

WORKING PAPERS IN ECONOMICS

POLLUTION CONTROL VERSUS ABATEMENT:
IMPLICATIONS FOR TAXATION UNDER
ASYMMETRIC INFORMATION*

by

William Jack

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ABSTRACT

This paper examines optimal taxation policies for controlling pollution under asymmetric information. Two important aspects of the social costs of pollution control are included; firstly, if a firm is not competitive, the shadow price of profits is less than unity, so that any reduction in profits due to pollution control should be weighted appropriately in welfare; secondly, control cost functions differ qualitatively if emissions are controlled by *ex post* abatement or by changing the whole production process. In the first case too much pollution occurs at the second-best optimum, while in the second, too little results.

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1. Introduction

Economists have long supported pollution control policies which incorporate all costs and benefits of emission reduction. Benefits are typically described as the reduction in environmental damage in money terms, while costs are identified with those incurred by firms in reducing their emissions.¹ Once these benefits and costs have been calculated, socially optimal emission levels can be implemented directly (command and control) or by the use of a Pigouvian tax.

This paper takes a closer look at the definition of the costs of emission control, and the implications for Pigouvian taxation under conditions of asymmetric information. Firstly, when polluting firms are not competitive, the shadow price of profits is less than one. Thus, in the case of a polluting monopolist studied here, only a fraction of the costs of abatement should be included in the social welfare function. We will show that this normative interpretation of welfare is identical to a positive definition of the objective function of an agency administering an environmental clean-up fund.

Secondly, firms can control their emissions in two qualitatively different ways: they can use so-called "end-of-pipe" abatement techniques, to treat raw waste or otherwise clean up emissions after they have been produced; or they can control the whole production process, including inputs and outputs, to produce a modified emission level, followed by some abatement if necessary. Since the latter assumes the variability of all factors of production, we shall refer to it as the long-run case, and to the former as the short-run case. These definitions are somewhat specific to this paper.

With complete information about short-run and long-run costs, the above observations could be easily incorporated into an optimal environmental policy. However, when the government does not know the firm's costs of emission control, we have a second-best optimal tax problem. In particular, emission taxes have both revenue and incentive effects.² In general the emissions chosen by a firm under the optimal tax will not be first-best optimal. The question is, will there be too much or too little pollution, compared with the first-best outcome?

The model used in this paper is similar to that of Baron and Myerson's (1982) of monopoly regulation with unknown costs. There, the monopolist in general earns information rents (unless it

¹ See, e.g. Roberts and Spence (1976).

² Just as in Mirrlees' (1971) optimal income tax problem, and Baron and Myerson's (1982) monopoly regulation model. We assume emission levels are costlessly observable.

is very inefficient) and produces too little output (unless it is very efficient). In our pollution control model, should we think of the firm as producing emissions, in which case we expect too little pollution at the second-best optimum, or as producing the "good" abatement, in which case we expect too much? It turns out that the first interpretation is valid in the long-run case, while the second describes the short-run situation.

The results depend on the definition of efficiency. In particular, a firm is relatively more efficient if:

- (a) it produces relatively less emissions for a given set of inputs;
- (b) a marginal increase in abatement effort lowers emissions relatively more; and
- (c) a marginal increase in other inputs into the production process increases emissions relatively less.

The short-run version of the analysis neglects the last of these sources of efficiency. On the other hand, the model is kept simple by assuming a fixed relationship, common to both the long and short run, between inputs and the marketed output.

The next section develops the structure of the model, with particular attention given to the issue of efficiency. Section 3 presents the solution to the optimal tax problem, and section 4 contains some comparative statics results. Conclusions drawn from the analysis are presented in Section 5.

2. The model

A monopolist combines inputs $\{z_0, z_1\}$ to produce a single marketed output x and emissions y , where

$$x = f(z_1) \quad , \quad y = g(z_0, z_1, \phi) \quad (1)$$

The input z_0 only affects the level of emissions, and can be thought of as an input to an end-of-pipe abatement process. On the other hand, z_1 can be considered a raw material input. The variable ϕ measures the firm's efficiency, and is distributed on a domain $[\phi^-, \phi^+]$ with positive density function $f(\cdot)$. The transformation functions are assumed to be sufficiently differentiable, and have the following properties:

