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Environmental innovation and the cost of pollution abatement

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Abstract

It is widely acknowledged in the literature that environmental innovation reduces the marginal cost of pollution abatement. In this paper we show that this is not necessarily the case and provide some unexpected outcomes.

Keywords: innovation, pollution abatement cost, environmental regulation

JEL codes: H23, L51

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1 Introduction

It is widely acknowledged in the literature that environmental innovation reduces marginal pollution abatement costs. For example, Palmer *et al.* (1995) claim that new pollution abatement technology reduces the marginal abatement cost at all pollution levels. More recently, Jaffe *et al.* (2005) 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 Fischer *et al.* (2003), Montero (2002) or Xepapadeas (1997), among others. Graphically, this is reflected by a decrease of the slope of the marginal abatement cost function (see Fig 1.a in the next section). Requate and Unold (2003) explain that innovation shifts the marginal abatement cost function to the left but they keep its shape unchanged, which is only part of the overall impact, as we will show.

In all this literature it is intuitively and unambiguously expected that, when an emission fee is imposed the innovator will pay a lower tax amount and bear a lower total abatement cost. These two arguments provide a clear incentive for polluters to adopt environmentally friendly technologies. 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. Actually, environmental innovation does not necessarily reduce the marginal cost of pollution abatement.

The paper is organized as follows. It is enlighting to first show the impact of innovation on the abatement costs in a simple linear example (actually, the one used in many papers). This is done in the first section. Section 3 generalizes the result and the conclusion follows.

2 A simple counter-example

Most of the articles referred to in the introduction use linear marginal abatement costs and assume that environmental innovation reduces the marginal abatement cost for all pollution levels, which boils down to reduce the slope of the function, as shown in Fig. 1a taken from Palmer et al. (1995). In this particular case, showing that innovation actually does not necessarily reduce the marginal abatement cost is straightforward, just by going back to the theoretical model.

A firm produces an output y with a single input x; the production function writes $y = \sqrt{x}$. Pollution is given by $p = \alpha y$, with $\alpha > 0$. All markets are competitive and all prices equal to unity. The firm's profit function is $\pi = y - x = \frac{1}{\alpha}p - \frac{1}{\alpha^2}p^2$ and the marginal abatement cost (MAC) function reads

$$MAC(p) = \frac{\partial \pi}{\partial p} = \frac{1}{\alpha} - \frac{2}{\alpha^2}p \tag{1}$$

Taking $\alpha = 1$ gives the decreasing function displayed in Fig. 1a. Assume now that environmental innovation reduces the pollution - output ratio, so that $\alpha = 0.5$, for example. From equation (1) it is clear that the MAC function shifts left and that its slope increases. So, the marginal abatement cost is not necessarily lower after innovation for every pollution level. Actually, this marginal cost is higher after innovation for pollution levels smaller than $\overline{p}$, the point where the two functions cross each others.

Insert Figure 1 about here

Two other unexpected outcomes can be stressed out from this example. First, a motive generally advocated for a firm to innovate is to pay less environmental taxes. It is clear from Fig. 1a that, for any proportional tax imposed on pollution above $\bar{\tau}$, the firm pollutes more and, consequently, pays more environmental taxes after innovation than before [1]. Second, however, the firm will always get a higher profit after innovation if pollution is taxed. So, the tax incentive to innovate is preserved.

Do these results still hold in a more general case?

3 Generalization

Let us consider a firm producing a desired output y by using a set of inputs $\mathbf{x} = \{x_1, ...x_N\}$ and a technology represented by a *production function* $f(\mathbf{x}) : \mathrm{R}_+ \rightarrow \mathrm{R}_+$. This function is increasing, strictly concave and verifies the Inada conditions. The firm also generates a set $\mathbf{p} = \{p_1, ...p_P\}$ of undesired outputs, namely polluting effluents. Some inputs may pollute (*e.g.*, the use of fossil fuels), some may not (*e.g.*, human knowledge) and some may reduce pollution (*e.g.*, the use of and environmental management system). Moreover, each input may give rise to many pollutants and each pollutant may flow from many inputs[2]. Let i be the index of inputs and j be the index of pollutants. The amount of pollutant p_j coming from the input x_i is noted p_{ij}. Thus, wee have that $p_j = \sum_i p_{ij}$. The pollutant p_{ij} is given by a *pollution function*

[1] This questions the issue of environmental performance. See Bréchet and Michel (2004) for a specific discussion on that point.

[2] As an example, coal combustion gives rise, among other pollutants, to the emission of CO_2, SO_2, NO_x and dust. Carbon emissions come from the combustion of all fossil fuels (liquid, gaseous and solid) but also, in some industries, from the process itself (e.g. cement, lime, steel...)

