

Innovation under taxes versus permits: how a commonly made assumption leads to misleading policy recommendations*

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Abstract

The literature on the impact of economic instruments (typically taxes and tradable permits) on the level of innovation is usually based on the assumption that innovation reduces the slope of the marginal abatement cost curve. This assumption, which usually leads to the conclusion that taxes induce higher levels of innovation than tradable permits, is however never motivated. In this short article, we analyse the assumption by introducing innovation in the production function of a polluting firm and by showing how it affects the corresponding marginal abatement cost curve. We show that the slope of the marginal abatement cost curve does not necessarily decrease with the level of innovation. As a consequence, previous analyses lead to misleading policy recommendations.

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1 Introduction

Since the seminal contribution by Weitzman (1974), the debate on whether polluting emissions should be controlled via prices or quantities (tradable permits) is still very active. Many contributions have looked at ways of deciding between them. These include the degree of uncertainty on the costs or the benefits of the control, the characteristics of the pollution problem at stake (e.g. flow versus stock pollution), etc.

When dealing with pollution problems, the development of more environmentally friendly technologies is often considered as being crucial. Decision makers are therefore akin to know the extent to which the use of an instrument enhances the incentives to innovate, and in particular which of the two main instruments (taxes and tradable permits) leads to the highest degree of innovation.

In a recent survey article, Jaffe et al. (2002) summarize the main findings on this issue: "... both auctioned and freely-allocated permits are inferior in their diffusion incentives to emission tax systems. Under tradable permits, technology diffusion lowers the equilibrium permit price, thereby reducing the incentive for participating firms to adopt" (p. 53).¹

In fact, such a result crucially depends on the assumption that marginal abatement costs decrease with the level of innovation. This is the standard assumption made in the literature, such as for instance in Downing and White (1986), Fischer et al. (2003), Goulder and Mathai (2000), Jung et al. (1996) and Milliman and Price (1989). However, none of these contributions offer any justification for its use. Fischer et al. (2003) simply state "Assuming innovation reduces marginal abatement costs is standard in the literature ..." (p. 526) while Jung and Krutilla (1996) write "At the firm level, we follow previous literature in assuming that technology adoption can be modeled simply as a decline in marginal abatement costs over a relevant region..." (p. 97) and quote Downing and White (1986) and Milliman and Price (1989) who do not offer any justification for it.

The purpose of this paper is to analyse such an assumption. We do so by introducing innovation in the production function of a polluting firm, which can be done in several alternative ways, and by rigorously deriving its marginal abatement cost curve. We observe that, under the most standard ways of accounting for innovation, the slope of the marginal abatement cost (MAC) curves does not necessarily decrease with the level of innovation. Hence, we question here the relevance of such a so commonly made assumption and, by the same token, the policy recommendations that derive from its use.

This article is organised as follows. In Section 2, we show, in a very simple set up, how the assumption of decreasing marginal abatement costs leads to the result stated above, i.e., there will be more innovation under taxes than under

¹They also add: "Because technology diffusion presumably lowers the aggregate marginal abatement cost function, it results in a change in the efficient level of control. Hence, following diffusion, the optimal agency response is to set a more ambitious target" (p. 54) We will refer to this statement in a subsequent footnote.

tradable permits, at least when the regulator does not react to the innovation. Section 3 gathers our main analyses: we introduce, in two standard alternative ways, innovation in the production function of a firm and we show how it affects the corresponding MAC curve. Our result, that MAC curves do not necessarily decrease with innovation, is then discussed in Section 4.

2 Marginal abatement costs and innovation: the usual assumption and its implications

By definition, the *MAC* curve associates to every level of emissions (or emission reductions) the cost of reducing the emissions by an additional unit (see Figure 1).² This cost comes from the substitution towards cleaner inputs and from a decrease in revenues (decrease in output). Let \bar{e} be the emissions level characterizing the laissez-faire situation. Then, the total abatement costs to reduce emissions from \bar{e} to \hat{e} is the area under the MAC curve between \bar{e} and \hat{e} .

