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Why environmental regulation may lead to no-regret pollution abatement

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Abstract

Empirical evidence support the existence of pollution abatement possibilities at negative costs, the so-called 'no-regret options'. We provide a microeconomic rationale for the existence of such potential at the firm's level under environmental regulation. An econometric application confirms that marginal pollution abatement cost curves with no-regret options are compatible with a standard production function, as stated in our theoretical model.

Key words: No-regret options, pollution, regulation

JEL codes: D20; Q50

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1 Introduction

In this paper we provide a microeconomic rationale for the existence of 'no-regret pollution abatement options' at the firm's level, that is, the opportunity to reduce pollution while increasing profits.

Many studies provide empirical evidence for such options, but most of them at countries or sectoral levels, rarely at the firm's level. The potential of no-regret opportunities to reduce greenhouse gases emissions, for example, has been highlighted by the Intergovernmental Panel on Climate Change: "Half of the potential reductions may be achieved by 2020 with direct benefits (energy saving) exceeding direct costs (net capital, operating and maintenance costs)." (IPCC, 2001, p. 40). More recently, a set of in-depth analyses of greenhouse gases abatement costs have been performed on behalf of the World Bank in several developing and transition countries. Carried out on a common bottom-up methodological framework, these studies identify no-regret options in most countries[1]. Another example is a study undergone by the German Fraunhoer Institute for the Belgian federal government: it establishes that Belgium could meet its the Kyoto commitment (*i.e.* a 7.5% abatement in 2010 with respect to the 1990's level) by negative or zero cost measures. A recent a very complete empirical analysis at the firm's level is the one by Isaksson (2005) with a plant-level data set comprising 162 abatement measures for nitrogen oxide emissions. It shows that "extensive emission reductions have been possible at very low or even zero or negative costs" (Isaksson, 2005, p. 118), though only one of the 162 measures reported

[1] Part of the National CDM/JI Strategy Studies (NSS), all these analyses are publicly available at *http://www.worldbank.org*.

costs-savings larger enough to outweigh the costs.

One cannot look down the fact that most economists feel uncomfortable with this evidence because it seems to conflict with the assumption of rational behavior. The standard microeconomic theory fails to explain what a so-called *free lunch*. The famous economists' metaphor cited by Porter and van der Linde (1995) is that $10 bills will never be found on the ground because someone would have already picked them up. As stressed out by Palmer *et al.* (1995) in the same journal, the question is neither to claim that firms are "ever-vigilantly perched on their efficiency frontier" (p. 120), nor to generalize the idea of free lunch on the simple basis on few empirical examples. The objective of our paper is not to provide a rational for the Porter hypothesis, that is, to the hypothesis that tightening environmental standards may increase firm's profit[2]. Instead, we show that pollution abatement is always costly but also that implementing internal environmental management may lead to increases in productivity. Thus, when comparing situations without, and with environmental regulation, it may happen that a firm gain from being green, what is called a no-regret option. It is clear that the possibility for such options to occur may have major implications for the debate on environmental regulation, competitiveness and growth (see *e.g.* Barbera and McConnel (1990), Jaffe *et al.* (1995) and the survey of Ambec and Barla (2005)).

When looking for empirical evidence for no-regret options the debate rapidly faces methodological issues. How do engineers calculate abatement

[2]A vast literature has been devoted to the Porter hypothesis. For a survey, see Ambec and Barla (2005).

costs? Is it coherent with standard economic concepts? Answering the former issue goes beyond the objective of this paper (note that the World Bank project presented above constitutes a good example of transparent and publicly available methodology). Stoft (1995) is probably the only author who tried to tackle the latter issue by developing a framework to reconciliate the economists' concept of production function with marginal abatement cost curves as built up by engineers. Without justification, however, Stoft assumed that the firms are below their production frontier, thus introducing *ad hoc* no-regret abatement options at the firm's level. Actually, two main strands of economic literature may be related to this issue. The first one quantifies the so-called X-inefficiencies and follows Farrell's (1957) definition of technical efficiency. These studies extract information from large bodies of data at the firm's level to determine the best production frontier and calculate the distance between each firm and this frontier. These approaches are characterized by parametric or non-parametric methods. They calculate but they do not explain. The second strand of literature focuses on the barriers to energy efficiency. The authors exhibit a panel of reasons for which the firms *seem* inefficient, while being fully rational but facing some hidden costs, that is, costs which are neglected in standard static and deterministic analyses. These costs are related, *e.g.*, to the uncertainty on future energy prices, to technological lock-in effects, to uncertainty on the characteristics on equipment goods... A survey of this literature can be found in Sorrel (2004). How useful these analyses are, they fail to propose a general rational for the possible existence of no-regret options at the firm's level under environmental regulation.

