105

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ANALYSIS

Why environmental management may yield no-regret pollution abatement options

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ABSTRACT

Empirical evidence supports 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 level. An econometric application confirms that pollution abatement cost curves with no-regret options are compatible with a standard production function, as stated in our theoretical model.

1. Introduction

In this paper we provide a microeconomic rationale for the existence of 'no-regret pollution abatement options' at the firm level, that is, less pollution with higher profits.

Many studies provide empirical evidence for such options, but most of them at country or sectoral levels, rarely at the firm level. The potential of no-regret opportunities to reduce greenhouse gas 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 identified no-regret options in most countries.[1] Another example is a study

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

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undertaken by the German Fraunhoer Institute for the Belgian Federal Government: it established that Belgium could meet its Kyoto commitment (*i.e.* a 7.5% abatement by 2010 compared to the 1990's level) by negative or zero cost measures. A comprehensive empirical analysis at the firm level is provided 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), although only one of the 162 measures reported costs-savings larger enough to outweigh the costs.

The fact that most economists feel uncomfortable with the very existence of no-regret options cannot be overlooked, for it seems to conflict with the assumption of rational behavior. Standard microeconomic theory fails to explain 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 already have picked them up. As stressed out by Palmer et al. (1995) in the same journal, the point 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 of a few empirical examples.

When looking for empirical evidence for no-regret options the debate rapidly encounters methodological issues. How do engineers calculate abatement costs? Is it consistent with economic concepts? Answering the first question goes beyond the scope of this paper (although, the World Bank project discussed above constitutes a good example of transparent and publicly available methodology). Stoft (1995) is probably the only author who has tried to tackle the second question by developing a framework to reconciliate the economists' concept of production function with marginal abatement cost curves as constructed by engineers. However, Stoft assumed without justification that the firm was below its production frontier, thus introducing *ad hoc* no-regret abatement options at the firm level.

Two main strands of economic literature are 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 level to determine the best production frontier and calculate the distance between each firm and this frontier. Some papers consider the joint production of good and bad outputs (see Färe et al., 1989 for example). An example of an application of this approach to investigate the Porter hypothesis is provided by Boyd and McClelland (1999). These studies can use either 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 have identified a number of reasons why the firm may *seem* inefficient, while being fully rational but facing some hidden costs, that is, costs which are neglected in standard static and deterministic analyzes. Such costs are related to, for example, uncertainty over future energy prices, technological lock-in effects, and uncertainty over the characteristics of equipment goods. A literature survey in the energy field can be found in Sorrel et al. (2004). However useful these analyses may be, they do not constitute a general rational for the possible existence of no-regret options at the firm level.

Our paper provides, within a standard static microeconomic framework, a rationale for no-regret options to exist, even though these options are likely to appear only in very specific contexts or in some firms. The issue is to understand the context in which these options may appear.

Our cornerstone is that the environment operates as a hidden–and, thus, neglected–productive factor within the production process, along with the usual production factors, capital and labor. By neglecting this productive factor, the firm may bear an opportunity cost. In other words, by considering how the environment interacts with the other production factors within its processes, the firm may be able to improve its *global* productivity. Taking pollution into account within the whole optimization process can be seen as a way of enlarging the production set of the firm, which may leave room for productive improvements. The fact that the environmental dimension cannot be separate from the economic one within the firm is clearly expressed by the U.S. Environmental Agency when it defines Environmental Management System as "a set of processes and practices that enable an organization to reduce its environmental impacts and increase its operating efficiency".[2] In the context of information programs for technology adoption for energy efficiency, Anderson and Newell (2004) give empirical evidence of this kind of effect and provide the following rationale: "by expanding the perceived range of investment opportunities available to firms, information programs may lead to the adoption of profitable but previously unimplemented technologies" (Anderson and Newell (2004), page 29). The same argument applies to our context. We show how environmental management sheds light on the productive contribution of the environment in the firm, and why this *may lead* to higher profits. Like Anderson and Newell we emphasize the words *may lead*, because even though such options do exist at the firm level, this does not mean that the firm will necessarily be able to benefit from them. Using our theoretical framework we provide a graphical illustration (in the spirit of Stoft, 1995). We also provide empirical evidence with an econometric application to the glass industry in Wallonia (Belgium).

