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A Note the Cost of Pollution Abatement*

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Environmental Innovation and the Cost of Pollution Abatement

Abstract

We show that the common assumption that innovation reduces the marginal abatement cost is wrong. We draw some implications about the incentives to innovate under environmental regulation. In particular, we find that adopting an environmental friendly technology may lead to more pollution and less profit at the firm level.

Keywords: innovation, pollution abatement cost, production function, environmental regulation

JEL codes: H23, L51

1 Introduction

It is widely acknowledged in the literature that environmental innovation reduces marginal pollution abatement costs. For example, Palmer *et al.* [7] claim that new pollution abatement technology reduces the marginal abatement cost at all pollution levels. More recently, Jaffe *et al.* [4] wrote that "technology innovations (...) typically reduce the marginal cost of achieving a given unit of pollution reduction". The same argument can also be found in Requate and Unold [8], Fischer *et al.* [3], Montero [6] and Xepapadeas [10], among other papers. Graphically, this is reflected by a decrease of the slope of the marginal abatement cost function (see Palmer *et al.*, [7]). Hence, when an emission fee is imposed, it is intuitively expected that the innovator will pay a lower tax amount and bear a lower total abatement cost. These two arguments thus provide an unambiguous incentive for polluters to adopt environmentally friendly technologies, and there exists an extensive literature comparing policy instruments with regard to their relative incentive to innovate, taking for granted the assumption that innovation reduces marginal abatement costs.

The objective of our paper is to question this assumption. In particular, we will show that the effects of innovation on profits may be ambiguous. Environmental innovation does not necessarily reduce the marginal cost of pollution abatement at all pollution levels. It may happen that the innovating firm pollutes more than the non-innovating one, depending on the policy instrument imposed by the regulator. The effect on profits can also be unexpected. As a consequence, some well-established implications concerning the incentive for innovation under environmental regulation should be reconsidered. This article extends the McKitrick's analysis (McKitrick [5]) of the analytical properties of marginal abatement cost functions in the case of environmental innovation.

The paper is organized as follows. In the next Section we present the firm and its technology, and we define environmental innovation. In Section 3 we set up the marginal abatement cost function and analyze how environmental innovation shapes this function. Section 4 discusses the implications under two environmental regulation regimes (command-and-control and tax). Our conclusions are presented in Section 5.

2 Marginal pollution abatement cost and innovation

Let us consider a firm producing an amount of output Y by using energy,E, and a vector of non-energy inputs, denoted X. We assume a well-behaved production function (increasing, concave and verifying the Inada conditions) $Y = F(X, E)$. The output is the numeraire. Pollution P results from energy combustion through a function $h(.)$ such that $P = h(E)$, where $h(.)$ is a twice continuously differentiable function with $h(0) = 0$ and $h^{'}(.) > 0$. We now consider environmental innovation.

Definition 1 *Environmental innovation is defined as a new pollution function,* $\widetilde{h}(.)$*, such that* $\widetilde{h}'(E) < h'(E)$*,* $\forall E \geq 0$*. This function has the following properties:* $\widetilde{h}(0) = 0$ *and* $\widetilde{h}'(E) > 0$*. It follows that* $\widetilde{h}(E) < h(E)$*,* $\forall E$*.*

This definition of environmental innovation is a very general one. It encompasses all particular specifications, such as the commonly used linear emission function. By adopting the innovation $\widetilde{h}(.)$ the firm reduces the pollution level of its energy consumption at the margin. This can be interpreted as adopting a new capital vintage with a lower pollution intensity or as slightly decreasing the pollution intensity of the whole energy consumption on all machines. From this definition the property that $\widetilde{h}(E) < h(E)$ stems naturally, which means that, on average, the pollution rate per unit of energy is also reduced, although to a lesser extent than at the margin. When pollution is taxed (see below), this specification is consistent with the standard assumption made in the industrial organization literature that innovation (broadly defined) reduces the marginal cost of production. In order to focus on the incentive to innovate, we will assume that innovation has no fixed costs.

Under perfect competition on all markets the program of the firm consists of maximizing its profit $\pi(X, E) = F(X, E) - p_X X - p_E E$ where p_X and p_E stand for input prices. The first-order conditions of this program give the optimal levels of inputs, X^* and E^*, and the optimal level of pollution, P^*.

