Mayo, 2007

Achieving an Environmental Target with an Emissions Tax under Incomplete Enforcement

Marcelo Caffera [a] *, Carlos Chávez [b]

[a] Department of Economics, Universidad de Montevideo, Prudencio de Pena 2440, CP 11600, Montevideo, Uruguay

[b] Department of Economics, Universidad de Concepción, Casilla 1987, Concepción Chile. Phone: (56 41)2203067, Fax: (56 41) 2254591, E-mail: cchavez@udec.cl.

Abstract: To set an emission tax consistent with a given environmental target, the regulator must know the firms' abatement cost functions. But this is never the case. Most of the textbooks in environmental economics have argued that this problem can be solved by a trial and error process through which the regulator imposes a tax level, then observes firms' emissions and adjusts the tax accordingly. We explore the consequences of using this type of rule on the possibility of achieving the aggregate emissions target in the context of incomplete enforcement and propose a simple alternative rule. Our results indicate that: (i) by using the trial and error process, the regulator is unable to set the appropriate tax level; consequently, the environmental target can never be reached; and (ii) the simple alternative rule that we propose allows the regulator to set the proper level of the tax based upon all the relevant information received from the firms.

JEL**:** *L51, Q28*

Keywords**:** Emissions Taxes, Under-reporting, Enforcement.

---

* Corresponding author. Phone: (598 2)7074461 ext. 308, Fax: (598 2) 7074461 ext. 325, E-mail: marcaffera@um.edu.uy. We gratefully acknowledge partial financial support for this collaborative research provided by the Facultad de Ciencias Económicas y Empresariales, Universidad de Montevideo; Facultad de Ciencias Económicas y Administrativas, Universidad de Concepción; and Dirección de Investigación, Universidad de Concepción.

1. Introduction

Emissions taxes are an opportunity to achieve a given environmental target in a cost-effective manner. However, one of the problems for their practical implementation is to set the appropriate tax level. To set the tax consistent with the aggregate emissions target the regulator must know the firms' abatement cost functions. But this is never the case. Interestingly, while recognizing this problem, most of the textbooks in environmental economics have also argued that it can be solved by a trial and error process through which the regulator imposes a tax level, then observes firms' emissions and adjusts the tax accordingly. [See for example Hanley, Shogren, and White (1997), Kolstad (2000), and Tietenberg (2000)].[1]

A crucial aspect that the trial and error process leaves aside is that it could be difficult for the regulator to observe the actual level of emissions. To overcome this problem, the regulator may ask firms to report their emissions. But even in this case the authorities may not be able to obtain the correct information because firms may under-report their emissions, if enforcement is not sufficient to induce truthful reports. We show that if this is the case, and the regulator treats the reported emissions as actual emissions, adjusting the tax based on the former may result in failure to achieve the environmental target. The actual aggregate level of emissions will be larger than the policy target and the difference between them will be larger the weaker the enforcement. Nevertheless, we argue that in such a situation the regulator can use a

[1] The same argument is found also in Cropper and Oates (1992). Field and Field (2003) argue instead that the regulator should observe environmental quality. This argument circumvents the problem of observing emissions, but in practice the environmental quality of a receptor body may be determined not only by the emissions of the regulated firms, but also by other pollution sources not subject to the tax (non-point pollution is an example). In this case, firms subject to the tax would end up paying for pollution they do not generate. Consequently, the level of the emissions tax would not be proper in this case either, unless the regulator has perfect knowledge of the transfer coefficients of each source of pollution, which is not a realistic situation either.

simple condition that characterises the solution to the optimization problem of the firms to derive their actual level of emissions, so that taxes can be properly adjusted.

The issue has not only theoretical relevance but also a practical one. One example is Colombia's wastewater discharge fee program implemented in 1997. In this program, in each compliance period the level of the fee ("tasa retributiva") is set according to a rule that considers two elements. First, an initial fee defined by the Ministry of the Environment for each basin and regulated pollutant. Second, an adjustment factor that increases or decreases the fee according to the difference between the *reported* aggregate level of emissions and the aggregate emissions target. The environmental target is defined by an agreement between the regional environmental authority and the regulated firms. This target is revised every five years. Each compliance period lasts six months. When the aggregate reported level of emissions equals the target, the level of the fee remains constant.