Within a standard static microeconomic framework our paper provides a rational for no-regret options to exist, even though these options are susceptible to appear only in very specific contexts or for some firms only. The issue is to understand in which context these options may appear. Our starting point is that pollution operates as a hidden -and neglected- factor in the production process, along with the usual production factors. While neglecting this factor, the firm may bear an opportunity cost. Put differently, the firm may gain by taking into account the productive contribution of pollution within the whole optimization process, thus enlarging its production set. We show how environmental regulation and management help internalizing this productive contribution and why they may lead to a profit increase when pollution is reduced. Using our theoretical framework we propose a graphical illustration (in the spirit of Stoft, 1995). We also provide empirical evidence with a simple econometric application in the glass industry in Wallonia (Belgium).

The article is organized as follows. Section 2 presents the firm's behavior in terms of environmental management under regulation. The opportunity cost of neglecting pollution and the existence of no-regret options at the firm's level are proved. Section 3 provides a graphical illustration and the econometric application is presented in Section 4. Section 5 concludes.

2 Environmental regulation and management

We shall consider two scenarios. The first one (called *business-as-usual*) corresponds to a situation in which pollution is neglected by the firm. Such situations prevailed some years ago for many pollutants for which even a mere reporting was not organized. It still prevails today for some pollutants in some sectors or firms (*e.g.* carbon dioxide emissions at firms' level are largely neglected in some sectors like transportation, buildings or market services). Under this scenario we consider a firm which maximizes its profit while neglecting pollution. In the second scenario (called the *green scenario*), firms are committed to a pollution quota, thus discovering (or recognizing) that they do have an impact on the environment. As a consequence, the firm would like to have a clear idea about its emission level and about its own ability to reduce it in order to comply the pollution constraint. In this purpose we assume that the firm sets up an environmental management system and hires an environmental manager. Actually, this scenario is the one many firms face today while environmental regulation and awareness spread. What we are interested in is the productive implications of the fact that the firm now takes pollution into account.

2.1 Production technology and pollution

The firm produces an homogeneous good taken as numeraire with a well-behaved (increasing, concave and homogeneous of degree one) production function $F(X)$ where X is the vector of N production factors, $X = \{X_1, ..., X_N\}$. Under the *business-as-usual* scenario, the output level is noted $\hat{Y}$. This activity results in the emission of a pollutant in quantity $P = \psi\hat{Y}$ $(\psi > 0)$, pollutant which is disregarded by the firm. Let assume that this pollution output ratio can be considered from a technological viewpoint as an increasing continuous function $\psi(z)$ of a technological index z,

$$\psi(z) = \frac{P}{F(X)} \tag{1}$$

Without loss of generality we assume that the function $\psi(.)$ is defined and inversible on R^{+}. The cost of pollution abatement is expressed in terms of output losses by choosing the index z applied to the output level (Stokey, 1998),

$$Y = zF(X) \tag{2}$$

The modeling *à la* Stokey (1998) allows to easily compare the two situations, with and without environmental regulation. We assume that the abatement cost $(1-z)F(X)$ is defined in $[0, F(X)]$, *i.e* $z \in [0,1]$. Eliminating z between (1) and (2) allows us to define a $(N+1)$-factor production function Φ, homogeneous of degree one, in which pollution is considered as an input for production,

$$\Phi(X,P) = \psi^{-1}(\frac{P}{F(X)})F(X) \tag{3}$$

Thus, the production function changes depending on whether environmental management is operative $(z < 1)$ or not $(z = 1)$. The overall production function is given by $Y = G(X,P) = \min\{F(X), \Phi(X,P)\}$. As a min-function, $G(X,P)$ is not differentiable at the point where the two terms $F(.)$ and $\Phi(.,.)$ are equal, *i.e.* for $z = 1$.

