Does Government Precommitment Promote Environmental Innovation?

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Abstract

This paper investigates the effect of credibility of environmental policies on environmental innovation and welfare. When the government precommits to an emission tax, the monopolist's abatement effort is lower than if the environmental policy is at the government's discretion. Time consistent emission tax is lower than optimal emission tax under precommitent. Finally, welfare is always higher if the government can commit to an emission tax.

Keywords: Monopoly, Non-credible policies, Precommitment, Emission Tax, Abatement Effort.

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1 Introduction

Recently,the theoretical literature has reflected a growing interest in issues related to the credibility of government policies. The credibility of government policies has mainly been analyzed in the context of macroeconomic policies,[1] however more recently credibility issues related to microeconomic policies have come under consideration.[2] A basic question raised in the policy context is whether the ability of the government to precommit to a specific policy measure has beneficial effects on various aspects of the economic activity, such as the innovation rate, economic growth, or welfare. Despite the importance that the credibility of government policies may have for environmental innovation and hence pollution control, this issue has not been addressed in the context of environmental economics so far.

This paper is a first attempt to analyze and compare the effects of environmental policies on environmental innovation and social welfare when the government can, or cannot, precommit to a specific level of emission taxes. For this purpose, we compare two scenarios: in the first the government precommits to an emission tax, and then a monopolist selects its abatement effort and output. This is the case that has been analyzed in the literature so far. In the second, the monopolist chooses its abatement effort first, then the government sets an emission tax, and finally the monopolist decides its output. The second scenario emerges whenever the government's policy is non-credible. If the government is unable to commit to an emission tax in the first stage, firms will rationally anticipate that the government will adjust its emission tax in response to their own environmental innovation efforts, hence it is as if the government were choosing the emission tax in the second stage. Moreover, in this case firms can strategically select their abatement efforts in order to influence the emission tax the government will eventually set.

Using specific functional forms for demand, cost of environmental innovation, production costs, and emission functions we compare equilibrium environmental innovation, emission taxes and welfare when the government can, or cannot, commit to a specific policy. Our main result is that the government's inability to commit to a level of emission tax, it has a benefi-

[1] See, for example, the survey by Persson and Tabellini (1997).

[2] See, for example, Maskin and Newbery (1990), Leahy and Neary (1995, 1996, 1997), Koujianou Goldberg (1995), Herguera *et al.* (1997).

cial impact on environmental innovation. In this case the monopolist spends more on abatement than if the government had precommited to a specific emission tax. The monopolist, by exhibiting environmentally friendly behavior, can strategically induce the government to substantially decrease its emission tax, or even to provide emission subsidies, and thus increase its profits. As a result, the emission tax set by the government is lower in the time consistent equilibrium than under precommitment. However, welfare is *always* lower if the government cannot precommit to a specific policy. The higher consumer surplus (due to the monopolist's output expansion) and the lower level of pollution are not sufficient to compensate for the increase in abatement expenditures due to the monopolist's overinvestment in clean technologies.

The rest of the paper is organized as follows. Section 2 introduces the general model. In section 3, our main results are derived for specific functional forms. Finally, section 4 concludes.

2 The General Model

We consider a monopolist producing a homogeneous good and facing a standard demand curve, $p(q)$. Pollution is a by-product of its production process. The monopolist, faced with a tax on its emissions t, can undertake an abatement effort (environmental innovation) w to reduce its emissions level, and thus reduce its tax burden. Environmental innovation increases costs but reduces emissions. Thus the cost function for the monopolist is defined by the strictly increasing convex function $c = c(q, w)$, while its emission function is defined as $s = s(q, w)$ .The emission function is increasing and convex in q for fixed w, and decreasing and convex in w for fixed q.

We compare two alternative scenarios: The traditional scenario, where the government precommits to an emission tax and then the monopolist, taking this tax as given, chooses its abatement and output. However, due to both the investment characteristics of abatement expenses, which imply that abatement represents a long-term decision as compared to the short-term output decision, and also the ability of the government to change the emission tax following normal legislative procedures, the tax structure determined in this scenario cannot be credible unless the government possesses a specific commitment mechanism. Once the abatement effort has been chosen by the monopolist, the emission tax determined through precommitment is not *ex post* optimal and therefore is not time consistent. The monopolist rationally anticipates a change in the emission tax once its abatement expenses are already sunk.