The regulator can control firms emissions either by imposing a tax t on emissions or by allocating a total quantity \hat{e} of tradable emission permits. In Figure 1, these are chosen in such a way that both instruments lead to equivalent outcomes –in terms of prices and quantities– (under certainty and before innovation takes place).³

If it is assumed that innovation simply decreases the slope of the MAC curve (from *MAC* to *MAC'*), as it is done in the literature mentioned above, then abatement costs are saved through the adoption of the new technology. The amount of abatement costs saved by adopting the innovation depends on the instrument. It amounts to areas 1 and 2 under the tax system but only to area 1 under the tradable permits scheme. In fact, the equilibrium level of emissions after innovation is no longer the same under both instruments. Under the tax regime, the equilibrium level of emissions decreases while, under the tradable permits, the level of emissions is still given by the total amount of permits, but the permits price goes down.

Thus, regulated firms are willing to pay more for a given new technology under the tax scheme than under the tradable permits system. Accordingly, the rents that an innovator may expect to capture from the sales of its new technology are larger under the tax than under the permits, and therefore the level of innovation is higher under the tax regime.^{4 5}

²The *MAC* curve depicted in Figure 1 is an aggregation (horizontal sum) of firms' MAC curves. It can also be interpreted as the MAC curve of a representative firm.

³It is implicitly assumed that both instruments are, ex-ante, distributionally equivalent, i.e., for instance, tax revenues are redistributed to the firms and permits are allocated freely or auctioned with the revenues of that auction being redistributed to the firms.

⁴If one allows the regulator to adjust the tax level or the amount of allocated permits after the new technology has been adopted, then equilibrium level of emissions would however be the same under both instruments (i.e., marginal abatement costs equal marginal abatement benefits). Hence, the abatement costs saved via the adoption of the new technology would also be the same under both instruments, leading to the same level of innovation.

⁵The purpose of this section was only to give a sketch of the arguments. For a more

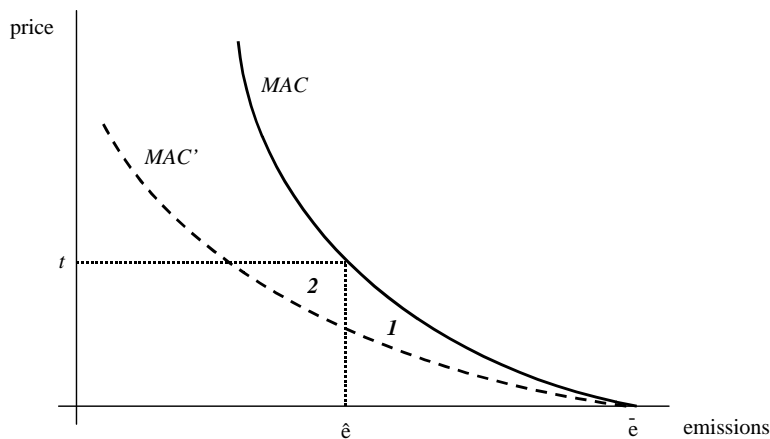


Figure 1: The traditional assumption and its implications

3 The building of marginal abatement cost curves with innovation

Let us now describe how innovation is likely to affect the production function of a polluting firm and thus the corresponding MAC curve of that firm.

3.1 Framework

Let us adopt the following notation. A firm produces the good y by mean of two inputs, x , which represents energy, and k , which represents capital (or a bundle of all non energy inputs). The emissions are denoted by e . We make the following two additional assumptions: the production function is of a Cobb-Douglas type and the level of emissions is linearly related to the amount of energy used the firm.⁶ Hence:

$$y = Ak^\alpha x^\beta \quad (1)$$

where A , α and β are positive parameters with $\alpha + \beta < 1$ (decreasing returns), and :

$$e = \frac{x}{a}. \quad (2)$$

comprehensive presentation, see for instance Fischer et al. (2003).

