**“The Cost-Effective Choice of Policy Instruments to Cap Aggregate Emissions with Costly Enforcement” Revised EARE1343 Response to Reviewers**

**Reviewer 1 Comments**

*1. The paper is an addition to the growing literature on the analysis and comparison of environmental policy instruments with costly monitoring and enforcement and, possibly, imperfect compliance by firms. In particular, the paper studies two ways of capping aggregate emissions of a pollutant: tradable pollution permits and firm-specific standards (in effect, non-tradable permits).

The paper builds, inter alia, on two recent related papers, viz. those of Stranlund (2007), who studies the question of whether to allow for some noncompliance in tradable permit systems, and Arguedas (2008), who studies a standards system with one firm. In essence this paper tries to extend Arguedas' analysis to a system with many firms.

There are three important results announced:
1. That standards should be firm-specific and perfectly enforced.
2. That total expected costs of an optimally designed tradable permit system are larger than corresponding costs of an optimal standards system, except when monitoring costs are identical across firms.
3. That when it is cost effective to induce violations, tradable permits minimize costs under "even more special conditions".

These claimed results are indeed important and interesting. Of particular interest is (2), e.g. when compared to the results of Chavez, Villena and Stranlund (2009) in a very similar setting where the result is derived that "under incomplete information, regulation based on each firm-specific emissions standards [sic] cannot be less costly than a transferable emissions permit system" (abstract of Chavez et al.). The two results appear to contradict each other, which would seem to call for some discussion and explanation of the intuitive reason for the contradiction. Unfortunately the author(s) do not offer such a discussion.*

First, before addressing this point by Reviewer 1, we should clarify that we have added a new condition under which a system of tradable permits is equally costly than a cost-minimizing system based on emission standards (in Proposition 4). This condition is$f’’(0)=0$; i.e: that the marginal penalty be constant in the level of violation. This added condition is not the result of new work. It is simply a result that we have not noticed before from the proof of Proposition 4.

Second, we agree with the reviewer that, in the former version of our paper, the result that, under special conditions, an optimally designed emission standards system is less costly than an optimally designed transferable emission permits system appears to contradict Proposition 2 in Chávez et al. (2009). In this respect, we have added a paragraph at the end of page 20 stating explicitly that the differences between the result in Chávez, et al. (2009) and ours is based on the difference in assumptions with respect to the regulator’s information about the firms’ abatement costs. Effectively, while Chávez et al. (2009) assume that the regulator cannot perfectly observe the firms’ abatement costs, on the contrary, following Arguedas (2008) and Stranlund (2009), we assume that the regulator can perfectly observe the firms’ marginal abatement costs when deriving the results in question. (We have clarified and made explicit this assumption, as also suggested by Reviewer 1. See point 2 below). It is this assumption that allows the regulator in our model to design a cost-minimizing system based on emission standards. As said in the revised version of the paper, Chávez et. al. (2009) assume imperfect information. Under this assumption, the regulator can only assure perfect compliance monitoring *all firms* as if they had the largest possible marginal abatement costs (regardless of how the standards are set). In this case, the regulator always (1) monitor some firms more frequently than needed, and (2) cannot assign emissions responsibilities (set the emission standards) in an abatement-cost minimizing way. These two reasons make the system based on emissions standards at least as expensive as the system based on transferable permits.

Third, under our assumption of perfect information we have been able to add new results to the literature related to the choice of instruments for pollution control; namely, (i) the optimal design of a command and control regulation requires to induce full compliance, which is taken as given in Chávez et. al. (2009), Malik (1992), Harford (1987), among others; and (ii) the policy designed in this way is less or equally costly than a policy that generates a uniform pollution price. (See our response to Reviewer 1’s comment 2 below).

Fourth, our re-examination of the comparison of policy instrument allowed us to uncover a result that was not noticed by Chávez et. al. (2009): optimally designed emission standards and transferable permits can result in the same expected costs when there are no differences in monitoring costs between firms and when the marginal penalty is constant. This result has important implications for the case when the regulator’s information on abatement costs is imperfect. We have added a new subsection at the end of section 4 (Section 4.3, pages 24-25) discussing the issues and assumptions besides the apparent contradiction between the relative cost-effectiveness of emission standards in our results and what environmental economists have been advocating for the last forty years. Moreover, motivated by the Reviewers concern on the treatment of information in our model we have also added a new section (Section 5 in the revised version of the paper) on imperfect information. (See our responses to Reviewer 1’s comment 2, which follows).

