Optimal enforcement policy and firm's decisions on R&D and emissions

Fatih Karanfil[*], Bilge Ozturk[†]

April 2007

Preliminary, do not quote

Abstract

In this paper we develop an environmental regulation model with asymmetric information where the enforcement mechanism should be designed based on the emission reports chosen by the firms and the emission signals that the enforcement agency receives. We consider two cases: first firms choose their emission levels and their emission reports second we include the technological progress. The effect of technological progress is twofold: it increases the production level and abates the emissions. We compare the equilibrium results with imperfect monitoring where the enforcement agency uses two different mechanisms with the perfect monitoring results. The mechanism using the gap between the emission signals and reports gives the same results with the perfect monitoring case whereas if only the emission signals are used for the enforcement mechanism we obtain better results compared with the perfect monitoring case: emissions are reduced, investments are increased. We conclude that if the aim of the enforcement agency is truthful revelation then the first mechanism does definitely better than the other. Instead, if the enforcement agency is concerned with the social welfare the other mechanism will be chosen.

Keywords: Optimal audit policy, R&D decision, environmental taxes
JEL classification: O30, Q55, Q58

[*]Corresponding author. University of Paris 1-Panthéon Sorbonne and Galatasaray University. Ciragan Cad. No:36, 34357 Ortakoy, Istanbul, Turkey. Tel:+902122274480-244 Fax:+902122582283 e-mail: fkaranfil@gsu.edu.tr

[†]Galatasaray University. e-mail: bozturk@gsu.edu.tr

1 Introduction

Environmental taxation is one of the instruments used to reduce pollutant emissions.[1] The initial idea behind the environmental tax is to compensate for a damage created by the externalities at the production or the consumption processes, to control and regulate the level of the damage and to achieve environmental improvements. The latter can also be achieved through energy saving technical progress and clean energy technologies. In this context environmental taxation becomes also an instrument to encourage the innovation activities. Consequently , environmental improvement depends on an optimal and efficient taxation scheme so as to regulate the level of pollutant emissions and to provide incentives to innovate. As the cost of the determination of pollutant emission levels of agents by the enforcement agencies is high, this usually depends on self-reporting behaviour. So the self-reporting behaviour becomes central in the regulation of negative externalities and the incentives for innovation and industrial growth. This paper focuses on the mechanisms that an enforcement agency can use to motivate the agents for a truthful behaviour and the behavioural implications of these mechanisms. We show that the penalties are not enough to motivate and auditing is necessary and this in return should vary with the situation the enforcement agency is dealing with.

[1] Harmonisation of economic and environmental goals is one of the main concern of policy makers. This has become crucial since the Kyoto Protocol, negotiated in December 1997, where countries committed to reduce their emissions of greenhouse gases and an enforcement branch is constituted to control the compliance of countries with their emission targets. There exists other instruments to reduce pollutant emissions: emission charges, environmental taxes, performance bands, liability payments and noncompliance fees. In this paper environmental taxes are considered since they emerge as potentially effective market instruments (see Watson et al. (1996)). Furthermore, Nellor (1997) argues that environmental taxes can replace taxes on labour since they imply lower social costs, boost economic activity and promote employment.

The pioneering study of Pigou (1920) suggested that corrective taxes are necessary to reduce activities that generate negative externalities and the level of these taxes is determined by the marginal damage created at the optimal level of the economic activity. However, as pointed out by Becker (1968), the determination of the level of damage caused by each agent is socially costly then the enforcement is preferably done with a certain probability. When the environmental pollution is concerned, the enforcement scheme relies on the self-reporting of agents. Kaplow and Shavell (1994) offers two advantages of this scheme: the saving of enforcement resources and the elimination of risk-bearing costs. As it is presented in Polinsky and Shavell (2000) the environmental enforcement literature followed from the studies on optimal penalties in law and economics, and especially the literature on mechanism design.[2] The main result of this literature is that when the enforcement agency increases monitoring and inspections the compliance with the restrictions and regulations can increase. A recent study on the issue Macho-Stadler and Pérez-Castrillo (2006) argues that the optimal audit policy in environmental regulation requires that the resources are devoted to the easiest-to-monitor firms and to those firms that value pollution the less. This analysis is based on a constant auditing probability. However, we show that endogenising the auditing probability with respect to the emission levels or some signals about the emission levels can improve the environmental outcome.