The objective of our paper is not to provide a rationale for the Porter hypothesis, *i.e.* the hypothesis that tightening environmental standards may increase firms' profits.[3] Instead, we show that pollution abatement is always costly but that implementing internal environmental management may lead to increases in factors' productivity. When comparing situations with and without environmental management, a firm may gain from going green, which is called a no-regret option. The debate on no-regret options is wider than the debate on the Porter hypothesis: it represents one possible explanation of the hypothesis, but it also has a wider scope. It is clear that the possibility of such options has 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's (2005) survey). This is something that will be discussed further below.

[2] See: www.epa.gov/EMS/.

[3] A vast literature has been devoted to the Porter hypothesis (see Ambec and Barla (2005) or Wagner (2004)).

The remainder of the article is organized as follows. Section 2 analyzes the effects of environmental management in firms. The existence of an opportunity cost related to the fact that pollution constitutes a productive factor for the firm is proved. Then, Section 3 defines no-regret pollution abatement options properly. The econometric application is provided in Section 4. The link between no-regret options and the Porter hypothesis is discussed in Section 5. Section 6 concludes.

2. The effects of environmental management

Let us consider a profit-maximizing firm. This firm pays no attention to the pollution caused by its productive activity for two reasons. First, in the absence of public environmental regulation polluting is free of charge. Why should the firm bother about its pollutant effluents since they can be disposed of free of charge? Second, pollution causes damages that are external to the firm. We call this situation *laissez-faire*. Until recently, *laissez-faire* was common for many pollutants for which even a reporting was not mandatory.[4] It still prevails today for some pollutants, some activity sectors and some firms (*e.g.* carbon dioxide emissions in sectors such as transportation, dwellings and market services are largely unregulated.).

We will analyze what happens when firms take the environment into account. There are many motives for this, for example societal pressures, concerns for corporate social responsibility, and the threat of public environmental regulation. We assume that the firm implements an Environmental Management System and hires an environmental manager. This situation is one than many firms face today, as green awareness becomes widespread. In contrast to the *laissez-faire* situation, the firm is now eager to monitor its emission level and to clearly understand its potential ability to curb these emissions. Firm's ignorance of the environmental impact of their activities must not be underestimated, but nor must their current desire to increase their awareness. Several large international consultancy agencies now offer their services to help firms assess their pollution level and scrutinize their abatement opportunities.

This is the key step we are interested in. What happens at the firm level when the firm moves from ignorance to awareness about the role of the environment in its production process? To be more precise, we are interested in the productive implications of that discover. To that end, we make use of a standard microeconomic setting.

2.1. Production technology and pollution

Let us assume perfect competition on input and output markets. The firm produces an homogeneous good taken as numeraire with an increasing, concave and homogeneous of degree one production function $F(X)$, where X is the vector of N production factors, $X=\{X_1,\ldots,X_N\}$. Under *laissez-faire* the output level is $\tilde{Y}$. This activity results in the emission of a pollutant in quantity $\hat{P}=\varphi\hat{Y}$ $(\varphi>0)$, pollutant which is neglected by the firm. Let us assume that this pollution output ratio φ can be considered from a technological viewpoint as an increasing continuous function $\varphi(z)$ of a technological index z,

$$\varphi(z) = \frac{P}{Y} \quad (1)$$

In the literature $\varphi(z)$ is also referred to as the firm's emission-intensity. Without loss of generality we assume that the function $\varphi(.)$ is defined and inversible on $\mathbb{R}^+$. The cost of pollution abatement is expressed in terms of output losses by choosing the index z applied to the output level (Stokey, 1998). The abatement cost is given by $(1-z)F(X)$ and defined in $[0,F(X)]$, *i.e* $z \in [0,1]$ and the output net of abatement costs is given by,

$$Y = zF(X) \quad (2)$$

Thus, for a given z, pollution level is defined by

$$P = \varphi(z)zF(X) = \psi(z)F(X) \quad (3)$$

where the function $\psi(z)$ is defined and inversible on $\mathbb{R}^+$.

