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Monitoring Abatement in the Presence of an Import Quota on CERs

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Abstract

I analyze whether or not a monitoring problem regarding abroad abatement can justify the import quotas on abroad emission certificates applied by several emission trading schemes. For this purpose I extend the Becker (1968) Crime and Punishment model by heterogeneity in the observability of compliance. I do so by incorporating a firm's cost minimizing choice of domestic and abroad CO_2 abatement into a monitoring framework in which firms have to meet an exogenously set emission standard. I find that the government can implement the first best abatement allocation under incomplete information, however, under incomplete information this allocation is not socially optimal. Instead, the government should in the presence of a monitoring problem introduce an import quota for abroad abatement that shifts the allocation from abroad to domestic abatement.

Keywords: Clean Development Mechanism, Import Quota on Certified Emission Reductions, Import Restrictions, Green House Gas Offset, Abatement, Monitoring, Incomplete Information, Information Asymmetry.

JEL classification: D21, D82, F53, Q58

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1 Introduction

The fight against climate change is a global public good. It makes no difference for the CO_2 concentration in the atmosphere at which place on earth pollutants are abated. However, the choice of the place can make a difference for the abatement costs that accrue.

From an economic view point, CO_2 abatement should be carried out wherever it is cheapest. This consideration was at the heart of the Clean Development Mechanism (CDM) when it was launched as part of the Kyoto Protocol in 1997. The CDM enables firms from industrialized countries to invest in registered CDM abatement projects abroad in developing countries. For each metric tonne of CO_2 abatement enabled by their investment, the firms receive one certified emission reduction (CER) in return. Firms can use the CERs generated by CDM projects to offset their domestic abatement obligation stemming from the negotiated environmental agreement that the Kyoto countries committed themselves to in 1997.¹ CDM projects range from methane avoidance in agriculture and photovoltaic power generation to large hydro power plants. Generally, any project that leads to emission reductions compared to a counterfactual baseline is admissible as a CDM project.²

The abatement of CO_2 emissions, while generating welfare benefits, accrues costs for the firms carrying out the abatement. Consequently, a government intending to induce abatement by its firms needs to provide incentives for these firms to select into abatement. That is, it needs to demand an amount that is to be abated by each firm and punish shortcomings, both of which is being done in reality.³ Presumably, while domestic abatement is easily observed by the government, abatement abroad demands some more observation effort. In other words, governments have incomplete information regarding abatement abroad and from this incomplete information arises a monitoring problem for the government. This assessment is backed by Kachi et al. (2014) mentioning that California is prejudiced against the CDM due to the fear of having little

¹Governments pass the abatement obligations they committed to on to the firms under their jurisdiction.

²A broad overview of the workings of the CDM in general can be found in Paulsson (2009), while the course of a CDM project is explicitly explained in Aresin (2013).

³An example for Germany: According to paragraph 15 of the German legal code on project mechanisms (§15, ProMechG), misreporting in validation or verification reports for emission abatement can be punished with fines of up to 100.000 EUR.

control over abatement occurring abroad.

Many governments allow the firms under their jurisdiction to participate in the CDM, but not without imposing some restrictions regarding the use of CERs. While Australia planned to allow 12.5% and South Korea is planning to allow up to 50% of its firms' abatement obligations to be covered by Kyoto abatement units such as CERs (Kachi et al. 2014), the European Union left it up to its member states to impose restrictions. The result was quotas that ranged between 0% and 22%, where Estonia is the strictest and Germany the laxest country. This percentage of allocated emission allowances is admissible in the form of CERs (Vasa 2011). California considered an alternative restriction, a discount for abroad abatement certificates, but this paper will focus on an import quota.⁴

Keeping in mind that CO_2 abatement is a global public good and that the efficient allocation of abatement would be one that exploits the lowest cost abatement options worldwide, it is surprising to observe governments discriminating against abatement carried out abroad. The discrimination restricts the firms' options, thereby not only forcing them to meet a specific abatement obligation, but, further, forcing them to choose less cost efficient abatement allocations than are possible in the absence of discrimination.