Therefore, when the government cannot credibly commit to a policy and is expected to change the emission tax after abatement expenses have been chosen, then a time consistent emission tax implies that the tax is *ex post* optimal, given abatement expenses and the firm's future output response to the emission tax. To determine this time consistent tax, we consider the following scenario. The monopolist first selects its abatement effort, then the government sets the emission tax, and finally the monopolist chooses its output. We begin our analysis with this second scenario.

2.1 Non-Credible Environmental Policies

2.1.1 Output Stage

The monopolist treats the emission tax t as given and chooses output, given its own abatement expenses, w, that are sunk at this stage, by solving the problem:

$$\max_q p(q)\, q - c(q, w) - t^* s(q, w)$$

with first order conditions for an interior solution

$$p + q\frac{\partial p}{\partial q} = \frac{\partial c}{\partial q} + \frac{\partial s}{\partial q} t^* \tag{1}$$

The profit maximizing level of output is a function of the tax t^* and the abatement effort w. That is, $q^* = g(t^*, w)$. Standard comparative static analysis indicates that:

$$\frac{\partial q^*}{\partial t^*} < 0,\ \frac{\partial q^*}{\partial w} > 0$$

Thus, an increase in taxation reduces output, while an increase in abatement increases the profit-maximizing output level.

2.1.2 Emission Tax Stage

The government's objective function is determined as the sum of consumer and producer surplus less environmental damages which are defined by a convex, in emissions, damage function $D(s(q,w))$. Given the profit-maximizing output $q^* = g(t^*, w)$, the government chooses the tax rate t^* by maximizing its objective function. Thus, the government solves:

$$\max_{t^*} \int_0^q p(u)\,du - c(q^*, w) - D(s(q^*, w))\,; \quad q^* = g(t^*, w)$$

The first order condition for this problem is

$$\left(p - \frac{\partial c}{\partial q} - D' \frac{\partial s}{\partial q}\right) \frac{\partial q}{\partial t^*} = 0, \text{ or } \; p - \frac{\partial c}{\partial q} - D' \frac{\partial s}{\partial q} = 0 \tag{2}$$

since $\frac{\partial q}{\partial t^*} < 0$.

Solving (2) for the optimal tax t^*, we determine this tax as a function of the abatement effort w, or $t^* = \tau(w)$. Comparative static analysis indicates that

$$\frac{\partial t^*}{\partial w} < 0$$

Thus increased abatement effort reduces the optimal emission tax.

2.1.3 Innovation Stage

In this stage the monopolist chooses abatement but treats the emission tax not as a fixed parameter but as a function of its own abatement effort. The monopolist solves the problem

$$\max_w p(g(\tau(w), w))\, g(\tau(w), w) - c(g(\tau(w), w), w) - \tau(w) s(g(\tau(w), w), w)$$

The first order condition for this, after some simplification, is:

$$\frac{\partial c}{\partial w} = -t^* \frac{\partial s}{\partial w} - \frac{\partial t^*}{\partial w} s\,, \; t^* = \tau(w) \tag{3}$$

2.2 Government Precommitment

The tax structure in the case of precommitment is well-known (Barnett 1980). Solving the problem backwards, the monopolist chooses output and abatement and then the government sets the optimal emission tax.[3]

2.2.1 Output - Innovation Stage

The monopolist treats the emission tax $\widetilde{t}$ as given and solves the problem:

$$\max_{q,w}\ p\left(q\right)q - c(q,w) - \widetilde{t}s\left(q,w\right)$$

with the usual first order conditions for interior solutions

$$p + q\frac{dp}{dq} = \frac{\partial c}{\partial q} + \widetilde{t}\frac{\partial s}{\partial q} \tag{4}$$

$$\frac{\partial c}{\partial w} = -\widetilde{t}\frac{\partial s}{\partial w} \tag{5}$$

Optimal output and abatement are determined as $\widetilde{q} = \widetilde{q}\left(\widetilde{t}\right)$ and $\widetilde{w} = \widetilde{w}\left(\widetilde{t}\right)$.