$$\begin{aligned} f'(z_1) &> 0 \quad , \quad f''(z_1) < 0 \quad ; \\ g_{z_0} &< 0 \quad , \quad g_{z_1} > 0 \quad , \quad g_{\phi} < 0 \quad ; \\ g_{z_0 z_0} &> 0 \quad , \quad g_{z_1 z_1} > 0 \quad , \quad g_{\phi \phi} < 0 \quad , \quad g_{z_1 \phi} < 0 \quad . \end{aligned} \quad (2)$$

where subscripts denote partial derivatives. Thus increasing z_0 reduces emissions, but at a decreasing rate, while expanding production of x necessarily increases them, at an increasing rate. A firm with a high value of the parameter ϕ is efficient both in absolute terms and at the margin. Higher efficiency means lower absolute emission levels for a given set of inputs, as well as a greater reduction in emissions for a marginal increase in z_0 , and a smaller increase in emissions for a marginal scaling up of production (i.e. a marginal increase in z_1). For convenience, we also assume that the generation of emissions and their abatement are independent at the margin. That is,

$$g_{01} = 0 = g_{10}. \quad (3)$$

The government levies an emission tax, so it is convenient to write profits as a function of the firm's emission level. Thus in the long-run, for a given level of emissions, y , a firm of efficiency ϕ purchases inputs $\{z_0, z_1\}$ at fixed prices $\{p_0, p_1\}$ and receives pre-tax profits

$$B(y, \phi) = \max_{\{z_0, z_1\}} R(x) - [p_0 z_0 + p_1 z_1] \quad (4)$$

$$s.t. \quad y = g(z_0, z_1, \phi) \quad \text{and} \quad x = f(z_1)$$

where $R(x)$ is the revenue earned from x . The function $B(\dots)$ is the reduced form value of pre-tax profits for a ϕ -efficiency firm choosing emissions y . If λ is a Lagrange multiplier, then the firm's Lagrangian is

$$\mathcal{L}(z_0, z_1, \lambda, \phi) = r(z_1) - [p_0 z_0 + p_1 z_1] + \lambda [y - g(z_0, z_1, \phi)]$$

where $r(z_1) = R(f(z_1))$. Assuming an interior solution, the first order conditions are

$$\frac{r' - p_1}{g_1} = \lambda = -\frac{p_0}{g_0}. \quad (5)$$

The necessary second order conditions include³

$$\frac{\partial^2 \mathcal{L}}{\partial z_1^2} = r'' - \lambda g_{11} < 0; \quad \frac{\partial^2 \mathcal{L}}{\partial z_0^2} = -\lambda g_{00} < 0. \quad (6)$$

These conditions are assumed to hold. Also, from the envelope theorem, we have

³ The cross derivatives are zero.

$$B_y(y, \phi) = \lambda > 0; \\ \text{and} \quad B_\phi(y, \phi) = -\lambda g_\phi > 0$$

so that higher emissions and greater efficiency yield larger pre-tax profits. From the first order conditions, recalling the conditions in (3), and writing $\{z_0^*(y, \phi), z_1^*(y, \phi)\}$ for the optimising input choices

$$B_{y\phi}(y, \phi) = \frac{d\lambda}{d\phi} = \frac{r''(z_1^*) \frac{\partial z_1^*}{\partial \phi} g_1 - (r'(z_1^*) - p_1) g_{1\phi}}{g_1^2}$$

Totally differentiating the left side of equation (5) and using the first condition of (6), $\partial z_1^* / \partial \phi > 0$, so the first term in the numerator has the same sign as r'' , while the second term is positive. We make the assumption that over the relevant range of interest, the second term dominates, so that in the long run, when all inputs are variable, $B_{y\phi}(y, \phi) > 0$. As an example, consider an exporting firm facing fixed world prices p_x , with constant returns to scale in production of the good x . In this case $r'(z_1) = p_x f'(z_1) = 0$, and the assumption is satisfied (as are the second order conditions). Thus in general we assume the pre-tax profits of the monopolist in the long run satisfy

$$B_y > 0, \quad B_\phi > 0, \quad B_{y\phi} > 0. \quad (7)$$

We model the short run decisions of the firm by assuming that production plans are fixed, and emissions can only be controlled by end-of-pipe abatement. That is, z_1 is fixed at some value \hat{z}_1 , so that for $y \leq \bar{y}(\hat{z}_1, \phi) = g(0, \hat{z}_1, \phi)$ the firm's pre-tax profits are given by

$$\hat{B}(y, \phi; \hat{z}_1) = r(\hat{z}_1) - [p_0 z_0(y, \phi; \hat{z}_1) + p_1 \hat{z}_1]$$