This paper adds to the literature on the CDM. More specifically, it adds to the literature on restricting the use of CERs generated under the CDM. Previous papers mainly focused on the fact that restricting the use of CERs breaks the pure offset character of the CDM (i.e. leads to emission reductions that can not be counted against the domestic abatement obligation) and argued that the net atmospheric benefits that arose from this made the governments' failure to prevent non-additionality more acceptable.⁵

Schneider (2009), Alexeew et al. (2010), Bakker et al. (2011) and Francois and Hamaide (2011) make this argument, but focus on restricting the use of CERs by means of a discount. Ranson and Stavins (2012) consider a CER limit and repeat the additionality argument. Also, Castro and Michaelowa (2010),

⁴Further restrictions imposed by the EU ETS, such as the exclusion of CERs from nuclear power plants or forestry projects and the restriction of source countries to Least Developed Countries, which have been active since 2012, are also not subject to this analysis.

⁵Non-additional projects are projects that are being carried out under the CDM and generate CERs, although they would have been taken on in the absence of the CDM as well. Hence, those projects fail to offset emissions compared to a counterfactual scenario without the CDM.

applying a graphic supply and demand analysis of the CER market, and Braun et al. (forthcoming), using an empirical analysis to explain the price spread between CERs and domestic European emission certificates, draw on the same arguments for restricting CER imports and consider quantity restrictions.

The paper at hand also considers a quantity restriction, but seeks to justify this restriction by the existence of a monitoring problem regarding abatement abroad instead of by additionality concerns.

That is, this paper examines the following question: Is it possible that the monitoring problem mentioned above can provide a rational explanation for the observed government decision to discriminate between abatement generated at home and abatement generated abroad by means of a quota on abroad abatement? To answer this question, I apply a classical monitoring framework as defined by Becker (1968), extend it by an abatement cost minimization problem subject to a minimum abatement constraint and introduce heterogeneous observability for abatement generated in different regions. The analysis reveals that governments can still implement the first best abatement allocation when information on abroad abatement is incomplete. However, it further shows that, while implementable, the first best abatement allocation is not the welfare maximizing one in the presence of incomplete information. Rather, starting from no quota at all, welfare under incomplete information increases when a quota is introduced and some abatement is shifted from abroad to domestic abatement compared to the first best allocation. This shift reduces the efficiency of the allocation, but at the same time increases the firm's incentive to comply, thereby reducing the monitoring cost.

Whether or not the government wants to shift all of the abroad abatement home or wants to allow for some abroad abatement depends on the monitoring cost, the fine, the abatement obligation and the cost of the last domestic and the first foreign unit of abatement. The smaller the monitoring cost, the larger the fine, and the abatement obligation, the higher the cost for the last unit of domestic, and the lower the cost for the first unit of foreign abatement, the more likely is it that the government allows abroad abatement.

To my knowledge I am the first one to consider a monitoring problem in this context. However, there are papers that examine monitoring problems in related environmental contexts. Arguedas (2008, 2013) both consider a framework in which compliance with a general environmental standard can

only be observed by means of monitoring and in which monitoring is costly. While Arguedas (2008) is after the socially optimal combination of standard and monitoring policy, Arguedas (2013), in an extension of the 2008 model, considers the optimality of a discount on the fine payable upon noncompliance. His discount depends on the amount a firm invested in abatement technologies. As Arguedas (2013) does, also I consider compliance with an environmental standard, but I model a quota. Furthermore, while the discount in Arguedas (2013) works in favor of the firms that are being granted the discount, my quota applies to abatement generated abroad and penalizes firms that are subject to it. While the two papers by Arguedas assume all abatement to be equally poorly observable, my essential extension to Becker (1968) is that I introduce heterogeneity regarding the observability of abatement carried out in different regions. A further paper, Arguedas and Rousseau (2015) also considers observability differences, but it introduces the heterogeneity on the side of the observer, as opposed to my heterogeneity on the side of the observed. In Arguedas and Rousseau the national authority that sets the standard is unable to observe the abatement being carried out, but a local agency that enforces the standard can observe the abatement. The paper at hand, in turn, allows one governmental regulator that takes the emission standard as exogenously given to perfectly observe domestic abatement, but assumes that abroad abatement is not observable free of cost for the regulator.