The paper is organized in five sections. In section 2, we present a positive behavioral model of an individual firm under an emissions tax system with self-reporting of emissions, when the firms have the opportunity to under – report them. Section 3 is devoted to the examination of basic results regarding the firm's optimal choices of actual and reported emissions under this scheme and its consequences on the regulator's possibility of achieving an aggregate emissions target adjusting the tax based on the reported level of emissions. We demonstrate that, when this is the case, the environmental target can never be reached. In light of these results, we propose a new simple alternative rule that allows the regulator to set the proper level of the tax based upon all the relevant information received from the firms. We discuss the implications of our results as well as implementation issues in section 4. Conclusions of our work are offered in section 5.

2. A Model of a Firm's Compliance Behavior under an Emissions Tax System with Self-Reporting of Emissions

In this section we present the basic framework for our analysis. First, we present the standard compliance model of an individual firm operating under an emissions tax system with self-reporting of emissions (Harford, 1987).

2.1. Basic Assumptions

Suppose the policy objective is to achieve a given aggregate level of emissions $E = E_0$ through an emissions tax system. The number of sources being regulated is n. Each source faces a constant marginal (per unit of emission) tax, τ. We assume that all sources are risk neutral. The firms' abatement costs function is given by $c(e,\alpha)$, which is strictly decreasing and convex in the actual level of emissions e; that is $c_e(e,\alpha) < 0$ and $c_{ee}(e,\alpha) > 0$. We distinguish between the sources under regulation by the vector α, which considers the individual source characteristics.[2]

The sources self-report emissions. We denote a source's emissions report as r. A reporting violation occurs if the source's reported level of emissions r is lower than the actual level of emissions e; that is $(e - r) > 0$; otherwise, the source is compliant.[3]

The source faces a probability of being audited, which we denote π. An audit provides the regulatory agency with perfect information with respect to the source's compliance status. If the source is audited and found to be in violation, the penalty $f(e - r)$ is imposed. We assume that in the case of zero violation the penalty is zero but the marginal penalty is greater than zero; that is $f(0) = 0$, $f'(0) > 0$. In the case of positive

[2] Abatement cost functions among firms can vary for many reasons, for example, differences in economic activities, production processes, abatement technologies, and the like.

[3] A second type of violation in this framework occurs when the source does not pay the tax bill consistent with the reported emissions. We do not consider this type of non-compliance; however, it could be important, as it is in the Colombian case (see Blackman, 2006).

violations, the penalty is strictly increasing and strictly convex [$f'(e-r) > 0$, $f''(e-r) > 0$]. We assume the emissions tax and the enforcement policy (the probability of being audited and the penalty function) are communicated to all firms. A source chooses the level of actual and reported emissions so as to minimize total expected compliance costs, which include its abatement costs, the tax bill and its expected penalty.[4] More formally, the firm solves the following problem,

$$\min_{\{e,r\}} c(e,\alpha) + r\tau + \pi f(e - r) \quad [1]$$

$$\text{s.a. } e - r \geq 0.$$

The Lagrange equation for this problem can be written as: $\theta = c(e,\alpha) + r\tau + \pi f(e-r) - \lambda(e - r)$; and the Kuhn – Tucker conditions are:

$$\theta_e = c_e(e,\alpha) + \pi f'(e-r) - \lambda = 0 \quad [2\text{-a}]$$

$$\theta_r = \tau - \pi f'(e-r) + \lambda = 0 \quad [2\text{-b}]$$

$$\theta_\lambda = (e-r) \geq 0,\ \lambda \geq 0,\ \lambda \times (e-r) = 0 \quad [2\text{-c}]$$

Equations [2 a-c] are necessary and sufficient to determine the firm's optimal choices of how much to emit and how much to report to the regulator.

[4] We assume that every firm is small enough so that its emissions report does not affect the tax. If one assumes the opposite (and that the firm has the information to calculate the effect of its reports on the tax), our argument still holds. In both cases the disclosure of actual emissions is costly to the firms.