where $z_0(y, \phi; \hat{z}_1)$ satisfies $y = g(z_0, \hat{z}_1, \phi)$. For $y > \bar{y}$, we define $\hat{B}(y, \phi; \hat{z}_1) = \hat{B}(\bar{y}, \phi; \hat{z}_1)$, and interpret \bar{y} as the maximum emission level allowed. However, we will assume that the severity of the environmental damage is such that the firm will be induced to discharge less than \bar{y} in equilibrium. Total differentiation of $y = g(z_0, \hat{z}_1, \phi)$ gives

$$\frac{\partial z_0}{\partial y} = \frac{1}{g_0}; \quad \frac{\partial z_0}{\partial \phi} = -\frac{g_\phi}{g_0} \quad \text{and} \quad \frac{\partial^2 z_0}{\partial y \partial \phi} = -\frac{1}{g_0^2} \left(g_{00} \frac{\partial z_0}{\partial \phi} + g_{0\phi} \right). \quad (8)$$

Thus, in the short run, the pre-tax profits of the monopolist satisfy

$$\hat{B}_y = -p_0 \frac{\partial z_0}{\partial y} > 0 ; \hat{B}_\phi = -p_0 \frac{\partial z_0}{\partial \phi} > 0 ; \text{ and } \hat{B}_{y\phi} = -p_0 \frac{\partial^2 z_0}{\partial y \partial \phi} < 0 . \quad (9)$$

as shown in Figure 1 below.

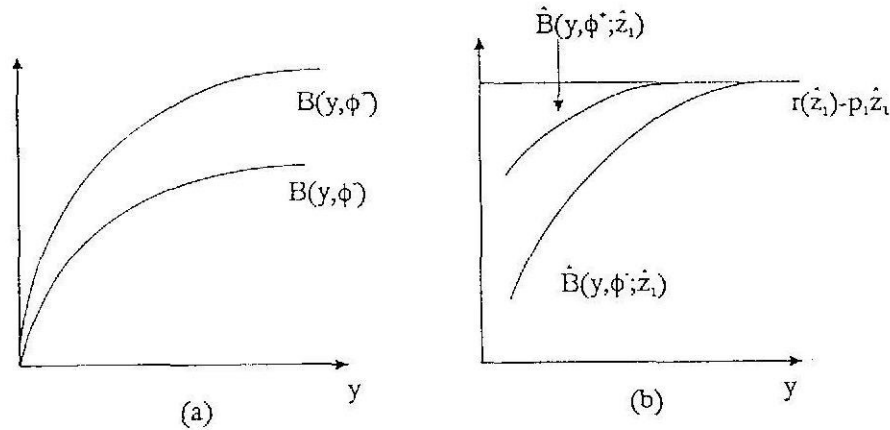


Figure 1 Benefit functions in (a) the long run when all inputs are variable, and (b) the short run, when z_1 , and hence output, is fixed, and ex post abatement is employed.

Comparing conditions (7) and (9), the marginal benefits from emissions increase with efficiency in the long run, but decrease with efficiency in the short run. This is because in the short run, the additional benefit from a higher level of emissions is equal to the reduction in abatement costs incurred and these are higher for less efficient firms. This distinction is important in the optimal tax problem, the solution to which rests on the single crossing property.

The government imposes a tax $t(y)$ on emissions in order to maximise the social welfare function

$$\begin{aligned} W &= E_y [r(y) - D(y) + \alpha \pi] \\ &= E_y [B(y, \phi) - D(y) - (1 - \alpha)\pi] \end{aligned} \quad (10)$$

where $D(y)$ is an increasing convex function which measures the environmental damage caused by emissions y .⁴ After-tax profits of the firm are $\pi = B - t$, and $\alpha < 1$. The welfare function

⁴ Some readers may prefer to include a measure of consumer surplus in the social welfare function. Such a benefit term may be explicitly incorporated in the function $D(\cdot)$. It is then assumed that the modified damage function is convex, although it may be initially decreasing.

has two interpretations. Firstly, taxes are distributed lump-sum to a representative consumer whose utility is additively separable in money and environmental damage. Welfare is the expected value of the weighted sum of the consumer's utility and profit. $\alpha < 1$ since the firm is not competitive.