Stranlund and Chavez (2000) do not model a general environmental standard, but a transferable emissions permit system, with a monitoring problem. They require their firms to self report on their emissions and the permits they hold and find that this self-reporting requirement can be used to reduce monitoring costs. In this paper, by contrast, the decrease in monitoring probability, and consequently the expected monitoring costs, results from implementing a second best abatement allocation where the use of an import quota shifts some of the abroad abatement home.

The following section presents the theoretical framework. First, the firm's decision is analyzed, then the government's decision, with and without an import quota and under complete and incomplete information. Section 3 concludes this paper.

2 Theoretical Framework

There is one government and one firm and there are two countries, home H and foreign F .⁶

In the first stage, the government seeks to maximize welfare by choosing its monitoring policy. As explained below in more detail, the monitoring policy mainly consists of a monitoring probability $\mu \in [0, 1]$.

In the second stage the firm chooses its domestic and abroad abatement, $x_H \in [0, \infty)$ and $x_F \in [0, \infty)$, with the intention of minimizing abatement costs, taking an exogenous abatement obligation $x^{min} > 0$ and the government's monitoring probability μ as given. While the government considers both, benefits, $b(\sum x_i)$ with $b'(\sum x_i) > 0$, $b''(\sum x_i) = 0$ and $i \in \{H, F\}$, and costs, $c(x_i)$ with $c'(x_i), c''(x_i) > 0$, $c(0) = 0$ and $i \in \{H, F\}$, the firm only cares about the cost of abatement. The abatement cost functions are publicly known. Likewise, both the firm and the government can observe domestic abatement. However, the government may not be able to observe the amount of abroad abatement carried out by the firm.

The firm complies with government legislation whenever the sum of domestic and abroad abatement matches or exceeds the abatement obligation x^{min} . If the abatement sum falls short of x^{min} , the firm does not comply. In case the firm does not comply and the non-compliance is detected, the firm has to meet its abatement obligation ex post and, in addition, pay a fine $S > 0$. For the government to detect a non-compliant firm it has to monitor, and monitoring produces the monitoring cost $m \geq 0$.

2.1 First Best

Under complete information, all abatement is observable for the government and there is no need for monitoring. The firm chooses domestic and abroad abatement x_H and x_F to minimize

$$C(x_H, x_F) = c(x_H) + c(x_F)$$

⁶This is equivalent to assuming one government and a continuum of homogeneous firms of mass one.

subject to the condition that the sum of domestic and abroad abatement must not fall short of the abatement obligation: $x_H + x_F \geq x^{min}$.

Lemma 1.

Under complete information, the firm chooses the allocation

$$x_H^{FB} = x_F^{FB} = x^{min}/2.$$

Proof.

From the equilibrium condition $c'(x_H) = c'(x_F)$ and due to the assumption that $c(\cdot)$ is increasing, convex and the same for both countries follows that $x_H^{FB} = x_F^{FB}$. Together with the other equilibrium condition, $x_H^{FB} + x_F^{FB} = x^{min}$, this implies that $x_H^{FB} = x_F^{FB} = x^{min}/2$. Since the firm has to pay a fine $S > 0$ and fulfill its abatement obligation ex post if it does not comply, it is optimal for the firm to comply. $\square$

As abatement costs increase progressively and are the same at home and abroad, it is cost minimizing for the firm to abate both at home and abroad and to equally distribute abatement between the two.

2.2 Second Best

Under incomplete information, the firm's decision is no longer aligned with the government's decision, and the government has to monitor and punish non-compliance to incentivize the firm to comply. For a given monitoring policy, if the firm decides to comply, it will choose x_H^* and x_F^* .⁷ Since the cost functions are commonly known, the government anticipates the optimal choice of a compliant firm. Therefore, I assume that the government always monitors the firm, if it observes that the firm's domestic abatement choice deviates from the optimal choice of a compliant firm. Otherwise, the government monitors the firm with probability $\mu \in [0, 1)$.⁸ That is, the government's monitoring policy is

$$p(x_H) = \begin{cases} \mu & \text{if } x_H = x_H^* \\ 1 & \text{if } x_H \neq x_H^* \end{cases}. \quad (1)$$

⁷Optimal choices of a compliant firm are marked with asterisks.