2.2 Individual choice of actual and reported emissions.

We now turn our attention to review some previously known results from the existing literature. We will use these results to explore the consequences of weak enforcement on setting the level of the emissions tax. We assume that the enforcement parameters (penalty and monitoring effort) are insufficient to induce truthful reports, so that $e > r$. We know that a firm will report truthfully ($e = r$) if $\tau \leq \pi f'(0)$. Therefore, our assumption implies that the environmental regulator is unable to set the penalty or the audit probability such that this condition holds. This can happen because: (a) the penalty function *f* is fixed and out of control of the environmental regulator, and (b) the environmental authority has a limited monitoring budget.[5]

Choice of emissions: Regardless of its compliance status, a firm chooses its emissions level such that

$$-c_e(e,\alpha) = \tau \qquad (3)$$

Equation (3) suggests that the firm's optimal choice of emissions, e^o, is a function of the tax level and its individual characteristics; that is $e^o = e(\tau,\alpha)$. [see for example Harford (1987)].

Choice of reported emissions: Given a choice of emissions, a non-compliant firm chooses its emissions report such that;

$$\tau = \pi f'(e(\tau,\alpha) - r) \qquad (4)$$

[5] We restrict our analysis to the cases where a zero emissions report is not optimal for the firm, or its equivalent, $\tau \leq \pi f'(e)$.

Equation (4) implicitly defines the reported level of emissions, r^o, as a function of the enforcement parameter, the tax level, and the individual source characteristics; that is, $r^o = r(\tau, \alpha, \pi)$.

The reporting violation: The extent of the reporting violation, *v*, is given by the difference between the reported and the actual level of emissions; that is,

$$v(\tau,\pi) = e(\tau,\alpha) - r(\tau,\alpha,\pi). \qquad (5)$$

Note that the extent of the reporting violation is independent of the individual firm's characteristics. This implies, perhaps surprisingly, that when firms with different abatement costs face a uniform enforcement pressure, they will all underreport in the same amount, regardless of their emissions' choices. This result is a direct application of Stranlund and Dhanda's (1999) Result 2, in the context of a perfectly competitive transferable emissions permit system, to an emissions' tax program.

2.3 Tax adjustment

We suppose that at the end of a compliance period the regulator adjusts the level of the tax in the following way: it compares the aggregate reported level of emissions, *R*, with the policy target, E_0**.** Let us define $D = R(\tau, \bar{\alpha}, \bar{\pi}) - E_0$; where $\bar{\alpha}, \bar{\pi}$, represents vectors containing each individual firm characteristics and monitoring probability, respectively. The adjustment rule is given by:

$$\Delta\tau = \beta(D) \qquad (6)$$

where $\Delta\tau$ is the change in the level of the emissions tax, $\beta(.)$ is a function such that $\beta(0) = 0$, and $\beta(D) > 0$ if $D > 0$ and $\beta(D) < 0$ if $D < 0$. Furthermore, assume that $\beta'(D) \geq 0\ \forall D$.[6] The marginal adjustment in the level of the emissions tax can be increasing, decreasing, or constant in the absolute value of *D*.

The regulator, however, would want to adjust the emissions tax level based on the gap between the actual level of aggregate emissions and the aggregate emissions target. Denoting this gap as D^*, with $D^* = E(\tau, \overline{\alpha}) - E_0$, we can write the desired tax adjustment as,

$$\Delta\tau^* = \beta(D*) \qquad (7)$$

Under an incompletely enforced emissions tax system, the following relation must hold,

$$R(\tau,\overline{\alpha},\overline{\pi}) = \sum_{i=1}^{n} r_i(\tau,\alpha,\pi) < \sum_{i=1}^{n} e_i(\tau,\alpha) = E(\tau,\overline{\alpha}) \qquad (8)$$

Given (8), we have two possible types of aggregate violations: a reported one, which occurs when the aggregate reported level of emissions is larger than the policy objective ($R(\tau, \overline{\alpha}, \overline{\pi}) > E_0$), and an actual one, which occurs whenever the actual level of aggregate emissions is larger than the policy objective ($E(\tau, \overline{\alpha}) > E_0$).