Even if the primary aim of the environmental regulation is to compensate for the damage created by pollutant activities, the motivation and incentives of polluters to innovate in energy efficient and cleaner technologies should also constitute an important component of the environmental enforcement mechanisms. The present study aims to include innovation activities of firms into the environmental regulation setup. In this

[2]For a detailed review of the literature see Cohen (1999). For the tax collection and regulation see also Border and Sobel (1987), Wagenhofer (1987) and Mookherjee and Png (1989).

context, we investigate the relationship between the enforcement mechanism and the innovative activities.

The paper is organized as follows. In the second section we describe the basic model where the only decision is the emission level and we compare the perfect information case with the asymmetric information case. In the asymmetric information case we propose two different mechanisms for the enforcement agency. In Section 3, we present another model where we combine the R&D investment decisions with the emission decisions. Again the previous analytical steps are followed. In section 4 we present the concluding remarks.

2 The model I - The auditing probability and the signal of the emission level

The basic model follows from Macho-Stadler and Pérez-Castrillo (2006). We consider a single competitive firm which chooses explicitly an emission level e. The firm benefits from emissions. The benefit from emissions is represented by the function $g(e)$ which satisfies ($g'(e) > 0$ and $g''(e) < 0$) and Inada conditions. The enforcement agency has to control the pollution and consequently the emission levels are taxed linearly at a rate t. In our model we do not deal with the determination of this rate. On the other hand since the enforcement agency can not perfectly monitor the damage or the emissions we are concerned with the enforcement policy and the emission levels that will be determined accordingly. In order to do so, we have to compare two cases: perfect monitoring and imperfect monitoring.

2.1 Perfect Monitoring

We suppose that the enforcement agency perfectly observes the emission levels. The profit of the firm is:

$$\Pi(e) = g(e) - te \tag{1}$$

The optimal level of emission is obtained through the maximisation of the profit and satisfies the following identity:

$$g'(e^{PM}) = t \tag{2}$$

Equation (2) states that the marginal benefit of polluting is equal to its marginal cost and the optimal level of emission is decreasing in t.

Next we have to deal with the situation where the enforcement agency does not have perfect information about the emission level and has to use available data to collect tax payments efficiently. The motivation of the next section will be to compare the optimal emission levels under perfect and imperfect monitoring.

2.2 Imperfect Monitoring

The level of emissions can not be observed perfectly, thus the enforcement agency should rely on the emission report given by the firm denoted by z. Here it is important to note that the reported emission level can be different than the true level. The rationality condition requires that z is not greater than e and in fact as firms are profit maximisers z satisfies $z \leq e$. It's costly to audit each firm and firms are audited with a probability α. The enforcement agency should determine this probability in such a way that will induce the firms to truly report their emission levels. In addition to the reported emission level z the enforcement agency receives a signal f that is correlated with e. As a result the enforcement agency should base its decision about the probability of auditing on these values. We will consider two alternatives. First the probability of auditing depends only the signal f and in the second case we will assume that the difference between the signal and the reported emission determines this probability.

We suppose that if the firm is caught the true level of emission can be covered. The firm that is audited and found underreporting must pay the tax on the unreported emission plus a penalty.

Assumption 1 The penalty takes the form $\theta(u)$ where $u = e - z$ and $u \geq 0$.

Assumption 2 $\theta(0) = 0$, $\theta'(u) > 0$, $\theta''(u) > 0$.