A second interpretation is to suppose that a government agency has responsibility for cleaning up any environmental damage caused by the firm, at a cost $D(\cdot)$. It can finance this by levying an emissions tax $t(y)$, and a proportional profits tax at a fixed rate α . It then minimises the expected value of the resulting deficit.⁵

In the long run, the government's optimisation problem is then to

$$\begin{aligned} \max_{\pi, y} W \\ \text{s.t. } y(\phi) \text{ maxs } B(y, \phi) - t(y) \\ \text{and } B(y(\phi), \phi) - t(y(\phi)) \geq 0 . \end{aligned} \quad (11)$$

The constraints are, respectively, those of incentive compatibility and individual rationality. In the short run, with the input z_1 fixed at \hat{z}_1 the optimisation problem is identical, with $\hat{B}(y, \phi; \hat{z}_1)$ replacing $B(y, \phi)$.

3. Optimal taxes

We assume that in both the long and short run cases, it is always optimal to have the monopolist discharging a positive amount of effluent. In the long run this requires $B_y(0, \phi) > D'(0)$, whilst the corresponding condition in the short run framework is $\hat{B}_y(0, \phi; \hat{z}_1) > D'(0)$.

Long run: In the long run case, the incentive compatibility constraints in the government's optimisation problem can be replaced by the two conditions⁶

$$\pi'(\phi) = B_y(y(\phi), \phi) ; \text{ and } y'(\phi) \geq 0 . \quad (12)$$

Ignoring the second monotonicity condition for the moment, we define the Hamiltonian by

$$H(y, \pi, \mu, \phi) = [B(y, \phi) - D(y) - (1 - \alpha)\pi]f(\phi) + \mu B_y(y, \phi)$$

where $\mu(\phi)$ is the costate variable. Standard application of the Maximum Principle then implies

⁵ Another interpretation of this kind of welfare function is in terms of foreign firm owners (Tirole (1988)).

⁶ See Mirrlees (1971).

$$\begin{aligned}
\frac{\partial H}{\partial y} &= [B_y(y, \phi) - D'(y)]f(\phi) + \mu(\phi)B_{y\phi}(y, \phi) \\
&= [B_y(y, \phi) - D'(y)]f(\phi) - (1-\alpha)(1-F(\phi))B_{y\phi}(y, \phi) \\
&= 0
\end{aligned}
\tag{13}$$

where $F(\cdot)$ is the cumulative density function of ϕ , and in the second step we have used the condition on the costate variable $\mu'(\phi) = (1-\alpha)f(\phi)$, with the transversality condition $\mu(\phi^*) = 0$. Thus, if the function $y(\phi)$ defined by

$$B_y(y, \phi) - D'(y) = \frac{(1-\alpha)(1-F(\phi))}{f(\phi)} B_{y\phi}(y, \phi) \tag{14}$$

is non-decreasing, it gives the emission level of a firm of type ϕ under the optimal tax.⁷ In this case, since the right hand side of (14) is positive for all $\phi < \phi^*$, emission levels are below their first-best optimal level, defined by $B_y(y, \phi) = D'(y)$. At points of invertibility of $y(\cdot)$, define $\phi(y) = y^{-1}(y)$. The tax function which implements the optimal emission schedule is then calculated as

$$t(y) = B(y, \phi(y)) - \pi(\phi(y)). \tag{15}$$

Short run: When the only means of emission control is by end-of-pipe abatement, the constraints in (11) become equivalent to the conditions

$$\pi'(\phi) = \hat{B}_\phi(y(\phi; z_1), \phi; z_1) ; \text{ and } y'(\phi; z_1) \leq 0. \tag{16}$$

The same solution technique can be employed as above, with an identical optimality condition to equation (14), with $\hat{B}(\cdot, \cdot, \cdot)$ substituted for $B(\cdot, \cdot)$. Now, modifications are necessary if $y'(\phi; z_1) > 0$ for some ϕ , where $y(\phi; z_1)$ is defined by the analogue of equation (14). Note now, however, that unless the monopolist is of type ϕ^* , its emission level will be too large, since $\hat{B}_{\phi\phi} < 0$.

Thus in the short run, when emission control is not an integral part of the firm's general production plan, the firm should be thought of as supplying the "good" abatement. However, in

the long run, when the level of effluent discharge is part of a full optimisation, the firm should be regarded as supplying emissions. With each of these interpretations, the standard results concerning the direction of inefficiency (e.g. Baron and Myerson (1982)) follow.