The modeling *à la* Stokey (1998) allows us to easily compare the two situations, with and without environmental management. Eliminating z between (1) and (2) and using the function $\psi(z)$ allows us to define a $(N+1)$-factor production function Φ, homogeneous of degree one, in which pollution appears as an input for production,

$$\Phi(X,P) = \psi^{-1}\left(\frac{P}{F(X)}\right)F(X) \quad (4)$$

Thus, the production function changes depending on whether environmental management is operative ($z \leqslant 1$) 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

Let us now turn to the firm's optimal behavior under the two situations. Under *laissez-faire*, output level is given by the N-factor production function $\hat{Y}=F(X)$. Because of perfect competition the vector of input prices $p=\{p_1,\ldots,p_N\}$ is given and the firm's programme writes

$$\max_{\{X\}}\pi = F(X) - pX \quad (5)$$

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

Under environmental management the firm is willing to reach an emission target $\bar{P}$. This target may be set up internally (by the firm itself) or externally (by the regulator, shareholders, stakeholders…). It is natural to assume that the pollution target must not outreach the *laissez-faire* pollution level, but it could also be equal to that level. Formally, this boils down to assume that $0<\bar{P}\leq\tilde{P}$. To tackle this target the firm hires an

[4] In Europe, it is only recently that comprehensive pollutant monitoring procedures have been generalized. For example, the first reporting year for the European Pollutant Emission Register (EPER) is 2001 (see: http://eper.ec.europa.eu).

environmental manager whose mission is twofold.[5] First, she/he has to report the actual emission level, *i.e.* the one under the *laissez-faire*. Second, she/he has to identify the technological opportunities that may allow the firm to reach the pollution target. These technological opportunities are represented by the function $\psi(z)=\varphi(z)z$ of the technological index z. The idea that firm's emission level P must not exceed the target $\bar{P}$ is formally expressed by the constraint $P\leq\bar{P}$. Using (3) this constraint can be re-written as $\varphi(z)zF(x)\leq\bar{P}$. Hence, under environmental management the problem of the firm now writes as follows,

$$\begin{cases} \max_{\{X,z\}} \pi = zF(X) - pX \\ \text{s.t. } \varphi(z)zF(X) \leq \bar{P} \end{cases} \tag{6}$$

We denote by μ the Lagrangian multiplier associated to the constraint and, by using the function $\psi(z)$,[6] the Lagrangian writes

$$\mathcal{L} = zF(X) - pX + \mu\left(\bar{P} - \psi(z)F(X)\right) \tag{7}$$

The value of X and z solutions of this problem are solutions of the following first-order conditions,

$$(z - \mu\psi(z))F_{X_i}(X) = p_i, \quad \forall i \in N \tag{8}$$

$$1 - \mu\psi'(z) \leq 0, (= 0 \text{ if } z<1) \tag{9}$$

$$\mu\left(\bar{P} - \psi(z)F(X)\right) = 0 \tag{10}$$

By fulfilling her job the environmental manager reveals that pollution operates as a hidden factor inside the firm's productive process, for it influences the productivity of all the production factors. This influence is identified as the multiplicative term $z-\mu\psi(z)$ in the first-order conditions. Because of this term, the marginal productivity of the production factors differs from their price, which is given to the firm.

The function $z-\mu\psi(z)$ is concave and its derivative is positive at $z=0$ (Jouvet, Michel and Rotillon, 2005). Thus, the contribution of pollution as a productive factor is embodied through all the other production factors' contribution. In the case where the emission target coincides with the emission level under *laissez-faire*, *i.e.* $\bar{P}=\tilde{P}$, there exists a range $[0,\tilde{\mu}]$ of alues of μ compatible with this pollution target. As long as $0\leq\mu\leq\tilde{\mu}$, $z=1$ and all factors' levels remain the same as under *laissez-faire*, $\tilde{X}$.

Furthermore, by considering relation (9) it appears that the highest value of μ compatible with $P=\bar{P}=\tilde{P}$ reads as follows,

$$\tilde{\mu} = \frac{1}{\psi'(1)} \tag{11}$$

Knowing the value of $\tilde{\mu}$ and using Eq. (8) the maximal impact of the environmental factor on the marginal productivity of input X_i ($\forall i \in N$) is given by $(1-\tilde{\mu}\psi(1))$.

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 the environment opens the door to a revaluation of the productive contribution of all production factors X_i. This productive contribution is valued (at most) by the multiplicative term $1-\tilde{\mu}\psi(1)$. Since the actual marginal productivity of the production factors is lower than their cost, there exists an opportunity cost associated with the fact that the environment was neglected by the firm. Consequently, the implementation of the Environmental Management System may lead to a profit increase in the firm. This is summarized in the following proposition.