Remark 1 *Notice that the expected tax payment of the firm should satisfy the following condition: $tz + \alpha(.)tu + \alpha(.)\theta(u) \leq te$. If the expected tax payment in case of underreporting exceeds the expected tax payment in case of truthfull revelation there will be an incentive to truthfully report the emission level. As a result the probability of auditing can not exceed $\frac{1}{\frac{\theta(u)}{tu}+1}$.*

2.2.1 Auditing probability as a function of the signal

The enforcement agency uses the signal to determine the probability of auditing. The reports are used for the determination of the amount of tax and the penalties.

Assumption 3 The probability of auditing is $\alpha(f)$.

Assumption 4 $\alpha(0) = 0$, $\alpha'(f) > 0$, $\alpha''(f) > 0$.

Consider the following profit function of a representative firm that will be audited with a probability of α:

$$\Pi(e, z) = g(e) - tz - \alpha(f)tu - \alpha(f)\theta(u) \tag{3}$$

The optimal level of emission e^{IMA} and the report z^{IMA} are obtained through the maximisation of the expected profit with respect to the true emission level e and the reported level z. The first order conditions are as follows:

$$\frac{\partial \Pi(e,z)}{\partial e} = g'(e) - \alpha'(f)(tu + \theta(u)) - \alpha(f)(t + \theta'(u)) = 0 \quad (4)$$
$$\frac{\partial \Pi(e,z)}{\partial z} = -t + \alpha(f)(t + \theta'(u)) = 0$$

Result 1 $e^{IMA} < e^{PM}$ for all $z^{IMA} < e^{PM}$ and $e^{IMA} = e^{PM}$ for $z^{IMA} = e^{PM}$. Note that $\left.\frac{\partial \Pi(e,z)}{\partial e}\right|_{e=e^{PM}} = -\alpha'(f)(t(e^{PM} - z^{IMA}) + \theta(e^{PM} - z^{IMA})) \leq 0.$

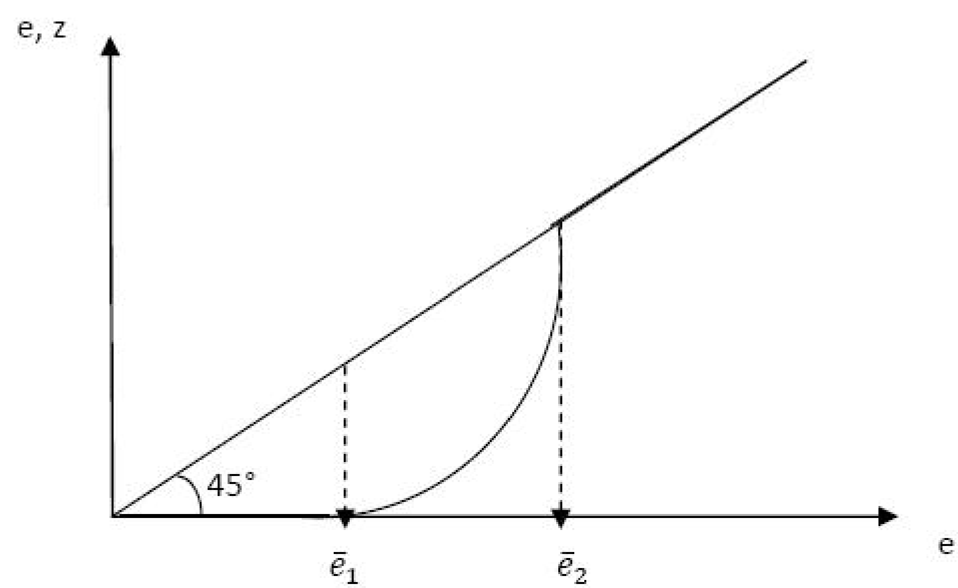

Figure 1: Firm's decision of the emission level and the report

This result is in contradiction with the result in Macho-Stadler and Pérez-Castrillo (2006) since when there is imperfect monitoring they show that the optimal emission level could be greater under the assumption that the auditing probability is exogenous. We see that altering this assumption leads to a completely different result.