⁸I exclude $\mu = 1$, for this is the less interesting case in which the firm is always monitored.

If the firm does not comply and is detected, in addition to fine $S > 0$, it has to meet its abatement obligation ex post, i.e., choose additional (domestic or abroad) abatement such that total abatement sums up to at least x^{min} . Hence, if the firm initially chooses (x'_H, x'_F) with $x'_H + x'_F < x^{min}$ and is detected, it has to pay S and to chooses additional abatement (x''_H, x''_F) such that $x'_H + x'_F + x''_H + x''_F \geq x^{min}$. I assume for simplicity that the additional abatement of an initially non-compliant firm has to be disclosed (or can be monitored by the government at no additional cost).

Consequently, if compliant (that is, when $x'_H + x'_F \geq x^{min}$), the firm has abatement cost

$$C(x'_H, x'_F) = c(x'_H) + c(x'_F), \quad (2)$$

while, if non-compliant (that is, when $x'_H + x'_F < x^{min}$), the firm has expected abatement cost

$$E[C(x'_H, x'_F)] = c(x'_H) + c(x'_F) + \mu(S + c(x''_H) + c(x''_F)). \quad (3)$$

Moreover, I assume that the government values revenues (the fine) and the firm's profits equally. Therefore, for the government, which receives fine S but at the same time takes into account the firm's costs, the fine is welfare neutral.

In addition to the exogenous minimum abatement obligation x^{min} the government can set a quota capping abroad abatement $x_F \leq x_F^{max}$. Backward induction allows to solve for the firm's equilibrium abatement and the government's policy choices.

2.2.1 The Firm's Decision

In the absence of a quota on abroad abatement, the firm chooses its domestic and abroad abatement x_H and x_F in the second stage to minimize the abatement cost in (2) and (3), taking into account the government's monitoring policy in (1).

Lemma 2.

a) *If compliant, the firm chooses the first best domestic and abroad abatement $x_H^* = x_F^* = x^{min}/2$.*

b) If non-compliant, the firm chooses domestic abatement $x_H = x^{min}/2$ and abroad abatement $x_F = 0$.

The proof of Lemma 2.2. can be found in the Appendix.

As under complete information, when complying, the firm chooses the smallest abatement sum ensuring compliance, x^{min} , and equally divides abatement between domestic and abroad abatement to minimize the cost. This is due to the fact that the abatement cost functions are convexly increasing and the same in both countries.

Given the government's monitoring policy, every domestic abatement choice except the compliant firm's optimal choice leads the government to monitor with certainty. With certain monitoring and hence certain punishment, choosing the compliant firm's amount at home generates smaller expected costs than any other choice for all levels of abroad abatement. That is, the firm chooses a compliant firm's level of abatement at home. However, abroad, where abatement is not observable for the government, the expected costs are the smallest when the firm chooses no abatement at all. This is due to the fact that fine S is constant and independent of the amount of foregone abatement.

In the presence of a quota on abroad abatement, the firm chooses its domestic and abroad abatement x_H and x_F in the second stage to minimize the abatement cost in (2) and (3), taking into account the government's monitoring policy in (1) and subject to a binding quota for abroad abatement (i.e., subject to the condition that $x_F \leq x_F^{max} < x^{min}/2$).

Lemma 3.

Given that the quota is binding,

a) *the firm chooses domestic abatement $x_H^* = x^{min} - x_F^{max}$ and abroad abatement $x_F^* = x_F^{max}$ if it is compliant.*

b) *the firm chooses domestic abatement $x_H = x^{min} - x_F^{max}$ and abroad abatement $x_F = 0$ if it is non-compliant, .⁹*

⁹Where $x_H^* = x^{min} - x_F^{max}$ and $x_F^* = x_F^{max}$, analogous to Lemma 2.2, also correspond to the first best domestic and abroad abatement choices that would be derived under complete information.