$h_{ij}(x_i) : \mathrm{R}_+ \rightarrow \mathrm{R}$, such that $p_{ij} = h_{ij}(x_i)$. For a polluting input this function has the following properties: it is inversible, $h_{ij}(0) = 0$, $h_{ij}(x_i) > 0$ and $h'_{ij}(x_i) > 0$.[3]

The output is the numeraire. The price vector for the inputs is $\mathbf{q} = \{q_1, ...q_N\}$. All markets are competitive. Without pollution constraint the program of the firm writes

$$\max_{\{\mathbf{x}\}} \pi(\mathbf{x}) = f(\mathbf{x}) - \mathbf{q}\mathbf{x} \tag{2}$$

which results in a unique solution, $\mathbf{x}^o$ and $\mathbf{p}^o = h(\mathbf{x}^o)$, referred to as the *laissez-faire.*

Let us note $\Omega_{ij}(p_{ij})$ the marginal abatement cost function related to pollutant p_{ij}. This function is defined for all $p_{ij} \in (0, p^o_{ij})$, where p^o_{ij} stands for the firm's optimal level of pollution under *laissez-faire.* This function gives the profit loss incurred when pollutant p_{ij} has to be reduced by one unit, all other things being equal. By substituting x_i by the inverse function $h^{-1}_{ij}(p_{ij})$ in the firm's program we obtain the profit level as a function of p^j_i, $\forall p_{ij} \in (0, p^o_{ij})$. The marginal abatement cost function $\Omega_{ij}(p_{ij})$ is given by the derivative of this profit function and it writes:

$$\Omega_{ij}(p_{ij}) \equiv \frac{\partial \pi}{\partial p_{ij}} = \frac{f'(x_i) - q_i}{h'_{ij}(x_i)} \tag{3}$$

At the firm's optimum under *laissez-faire* equation (3) equals zero since $f'(x_i) = q_i$, $\forall i$, which results in a pollution level $p_{ij} = p^o_{ij}$. If a restriction $\overline{p}_{ij}$ were imposed on pollution such that $0 < \overline{p}_{ij} < p^o_{ij}$, then the maximization problem would lead to an optimal input level x^*_i such that $x^*_i < x^o_i$. As a consequence, $f'(x_i) > q_i$ and the firm would experience a profit loss, the marginal abatement cost being given by equation (3).

We can now define environmental innovation when applied to polluting inputs.

Definition *Environmental innovation leads to a new pollution function, $\widetilde{h}_{ij}(x_i)$. This function has the same properties as $h_{ij}(x_{ij})$, except that $0 < \widetilde{h}'_{ij}(x_i) < h'_{ij}(x_i)$, for all polluting input x_i.*

Environmental innovation reduces the marginal pollution intensity of the production process. In other words, an increase in output will lead to a lower increase in pollution after innovation. This also means that the marginal productivity of pollution is higher after innovation. Under our definition of environmental innovation, the assumption that $\widetilde{h}_{ij}(0) = h_{ij}(0) = 0$ yields $\widetilde{h}_{ij}(x_i) < h_{ij}(x_i)$, for all polluting input. So, innovation also reduces the total amount of pollution. Stemming from

[3] For the other productive inputs this function has the following properties. If the input is non-polluting, $h_{ij}(x_i) = 0$. If the input is depolluting, $h_{ij}(x_i) < 0$ and $h'_{ij}(x_i) < 0$.

the definition of the *pollution function*, this definition of environmental innovation is also a very general one. It can represent, for instance, improvements of some inputs' efficiency, end-of-pipe devices or process innovations.

In order to focus on the incentive to innovate we assume that innovation has no fixed cost.

We are now able to analyze how environmental innovation shapes the marginal abatement cost function. Let us note the marginal abatement cost function after environmental innovation $\widetilde{\Omega}_{ij}(p_{ij})$. The issue is to check whether $\widetilde{\Omega}_{ij}(p_{ij})$ is smaller or greater than $\Omega_{ij}(p_{ij})$, $\forall p_{ij} \in (0, p^o_{ij})$. This is be done by comparing equation (3) before and after environmental innovation. It leads to the following proposition.