Remark 2 *The optimal emission report is obtained through the identity:* $\alpha(f) = \frac{t}{t+\theta'(u)}$*. The difference between the reported and the true level should decrease as the probability of auditing increases (* $\lim_{\alpha(f)\to 0} \theta'(u) = \infty$ *and* $\lim_{\alpha(f)\to 1} \theta'(u) = 0$*). That is in accordance with the intuition.*

Proposition 3 *For a given level of tax rate* t *and penalty function* $\theta(u)$ *the optimal level of emission and report decisions for the firm are* (e^{IMA}, z^{IMA})*:*
if $e \geq \bar{e}_2$ *then* $e^{IMA} = e^{PM}$ *and* $z^{IMA} = e^{IMA}$*.*
if $\bar{e}_1 < e < \bar{e}_2$ *then* $e^{IMA} < e^{PM}$ *and* e^{IMA} *satisfies (4) with* $z^{IMA} < e^{IMA}$*.*
if $e < \bar{e}_1$ *then* $e^{IMA} < e^{PM}$ *and* e^{IMA} *satisfies (4) with* $z^{IMA} = 0$*.* $\bar{e}_2$ *satisfies the condition* $(1-\alpha(f))t = \alpha(f)\theta'(0)$ *and* $\bar{e}_1$ *satisfies* $(1-\alpha(f))t = \alpha(f)\theta'(\bar{e}_1)$

2.2.2 Auditing probability as a function of the difference between the signal and the report

In the previous section the enforcement agency uses the signal to determine the auditing probability. Another approach at this point can be to use the difference of the emission signal and the emission report to determine the auditing probability.

Assumption 5 The probability of auditing is $\alpha(v)$ where $v = f - z$.

Assumption 6 $\alpha(0) = 0$, $\alpha'(v) > 0$, $\alpha''(v) > 0$.

The profit of the firm becomes:

$$\Pi(e, z) = g(e) - tz - \alpha(v)t(e - z) - \alpha(v)\theta(u) \tag{5}$$

The optimal level of emission e^{IMB} and the report z^{IMB} are obtained through the maximisation of the expected profit with respect to the true emission level e and the reported level z. The first order conditions are as follows:

$$\frac{\partial \Pi(e,z)}{\partial e} = g'(e) - \alpha'(v)(tu + \theta(u)) - \alpha(v)(t + \theta'(u)) = 0 \qquad (6)$$
$$\frac{\partial \Pi(e,z)}{\partial z} = -t + \alpha'(v)(tu + \theta(u)) + \alpha(v)(t + \theta'(u)) = 0$$

Result 2 $e^{IMB} = e^{PM}$. Adding up the first order conditions we obtain $g'(e^{IMA}) = t$

3 The model II - The investment in R&D

In the Model I, the firms benefit from emissions since the latter is used as a proxy for the level of production. However, the search for cleaner technologies are also on their agenda. The introduction of R&D investment as a means to reduce emission levels for a given level of production and to increase the productivity requires another analytical framework. The motivation of this current model is to analyse the forces that determine, on the one hand, the rate of technological change driven by R&D investment and on the other hand the optimal level of emissions which are also affected by the technological progress.

Production is determined by the technological level A and, as in the previous model, the benefits from polluting $g(e)$. The firms conduct R&D activities to increase their productivity and to decrease the level of emission of pollution. The level of R&D investment is denoted by x. The impact of the investment in R&D x is twofold: it decreases the level of emissions ($e'(x) < 0$ and $e''(x) > 0$) and increases the global productivity ($A'(x) > 0$ and $A''(x) < 0$). Note that there is a trade-off between the technological progress and the benefit from emissions. The production function is given by the following equation:

$$Q(x) = A(x)g(e(x)) \qquad (7)$$

Assumption 7 The marginal product of investment is nonnegative $\Delta Q(x) = \Delta A(x)\Delta x + \Delta g(e(x))\Delta e \Delta x \geq 0$.