Proof.

a) Given a binding quota $x_F^* = x_F^{max} < x^{min}/2 < x^{min} - x_F^{max} = x_H^*$. Therefore, it holds that

$$c'(x_F^*) < c'(x_H^*).$$

If the firm chooses $x'_F > x_F^{max}$ the marginal costs are $c'(x'_F) > c'(x_F^*)$. But as the government only counts $x_F = x_F^{max}$ towards the firm's abatement obligation, x_H must be $x_H^* = x^{min} - x_F^{max}$ to ensure compliance. With allocation (x_H^*, x'_F) the abatement cost is strictly higher than with (x_H^*, x_F^*) , hence $x'_F > x_F^{max}$ can not be optimal.

Likewise, the choice $x'_F < x_F^{max}$ (and $x'_H > x^{min} - x_F^{max}$) can not be optimal, as allocation (x'_H, x'_F) would imply $c'(x'_F) < c'(x_F^*) < c'(x_H^*) < c'(x'_H)$.

b) The proof for the non-compliant firm, follows the same line of argumentation as the proof of Lemma 2.2. $\square$

Given a binding quota on abroad abatement, it is cheapest for the firm to abate the exact amount of the quota abroad when complying. The reason being that, with a binding quota, the optimal amount of abroad abatement that the firm would choose in the absence of the quota is larger than the amount allowed under that quota. Any allocation deviating from the one that is optimal in the absence of the quota increases the abatement costs, but the cost increase is larger the larger the deviation. The firm, consequently, chooses the smallest deviation possible. At home, the firm chooses the lowest possible amount guaranteeing compliance, given the choice of an amount equal to the quota abroad.

Regarding the non-compliance choices the same logic applies as in the case without the quota. Every domestic abatement choice except for the compliant firm's optimal choice leads the government to monitor with certainty. That is, at home the firm chooses the compliant firm's level of abatement. However, abroad, where abatement is not observable for the government, the firm chooses no abatement at all.

Any quota smaller than the efficient abroad abatement in the absence of the quota is a binding quota. Therefore, for illustration purposes I hereafter denote the quota as $x_F^{max} = (x^{min}/2) - \Delta$ which implies the compliance allocation is $(x_H^*, x_F^*) = ((x^{min}/2) + \Delta, (x^{min}/2) - \Delta)$ and the non-compliance allocation is

$(x_H, x_F) = ((x^{min}/2) + \Delta, 0)$. That is, compared to the optimal allocation without a quota, some of the abroad abatement is shifted homeward with a quota.

2.2.2 The Government's Decision

The government can only affect the firm's choice through the monitoring policy it implements in the first stage. I assume that the government can perfectly observe the domestic abatement of the firm, but abroad abatement is initially unobserved and only disclosed upon request. Making this request causes monitoring cost m for the government. That is, the government balances the benefits of abatement, $b(\sum x_i)$ with $i = \{H, F\}$, against the monitoring cost. If the monitoring cost was very large compared to the benefits of abatement, the government would never monitor to induce compliance (the monitoring probability would be $\mu = 0$) and the firm would never comply. In this case there would be no monitoring problem. Thus, I assume that the benefits of abatement are sufficiently high compared to the monitoring cost, such that the government wants to monitor with a positive probability and wants to induce compliance.

Proposition 1.

Under incomplete information, the government can implement the first best abatement allocation $x_H^{FB} = x_F^{FB} = x^{min}/2$ by choosing the monitoring probability

$$\mu^* = \frac{c\left(\frac{x^{min}}{2}\right)}{S + c\left(\frac{x^{min}}{2}\right)}.$$

Proof.

The firm chooses to comply whenever it is indifferent between compliance and non-compliance: $C(x^{min}/2, x^{min}/2) = E[C(x^{min}/2, 0)]$. This is the case if $2c(x^{min}/2) = \mu(S + c(x^{min}/2)) + c(x^{min}/2)$, which reduces to

$$\mu^* = c(x^{min}/2)/(S + c(x^{min}/2)). \quad \square$$

The government can implement compliance with the monitoring probability that makes the firm indifferent between compliance and non-compliance.

When compliance is induced and the monitoring probability is set optimally, the expected welfare is

$$W^* = b\left(\sum x_i^*\right) - \sum c(x_i^*) - \mu^* m,$$

with $i = \{H, F\}$.