Proposition 1. *By implementing an Environmental Management System a firm may experience a profit increase. The upper-bound profit increase is* $\tilde{\Omega}=\tilde{\mu}\psi(1)F(\tilde{X})$.

At this stage of the paper it is important to stress that the issue is not about emission reduction. What makes the profit increases is the re-optimization of the productive combination of all factors after having discovered the productive contribution of the environment. By implementing an Environmental Management System the firm is susceptible to increase its profit level compared to *laissez-faire*. This profit increase is maximal when pollution is unabated, for pollution abatement always entails a cost to the firm.

3. No-regret pollution abatement options

What may happen if the firm intended to curb its pollution level below *laissez-faire*? The issue now consists in comparing the potential profit increase yielded by the Environmental Management System to the cost associated with pollution abatement. In that purpose, let us define the *genuine abatement cost*, $\Lambda(P)$: it is given by the difference between the potential benefit raised by the environmental management ($\tilde{\Omega}$) and the abatement cost, which is formally written as $(1-z)F(X)$, for all $z \in (0,1)$. By combining these expressions the *genuine abatement cost* is written as,

$$\Lambda(P) = (1-z)F(X) - \tilde{\Omega} \Leftrightarrow \left(1 - z - \frac{\psi(1)}{\psi'(1)}\right)F(X), \forall P<\tilde{P} \tag{12}$$

By definition, $z = \psi^{-1}\left(\frac{P}{F(X)}\right)$. Thus, there exists a unique $\hat{P}<\tilde{P}$ such that $\Lambda(\hat{P})=0$. It is given by $\hat{z} = 1-\frac{\psi(1)}{\psi'(1)}$. This leads to the following proposition, which proves the existence of no-regret pollution abatement options.

Proposition 2. *When proposition 1 holds, then, in comparison with laissez-faire, a pollution abatement rate up to* $\hat{z} = 1-\frac{\psi(1)}{\psi'(1)}$ *is compatible with higher profits*.

For small pollution abatement levels the genuine abatement cost $\Lambda(P)$ is negative because the benefits raised by the environmental management exceed the abatement cost. This holds up to $\hat{z}$. In this case the firm reduces its pollution level but its profit is still higher than under *laissez-faire*, a typical no-regret option. Yet, since the abatement cost is strictly increasing with pollution abatement, and since the potential benefit $\tilde{\Omega}$ is strictly smaller than the total profit, there necessarily exists a unique pollution level $0<\hat{P}<\tilde{P}$ (and a

[5] In our analysis we neglect the hiring and wage costs of the environmental manager, thus considering these costs as negligible in comparison with the firm's total production cost. Considering a positive cost would not change the outcome of the analysis.

[6] We thank a reviewer for having pointed out the right interpretation of function ψ (z).

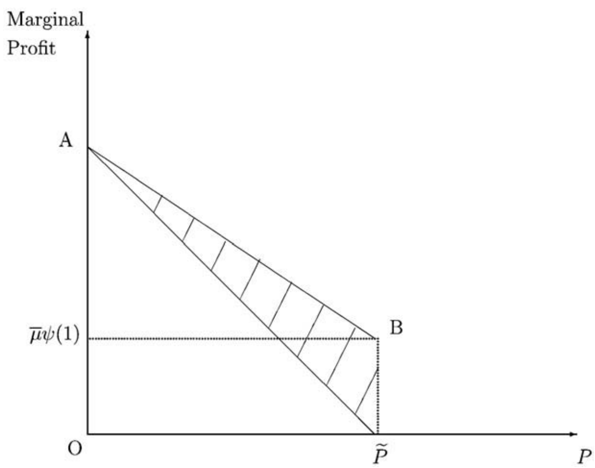

Fig. 1 – The maximal potential benefit.

unique abatement rate $0 < \hat{z} < 1$) such that the two arguments of the Λ function coincide. At that point the firm is indifferent between *laissez-faire* (with a pollution level $P=\tilde{P}$) and the situation with environmental management (with a pollution level $P=\overline{P}<\tilde{P}$). More stringent pollution abatement rates would yield a positive global cost to the firm.