We define the marginal abatement cost (MAC, hereafter) function as the loss of profit when pollution is reduced by one unit, all other things being equal (see McKitrick [5]). By substituting E by the inverse function $h^{-1}(P)$ in the firm's program we obtain the profit level as a function of P, $\forall P < P^*$. The MAC function is given by the derivative of this function and it writes,

$$MAC(P) \equiv \frac{\partial \pi(X^*(E), E)}{\partial P} = \frac{1}{h'(E)}\left(F_E - p_E\right) \tag{1}$$

where $X^*(E)$ stands for the optimal vector of inputs resulting from the maximization problem for any level of energy consumption. At the firm's optimum, (1) equals zero since $F_E = p_E$, and $P = P^*$. If a constraint $\overline{P}$ were to be imposed on pollution, $0 < \overline{P} < P^*$, then we would have $E < E^*$ and $F_E - p_E > 0$ and the firm would bear a profit loss, the marginal loss being given by (1). The slope of this function is

$$\frac{MAC(P)}{\partial P} \equiv \frac{\partial^2 \pi}{\partial P^2} = \frac{1}{[h'(E)]^2}\left(F_{EE} - \left(F_E - p_E\right)\frac{h''(E)}{h'(E)}\right) \tag{2}$$

If $h(.)$ is convex, then $\partial^2\pi/\partial P^2 < 0$ and the marginal abatement cost function is strictly decreasing. If $h(.)$ is concave, the marginal abatement cost function decreases from a positive value (since $\lim_{E\to 0}\partial\pi/\partial P > 0$) to zero where its slope is given by $\lim_{E\to E^*}\partial^2\pi/\partial P^2 = F_{EE}/[h'(E)]^2 < 0$.

These two equations allow us to see how environmental innovation shapes the MAC function. Firstly, innovation reduces the optimal pollution level in the *laissez-faire*: since $\widetilde{h}(E) < h(E)$, $\forall E > 0$, then $\widetilde{P} = \widetilde{h}(E^*) < P^* = h(E^*)$, where $\widetilde{P}$ is the pollution level solution of the firm's maximization problem after innovation. This gives the motivation of the firm to innovate, lowering its pollution level, but notice that this is not necessarily the case for all energy consumption level. Secondly, the *slope* of the MAC function is also modified. At the optimal pollution level this slope is unambiguously greater (in absolute terms) after innovation than before since $\lim\limits_{E\to E^*} \partial^2\pi/\partial P^2 = F_{EE}/[h'(E)]^2 > \lim\limits_{E\to E^*} \partial^2\widetilde{\pi}/\partial P^2 = F_{EE}/[\widetilde{h}'(E)]^2$. However, because of the cross-elasticities among production factors, this does not necessarily hold for every pollution or energy level lower than E^*. It may be that, for some pollution levels, the slope of the MAC function after innovation is greater than before innovation, or the reverse. In other words, the innovating firm may face higher marginal abatement costs if it has to reduce pollution below its optimal level in the absence of environmental regulation, although this may change for further abatements.

The following proposition summarizes the impact of environmental innovation on the MAC function in the general case.

Proposition 2 *Adopting environmental innovation leads to a lower optimal pollution level in the absence of environmental regulation and a steeper marginal abatement cost curve at this pollution level.*

Thus, the common assumption that environmental innovation reduces the marginal abatement cost is far from always being true. Moreover, the usual graphical representation of the impact of innovation on a MAC function, as proposed by many articles in the literature, is misleading. We illustrate this with two examples.

Example 3 ***: the linear case.*** *Let the production function be* $y = \sqrt{x}$ *and pollution given by* $p = \alpha y$*, with* $\alpha = 1$ *and* $\widetilde{\alpha} = 0.5$*. All prices are equal to unity. Figure 1 displays the two MAC functions.*

Example 4 ***: the non-linear case****. Let the production function be* $y = \sqrt{x}$ *and pollution given by* $p = y^{\alpha}$*, with* $\alpha = 1.5$ *and* $\widetilde{\alpha} = 1.1$*. All prices are equal to unity. Figure 2 displays the two MAC functions.*

*** Insert Figure 1 and Figure 2 ***

In the linear case (Fig. 1), the two MAC functions have the following properties. They cross each other once and the areas below these two functions are equal (they represent the firm's total profit). Innovation increases (in absolute terms) the slope of the MAC function. For low pollution levels, the marginal abatement cost is higher after innovation. In the non-linear case, the functions cross twice. Innovation increases (in absolute terms) the slope of the MAC function when pollution is close to its optimal level without regulation, but it reduces it (in absolute terms) for lower pollution levels. The marginal abatement cost is higher after innovation for medium pollution levels.