Remark 4 *The first term is positive and the second term is negative. The marginal increase in productivity should compensate for the decrease in the emission level at the new technological level.*

The technological progress is achieved through investing in R&D but this investment is costly. The cost of R&D is given by $h(x)$.

Assumption 8 There are decreasing returns to scale in R&D expenditures ($h'(x) > 0$ and $h''(x) > 0$).

The remaining structural and behavioural assumptions are the same with the Model I. We compare two cases: perfect monitoring and imperfect monitoring.

3.1 Perfect Monitoring

Since there is perfect monitoring, the firm makes tax payments on the true emission level. The representative firm maximises the following equation:

$$\Pi(x) = A(x)g(e(x)) - te(x) - h(x) \tag{8}$$

The optimal level of emission is obtained through the maximisation of the profit with respect to the R&D investment level and satisfies the following identity:

$$\frac{\partial \Pi(x,z)}{\partial x} = A'(x)g(e(x)) + A(x)g'(e)e'(x) - te'(x) - h'(x) = 0 \tag{9}$$

Rearranging the equation (9) yields the optimal level of investment x^{PM}:

$$A'(x^{PM})g(e(x^{PM})) + A(x^{PM})g'(e(x^{PM}))e'(x^{PM}) + te'(x^{PM}) = h'(x^{PM}) \tag{10}$$

Equation (10) states that the marginal benefit of investing is equal to its marginal cost.

3.2 Imperfect Monitoring

In this section we analyse the differences in the behaviour of the firm about R&D expenditures in two contexts that we introduced for the Model I. In the first, the probability of auditing depends only on the signal f. In the second the probability becomes a function of the difference between f and z.

3.2.1 Auditing probability as a function of the signal

Consider a representative firm that maximises the following equation:

$$\Pi(x,z) = A(x)g(e(x)) - tz - \alpha(f)t(e(x)-z) - \alpha(f)\theta(u) - h(x) \qquad (11)$$

The first-order conditions for the equation (11) give the following identities:

$$\begin{aligned} 0 &= \frac{\partial \Pi(x,z)}{\partial x} = A'(x)g(e(x)) + A(x)g'(e)e'(x) \qquad (12) \\ & \quad -\alpha'(f)e'(x)(tu+\theta(u)) - \alpha(f)(te'(x)+\theta'(u)e'(x)) - h'(x) \\ 0 &= \frac{\partial \Pi(x,z)}{\partial z} = -t + \alpha(f)(t+\theta'(u)) \end{aligned}$$

Result 3 $x^{IMC} > x^{PM}$ and $x^{IMC} = x^{PM}$ for $z^{IMC} = e(x^{PM})$. Note that $\left.\frac{\partial \Pi(x,z)}{\partial x}\right|_{x=x^{PM}} = -\alpha'(f)e'(x)(t(e(x^{PM}) - z^{IMC}) + \theta(e(x^{PM}) - z^{IMC})) \geq 0$.

3.2.2 Auditing probability as a function of the difference between the signal and the report

The representative firm maximises the following equation:

$$\Pi(x,z) = A(x)g(e(x)) - tz - \alpha(v)t(e(x)-z) - \alpha(v)\theta(u) - h(x) \qquad (13)$$

The optimal level of R&D and report are obtained through the maximisation of the profit with respect to the R&D investment level and the emission report. The first order conditions are as follows:

$$\begin{aligned} 0 &= \frac{\partial \Pi(x,z)}{\partial x} = A'(x)g(e(x)) + A(x)g'(e)e'(x) \\ & \quad -\alpha'(v)e'(x)(tu+\theta(u)) - \alpha(v)(te'(x)+\theta'(u)e'(x)) - h'(x) \\ 0 &= \frac{\partial \Pi(x,z)}{\partial z} = -t + \alpha'(v)(tu+\theta(u)) + \alpha(v)(t+\theta'(u)) \end{aligned} \tag{14}$$

Result 4 $x^{IMD} = x^{PM}$. Adding up the first order conditions we obtain $A'(x)g(e(x)) + A(x)g'(e(x))e'(x) + te'(x) = h'(x)$.