As already stressed, the firm always bears a cost when pollution is abated. So the firm will always prefer not to abate pollution in the absence of binding public pollution regulation. But the very existence of the higher profits due to the environmental management makes pollution abatement less harmful. Up to the abatement rate $\tilde{z}$, the firm is better-off.

A graphical illustration is given in Fig. 1. The *x*-axis represents the emission level while the *y*-axis represents the marginal profit of the firm (for the sake of simplicity, linear functions are considered).[7] In the *laissez-faire*, the pollution level is ($\tilde{P}$) and the firm's profit is given by the area $OA\tilde{P}$. After having implemented the Environmental Management System the firm re-evaluates the marginal productivity of its production factors and the monetary value of the maximal potential benefit for this firm without changing emissions level is given by the area $AB\tilde{P}$. The vertical jump at $\overline{P}=\tilde{P}$ reflects that a discontinuity occurs and the size of this jump is given by $\tilde{\mu}\psi(1)$.

The building of the genuine abatement cost curve stems from the previous Figure. In Fig. 2 pollution abatement is indicated on the *x*-axis as $\Delta P=|\overline{P}-\tilde{P}|$ and the abatement cost, $\Lambda(|\overline{P}-\tilde{P}|)$, is shown on the *y*-axis. Because of the existence of no-regret options the abatement curve starts for negative values. Then, if the firm reduces its pollution level that cost increases, thus reducing the benefits raised by the Environmental Management System. The abatement threshold $\hat{P}$ is such that the genuine cost is nil. At that pollution level the firm is indifferent between *laissez-faire* and environmental management with pollution abatement.

Before proceeding further, the following example gives an explicit expression of that potential profit increase in the case of a Cobb–Douglas production function.

[7] This graphical illustration is widely used in the literature. Its rationale is fully explained in Bréchet and Jouvet (2008).

Example. The Cobb–Douglas case. The firm is price-taker and output is taken as numeraire. Consider a Cobb–Douglas production function $Y=AK^{\alpha}L^{1-\alpha}$ (with $0<\alpha<1$ and the pollution function $P/Y=\varphi z^{\beta}$ (with $0<z\leq 1$ and $\beta>0$). Under laissez-faire, $z=1$ and the pollution level is $\tilde{P}=\varphi\tilde{Y}$ (with $\varphi>0$). The cost of pollution abatement is $(1-z)AK^{\alpha}L^{1-\alpha}$. Under environmental management the pollution function becomes

$$\frac{P}{AK^{\alpha}L^{1-\alpha}} = \Psi(z) = \varphi z^{\beta+1} \tag{13}$$

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

$$z = \left(\frac{P}{\varphi AK^{\alpha}L^{1-\alpha}}\right)^{\frac{1}{1+\beta}} \tag{14}$$

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

$$\Phi(K,L,P) = \left(\frac{P}{\varphi}\right)^{\frac{1}{1+\beta}} A^{\frac{\beta}{1+\beta}} K^{\frac{\alpha\beta}{1+\beta}} L^{\frac{(1-\alpha)\beta}{1+\beta}} \tag{15}$$

The highest value of μ compatible with $z=1$ reads $\overline{\mu}=1/(\varphi(1+\beta))$. As long as $0\leq\mu\leq\overline{\mu}$, $z=1$ and both capital and labor levels remain unchanged with respect to the laissez-faire. While considering an emission target $\overline{P}$ such that $0<\overline{P}\leq\tilde{P}$, the firm's profit at the optimum is given by $\pi^{*}(\overline{P})=\Phi(K^{*},L^{*},\overline{P})-wL^{*}-RK^{*}$ with $L^{*}=\frac{(1-\alpha)\beta}{1+\beta}\frac{\Phi(K^{*},L^{*},\overline{P})}{w}$ and $K^{*}=\frac{\alpha\beta}{1+\beta}\frac{\Phi(K^{*},L^{*},\overline{P})}{R}$. Hence, the profit is positive and given by

$$\pi^{*}(\overline{P}) = \frac{1}{1+\beta}\Phi\left(K^{*},L^{*},\overline{P}\right) \tag{16}$$

This profit function is increasing in $\overline{P}$. Thus, reducing pollution is costly. It can easily be checked that $\lim_{\overline{P}\to\tilde{P}}\pi(P)=\tilde{\Omega}$: this gives the maximal profit increase in comparison with the laissez-faire when emission level remains unchanged. The abatement rate at which the genuine abatement cost is zero is $\hat{z}=\frac{\beta}{1+\beta}$.