3 Policy implications: incentives to innovate under pollution regulation

In this section we compare the incentives for a firm to adopt a more environmentally friendly technology when pollution is regulated. To this end we consider two firms with the same production function $F(X, E)$ but two different pollution functions, $h(.)$ and $\widetilde{h}(.)$. We shall naturally call the former firm the *dirty firm* and the latter one the *clean firm.* We still assume that the fixed cost of innovation is zero. Calling the situation without environmental regulation *laissez faire* we successively analyze the effects of command-and-control and tax regulation.[1]

3.1 Command-and-control regulation

Let us first consider the case of a quota on pollution. If this quota is expressed with respect to the firm's unregulated pollution level, then the abatement cost will unambiguously always be higher for the clean firm than for the dirty one. This holds regardless of whether the quota is expressed in relative terms (*e.g.* a 10 pc reduction w.r.t. *laissez faire*) or in absolute terms (*e.g.* x tons reduction). This results from the fact that, starting from a lower pollution

[1]One straightforward implication of our results concerns the choice of policy instrument under uncertainty (prices versus quantities), as shown by Weitzman [10], since innovation modifies the slope of the marginal abatement cost curve. This will not be discussed here.

level due to a more efficient technology, the clean firm faces higher marginal abatement costs than the dirty one when further abatement is imposed. In this case, there is a clear disincentive for the firm to innovate. If the pollution quota is set at the same level for the two firms, independently of the pollution level under *laissez-faire*, then the clean firm will lose less profit than the dirty one. The main conclusion is that command-and-control measures based on current practices (such as benchmarking procedures or grand-fathering) clearly provide no incentive for environmental innovation.[2]

3.2 Tax regulation

Let us now consider a uniform tax τ on pollution. The firm's profit (*e.g.* for the dirty firm) writes $\pi^{\tau} = F(X, E) - p_X X - p_E E - \tau h(E)$. The first-order condition on E for the two firms becomes $F_E - \tau h^{'}(E^{\tau}) = p_E$ and $F_E - \tau \widetilde{h}'(\widetilde{E}^{\tau}) = p_E$, where $E^{\tau}$and $\widetilde{E}^{\tau}$denote the optimal energy demand under the tax regulation. Since the two firms face the same energy price and since $\widetilde{h}'(.) < h^{'}(.)$, $\forall E$, $\widetilde{E}^{\tau} > E^{\tau}$ if $F_{EE} - \tau h^{''}(E) < 0$. This holds under two conditions: firstly, if the pollution function $h(.)$ is not too convex[3], and, secondly, if the tax rate τ is not too high. This condition requires the profit

[2]Another well-known results is that, with heterogeneous firms, command-and-control regulation is not cost-efficient.

[3]For most pollutants and technologies this condition on $h(.)$ will hold. For carbon dioxide, for example, this function is linear, if single-fuel based, or concave, if multi-fuel based.

function under the tax regime to be concave with respect to pollution. What this condition reveals is that, in the general (non-linear) case, the shape of the profit function, and therefore the shape of the MAC functions, depends on the tax level. Let us use our examples to highlight some implications.

Even though the clean firm's pollution is lower than that of the dirty firm under *laissez-faire* it may become higher if the tax on pollution is high enough. In the linear case (Example 1) the threshold tax rate is given by the intersection of the two MACs ($\widehat{\tau}$ in Fig. 1). Despite this potential adverse effect (it means that the clean firm pays more tax than the dirty one), in the linear case the clean firm always gains from innovating because its total profit under the tax regime is always higher than that of the *dirty firm*. This shows that the firms' ranking in terms of environmental performance is influenced by the policy regime (see Bréchet and Michel [1] for a general discussion of environmental performance in an equilibrium setting). Things become much trickier in the non-linear case (Example 2). If the function $h(.)$ is highly convex then the fact that the clean firm gets a lower profit than the dirty one under the tax regime cannot be ruled out. Actually, when computing total profits with a tax on pollution in our example we find that the clean firm has a higher profit than the dirty one only for medium tax levels, *i.e.* $\tau \in (0.5,\ 1)$. Furthermore, the non-linear example reveals that introducing a tax on pollution not only moves the curve downwards (as in the linear case) but also alters its whole shape. As a consequence, the graphical analysis in which the optimal pollution level is given by the intersection between the tax rate and the MAC curve without tax (as in the linear case) is no longer valid.