Proposition 2.

Under incomplete information, the welfare maximizing choice differs from the first best choice of abatement $x_H^{FB} = x_F^{FB} = x^{min}/2$. Instead, the government prefers to set a strictly positive quota, such that $x_F^ < x^{min}/2$.*

Proof.

Using Lemma 2.3 and a quota, $x_F^{max} = (x^{min}/2) - \Delta$, the compliant firm chooses $x_H^* = (x^{min}/2) + \Delta$, $x_F^* = (x^{min}/2) - \Delta$

and the non-compliant firm chooses $x_H = (x^{min}/2) + \Delta$ and $x_F = 0$.

That is, the monitoring probability implementing compliance becomes

$$\mu^*(\Delta) = \frac{c\left(\frac{x^{min}}{2} - \Delta\right)}{S + c\left(\frac{x^{min}}{2} - \Delta\right)}.$$

Then the corresponding optimal welfare is

$$\begin{aligned} W^*(\Delta) &= b\left(x^{min}\right) - c\left(\frac{x^{min}}{2} + \Delta\right) - c\left(\frac{x^{min}}{2} - \Delta\right) \\ &\quad - \frac{c\left(\frac{x^{min}}{2} - \Delta\right)}{S + c\left(\frac{x^{min}}{2} - \Delta\right)} m. \end{aligned}$$

Deriving the welfare with respect to Δ yields

$$\begin{aligned} \frac{\partial W^*(\Delta)}{\partial \Delta} &= -c'\left(\frac{x^{min}}{2} + \Delta\right) + c'\left(\frac{x^{min}}{2} - \Delta\right) \\ &\quad + \frac{\left(S + c\left(\frac{x^{min}}{2} - \Delta\right)\right) c'\left(\frac{x^{min}}{2} - \Delta\right)}{\left(S + c\left(\frac{x^{min}}{2} - \Delta\right)\right)^2} m \end{aligned} \tag{4}$$

$$- \frac{c\left(\frac{x^{min}}{2} - \Delta\right) c'\left(\frac{x^{min}}{2} - \Delta\right)}{\left(S + c\left(\frac{x^{min}}{2} - \Delta\right)\right)^2} m. \tag{5}$$

That is

$$\frac{\partial W^*}{\partial \Delta} \Big|_{\Delta=0} = \frac{Sc' \left(\frac{x^{min}}{2} \right)}{\left(S + c \left(\frac{x^{min}}{2} \right) \right)^2} m > 0,$$

as S , m and $c'(\cdot) > 0$. □

Once information is incomplete and the government has to exert costly monitoring to verify abroad abatement, the government faces a trade-off. It is a trade-off between distorting the allocation of domestic and abroad abatement and increasing the firm's incentive to comply by reducing the amount of abatement to be implemented abroad and thereby reducing the monitoring probability necessary to induce compliance. Shifting abroad abatement to home, starting from the first best allocation $x_H^{FB} = x_F^{FB} = x^{min}/2$ where the distortion is zero, results in a negative welfare effect from the distortion that is smaller than the positive welfare effect from the increased compliance incentive of the firm. This is due to the assumption of increasing, but equal abatement cost functions at home and abroad.¹⁰

The introduction of a marginal shift increases welfare, but what remains to be identified is the optimal shift from abroad to domestic abatement.

Claim 1.

If

$$c'(0) \left[1 + \frac{m}{S} \right] - c'(x^{min}) < 0 \tag{6}$$

then the optimal quota is such that $\Delta^{opt} \in (0, x^{min}/2)$ and the amount of abroad abatement is positive.

Proof.

Taking equation (4) at $\Delta = x^{min}/2$ yields

$$\frac{\partial W^*(\Delta)}{\partial \Delta} \Big|_{\Delta=x^{min}/2} = c'(0) \left[1 + \frac{m}{S} \right] - c'(x^{min}).$$

¹⁰If the abatement costs at home were larger than abroad, $c_H(\cdot) \geq c_F(\cdot) \forall x_H, x_F$, the condition under which welfare increases with a shift from abroad to domestic abatement would no longer be always fulfilled. Rather, the difference between the domestic and abroad abatement cost functions, $c_H(\cdot)$ and $c_F(\cdot)$, and their relation to the monitoring cost m will then play a role.