4. An econometric application

In this section we apply our theoretical model to the glass industry in Wallonia (Belgium) by carrying out an econometric

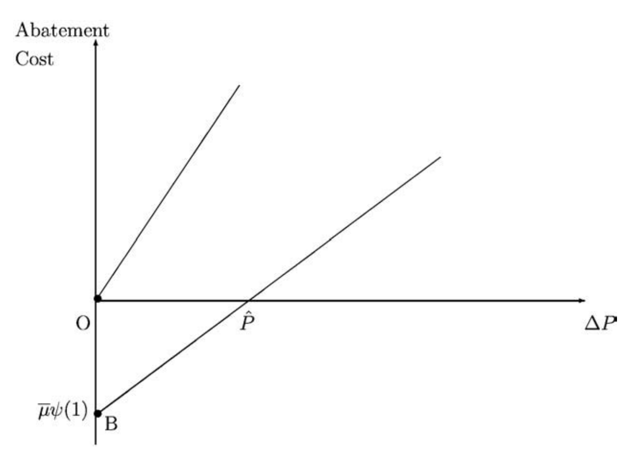

Fig. 2 – The no-regret case.

estimation. The dataset was established by ECONOTEC on behalf of the regional administration in charge of the environmental policy.[8] ECONOTEC provided us with a set of technological abatement measures for carbon dioxide emissions. On the basis on energy audits undertaken at the firms' level they identified (i) a set of technological options and, associated to each option, (ii) the fixed cost (expertise and investment cost) and (iii) the operational costs (labor costs, fuel costs and maintenance costs). For each measure the benefit in terms of carbon emission reduction is also calculated. These measures are then extrapolated at the branch level to have an idea of their global impact in terms of greenhouse emission abatement and private costs. Because long-lasting investments are sometimes involved, all the variables are calculated over a decade and then annualized. All monetary variables (fixed and operational costs) are expressed in 2010 units. Then, all the measures are ranked in increasing order of marginal cost. All in all, 32 abatement measures are available, of which four at a negative cost.

It is important to stress that these are actual data coming from energy audits carried out at the firm level. The data do not come from engineering forecasts. They represent a snapshot of the technological opportunities available for emission abatement in that industry today.

By using the Cobb–Douglas specification presented in Section 3, the cost of pollution abatement is given by

$$(1-z)F(K,L) = AK^{\alpha}L^{1-\alpha} - \left(\frac{P}{\varphi}\right)^{\frac{1}{1+\beta}} A^{\frac{\beta}{1+\beta}} K^{\frac{\alpha\beta}{1+\beta}} L^{\frac{(1-\alpha)\beta}{1+\beta}} \quad (17)$$

and the marginal abatement cost writes

$$MAC = -\frac{1}{1+\beta}\varphi^{-\frac{1}{1+\beta}} P^{-\frac{\beta}{1+\beta}} A^{\frac{\beta}{1+\beta}} K^{\frac{\alpha\beta}{1+\beta}} L^{\frac{(1-\alpha)\beta}{1+\beta}} \quad (18)$$

The marginal abatement cost curve to be estimated rises from Eq. (18),

$$\ln(-MAC) = \ln\theta - \theta\ln\varphi + (1-\theta)\ln A - (1-\theta)\ln P + (1-\theta)[\alpha\ln K + (1-\alpha)\ln L] \quad (19)$$

with $\theta-1/(1+\beta)$. Among the 32 measures identified by the energy audits in the glass industry, 4 have a negative cost. For that reason, a constant T is introduced in the left-hand side of the equation to be estimated to avoid a negative argument in the log function. Considering that θ, φ and A are parameters we can define the two following constants $\xi_1 = ln\theta - \theta ln\varphi + (1-\theta) lnA$ and $\xi_2 = (1-\theta)$. Finally, the equation to be estimated writes

$$ln(-MAC + T) = \xi_1 - \xi_2 lnP + \xi_2[\alpha lnK + (1-\alpha)lnL] + \varepsilon \quad (20)$$

where ε is the error term. Eq. (20) 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 $\tilde{\mu}$ 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 $\tilde{\Omega}$ associated with pollution abatement at negative costs amounts to 29% of the output value. We can also compute the value of $\hat{z}=0.77$. This means that firms may experience a profit increase if the pollution abatement rate does not exceed −23%.