4 Conclusion

In this paper we have shown that environmental innovation does not necessarily decrease the marginal cost of pollution abatement, as widely assumed in the literature. Actually, the marginal abatement cost function in the general case before and after innovation cannot be compared because the whole shape of this function is altered by policy instruments. Thus, the simple graphical analysis based on marginal abatement costs functions may lead to false conclusions[4]. Importantly, by comparing command-and-control regulation and emission fees we have shown that, in some cases, the incentive for environmental innovation is ambiguous in the sense that profit levels can

[4]Some applied studies also make use of MAC functions in the analysis of the carbon market, since the seminal paper by Ellerman and Decaux [2]. The MAC functions considered at the macro-level represent the marginal GDP loss incurred for any abatement constraint imposed on the whole economy and evaluated in a general equilibrium setting. Each point of the macro-MAC curve corresponds to a particular *counterfactual* general equilibrium of the economy expressed with respect to the initial equilibrium regarded as the *business-as-usual*scenario. Such functions should not be interpretated as micro-level abatement cost functions. All the studies involving applied macro-MAC functions assume that technological progress reduces the marginal abatement cost.

be lower after innovation. When a tax is imposed on pollution, it may be that the innovating firm (the clean one) gets a lower profit than the non-innovating firm (the dirty one). In the linear case, this cannot happen, but the clean firm may pollute more than the dirty one for strong abatement levels. Clearly, having reconsidered the effect of environmental innovation on pollution abatement costs yields unexpected results and opens the door for further researches.

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Figure 1: MAC functions in the linear case

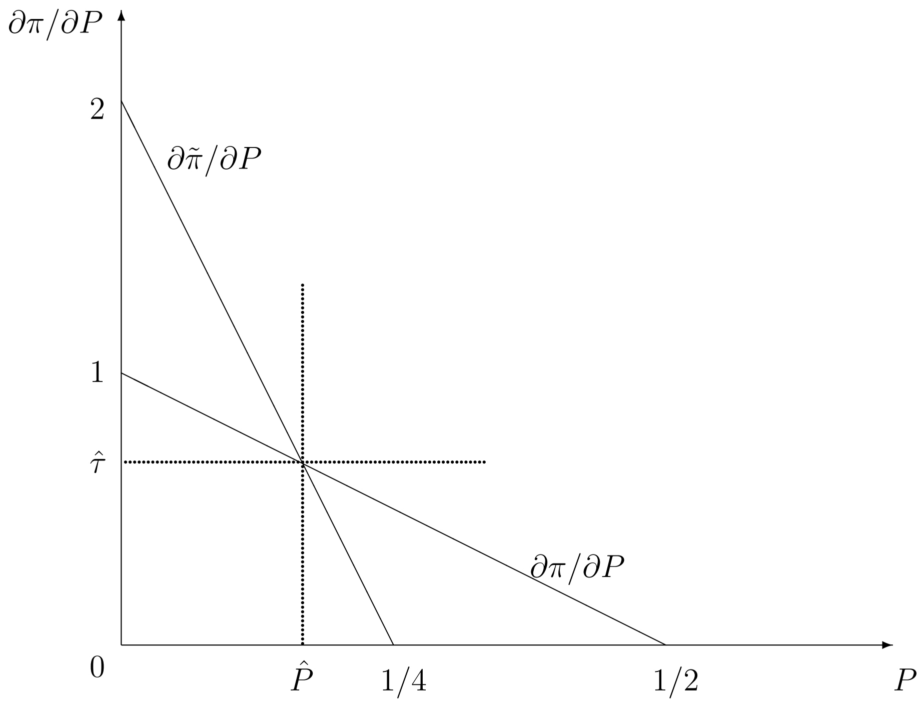

Figure 2: MAC functions in the non-linear case