These results may be compared with the outcomes under policies which attempt to implement first-best emission levels in the short-run and long-run. In both cases full optimality is characterised by Pareto efficiency and zero profits. Let $t^*(y)$ define the locus of emission/tax pairs which satisfy these conditions in the long run problem. Similarly, $\hat{t}^*(y)$ describes the locus of such pairs in the short run problem. Let $\phi^*(y)$ and $\hat{\phi}^*(y)$ be defined respectively by

$$B_y(y, \phi) = D'(y) \quad \text{and} \quad \hat{B}_y(y, \phi; z_1) = D'(y).$$

(The dependence of \hat{t}^* and $\hat{\phi}^*$ on z_1 is suppressed for convenience.) Then $\phi^{**}(y) > 0$ since $B_{y\phi} > 0$ in the long run, while $\hat{\phi}^{**}(y) < 0$, since $\hat{B}_{y\phi} < 0$. Therefore

$$\begin{aligned}
t^{**}(y) &= \frac{d}{dy}(y, \phi^{**}(y)) \\
&= B_y(y, \phi^{**}(y)) + B_\phi(y, \phi^{**}(y))\phi^{**\prime}(y) \\
&> B_y(y, \phi^{**}(y))
\end{aligned}$$

while

$$\begin{aligned}
\hat{t}^{**}(y) &= \frac{d}{dy}\hat{B}(y, \hat{\phi}^{**}(y); z_1) \\
&= \hat{B}_y(y, \hat{\phi}^{**}(y); z_1) + \hat{B}_\phi(y, \hat{\phi}^{**}(y); z_1)\hat{\phi}^{**\prime}(y) \\
&< \hat{B}_y(y, \hat{\phi}^{**}(y); z_1).
\end{aligned}$$

These properties are illustrated in Figure 2, and show that in each case the first-best tax function is not incentive compatible (i.e. marginal tax rates are not equal to marginal benefits at the optimal emission levels). In the long run case, using the tax $t^*(y)$ will result in too little pollution, while in the short run, using the tax $\hat{t}^*(y)$ leads to too much. These qualitative features of the incentive incompatible first-best policies carry over to the second-best solutions, which explicitly account for the incentive constraints.

⁷ If $y(\phi)$ is not monotone the solution is modified by smoothing out the peaks and troughs. Guesnerie and Laffont (1984) present an algorithm for calculating the necessary modifications.

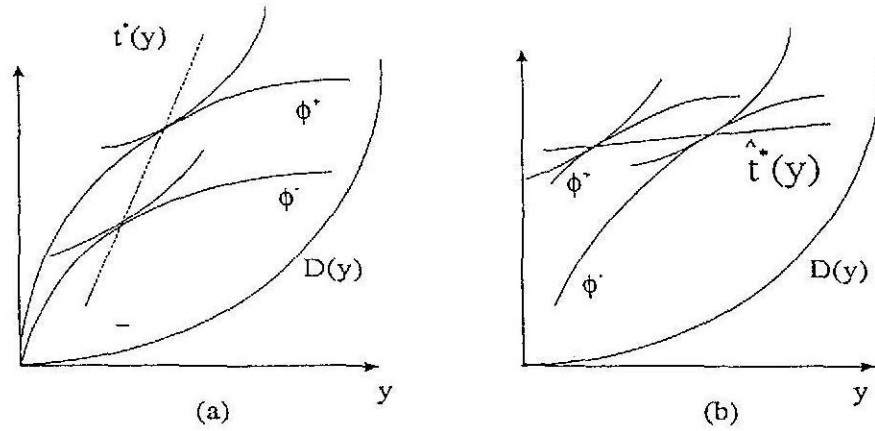


Figure 2 First-best emission/tax pairs in (a) the long run, and (b) short run problems.

4. Comparative statics

Recall the positive interpretation of the parameter α as a proportional profits tax. We now examine how its value will impact upon the optimal emission tax $t_\alpha(\cdot)$ when all inputs are variable, where the subscript is introduced in this section to allow variability of α . We depart from the explicit description of the firm's benefits of section 2, and instead assume that they can be written in a multiplicative form as

$$B(y, \phi) = \phi \beta(y) \quad (17)$$

with $\beta' > 0$ and $\beta'' < 0$.