That is, $\partial W(\Delta)/\partial \Delta|_{\Delta=(x^{min}/2)} < 0$ if condition (6) is fulfilled.

Since $\Delta \in [0, x^{min}/2]$ by definition, $\partial W(\Delta)/\partial \Delta|_{\Delta=(x^{min}/2)} < 0$ is sufficient for $\Delta^{opt} < x^{min}/2$ and from Proposition 2.2 is known that $\Delta^{opt} > 0$. $\square$

Welfare decreases in Δ at the upper bound $\Delta = x^{min}/2$, if condition (6) holds. Thus, reducing Δ to $\Delta < x^{min}/2$ generates a welfare increase, implying that $\Delta^{opt} < x^{min}/2$ and abroad abatement is positive. Condition (6) is more likely to be fulfilled the smaller marginal cost $c'(0)$ and monitoring costs m and the larger fine S , abatement obligation x^{min} , and marginal cost $c'(x^{min})$. The intuition behind this is the following. A smaller monitoring cost, makes the government more willing to allow for abroad abatement that brings along the need for monitoring. A larger fine S makes the likelihood for non-compliance smaller such that the government is more willing to allow for the less observable abatement abroad.

A larger abatement obligation x^{min} increases the efficiency benefits from dividing abatement between home and abroad, due to the convex cost functions. Likewise, the more convex the costs functions, the larger are efficiency benefits from dividing abatement between home and abroad. If $c'(0)$ is small, the first unit of abroad abatement is cheap and if $c'(x^{min})$ is large, the last unit of domestic abatement is expensive, thus, the government would want to allow for abroad abatement and shift some domestic abatement abroad.¹¹

If condition (6) is violated the solution for Δ^{opt} may be such that no abroad abatement is allowed, provided that the assumptions over the cost functions ensure that welfare is strictly concave in Δ .¹² However, there is empirical evidence for abroad abatement, suggesting that the solution for Δ^{opt} should be an interior one, such that abroad abatement occurs.

3 Conclusion

This paper considers a classical monitoring framework with a representative firm that minimizes abatement costs subject to an emission standard. Further,

¹¹For quadratic cost functions $c'(0)=0$, which implies that condition (6) would then always be fulfilled.

¹²Convexity of the cost function $c(\cdot)$ does not guarantee concavity of the welfare function, due to the last term of the welfare function $-c(x^{min}/2-\Delta)m/(S+c(x^{min}/2-\Delta))$, containing the monitoring probability of the government.

the regulator monitoring the firm faces heterogeneous observability of abatement carried out at home versus carried out abroad. I find that it is feasible for a regulator to choose its policy such that the first best abatement allocation is implemented even under incomplete information regarding abroad abatement. I show, however, that this first best allocation is not socially optimal under incomplete information. In fact, a government concerned with welfare maximization should apply a quota to restrict the use of abroad abatement certificates. Such a quota, inducing a shift from abroad to domestic abatement, reduces the firm's incentive for non-compliance. As non-compliance becomes less likely, the government can induce compliance via a smaller monitoring probability than without a quota, which implies that expected monitoring costs are smaller. The quota, of course, simultaneously distorts the abatement allocation of the firm away from the efficient allocation, which affects welfare negatively. However, at the margin, this negative distortion effect is smaller than the positive effect reducing the monitoring expenditure. That is, at least a small quota on abroad abatement should always be welfare enhancing in this framework. The results might not apply if the policy measure of choice was not a quota, but a discount on/an allowability reduction for abroad abatement.

Furthermore, my results suggest that while a small quota on abroad abatement should be welfare enhancing, the government might not want to fully prohibit abroad abatement altogether, but might want to allow for some. The government is more likely to allow for abroad abatement, the smaller the monitoring cost and the cost for the first unit of abroad abatement and the larger the fine for non-compliance, the abatement obligation and the cost of the last unit of domestic abatement.

Appendix

Proof of Lemma 2.2.

Proof.