4 Conclusion

In Turkey, the revenue raised from environmentally related taxes represents 1.7% of GDP in 1995 while it reaches 5.2% in 2003. The share of the environmental tax revenue represents less than 7% of total tax revenue in 1995 and it corresponds to 16% of total tax revenue in 2003. This corresponds to 130% of increase for a period of 8 years (OECD, 2001). The investigation of emission levels per output reveals an increasing pattern. It is obvious that the environmental regulation system even tough collects a considerable amount of taxes does not motivate for any innovative activities. The reason behind this can be seen in the taxation scheme: there is a lump sum tax for pollutant emissions regardless of the emission level. This paper considers an environmental tax per emission and provides two different enforcement mechanisms. In Turkish case the correction of the environmental regulation framework would require the application of environmental tax per emission first and an appropriate choice of enforcement mechanism for incentives for innovation.

In this paper we presented two different mechanisms for the enforcement agency. One of the mechanisms does definitely better as far as truthful revelation is concerned. On the other hand the results with the other mechanism may differ from the optimal results under perfect information. We may achieve better results on both models, since the enforcement mechanism induces agents to make less pollution in the Model I and more investment in R&D and less emission in the Model II. We reach the conclusion that the enforcement mechanism should be designed according to the situation that we analyse.

References

[1] Becker, G.S. 1968. *Crime and Punishment: An Economic Approach*. The Journal of political economy. 76-2: 169-217.

[2] Border, K.C. 1987. *Samurai Accountant: A Theory of Auditing and Plunder*. The Review of economic studies. 54-4: pp.525-540.

[3] Cohen, M. A. 1999. *Monitoring and Enforcement of Environmental Policy*. International Yearbook of Environmental and Resource Economics, Volume III, edited by Tom Tietenberg and Henk Folmer; Edward Elgar.

[4] Kaplow, L. and Shavell, S. 1994. *Optimal Law Enforcement with Self-Reporting of Behavior*. The Journal of Political Economy. 102-3: 583-606.

[5] Macho-Stadler, I. and Pérez-Castrillo, D. 2006. *Optimal enforcement policy and firms' emissions and compliance with environmental taxes*. Journal of Environmental Economics and Management. 51: 110-131.

[6] Mookherjee, D. and Png, I. 1989. *Optimal Auditing, Insurance, and Redistribution*. The Quarterly Journal of Economics. 104-2: pp. 399-415.

[7] Nellor, D.C.L. 1997. *Fiscal and macroeconomic aspects of environment taxes*. In: Blejer, M.I., Ter-Minassian, T. (Ed.), Economic Reform Essays in Honour of Vito Tanzi, Routledge.

[8] Organisation for Economic Co-Operation and Development (OECD), 2001. Consumption Tax Trends. *OECD*. Paris.

[9] Pigou, A.C. 1920. The economics of Welfare. *Macmillan*. London.

[10] Polinsky, A. M. and Shavell, S. 2000. *The Economic Theory of Public Enforcement of Law*. Journal of Economic Literature. 38: 45-76.

[11] Wagenhofer, A. 1987. *Investigation Strategies with Costly Perfect Information*. In Agency Theory, Information, and Incentives, edited by Gunter Bamberg and Klaus Spremann. *Springer-Verlag*. Berlin.

[12] Watson, R.T., Zinyowera, M.C., Moss, R.H. 1996. *Technologies, policies and measures for mitigating climate change*. Technical Paper, IPCC: WG-2, http://www.gclio.org/ipcc/techrepI/toc.html.