2.2 The unexpected effects of environmental management

Under the *business-as-usual* scenario the output level is given by the N-factor production function $\hat{Y} = F(X)$. Assuming perfect competition the vector of input prices $p = \{p_1, ...p_N\}$ is given and the firm's programme writes

$$\max_{\{X\}} \pi = F(X) - pX \tag{4}$$

leading to N first-order conditions of the form $F_{X_i}(\widetilde{X}) = p_i$, $\forall i \in N$. The pollution level is given by $\widetilde{P} = \psi F(\widetilde{X})$.

Under the *green scenario* the firm is subject to an emission quota $\bar{P}$ such that $0 < \bar{P} \leq \widetilde{P}$. To tackle this new constraint the firm hires an environmental manager whose mission is twofold [3]. Firstly, she has to report the actual emissions level, *i.e.* the one under the *business-as-usual* scenario. Secondly, she has to identify the technological opportunities to comply with the pollution constraint. We represented these technological opportunities with the function $\psi(z)$ of the technological index z. Using (1) the constraint $P \leq \bar{P}$ can be re-written as $\psi(z)F(X) \leq \bar{P}$. Under environmental regulation the problem of the firm now reads

$$\max_{\{X,z\}} \pi = zF(X) - pX \tag{5}$$

[3] In our analysis we neglect the hiring and wage costs of the environmental manager. This boils down to assume that these cost are small compared to the total production cost of the firm. Still, considering a positive cost would not change the outcome of the analysis.

subject to $\psi(z)F(X) \leq \bar{P}$. We denote μ the Lagrangian multiplier of this constraint and this Lagrangian writes

$$\mathcal{L} = zF(X) - pX + \mu(\bar{P} - \psi(z)F(X)) \tag{6}$$

The value of X and z solutions of this problem are solutions of the following FOCs,

$$(z - \mu\psi(z))F_{X_i}(X) = p_i, \quad \forall i \in N \tag{7}$$

$$1 - \mu\psi'(z) \leq 0, (= 0 \;\; if \quad z < 1) \tag{8}$$

$$\mu(\bar{P} - \psi(z)F(X)) = 0 \tag{9}$$

By doing her job the environmental manager reveals that pollution operates as a hidden factor within the production process and interacts with the other production factors. In the FOCs, this is reflected by the fact that the factors' marginal productivity differs from their price this productive interaction being the multiplicative term $z - \mu\psi(z)$. The function $z - \mu\psi(z)$ is concave and its derivative is positive at $z = 0$ (Jouvet, Michel and Rotillon, 2005). If the constraint is not binding, *i.e.* $\bar{P} = \widetilde{P}$, there exists a range $[0, \widetilde{\mu}]$ of values of μ compatible with this pollution target. As long as $0 \leq \mu \leq \widetilde{\mu}$, $z = 1$ and all factors' level remain unchanged in comparison with the *business-as-usual* scenario (*i.e.* $\widetilde{X}$).

Considering the relation (8), the highest value of μ compatible with no abatement is defined by

$$\widetilde{\mu} = \frac{1}{\psi'(1)} \tag{10}$$

Knowing the value of $\widetilde{\mu}$ and using equation (7) the maximal impact of the environmental factor on the marginal productivity of the input X_i ($\forall i \in N$) writes $(1-\widetilde{\mu}\psi(1))F_{X_i}(\widetilde{X})$, which is lower than $F_{X_i}(\widetilde{X}) = p_i$. So, under the *business-as-usual* scenario, the contribution of pollution to production is embodied in the other production factors' contribution, and it is unpaid. Following Worcester's terminology (Worcester, 1969) we can disentangle this contribution as the combination of the two parameters identified above, namely a *technological rent,* $\psi(1)$, and a *pecuniary rent,* μ. Thus, discovering the productive contribution of pollution opens the door to a revaluation of the productive contribution of each factor X_i, the latter being valued (at most) by the multiplicative term $1-\widetilde{\mu}\psi(1)$. Since the actual marginal productivity of the production factors is lower than their cost, there exists an opportunity cost associated to the fact that the environmental factor was neglected. This is summarised in the following proposition.