3. Tax Adjustment to Achieve an Environmental Target under Incomplete Enforcement

In this section, we present the results of our work. We start by exploring the effect of using the trial and error process to adjust the tax on the possibility of achieving an environmental target, when enforcement is not sufficient to induce truthful reports. After demonstrating that an environmental target can never be reached in this way, we propose a simple rule that a regulator can use to infer actual emissions and hence set the tax level that yields the environmental target.

[6] An example of the adjustment rule that we have in mind is given by the Colombian case, where: $\tau_{t+1} - \tau_t = \beta(D) = \tau_t \times k$, $k > 0\ \forall\ D = R_t - E_0 > 0$, and $k = 0\ \forall\ D \leq 0$, with *t* being a time index for the compliance period. However, our case allows both, upward and downward, and non-constant adjustments in the tax level.

Lemma 1. *Suppose an aggregate violation is reported. When the regulator increases the tax: (a) actual emissions decrease, (b) reported emissions decrease, and (c) under-reporting increases. The opposite holds when an aggregate compliance is reported and the regulator decreases the tax.*

Proof of Lemma 1.
(a) From (3) we know that $-c_e(e(\tau,\alpha),\alpha) \equiv \tau$. Differentiating this expression with respect to τ and rearranging we obtain $e_\tau = -1/c_{ee} < 0$.
(b) From (4) we know that $\tau - \pi f'(e(\tau,\alpha) - r(\tau,\alpha,\pi)) \equiv 0$. Differentiating with respect to τ and rearranging we obtain $r_\tau = e_\tau - 1/\pi f'' < 0$.
(c) From (b) we know that $e_\tau - r_\tau = 1/\pi f'' > 0$. **QED.**

Lemma 1 suggests that when facing an increase in the level of the emissions tax, individual sources will respond by decreasing not only the level of actual emissions, but also the level of reported emissions. The intuition of this latter result is the following: as the tax increases, the marginal cost of an emissions report also increases, therefore firms will respond by reducing their reported emissions. Although both actual emissions and reported emissions decrease in response to the increase in the tax level, the extent of the unreported level of emissions increases. This happens because, given the enforcement parameters, an increase in the tax makes the difference $\tau > \pi f'(0)$ larger, increasing the incentive to conceal emissions. Figure 1 illustrates the situation for a given individual firm, assuming marginal abatement costs are decreasing at a constant level (c_{ee} is a constant). From equation (4), if the tax level is set at τ_0, each firm will report $r(\tau_0)$, where the marginal expected fine $\pi f'[e(\tau_0) - r]$ equals the tax, and emit $e(\tau_0)$, where the marginal abatement cost $-c_e(e,\alpha)$ equals the tax. The amount of under-reporting is then $e(\tau_0) - r(\tau_0)$. When the tax increases from τ_0 to τ_1 under-reporting increases to $e(\tau_1) - r(\tau_1)$.

Figure 1 about here

Based on Lemma 1, the following lemma also holds,

Lemma 2. When *an aggregate violation is reported, the regulator increases the emissions tax less than the necessary amount to achieve the environmental target. When an aggregate over compliance is reported, the regulator responds by reducing the emissions tax, and three cases are possible:*

- *i)* *The regulator decreases the emissions tax more than necessary to achieve the environmental target.*
- *ii)* *An emissions tax reduction is implemented when an increase was necessary to achieve the environmental target.*
- *iii)* *An emissions tax reduction is implemented when it was not necessary to achieve the environmental target.*

Proof of Lemma 2. An aggregate reported violation implies that $D = R(\tau, \bar{\alpha}, \bar{\pi}) - E_0 > 0$. Then, by Equation (6), $\Delta\tau > 0$. Also, from equation (8), $R(\tau, \bar{\alpha}, \bar{\pi}) < E(\tau, \bar{\alpha})$, and therefore $E_0 < E(\tau,\alpha)$. Finally, from Equation (7), $\Delta\tau^* > 0$ and, given $R(\tau, \bar{\alpha}, \bar{\pi}) - E_0 < E(\tau, \bar{\alpha}) - E_0$ and the structure of equations (6) and (7), it follows that $\Delta\tau^* > \Delta\tau > 0$.