For a compliant firm, see proof of Lemma 2.1.

b) Suppose that the firm is non-compliant and chooses (x'_H, x'_F) such that $x'_H + x'_F < x^{min}$.

If $(x'_H, x'_F) = (x^{min}/2, 0)$ then the firm's expected costs are

$$E \left[C \left(\frac{x^{min}}{2}, 0 \right) \right] = c \left(\frac{x^{min}}{2} \right) + \mu \left(S + c \left(\frac{x^{min}}{2} \right) \right). \quad (7)$$

In (7), the firm has a cost of domestic abatement equal to $c(x^{min}/2)$. Moreover, with probability μ it is monitored and has to pay fine S plus the cost of the required ex post abatement. Given $x'_H = x^{min}/2$ the cost-minimizing ex post abatement choice is $(x''_H, x''_F) = (0, x^{min}/2)$, which yields additional costs of $c(x^{min}/2)$.

Suppose first that $x'_F \geq x^{min}/2$. Since the firm is non-compliant, this implies that $x'_H < x^{min}/2$. Thus, the firm is monitored with probability one and its cost is

$$C(x'_H, x'_F) = c(x'_F) + S + c(x^{min} - x'_F)$$

where $(x''_H, x''_F) = (x^{min} - x'_F - x'_H, 0)$ is the ex post cost-minimizing abatement choice (Since x'_F is already larger than $x^{min}/2$, there will be no further abroad abatement.). With

$$c(x'_F) + S + c(x^{min} - x'_F) > c \left(\frac{x^{min}}{2} \right) + S + c \left(\frac{x^{min}}{2} \right) > E \left[C \left(\frac{x^{min}}{2}, 0 \right) \right],$$

the firm is strictly better off when choosing $(x'_H, x'_F) = (x^{min}/2, 0)$ than when choosing $x'_F \geq x^{min}/2$ (and $x'_H < x^{min} - x'_F$).

Now suppose that $x'_F < x^{min}/2$.

If the firm chooses $x'_H > x^{min}/2$, it is monitored with probability one.

Since the ex post cost-minimizing abatement choice is

$(x''_H, x''_F) = (0, x^{min} - x'_H - x'_F)$, its cost is

$$\begin{aligned} C(x'_H, x'_F) &= c(x'_H) + c(x'_F) + S + \left(c(x^{min} - x'_H) - c(x'_F) \right) \\ &> c\left(\frac{x^{min}}{2}\right) + S + c\left(\frac{x^{min}}{2}\right) \\ &> E\left[C\left(\frac{x^{min}}{2}, 0\right)\right]. \end{aligned}$$

If the firm chooses instead $x'_H < x^{min}/2$, its cost-minimizing ex post abatement choice is $(x''_H, x''_F) = (x^{min}/2 - x'_H, x^{min}/2 - x'_F)$ which yields a total cost of

$$\begin{aligned} C(x'_H, x'_F) &= (x'_H) + c(x'_F) + S + \left(c\left(\frac{x^{min}}{2}\right) - c(x'_H) \right) \\ &\quad + \left(c\left(\frac{x^{min}}{2}\right) - c(x'_F) \right) \\ &= S + c\left(\frac{x^{min}}{2}\right) + c\left(\frac{x^{min}}{2}\right) \\ &> E\left[C\left(\frac{x^{min}}{2}, 0\right)\right]. \end{aligned}$$

Finally, if $x'_H = x^{min}/2$, the firm is monitored with probability μ only. The ex post cost-minimizing abatement equals $(x''_H, x''_F) = (0, x^{min}/2)$. This yields an expected cost of

$$\begin{aligned} E\left[C\left(\frac{x^{min}}{2}, x'_F\right)\right] &= c\left(\frac{x^{min}}{2}\right) + c(x'_F) + \mu \left(S + c\left(\frac{x^{min}}{2}\right) - c(x'_F) \right) \\ &= c\left(\frac{x^{min}}{2}\right) + (1 - \mu) c(x'_F) + \mu \left(S + c\left(\frac{x^{min}}{2}\right) \right), \end{aligned}$$

which is strictly higher than $E[C(x^{min}/2, 0)]$ for all $x'_F > 0$, $\mu < 1$. Altogether, this shows part b). $\square$

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