⁶Our analysis can easily be performed with a one factor production function characterised by general (convexity) properties. In this article, we have chosen to enrich the analysis by accounting for two inputs in order to capture substitution effects. To that purpose, we use the Cobb-Douglas function since it is very often used in economic applications and because the aim of this short article is to question an established assumption rather than to derive a new general result.

We consider two types of innovation. The first one corresponds to the development of new end-of-pipe devices (tail-end cleaning equipment). Such a technology has the property to reduce the ratio emissions/input. The second one is the familiar increase in efficiency. The investment in end-of-pipe cleaning equipment is simply modeled by an increase in the positive parameter a while the increase in efficiency corresponds to an increase in the positive parameter A .⁷

3.2 Derivation of the MAC curves

In order to derive the MAC curve, we follow the standard technique (see for instance Montgomery (1972) or McKittrick (1999)). We compute the total abatement costs by subtracting the profit level at a given (constrained) level of emissions from the profit level at the laissez-faire equilibrium (no constraint on emissions).

Let us first characterise the unconstrained situation, i.e., the baseline. The problem of the firm is

$$\max_{k, x \geq 0} y - rk - qx \quad (3)$$

subject to (1) and (2) where r and q are the prices of capital and energy respectively. The first order condition w.r.t. k leads to :

$$k = \left[\frac{\alpha Ax^\beta}{r} \right]^{\frac{1}{1-\alpha}} \quad (4)$$

so that (3) can be rewritten :

$$\max_{x \geq 0} \pi(x) = \left\{ [1 - \alpha] A^{\frac{1}{1-\alpha}} \left[\frac{\alpha}{r} \right]^{\frac{\alpha}{1-\alpha}} x^{\frac{\beta}{1-\alpha}} - qx \right\} \quad (5)$$

The function π is globally concave and admits a unique maximum at :

$$\bar{x} = \left[\frac{\beta A^{\frac{1}{1-\alpha}} \left[\frac{\alpha}{r} \right]^{\frac{\alpha}{1-\alpha}}}{q} \right]^{\frac{1-\alpha}{1-(\alpha+\beta)}} \quad (6)$$

Baseline profits and emissions are thus equal to :

$$\bar{\pi} = [1 - \alpha] A^{\frac{1}{1-\alpha}} \left[\frac{\alpha}{r} \right]^{\frac{\alpha}{1-\alpha}} \bar{x}^{\frac{\beta}{1-\alpha}} - q\bar{x} \quad (7)$$

$$\bar{e} = \frac{\bar{x}}{a} \quad (8)$$

Let us now consider the problem of the firm when its level of emissions is constrained, i.e:

$$e \leq \hat{e}.$$

⁷With a Cobb-Douglas production function, applying an efficiency parameter to output or to one of the two inputs, leads to the same outcome.

Note that such a constraint is binding only if $\hat{e} < \bar{e}$. Then, the corresponding levels of energy consumption and profits are :

$$\begin{aligned}\hat{x} &= a\hat{e} \\ \hat{\pi} &= [1 - \alpha] A^{\frac{1}{1-\alpha}} \left[\frac{\alpha}{r} \right]^{\frac{\alpha}{1-\alpha}} \hat{x}^{\frac{\beta}{1-\alpha}} - q\hat{x}\end{aligned}$$

The Total Abatement Cost (TAC) curve is the difference between constrained and baseline profits for different levels of the emission constraints :

$$TAC = \hat{\pi} - \bar{\pi}.$$

In the present framework, for a given technology, the firm reduces its emissions by both reducing its output and substituting capital to energy. Indeed, for decreasing levels of the constraint \hat{e} , $\hat{y} = A^{\frac{1}{1-\alpha}} \left[\frac{\alpha}{r} \right]^{\frac{\alpha}{1-\alpha}} (a\hat{e})^{\frac{\beta}{1-\alpha}}$ decreases while the capital/energy ratio $\hat{k}/\hat{x} = \left[\frac{\alpha A}{r} \right]^{\frac{1}{1-\alpha}} (a\hat{e})^{\frac{\beta}{1-\alpha}-1}$ increases. The TAC curve measures the costs associated with both processes.