Proposition *For every pollution level below the optimal one after innovation, environmental innovation decreases (resp. increases) the marginal pollution abatement cost if the decrease of the pollution intensity is large enough (resp. small enough) compared to the increase of the marginal productivity of pollution.*

Proof *We want to compare $\Omega_{ij}(p_{ij})$ and $\widetilde{\Omega}_{ij}(p_{ij})$ for a given $p_{ij} \in (0, \widetilde{p}^o_{ij})$. We know that $\widetilde{p}_{ij} = \widetilde{h}_{ij}(x_i) < p_{ij} = h_{ij}(x_i)$, $\forall i$. It follows that, for any given $p_{ij} \in (0, \widetilde{p}^o_{ij})$, $\widetilde{x}_i = \widetilde{h}^{-1}_{ij}(p_{ij}) > x_i = h^{-1}_{ij}(p_{ij})$. So the numerator of $\widetilde{\Omega}_{ij}(p_{ij})$ is smaller than the one of $\Omega_{ij}(p_{ij})$. As for the denominator, the one of $\widetilde{\Omega}_{ij}(p_{ij})$ is smaller or greater than the one of $\Omega_{ij}(p_{ij})$ depending on whether $\widetilde{h}'_{ij}(\widetilde{x}_i(p_{ij}))$ is greater or smaller than $h'_{ij}(x_i(p_{ij}))$, $\forall p_{ij} \in (0, \widetilde{p}^o_{ij})$.*

The impact of innovation on the abatement cost is twofold. On the one hand, it reduces the pollution intensity of production in the *laissez-faire* (since $\widetilde{p}^o_{ij} = \widetilde{h}_{ij}(x^o_i) < p^o_{ij} = h_{ij}(x^o_i)$), and for any output levels below, but, on the other hand, it increases the marginal productivity of pollution, thus making the MAC function steeper. The linear example presented in the previous section clearly shows that, the smaller the first effect, the smaller the possibility that the marginal abatement cost is reduced after innovation. In the general case, however, one cannot be sure that the slope is always higher after innovation for every pollution levels: it also depends on how innovation alters the second derivative of the pollution function. Finally, in the general case it may happen, as in the example, that the innovating firm pollutes more when a tax is imposed on pollution.

4 Conclusion

In this paper we have shown that, as widely assumed in the literature, environmental innovation does not necessarily reduce the marginal cost of pollution abatement.

Moreover, we have shown with an example that, under environmental regulation (an emission tax), a firm may be worse-off after innovation. These results may have many implications on major policy issues. In particular, it calls for revisiting the ranking of environmental policy instruments (permits, taxes and standard) about their incentive to innovate.

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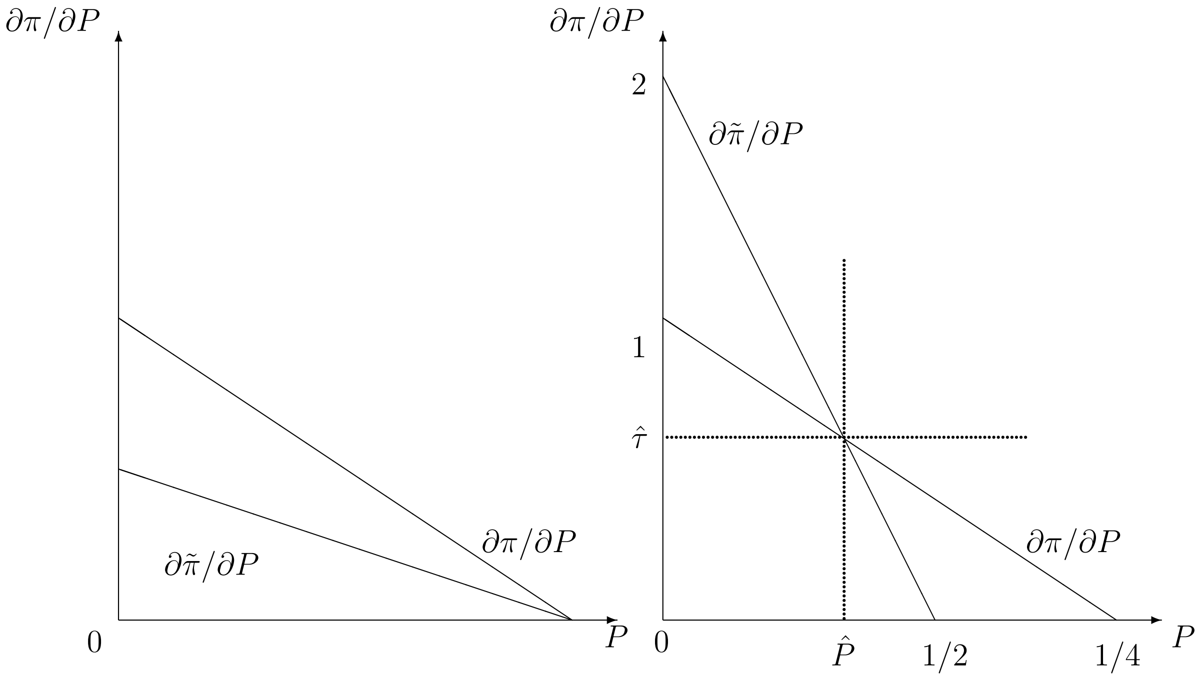
Figure 1. The effect of innovation on the MAC function



a: According to Palmer *et al.* (1995) b: The adequate representation

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