An aggregate reported over compliance implies that $D = R(\tau, \bar{\alpha}, \bar{\pi}) - E_0 < 0$. Equation (6) implies that $\Delta\tau < 0$. From equation (8), $R(\tau, \bar{\alpha}, \bar{\pi}) < E(\tau, \bar{\alpha})$. Then, three cases are possible, (i) $E(\tau, \bar{\alpha}) < E_0$; (ii) $E(\tau, \bar{\alpha}) > E_0$; and (iii) $E(\tau, \bar{\alpha}) = E_0$. From equation (7), it follows that for each case the proper tax adjustment should be: $\Delta\tau^* < 0$; $\Delta\tau^* > 0$, and $\Delta\tau^* = 0$, respectively. Then, the three possible cases are the following:

- i) From $R(\tau, \bar{\alpha}, \bar{\pi}) - E_0 < E(\tau, \bar{\alpha}) - E_0 < 0$, and the structure of equations (6) and (7) it follows that $\Delta\tau < \Delta\tau^* < 0$.
- ii) From $R(\tau, \bar{\alpha}, \bar{\pi}) - E_0 < 0$, $E(\tau, \bar{\alpha}) - E_0 < 0$, $\Delta\tau < 0$; and $\Delta\tau^* > 0$;
- iii) From $R(\tau, \bar{\alpha}, \bar{\pi}) - E_0 < 0$, $E(\tau, \bar{\alpha}) - E_0 = 0$, $\Delta\tau < 0$; and $\Delta\tau^* = 0$. **QED.**

Lemma 2 is straightforward. It says that under incomplete enforcement of reported emissions the regulator cannot only adjust the tax in the incorrect magnitude, but more importantly, it can adjust the tax in the wrong direction.

Based on Lemmas 1 and 2, we are now ready to establish our first proposition.

Proposition 1. *When enforcement is insufficient to induce truthful reports, and the tax is adjusted according to a trial and error process based on reported emissions, the aggregate emissions target is never reached.*

Proof of Proposition 1. Under incomplete enforcement, $R(\tau, \bar{\alpha}, \bar{\pi}) < E(\tau, \bar{\alpha})$. In this case, two situations are possible:

i) $R(\tau, \bar{\alpha}, \bar{\pi}) < E_0$: from Equation (6) $\Delta\tau < 0$ and from *Lemma1* $R(\tau, \bar{\alpha}, \bar{\pi})$ and $E(\tau, \bar{\alpha})$ increase until $R(\tau,\alpha,\pi) = E_0 < E(\tau, \bar{\alpha})$.

ii) $R(\tau, \bar{\alpha}, \bar{\pi}) > E_0$: from Equation (6) $\Delta\tau > 0$ and from *Lemma1* $R(\tau, \bar{\alpha}, \bar{\pi})$ and $E(\tau, \bar{\alpha})$ decrease until $R(\tau, \bar{\alpha}, \bar{\pi}) = E_0 < E(\tau, \bar{\alpha})$. **QED**.

Proposition 1 says that when the enforcement is weak, a regulator that treats the reported level of emissions as the true level imposes a cost on society in the form of a lower level of environmental quality, as compared to the initially desired one. Furthermore, this cost is unnecessary because the regulator already has all the information to solve the problem, as Proposition 2 makes it clear.

Proposition 2. *Under an incompletely enforceable tax system, a regulator can still achieve the environmental target using firms' reports to infer the actual level of emissions, and in this way calculate the correct tax.*

Proof of Proposition 2. For every tax level τ the firm selects r^o, the level of emissions to report to the regulator, according to equation (4). Once the regulator receives this report, it has all the information to infer the actual level of emissions e. Provided that f is strictly convex and f' is monotonically increasing, by the inverse function theorem f' has a monotonically increasing inverse function. Let denote the inverse function of f' as g. From equation (4) we can write $f'(e^o - r^o) = \tau / \pi$. Applying g to both sides we obtain $g(f'(e^o - r^o)) = e^o - r^o = g(\tau/\pi)$, from which follows that $e^o = g(\tau/\pi) + r^o$. By repeating this calculation for every regulated firm, the regulator can infer E and τ^*, the tax level that produces $E = E_0$. **QED**.