The Marginal Abatement Cost (MAC) curve is then defined as the derivative of the TAC curve w.r.t. the level of the constraint :

$$MAC = \frac{\partial \hat{\pi}}{\partial \hat{e}} = \beta A^{\frac{1}{1-\alpha}} \left[\frac{\alpha}{r} \right]^{\frac{\alpha}{1-\alpha}} a (a\hat{e})^{\frac{\alpha+\beta-1}{1-\alpha}} - qa \quad (9)$$

These two functions are defined on the interval $[0, \bar{e}]$. Given the shape of $\pi(x)$ (see (5)), MAC is a positive convex function of \hat{e} , decreasing from $+\infty$ to 0 (see Figure 2 hereafter).

3.3 Innovation and the slope of the MAC curve

The MAC function depends on the state of technology through the parameters a and A . To see how the MAC function is modified by changes in these parameters, we take the partial derivatives of MAC w.r.t. to these parameters.

Thus, we have:

$$\frac{\partial MAC}{\partial a} = \frac{\beta}{1-\alpha} \beta A^{\frac{1}{1-\alpha}} \left[\frac{\alpha}{r} \right]^{\frac{\alpha}{1-\alpha}} (a\hat{e})^{\frac{\alpha+\beta-1}{1-\alpha}} - q \quad (10)$$

We know that the profit function π defined by (5) is globally concave and admits a unique maximum at \bar{x} (defined by (6)). Thus, $\pi'(x) > 0, \forall x \in]0, \bar{x}[$, so that $\beta A^{\frac{1}{1-\alpha}} \left[\frac{\alpha}{r} \right]^{\frac{\alpha}{1-\alpha}} (a\hat{e})^{\frac{\alpha+\beta-1}{1-\alpha}} > q$. However, $\frac{\beta}{1-\alpha} < 1$ because of decreasing returns of scale, so that $\partial MAC/\partial a$ can be positive or negative. In the left neighbourhood of \bar{e} , MAC is close to 0, as shown in Figure 2, so that $\beta A^{\frac{1}{1-\alpha}} \left[\frac{\alpha}{r} \right]^{\frac{\alpha}{1-\alpha}} (a\hat{e})^{\frac{\alpha+\beta-1}{1-\alpha}} \approx q$, which gives $\partial MAC/\partial a < 0$. This is consistent with the fact that $\partial \bar{e}/\partial a > 0$ (which follows from (8)). Moreover, for decreasing values of \hat{e} , $\partial MAC/\partial a$ is increasing and tends to infinity. So for \hat{e} “sufficiently”

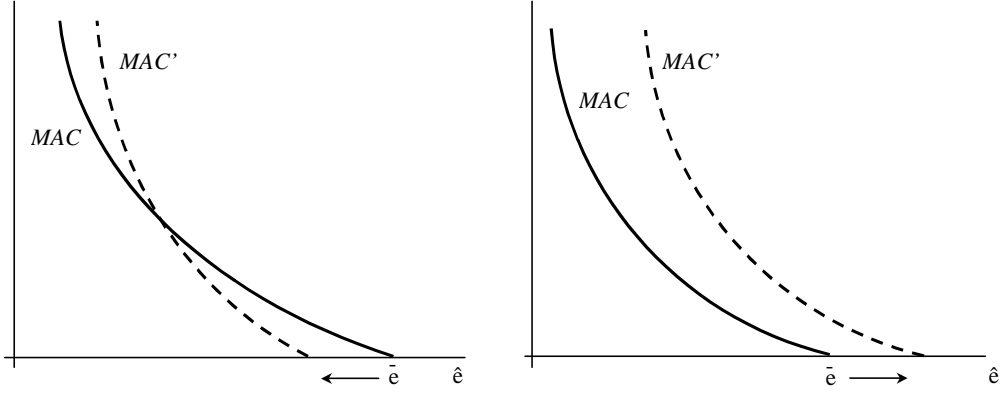


Figure 2: Innovation and the slope of the MAC curve (Figure 2-1 (left): end-of-pipe innovation - Δa ; Figure 2-2 (right): productivity innovation - ΔA)

small, $\partial MAC/\partial a$ must be positive. The way MAC evolves with a is illustrated in Figure 2-1.