2.2.2 Emission Tax Selection

Given $\widetilde{q} = \widetilde{q}\left(\widetilde{t}\right)$ and $\widetilde{w} = \widetilde{w}\left(\widetilde{t}\right)$, the government determines the optimal tax to maximize total welfare (as above):

$$\max_{\widetilde{t}} \int_0^q p\left(u\right)du - c(\widetilde{q},\widetilde{w}) - D\left(s(\widetilde{q},\widetilde{w})\right); \quad \widetilde{q} = \widetilde{q}\left(\widetilde{t}\right),\ \widetilde{w} = \widetilde{w}\left(\widetilde{t}\right)$$

Using the monopolist's profit maximizing conditions (4) and (5) the optimal tax is determined as:

$$\widetilde{t} = D' - \frac{p}{\mid \varepsilon \mid}\frac{\partial \widetilde{q}}{\partial s}$$

where ε is the elasticity of demand.

[3] Output and abatement can be chosen sequentially, first abatement then output, or simultaneously without any change in the results.

Comparing condition (3) with (4) reveals the basic difference between the case of non-credible environmental policies and the case where the government is able to precommit to a policy. In the latter, optimal abatement is determined at the level where marginal abatement cost equals marginal tax savings due to abatement. On the other hand, in the discretionary case optimal abatement is determined through (3) at the level where marginal abatement cost equals marginal tax savings due to emission reduction from abatement, $-t^*\frac{\partial s}{\partial w}$, plus marginal tax savings due to tax rule reduction from an increase in abatement, $-s\frac{\partial t^*}{\partial w}$. Therefore, in the non-credible policy case the choice of abatement is affected by the effect that the abatement itself has on the emission tax, through the term $\frac{\partial t^*}{\partial w}$, while in the precommitment case no such effect exists. This second round effect on abatement causes deviation between optimal environmental innovation and optimal emission taxes in the precommitment and time consistent cases.

3 The Linear-Quadratic Case

In this section, for tractability reasons, we will consider specific functional forms. Assume that market demand is linear, $P(q) = a-q$. The cost function is assumed to be additively separable in production costs and environmental innovation costs, i.e. $c(q, w) = cq + \gamma\frac{w^2}{2}$. There are constant returns to scale in production, i.e. the marginal production cost c is constant. On the other hand, innovation costs are quadratic in innovation effort w, i.e. the marginal innovation cost is increasing in w, with γ representing the degree of decreasing returns to scale of innovation effort. Further, total emissions are proportional to output, $s(q, w) = q(v-w)$, where v are the emissions per unit of output with the current technology. The monopolist, by investing an amount of $\gamma\frac{w^2}{2}$ in environmental R&D, can reduce its unitary emissions by w. Finally, the damage function is assumed to be linear in total emissions, i.e. $D(q, w) = d(v - w)q$, where d represents the marginal damage.[4]

[4]This is a rather restrictive assumption which most probably drives out our strong welfare result. As we shall see, welfare is *always* lower if the government is unable to precommit to a specific policy. If the damage function were convex, then the beneficial effect of the more environmentally friendly technology could outweigh the excessive investment made by the monopolist, leading thus to an increase in welfare under time consistent emission taxes. We thank Massimo Motta for pointing this out to us.

As environmental R&D effort is a long-run decision variable for the monopolist, we will assume that abatement effort is chosen first, and then follows the decision on output.[5] In section 3.1 we analyze the case of time consistent emission taxes, while in section 3.2 the precommitment case is treated. Finally, section 3.3 compares the results when the government can, or cannot, precommit to an emission tax.

3.1 Non-credible Environmental Policies

3.1.1 Output Selection

In the last stage, the monopolist chooses its output to maximize profits:

$$\max_q[(a-q)q - cq - \frac{1}{2}\gamma w^2 - t(v-w)q]$$

where t is the tax per unit of emissions. The first order condition is:

$$a - q^m - c - t(v-w) = q^m \qquad (6)$$

Let $A = a - c$, where A is a measure of the market size. From (6) the optimal output is:

$$q^m = \frac{1}{2}(A - t(v-w)) \qquad (7)$$

and the monopolist's profits are:

$$\pi^m = (q^m)^2 - \frac{1}{2}\gamma w^2 \qquad (8)$$

Note that the monopolist's output and profits decrease with the emission tax, t, and increase with the market size, A. Further, output (and gross profits) increase with the monopolist's abatement effort, w.