Proposition. *A firm may experience a profit increase while committed with a pollution constraint. The maximal profit increase is given by* $\widetilde{\Omega} = \widetilde{\mu}\psi(1)F(\widetilde{X})$.

Example 1 ***The Cobb-Douglas case****. Consider a Cobb-Douglas production function* $Y = AK^{\alpha}L^{1-\alpha}$ *(with* $0 < \alpha < 1$*). The firm is price-taker and output is taken as numeraire . Under the* business-as-usual scenario *the pollution level is* $\widetilde{P} = \psi\widetilde{Y}$ *(with* $\psi > 0$*). Let the pollution function be* $P/Y = \psi z^{\beta}$ *(with* $0 < z \leq 1$ *and* $\beta > 0$*). The cost of pollution abatement is* $(1-z)AK^{\alpha}L^{1-\alpha}$. *Under the* green scenario *the pollution function writes*

$$\frac{P}{AK^{\alpha}L^{1-\alpha}} = \Psi(z) = \psi z^{\beta+1} \tag{11}$$

By substitution, the previous equations allow us to define the technological index z as a function of pollution, capital and labor,

$$z = \left(\frac{P}{\psi A K^{\alpha} L^{1-\alpha}} \right)^{\frac{1}{1+\beta}} \tag{12}$$

and we get a three-factor production function, homogeneous of degree one of capital, labor and pollution,

$$\Phi(K, L, P) = \left(\frac{P}{\psi} \right)^{\frac{1}{1+\beta}} A^{\frac{\beta}{1+\beta}} K^{\frac{\alpha\beta}{1+\beta}} L^{\frac{(1-\alpha)\beta}{1+\beta}} \tag{13}$$

As shown in the previous section, the highest value of μ compatible with $z = 1$ reads $\overline{\mu} = 1/(\psi(1+\beta))$. As long as $0 \leq \mu \leq \overline{\mu}$, $z = 1$ and both capital and labor levels remain unchanged with respect to the business-as-usual *situation. While considering an emission constraint $\bar{P}$ such that $0 < \bar{P} \leq \widetilde{P}$, the firm's profit at the optimum is given by $\pi^*(\bar{P}) = \Phi(K^*, L^*, \bar{P}) - wL^* - RK^*$ with $L^* = \frac{(1-\alpha)\beta}{1+\beta} \frac{\Phi(K^*, L^*, \bar{P})}{w}$ and $K^* = \frac{\alpha\beta}{1+\beta} \frac{\Phi(K^*, L^*, \bar{P})}{R}$. Hence, the profit becomes positive and is given by*

$$\pi^*(\bar{P}) = \frac{1}{1+\beta} \Phi(K^*, L^*, \bar{P}) \tag{14}$$

This profit function is increasing with $\bar{P}$. It can easily checked that $lim_{\bar{P} \to \widetilde{P}} \pi(\bar{P}) = \widetilde{\Omega}$.

3 No-regret options for pollution abatement

We can illustrate the fact that emission reductions can be associated with an increase of the firm's profit by using the marginal abatement cost curves (MAC, hereafter). For the sake of simplicity, linear functions will be considered in the figures. In Fig. 1, the horizontal axis represents the emissions level and the vertical axis represents the marginal profit for a given firm. In the absence of environmental regulation the pollution level ($\widetilde{P}$) corresponds to the zero marginal profit condition. The profit of this firm is the area $OA\widetilde{P}$. When subject to the environmental regulation, the firm re-evaluates the marginal productivity of its factors and the monetary value of the maximal potential benefit for this firm without changing emissions level is $AB\widetilde{P}$. The vertical jump at $\bar{P} = \widetilde{P}$ reflects that a discontinuity occurs and the size of this jump is given by $\widetilde{\mu}\psi(1)$.