The economic intuition is the following. An increase in a has two effects. Given \bar{x} (which does not depend on a), the first effect consists in a decrease of the baseline emissions (\bar{e}), which means, other things being equal, a lower effort to comply with the objective (\hat{e}), thus a lower cost to emit \hat{e} . The second effect follows from the fact that the innovation translates into a more efficient baseline from an environmental point of view (i.e., characterised by higher capital/emissions and output/emissions ratios). Ceteris paribus, all further measures to meet \hat{e} are thus more costly w.r.t. the previous baseline, so that the MAC curve becomes steeper.

Let us now consider an increase in A . From (9), it is clear that $\forall \hat{e}$, $\partial MAC/\partial A > 0$. Furthermore, given (8) and (6), it is also clear that $\partial \bar{e}/\partial A > 0$. So an increase in the productivity parameter A translates into a shifting of the MAC curve to the upper right, with an extension of its domain. This is depicted in Figure 2-2. The economic intuition is the following. An increase in A implies an increase of the global productivity of inputs, which induces the firm to produce more and to use more inputs (a.o. energy). Accordingly, the baseline emissions (\bar{e}) increase. Thus the cost (the loss of profits to realise a certain objective \hat{e}) is higher, so that the MAC curve shifts to the right.

4 Discussion

By introducing innovation in the production function of a polluting firm in two standard ways, we have shown that an increase in the level of innovation does not necessarily and solely lead to a decrease of the slope of the corresponding

marginal abatement cost curve. In fact, our analysis reveals that (i) the slope of the MAC curve may increase and (ii) the baseline (unconstrained) level of emissions may also change with the level of innovation.

Then, it is obvious that the policy recommendations presented in Section 2 –on the choice between the price (tax) and the quantity (tradable permits) instruments regarding their impact on innovation– which are based on the assumption that innovation reduces the slope of the MAC curve, are misleading. Such recommendations will in fact differ according to the type of innovation under consideration. This issue certainly deserves further analysis.

5 References

Downing, P. and L. White (1986), "Innovation in pollution control", *Journal of Environmental Economics and Management* 13, 18-29.

Fischer, C., I. Parry and W. Pizer (2003), "Instrument choice for environmental protection when technological innovation is endogenous", *Journal of Environmental Economics and Management* 45, 523-545.

Goulder, L. and K. Mathai (2000), "Optimal CO₂ abatement in the presence of induced technological change", *Journal of Environmental Economics and Management* 38, 1-38.

Jaffe, A., R. Newell and R. Stavins (2002), "Environmental Policy and Technological Change", *Environmental and Resource Economics* 22: 41-69.

Jung, C., K. Krutilla and R. Boyd (1996), "Incentives for advanced pollution abatement technology at the industry level: an evaluation of policy alternatives", *Journal of Environmental Economics and Management* 30, 95-111.

McKittrick, R. (1999), "A Derivation of the Marginal Abatement Cost Curve", *Journal of Environmental Economics and Management* 37, 306-314.

Milliman, S. and R. Price (1989), "Firm incentives to promote technological change in pollution control", *Journal of Environmental Economics and Management* 17, 247-265.

Montgomery, W. (1972), "Markets in Licences and Efficient Pollution Control Programs", *Journal of Economic Theory* 5, 395-418.

Weitzman, M. (1974), "Prices vs. quantities", *Review of Economic Studies* 41, 477-491.