[5] Of course, if the government can precommit to an emission tax, then the outcome will be the same regardless of whether the monopolist chooses its abatement effort and output simultaneously, or sequentially. If, however, the government cannot credibly commit to an emission tax, then these outcomes are different, and the sequential choice is the right way to model the situation. Note that in the presentation of the general model, output and abatement are chosen simultaneously in the precommitment case.

3.1.2 Government's Choice of Emission Tax

In the second stage, the government chooses the emission tax that maximizes total welfare, taking into account the monopolist's reaction in the subsequent output selection stage. The total welfare is defined as the (unweighted) sum of consumer surplus, monopolist's profits and environmental damages due to the monopolist's emissions. Given that the monopolist selects output according to (7), the government solves:

$$\max_{t^*} \int_0^{q^m} (a - c - x)dx - d(v - w)q^m - \frac{1}{2}\gamma w^2$$

which is equivalent to:

$$\max_{t^*}[Aq^m - \frac{1}{2}(q^m)^2 - d(v - w)q^m - \frac{1}{2}\gamma w^2] \tag{9}$$

The first order condition is:

$$[A - q^m - d(v - w)]\frac{dq^m}{dt} = 0 \tag{10}$$

where $\frac{dq^m}{dt} = -\frac{1}{2}(v - w) < 0$. Then, from (7), we get the optimal tax on the monopolist's emissions,

$$t^* = 2d - \frac{A}{v - w} \tag{11}$$

Note that the optimal emissions tax increases with the marginal damage, d, and the unitary emissions with the current technology, v, and decreases with the market size, A. More interestingly, it decreases with the monopolist's abatement effort, w. Therefore, the monopolist, by increasing its environmental innovation expenditures, can *strategically* induce a lower tax on its emissions.

Now, substituting (11) into (7) and (8), we get the monopolist's output and profits:

$$q^m = A - d(v - w) \tag{12}$$

$$\pi^m = (A - d(v - w))^2 - \frac{1}{2}\gamma w^2 \tag{13}$$

That is, the monopolist's output (and gross profits) increase with its abatement effort. Finally, by (9) total welfare is:

$$TW^* = \frac{1}{2}(A - d(v - w))^2 - \frac{1}{2}\gamma w^2 \tag{14}$$

3.1.3 Environmental Innovation Selection

In the first stage, the monopolist chooses its abatement effort to maximize its profits, taking into account that its decision will affect the government's optimal policy in the subsequent stage. Thus, the monopolist solves (see (13)),

$$\max_{w}[A - d(v - w)]^2 - \frac{1}{2}\gamma w^2$$

The first order condition is:

$$2(A - d(v - w^m))d = \gamma w^m$$

hence, the optimal abatement effort for the monopolist when the government cannot credibly commit to an emissions tax is,

$$w^m = \frac{2d(A - dv)}{\gamma - 2d^2} \tag{15}$$

To simplify the analysis, define $r = \frac{2d^2}{\gamma}$ and $s = \frac{vd}{A}$.Observe that, r is a measure of marginal pollution damage relative to the degree of decreasing returns of abatement costs; r increases with the marginal pollution damage and decreases as the abatement cost function becomes more convex. On the other hand, s is the per unit of output damage when producing with the current technology relative to the market size; s decreases with the market size, and increases with the marginal pollution damage and the initial unitary emissions of the monopolist. Note that for an interior solution to exist in our problem, that is, $0 < w^m < v$, the following condition must hold: $r < s \leq 1$. In what follows, we will also assume that $s > \underline{s}(r) > 0.25$, where $\underline{s}(r)$ solves $4s^2 - 2s + r = 0$, hence $\underline{s}$ is decreasing in r [6]. We can now express optimal innovation effort, emission tax, output, profits and total welfare as functions of s and r.

$$w^m = \frac{r(1 - s)}{s(1 - r)}v \tag{16}$$

[6] That is, v and d are sufficiently high (relative to the market size) to justify a tax on emissions, at least for the case where the government can precommit to an emission tax. We will see this in the next subsection.