Figure 2 illustrates Proposition 2. Assume that the regulator initially estimates that the aggregate marginal abatement cost curve is given by $-\hat{C}'$ and sets τ_0 accordingly.[7] Assume these results in an aggregate reported level of emissions $R_0 = \sum_n r(\tau_0) > E_0$. The regulator then uses this information to derive $E(\tau_0)$ and increases the tax to, say τ_1, according to $\Delta\tau = \beta(E(\tau_0) - E_0)$. This new tax level results in a new aggregate level of reported emissions R_1. But this is irrelevant, because the regulator can use condition (4) again to derive the new actual level of aggregate emissions consistent with the new tax level, $E(\tau_1)$. At this point the regulator has "found" points (1) and (2) in the graph and, assuming linearity, it can use these two points to draw the actual aggregate abatement cost curve $-C'$ and set the tax $\tau *$. Alternatively, without assuming linearity, the regulator can continue adjusting the tax until E_0 is reached.

Figure 2 about here

[7] The regulator could have asked the firms to report their abatement cost functions. We know from Kwerel (1977) and Bulckaen (1997) that under a tax scheme this would result in under-reporting of abatement cost functions. Note that our suggestion "solves" the asymmetric information problem between the regulator and the firms differently; namely; by asking the firms to report emissions. We consider that this alternative may be more easily implemented than asking firms to report their abatement cost functions.

Up to this point, we have assumed that the enforcement parameters are insufficient to induce truthful reports. In other words, that $\tau > \pi f'(0)$. But another option for a regulator with a limited enforcement budget could be to start the tax adjustment process choosing τ such that $\tau \leq \pi f'(0)$. By this way it can assure truthful reports and adjust the tax properly.[8] Nevertheless, this is not a general solution. Eventually, while increasing the tax, the regulator can reach a tax level $\tilde{\tau}$, such that $\tilde{\tau} = \pi f'(0)$. Above this tax, the regulator will not be able to induce truthful reports of emissions, and he will need to use Proposition 2 to infer actual emissions as we have previously described.[9]

4. Discussion

Our suggestion to infer the actual level of emissions from equation (4) is useful regardless of the the regulator's enforcement budget. Proposition 2 works with arbitrarily low enforcement costs. That is, the regulator can set the monitoring probability π arbitrarily low and still be able to infer the actual level of emissions. Even more, we know from the existing literature that, with uniform enforcement pressure across firms, the extent of the reporting violation, $v(\tau, \pi)$, will be the same for all firms, regardless of their individual characteristics (see Stranlund and Dhanda, 1999, page 273). This implies that the regulator could just use the report of a single firm to derive its actual level of emissions and multiply the extent of its reporting violation by the

[8] A possible drawback of this solution is that with an initially low tax, the level of environmental quality might only improve marginally with respect to the unregulated situation during the first stages of the regulatory period.

[9] We are considering the case of $R = \sum_n r(\tau) > E_0, \forall \ \tau < \tau^*$, and $\tilde{\tau} < \tau^*$.

number of firms to obtain the aggregate level of actual emissions from the difference between the aggregate level of violations and reported emissions.

Under weak enforcement of an emissions tax system, increasing the tax can generate a significant amount of under-reporting, as reported emissions decrease at a larger rate than actual emissions (see Lemma 1). This can be a negative aspect of the method we are proposing. However, as just said, the actual level of emissions decreases while the regulator increases the tax. Therefore, there is no trade-off between inferring the actual level of emissions at a low cost and the resulting environmental quality when the regulator follows Proposition 2. Furthermore, the regulator can stabilize the level of the reporting violation by making it independent of the tax level. Following Stranlund and Chávez (2000), the regulator can tie the marginal penalty to the tax, thus being able to ensure a constant level of reporting violation. To see that, set $f(v) = \tau \times \eta(v)$, with $\eta(0) = 0$, $\eta'(0) > 0$, and $\eta''(v) > 0$. Using condition (4), we know that the firm will now choose how much to under-report according to $\tau = \pi\tau\eta'(v)$, from which it follows that $v^* = v(\pi)$.