 *2. I suspect the crucial difference lies in assumptions about information: whereas information on abatement costs is asymmetric in Chavez et al. (2009), there seems to be an implicit assumption in this paper about the regulator having perfect information about firms. However, I must confess to being quite confused about what the information assumptions really are. On page 7 the author(s) say that the regulator can only observe the "type" of a firm, having a "subjective probability distribution over the possible abatement cost functions of every type of firm". In the regulator's optimization problem, the side-conditions are imposed that actual emissions from each individual firm are equal to the subjective expected best response function of the firm (page 8); furthermore, that these actual emissions sum up to the emissions cap, E. It seems to me that the upshot of this is that the regulator really does have perfect information about each firm. Otherwise, how can he guarantee that each individual firm emits exactly what he expects it to emit? And then it is not surprising - it is actually fairly obvious - that a standards system is going to be superior to a tradable permit system.*. *I have already confessed to being confused about the modeling of information in the paper, but at a minimum that shows that the author(s) really need to present their analysis in a much better way.*

We agree. Following Reviewer’s 1 concern and suggestion, we have clarified in the revised version of the paper that our model assumes perfect information of the regulator on the firms’ pollution control costs. (See also our response to the previous comment). This revision has resulted in a change in notation throughout the paper. More importantly, motivated by this comment, we have extended our analysis to consider the implications of considering imperfect information. This is done in a new Section 5. This effort has produced new results. First, we have been able to show that the presence of imperfect information changes the condition under which it is optimal to induce perfect compliance. More specifically, we found that when monitoring and sanctioning costs are relevant, and there is imperfect information between the regulator and a regulated firm, the decision to whether or not it is optimal to induce perfect compliance with an emissions standard, depends on the regulator`s uncertainty about the firms’ responses in terms of emissions to changes on the level of the monitoring probability and the emission standard. Second, we have also been able to show that, unlike the case of perfect information, the regulator does not necessarily has to induce perfect compliance with the emission standards if it uses a constant marginal penalty in the case of imperfect information. These new results and related discussions are included in the new section 5.1 of the revised version of the paper. (See pages 25-28).

Finally, we end the revised version of the paper with a new subsection 5.2 where we discuss the impact of the assumption of imperfect information on the decision whether to induce perfect compliance or not in the case of transferable permits, and its consequences on the issue of instrument choice. In this new sub-section we are able to obtain new important results. In the case of a constant marginal penalty, the regulator knows that it has to perfectly enforce the program. Moreover, following a simple rule to tie the penalty to the price of the permits proposed by Stranlund (2007), the regulator can do this without the need to know the abatement costs of the firms. We show that this is not necessarily the case when the marginal penalty is not constant. In this case, the regulator does not know with certainty whether it has to perfectly enforce the program or not because in the latter case it cannot surmount the informational problem. A clear result follows from this discussion: a cost-minimizing regulator that does not have perfect information on the abatement costs of the firms should use tradable permits and a constant marginal penalty tied to the price of the permits as in Stranlund (2007).

*3. Provided the author(s) are able to model information in a lucid and convincing way intuitive explanation needs to be given for the contradicting results of this paper and Chavez et al.*

As discussed previously, we have addressed this Reviewer’s concern in our response to his/her comment 1.

*4. In general the writing and presentation can, and should, be improved substantially.*

*Also, there are many typos and language errors and the reference list should be cleaned up.* *These are of course easy to fix once the major question of how exactly information is modeled has been resolved.*

As part of our efforts to improve our revised version, the manuscript was subject to a revision by a professional English editor. We have also cleaned up and checked the reference list.

**Reviewer 2 Comments**

*The paper is nicely motivated and the extensions of previous work in the field are clean and relevant. The main point that the authors make, as I see it, is that previous comparative studies of standards vs. tradable permits have not paid adequate attention to monitoring and sanctioning costs of the instruments. If this is done, according to the authors, the support for tradable permits based on cost-effectiveness arguments, is weakened and instead emission standard seem to minimize costs.  Important criteria are that the standards are firm specific, as are efforts by the regulator to induce compliance and sanctions.*
*1. The math seems correct, so in that sense the authors succeed in convincing me that emission standards may be more cost effective than tradable permits. However,* ***I have one main problem*** *with the argument that the authors make, and* ***that is the very brief discussion of the possibilities for a regulator of setting correct firm specific emission standards and to tailor enforcement efforts based on firm specific characteristics****. Both of these factors will depend crucially on the specific marginal abatement costs of the firm, which are notoriously difficult to know. If at all possible, it is sure to be costly to obtain this information. As the authors note in passing, one of the primary arguments in favour of tradable permits is that the regulator does not have to know the marginal abatement costs of firms in order to design the policy. The authors do discuss this briefly in relation to their findings (for example on page 20, second paragraph) and they recognize that this point makes it difficult to make clear policy recommendations. Hence they seem aware of this challenge.* ***I think the paper would become stronger if this discussion was made deeper and, even better, formalized****.* *For instance, it would be possible, I think, to introduce a variable capturing the costs to the regulator of obtaining information of marginal abatement costs into the several of the expressions in the paper. This may make results more ambiguous in some cases, but it would also make the conclusions more convincing to me.*

We agree with Reviewer 2 on the relevance of the information problem for our results on the relative cost-effectiveness of emission standards to hold. Motivated by the Reviewer’s concern we have extended the discussion on the practical implementation problems to be faced by a regulator to set firm specific emissions standards and designing and implementing targeting enforcement efforts at the end of section 4 (Section 4.3, pages 24-25). Moreover, we have also added a new section (Section 5) on imperfect information. In this section we have formalized the regulator’s problem with imperfect information and derived the condition under which it is expectedly cost-effective to induce perfect compliance in a system of emission standards in this circumstance. We have also discussed the same problem under tradable permits and concluded that it is only with tradable permits and a constant marginal penalty that the regulator can surmount the informational problem and attain cost-effectiveness.

