: 53: 196 - 212.
Stranlund JK (2007) The regulatory choice of noncompliance in emissions trading programs. Environmental and Resource Economics 38:99-117
Stranlund, J. K., J. J. Murphy y J. M. Spraggon (2008). "Imperfect Enforcement of Emissions Trading and Industry Welfare: A Laboratory Investigation, Forthcoming in the *Handbook on Experimental Economics and the Environment*, John List and Michael Price (eds.), Edward Elgar Publishing.