Insert figures 1 and 2 about here

The building of the MAC curve stems from the previous Figure. In Figure 2 pollution abatement is indicated on the horizontal axis as $\Delta P = \left|\bar{P} - \widetilde{P}\right|$ and the marginal abatement cost is shown on the vertical axis. In the *business-as-usual* scenario the MAC curve starts from the origin and its slope is the slope of the marginal profit curve as given in Figure 1. Under environmental regulation, and if no-regret options exist for pollution abatement, then two phenomena occur. Firstly, the MAC curve moves downward and a discontinuity appears at the origin, the maximal value of the latter being given by the value of $\widetilde{\mu}\psi(1)$. Secondly, the slope of the MAC curve changes: it is all the flatter as the opportunity cost associated to pollution is important.

The area below the horizontal axis and above the MAC curve represents the potential of no-regret pollution abatement measures and the point C where the MAC curve crosses the axis indicates the optimal abatement level for this firm, *i.e.* the one at which the marginal abatement cost is zero and the total benefit is maximal.

4 An econometric application

In this section we apply our theoretical model to the glass industry in Wallonia (Belgium) by carrying out an econometric estimation. The dataset was collected during auditing procedures at the firm's level on behalf of the regional administration in charge of the environmental policy[4]. They provide a set of technical abatement options for carbon dioxide and the fixed and operational costs associated. These costs are annualized and discounted to be expressed in 2010, the reference year. Then these measures are ranked in increasing order of marginal cost. All in all 32 abatement options are available, of which four at a negative cost. Using the Cobb-Douglas specification presented in Section 2, the cost of pollution abatement is given by

$$(1-z)F(K,L) = AK^{\alpha}L^{1-\alpha} - \left(\frac{P}{\psi}\right)^{\frac{1}{1+\beta}} A^{\frac{\beta}{1+\beta}} K^{\frac{\alpha\beta}{1+\beta}} L^{\frac{(1-\alpha)\beta}{1+\beta}} \tag{15}$$

[4]The data were collected by ECONOTEC, a consultancy agency specialized in energy audits and technico-economic evaluation in the field of energy and the environment (*www.econotec.be*).

and the marginal abatement cost writes

$$MAC = -\frac{1}{1+\beta}\psi^{-\frac{1}{1+\beta}}P^{-\frac{\beta}{1+\beta}}A^{\frac{\beta}{1+\beta}}K^{\frac{\alpha\beta}{1+\beta}}L^{\frac{(1-\alpha)\beta}{1+\beta}} \tag{16}$$

The marginal abatement cost curve to be estimated rises from equation (16),

$$ln(-MAC) = ln\theta - \theta ln\psi + (1-\theta)lnA - (1-\theta)lnP + (1-\theta)[\alpha lnK + (1-\alpha)lnL] \tag{17}$$

with $\theta = 1/(1+\beta)$. Considering that the marginal abatement cost may eventually be negative for first pollution abatement efforts, we add a positive constant T in the logarithm of the left hand side of this expression such that $(-MAC+T) > 0$. Considering that θ, ψ and A are parameters we can define the two following constants $\xi_1 = ln\theta - \theta ln\psi + (1-\theta)lnA$ and $\xi_2 = (1-\theta)$. Finally, the equation to be estimated writes

$$ln(-MAC+T) = \xi_1 - \xi_2 lnP + \xi_2[\alpha lnK + (1-\alpha)lnL] + \varepsilon \tag{18}$$

where ε is the error term. Equation (18) is estimated by OLS. All the coefficients are statistically significant and have the expected sign: $\xi_1 = 0.703$ (*t-stat*: 64.3), $\xi_2 = 3.956$ (*t-stat*: 155.0) and $\alpha = 0.301$ (*t-stat*: 13.3). This result provides empirical evidence for two results. First, no-regret abatement options as represented by MAC curves built by the engineers are compatible with a standard well-behaved three-factor production function (a Cobb-Douglas function in this example). Second, this estimation evaluates the current potential for no-regret carbon dioxide abatement options in the glass industry in Wallonia. Knowing that $\xi_2 = (1-\theta)$ we get that $\theta = 0.297$ and $\beta = 2.367$. So the value of $\widetilde{\mu}$ can also be computed. Considering the current emission and output levels in the glass industry in Wallonia in 2003, we calculate that the maximal profit increase $\widetilde{\Omega}$ associated to pollution abatement at negative costs amounts to 29% of the output value.