The Reviewer has also suggested that we “introduce a variable capturing the costs to the regulator of obtaining information of marginal abatement costs into the several of the expressions”. We did consider this suggestion; however, we concluded that it might be too ad-hoc to proceed as suggested by the Reviewer. In particular, we cannot see how adding the costs of capturing information in our model will interact with the regulatory design we study (optimality of compliance, monitoring efforts, emission standards). As previously noticed, we remove the assumption of perfect information about the abatement costs functions of the regulated firms in a new Section 5. By doing so, we were able to produce a number of new results: (i) We have been able to show that the presence of imperfect information changes the condition under which it is optimal to induce perfect compliance. As suggested by this comment by the Reviewer 2, the consideration of imperfect information made some of our results more ambiguous. More specifically, we found that when monitoring and sanctioning costs are relevant, and there is imperfect information between the regulator and a regulated firm, the decision to whether or not it is optimal to induce perfect compliance with an emissions standard, depends on the level of uncertainty of the regulator on the response of the firms, in terms of emissions, to changes in the monitoring probability and the emission standard; (ii) We have also been able to show that unlike the case of perfect information, the regulator does not necessarily has to induce perfect compliance with the emission standards if it uses a constant marginal penalty in the case of imperfect information. These new results and related discussions are included in the new section 5.1 of the revised version of the paper. (See pages 25-28).

*2. Another point, which the authors only discuss briefly in relation to monitoring costs, is dynamic effects of allowing non-compliance. Even if non-compliance may be cost-effective in a static setting, it may be that if firms learn that a certain level of non-compliance is tolerated based on for example expected litigation costs as the authors mention, firms could start to act strategically. Further, the credibility and political support of the program may erode. Perhaps this point is not central in the paper, but it could be worth a few sentences of acknowledgement.*

We have incorporated a footnote at the beginning of Section 3 (page 12) acknowledging that we do not consider the dynamic effects of allowing non-compliance in this paper. Motivated by the Reviewer’s suggestion, we have also added the following text in the footnote: “The analysis of this paper is static. Therefore, it does not consider the potential dynamic effects of allowing non-compliance, which were suggested to us by a Reviewer of this journal. We acknowledge that, if the regulator tolerates a certain level of violation, this could trigger a strategic behaviour on the part of the firms in a dynamic context and, under these circumstances, the credibility and political support of the program may erode over time. However, we want to emphasise that, as we show latter in the paper, when the regulator can choose the emission standard, monitoring effort, and the structure of the penalty, the optimal design of the policy must induce perfect compliance. Therefore, the potential perverse dynamic effects of allowing non-compliance are avoided in the cost-effective design of the programs.”

*3. A general comment is that the paper would benefit from a more direct language, with shorter sentences and a more accessible language. If the authors have time to let a professional editor go through it with those eyes it may be a good investment.*

We agree. As part of our efforts to improve our revised version, the manuscript was subject to an English grammar and spelling check revision by a professional English editor.

*4. Other, more minor comments:
a) The paper would benefit from a clearer definition of the terms "enforcement", and "sanctioning", and I recommend another read through in order to ensure the language is consistent throughout the paper. In most cases it is clear what the authors mean, but not always.*

Motivated by this comment by Reviewer 2, we have added the following footnote in page 3 reading: “We use the term enforcement to refer to the set of actions to induce compliance. These actions include, among others, monitoring emissions and sanctioning detected violations.” (See also our response to Reviewer 2’s comment 3).

 *b) It would help the reader if the definitions of some variables in the expressions were repeated.*

The Reviewer has not provided any specific suggestion regarding which definitions of variables need to be repeated. Considering the current length of the paper and the fact that we use standard notation in this literature, we have decided to avoid repetition throughout the paper. However, we are ready to repeat definitions of variables if needed.

 *c) Choice of words; I react to the expression "induce non-compliance". English is my second language so perhaps this is a correct choice of words, but to me "allow non-compliance" makes more sense.*

We have changed the choice of words as suggested by the reviewer.

 *5. Spelling and grammar:*

*p. 2 Introduction, second paragraph, first sentence "...costs of capPing emissions."*

We have changed this in the second row of the second (incomplete) paragraph in page 3 of the revised version of the paper.

*p 4, first sentence: two "with"*

We have changed this in the revised version of the paper.

*p 5, second paragraph remove TO in "We then let the regulator TO..."*

As suggested, we have changed this in the revised version of the paper.

*p. 5, section 2, first sentence. Order of words: "...when IS IT cost effective..."*

We have changed this in the the revised version of the paper.

*p. 11, section 3.1, last paragraph "...complete abAtement costs..."
section 4.2, last sentence "...optimally designED..."*

We have changed this in the revised version of the paper.