As shown in Figure 2, our illustration of Proposition 2 considers quadratic abatement cost functions. Nevertheless, the aggregate marginal abatement cost function can decrease at a constant, increasing, or decreasing rate. In the first case, the regulator only needs two rounds to set the appropriate tax. In the second and third cases, the regulator will need to adjust the tax iteratively to find its correct level. Consequently, the process might take more time than in the first case. But in spite of the time span that the process might take, the fundamental result of Proposition 2 still holds, given our assumptions on the structure of the firms' abatement cost functions.

The previous discussion is based on the assumption that the penalty function is strictly increasing and convex in the extent of each firm's reporting violation. The regulator's ability to infer the true emissions depends on this assumption, thus far. We acknowledge that this penalty structure might not be commonly used in real world applications, thus limiting its practical implementation. A more real penalty scheme might involve constant marginal penalties. In this direction, let us now consider the case where $\tau > \pi \delta$, with δ being the constant marginal penalty. If this is the case, it is easy to show that $e > r = 0$, and the report will not provide any useful information to infer the true emissions. Consequently, Proposition 2 does not work. The regulator can only solve this problem by changing the penalty structure. Otherwise, if it sets $\tau \leq \pi\delta$, it will initially ensure truthful reports but it will not be able to achieve an environmental target stricter than the level of aggregate emissions consistent with $\tau = \pi\delta$. It follows from this analysis that a regulator with a low enforcement budget and a penalty structure involving a constant marginal sanction will not be able to pursue a stringent environmental target. This is particularly true when the penalty structure is exogenous to the environmental regulator.

5. Conclusion

A regulator who wants to achieve a given environmental target through an emissions tax but is unable to enforce truthful reports of emissions by firms, will not succeed when following a tax-adjustment rule based on the gap between the aggregate reported level of emissions and the aggregate emissions target. To be able to achieve the environmental target, the regulator needs to adjust the tax based on actual emissions. We propose a simple method to infer actual emissions as a way to adjust the tax correctly. This method is based on the optimality conditions for the choice of the actual and reported level of emissions by the firms. The method does not require more information than the one that is already available to the regulator, and is easily implementable. Finally, but no less importantly, the regulator can set the monitoring probability arbitrarily low and still be able to infer the actual level of emissions. In other words, the method that we propose works with an arbitrarily low enforcement budget.

References

Blackman, A., 2006. Economic Incentives to Control Water Pollution in Developing Countries. How Well Has Colombia's Wastewater Discharge Fee Program Worked and Why? Resources 161, 20-23.

Bulckaen, F., 1997. Emissions Charge and Asymmetric Information: Consistently a Problem? Journal of Environmental Economics and Management 34, 100-106.

Cropper, M., Oates, W., 1992. Environmental Economics. A Survey. Journal of Economic Literature 30, 1675-1740.

Field, B., Field, M., 2003. Economía Ambiental. McGraw-Hill, Madrid.

Guzmán, Z. Estudio sobre el caso Colombiano en la Aplicación de Instrumentos Económicos: La Tasa Retributiva. Documento de trabajo no publicado.

Hanley, N., Shogren, J., White, B., 1997. Environmental Economics in Theory and Practice. Oxford University Press.

Harford, J., 1987. Self-Reporting of Pollution and the Firm's Behavior under Imperfectly Enforceable Regulations. Journal of Environmental Economics and Management 14, 293-303.

Kolstad, C., 2000. Environmental Economics. Oxford University Press.

Kwerel, E., 1977. To Tell the Truth: Imperfect Information and Optimal Pollution Control, Review of Economic Studies 44, 595-601.

Stranlund, J., C. Chávez.. 2000. Effective Enforcement of a Transferable Emissions Permit System with a Self-Reporting Requirement. Journal of Regulatory Economics 18(2), 113-131.

Stranlund, J., K. Dhanda. 1999. Engogenous Monitoring and Enforcement of a Transferable Emissions Permit System. Journal of Envinmental Economics and Management 38(3), 267-282.

Tietenberg, T., 2000. Environmental and Natural Resource Economics. Fifth Edition. Addison-Wesley Longman.

.