5 Conclusion

In this paper we provide a microeconomic rational why no-regret pollution abatement options (*i.e.* pollution reductions at negative costs) may exist at the firm's level. By recognizing that pollution is a production factor, we show how neglecting its interactions with the other production factors in the production process may represent an opportunity cost for the firm. Put differently, enlarging the production set with this polluting factor may lead to a profit increase at the firm's level. The basic argument may be illustrated with a revisited version of the Porter and van der Linde's metaphor quoted at the beginning of this article: $10 bills may perfectly stay on the ground of the cellar if there is nobody to switch on the light. Switching on the light is the environmental manager's mission. Our econometric application confirms that marginal abatement cost curves with no-regret options, as built up by engineers, are fully compatible with a standard production function, as used in economics. So, in contrast with previous works (essentially Porter and van der Linde (1995) and Stoft (1995)), our paper provides a framework for analysing no-regret options which is both formal and general. Importantly, in our setting pollution abatement always has a cost, but this cost may be outweighed, to a certain extend, by productive improvements revealed when implementing internal environmental management.

One of the avenues for further research would be to analyze the firm's capacity to benefit from this opportunity cost. It may be possible for a firm to identify no-regret measures but not to be able to benefit from them. The reason is that the firm's ability to increase its profit will depend on the markets' structure and on the firm's capacity to exert its market power (if there exists). Hence, the very existence and the implementation of no-regret options are not only a matter of technological choice but also a matter of adequate internal management considering the markets' structure. Another natural extension would concern policy implications. These are threefold. First, there should be a serious re-examination of macroeconomic costs of pollution abatement in the case where net benefits can be expected in some sectors or firms. Second, the existence of no-regret measures would certainly question the relative efficiency of policy instruments. In particular this may provide a rational to the firms' participation in voluntary pollution abatement programmes[5]. These ones should be chosen so as to extract this potential as much as possible, whenever it exists. Third, and finally, the capture of this rent raises redistributive issues among firms.

[5] An assessment of these programmes has been made by the OECD: see OECD (2003).

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Figure 1: The maximal potential benefit

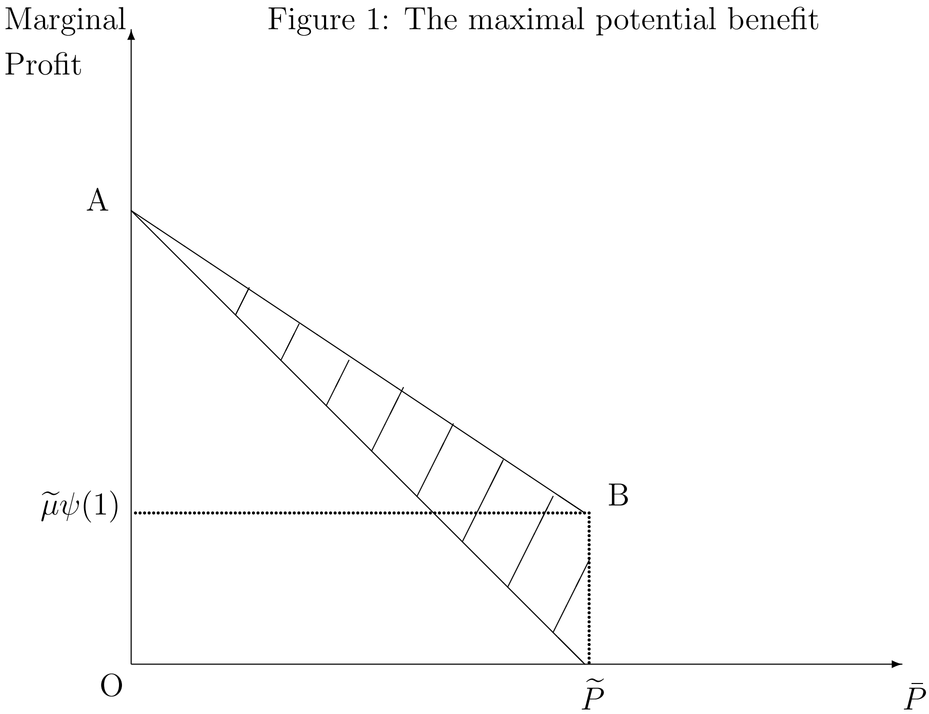

Figure 2: The no-regret case