[8] ECONOTEC is a consultancy agency specialized in energy audits and technico–economic evaluations in the field of energy and the environment (www.econotec.be).

5. No-regret options and the Porter hypothesis

In the debate about the relationship between environmental regulation and competitiveness, Porter and van der Linde (1995) introduced a new perspective by suggesting that both could be enhanced. This is now called *the Porter hypothesis*, and a vast literature is devoted to it. For recent surveys of the literature, see Barbera and McConnel (1990), Jaffe et al. (1995), Ambec and Barla (2005) and Wagner (2004).

By suggesting a *win–win* situation in the sense in which environmental regulation could improve both the quality of the environment and the firm's competitiveness, the Porter hypothesis rapidly came to the front of policy debates. However, it was strongly criticized by economists driven by the idea that if such opportunities existed, firms would not have to be triggered by an extra cost.

Many strands of economic theory have tried to justify the Porter hypothesis, with varying degree of success. In a dynamic context, Xepapadeas and de Zeeuw (1999) developed a model in which the downsizing and modernization of firms subject to environmental policy increases the average productivity and has positive effects on the marginal decrease in profits and environmental damage. Feichtinger et al. (2005) allowed for nonlinearities and generalized Xepapadeas and de Zeeuw's (1999) results. They determined scenarios in which their results do not apply, in particular when the acquisition cost of investment decreases with the age of the capital stock. They showed that, in the presence of learning, implementing a stricter environmental policy with the aim of reaching a certain target of emissions reduction has a strongly negative effect on industry profits. This implies quite the opposite of the Porter hypothesis. Mohr (2002) derived results consistent with Porter's hypothesis by employing a general equilibrium framework with a large number of agents, external economies of scale in production, and discrete changes in technology. He showed that endogenous technical change makes Porter's hypothesis feasible, but also that a policy that produces results consistent with Porter's hypothesis is not necessarily optimal. Ambec and Barla (2002) showed that, by reducing agency costs, an environmental regulation may enhance pollution-reducing innovation while at the same time increasing firm's private benefits.

It must be clear that our paper does not provide a rationale for the Porter hypothesis *as such*. What we have shown is that pollution abatement is always costly for the firm. The potential benefit for pollution management does not result from any external regulation but from the implementation of an in-house Environmental Management System which reveals potential increases in factor productivity. By comparing situations with and without environmental management, the firm may gain from going green (the so-called no-regret option) up to some pollution abatement level. The debate on no-regret options is thus wider than the debate on the Porter hypothesis. It provides, for example, a rationale for voluntary pollution abatement agreements.

6. Conclusion

In this paper we have provided a microeconomic rationale for no-regret pollution abatement options at the firm level, *i.e.* pollution reductions at negative costs. By recognizing that the environment is a production factor, we show how neglecting its interactions with the other production factors in the production process may constitute an opportunity cost for the firm. In other words, enlarging the production set with this polluting factor may lead to an increase in profits. Our 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 well stay on the floor of the cellar if there is nobody to switch on the light. Switching on the light is the environmental manager's job. 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 economic theory. So, in contrast to previous studies (essentially Porter and van der Linde (1995) and Stoft (1995)), our paper provides a framework for analyzing 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 extent, by the improvement of firm's global productivity when the Environmental Management System is implemented.

One avenue for further research is to analyze the firm's capacity to benefit from this opportunity cost. It may be that the firm identifies no-regret measures but is unable to benefit from them, because the firm's ability to increase its profit depends on the market structure and the firm's capacity to exert some market power. Hence, the existence and implementation of no-regret options are not only a matter of technological choice but also depend on adequate internal management, taking the market structure into account. Another natural extension concerns policy implications. These are threefold. First, there should be a serious re-examination of the macroeconomic costs of pollution abatement when net benefits can be expected in some sectors or firms. Second, the existence of no-regret measures certainly calls into question the relative efficiency of policy instruments. In particular it may provide a rational for the firms' participation in voluntary pollution abatement programmes, which should be chosen so as to extract as much as possible of this potential, whenever it exists.[9] Third, and finally, the capture of this rent raises redistributive issues among firms.

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

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