Using equations (12) and (15), let us write the tax paid by a ϕ -type firm as

$$t_\alpha(\phi) = B(y_\alpha(\phi), \phi) - \int_{\phi}^{\phi} B_\phi(y_\alpha(\phi'), \phi') d\phi' \quad (18)$$

(where the same notation is used for the tax as a function of emissions and type, without confusion). Then the tax paid by a ϕ -type firm varies with α according to

$$\frac{dt_\alpha}{d\alpha}(\phi) = \phi \beta'(y_\alpha(\phi)) \frac{dy_\alpha}{d\alpha}(\phi) - \int_{\phi}^{\phi} \left(\beta'(y_\alpha(\phi')) \frac{dy_\alpha}{d\alpha}(\phi') \right) d\phi'. \quad (19)$$

Now

$$\frac{d}{d\phi} \left(\beta'(y_\alpha(\phi)) \frac{dy_\alpha}{d\alpha}(\phi) \right) = \beta''(y_\alpha(\phi)) \frac{dy_\alpha}{d\phi}(\phi) \frac{dy_\alpha}{d\alpha}(\phi) + \beta'(y_\alpha(\phi)) \frac{d}{d\phi} \left(\frac{dy_\alpha}{d\alpha}(\phi) \right). \quad (20)$$

The first term on the right hand side is negative since $\beta(\cdot)$ is concave, $y_\alpha(\phi)$ is non-decreasing in ϕ , and, with $\eta(\phi) = (1-F(\phi))/f(\phi)$,

$$\frac{dy_\alpha}{d\alpha}(\phi) = \frac{-\eta(\phi) B_{y\phi}(y_\alpha, \phi)}{B_{yy}(y_\alpha, \phi) - D''(y_\alpha) - (1-\alpha)\eta(\phi) B_{y\phi}(y_\alpha, \phi)} > 0$$

at a maximum (the denominator is negative if the second order conditions hold).

Proposition: When benefits are multiplicatively separable in emissions and the efficiency parameter, $\phi^* = 0$, and there is no pooling, an increase in the profits tax, α , leads to a reduction in the optimal emissions tax.

Proof: Differentiation of equation (14) with $B(y, \phi) = \phi \beta(y)$ gives

$$y'_\alpha(\phi) = \frac{(1-\alpha)\eta'(\phi)\beta'(y)}{\phi\beta''(y) - D''(y) - (1-\alpha)\eta(\phi)\beta''(y)}$$

This is positive if and only if $\eta'(\phi) < 0$, so that the assumption of no pooling is equivalent to this condition. Thus

$$\frac{d}{d\alpha} y'_\alpha(\phi) = \frac{-\eta' \beta' [\phi \beta'' - D'' - (1-\alpha)\eta \beta''] - (1-\alpha)\eta' \beta' \eta \beta''}{[\phi \beta'' - D'' - (1-\alpha)\eta \beta'']^2}$$

Since $\eta'(\phi) < 0$, this expression is negative. Therefore, the function

$$\beta'(y_\alpha(\phi)) \frac{dy_\alpha}{d\alpha}(\phi)$$

is decreasing in ϕ . Hence the derivative in equation (19) is negative, if $\phi^* = 0$.

5. Conclusions

This paper has considered in detail the definition of the costs to firms of emission control, and the implications for optimal emission taxes under conditions of asymmetric information. It has been assumed that emission levels are costlessly observable but that the technological relationship between inputs and emissions is not. The first of these is indeed a strong assumption but, in the monopoly case in particular, may be innocuous, since there will be a well defined relationship between ambient air or water quality and emission levels given by the function $D(y)$.

Not surprisingly, with incentive constraints and a non-unitary shadow price of profits, the optimal tax induces the monopolist to discharge effluent at a level different to the first-best. However, the direction of this effect depends upon the process by which emissions are controlled. When all inputs are variable, an efficient firm gains more from a marginal increase in emissions than an inefficient firm. However, when *ex post* abatement is employed, an efficient firm is one which loses less from a reduction in emissions - that is, one that has low abatement costs. This in turn means that the value to such a firm of a marginal increase in emissions is less. This difference between marginal benefits from the discharge of emissions means that under a long-run policy, too little pollution occurs relative to the first-best, but that if the government implements a short-run control policy too little abatement is undertaken by the firm.

Using the interpretation of an environmental clean-up fund, we would expect that the ability to impose higher profits taxes (which are non-distortionary in this model) would reduce the dependence of the agency on the emission tax. In fact, this intuition was shown to be correct in the illustrative case of a multiplicative benefit function.

No attempt has been made to develop a full dynamic model with which to investigate the question of the appropriate time horizon for the government to adopt. This would require knowledge of the time path of future damages, which is likely to be highly uncertain, as well as a careful definition of welfare in an intertemporal context.

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