$$t^* = d - \frac{d(1-s)}{s-r} = d\frac{2s-r-1}{s-r} \tag{17}$$

$$q^m = \frac{\gamma}{2d}w^m = \frac{(1-s)}{1-r}A \tag{18}$$

$$\pi^m = \frac{(1-s)^2}{1-r}A^2 \tag{19}$$

$$TW^* = \frac{(1-2r)(1-s)^2}{2(1-r)^2}A^2 \tag{20}$$

Note that if $s \leq \frac{1+r}{2} < 1$ then $t^* \leq 0$, i.e. the time consistent tax is negative. As the monopolist has decreased substantially its unitary emissions by overinvesting in abatement technology, the government, through emission subsidies, partially corrects for the inefficiency provoked by the monopolist's market power. Note further that, when $r > 0.5$ (for instance, if γ is relatively small and d sufficiently high), total welfare turns out to be negative. Innovation expenditures are so high that they do not compensate for the decrease in the environmental damages and the increase in the consumer surplus.

3.2 Government Precommitment to an Emissions Tax

The output selection stage is the same as above. Thus, the optimal output and profits are given by (7) and (8).

3.2.1 Environmental Innovation Selection

The monopolist chooses its abatement effort to maximize profits:

$$\max_w [(q^m)^2 - \frac{1}{2}\gamma w^2]$$

The first order condition is:

$$2q^m \frac{dq^m}{dw} = \gamma w \tag{21}$$

where from (7) we have that $\frac{dq^m}{dt} = \frac{t}{2}$, hence (21) becomes

$$t(A - t(v - \widetilde{w}^m)) = \gamma \widetilde{w}^m$$

Solving we obtain the optimal environmental innovation effort, output and profits for the monopolist. Let $t_n = \frac{t}{d}$, that is, t_n is the emission tax relative to marginal damage. Then:

$$\widetilde{w}^m = \frac{t(A - tv)}{2\gamma - t^2} = \frac{vt_n(1 - t_n s)}{s(\frac{4}{r} - t_n^2)} \tag{22}$$

$$\widetilde{q}^m = \frac{\gamma}{t}\widetilde{w}^m = \frac{\gamma(A - tv)}{2\gamma - t^2} \tag{23}$$

$$\widetilde{\pi}^m = \frac{\gamma(A - tv)^2}{2(2\gamma - t^2)} = \frac{(1 - t_n s)^2}{r(\frac{4}{r} - t_n^2)}A^2 \tag{24}$$

3.2.2 Optimal Emissions Tax

The government chooses the emissions tax that maximizes total welfare, taking into account how the monopolist will react to its environmental policy:

$$\max_t \int_0^{\widetilde{q}^m} (a - c - x)dx - d(v - \widetilde{w}^m)\widetilde{q}^m - \frac{1}{2}\gamma(\widetilde{w}^m)^2$$

Equivalently,

$$\max_t [A\widetilde{q}^m - \frac{1}{2}(\widetilde{q}^m)^2 - d(v - \widetilde{w}^m)\widetilde{q}^m - \frac{1}{2}\gamma(\widetilde{w}^m)^2]$$

Substituting output and innovation effort from (23) and (22) we obtain the total welfare as a function of t:

$$\begin{aligned} \widetilde{TW} &= \frac{\gamma(A - tv)[vt^3 - 3At^2 + (2Ad + \gamma v)t + (3A - 4dv)\gamma]}{2(2\gamma - t^2)^2} \\ &= \frac{A^2(1 - t_n s)[st_n^3 - 3t_n^2 + 2(1 + \frac{s}{r})t_n + \frac{2}{r}(3 - 4s)]}{r(\frac{4}{r} - t_n^2)^2} \end{aligned} \tag{25}$$

The first order condition after some manipulations becomes:

$$\frac{d\widetilde{TW}}{dt} = \frac{\gamma A^2 d^3}{(2\gamma - t_n^2 d^2)^3}[\mu_4 t_n^4 - \mu_3 t_n^3 + \mu_2 t_n^2 - \mu_1 t_n + \mu_0] = 0 \tag{26}$$

where

$$\mu_4 = 2s \quad \mu_3 = 3 + 2s + \frac{10s^2}{r} \quad \mu_2 = 3(1 + \frac{6s}{r} + \frac{4s^2}{r})$$
$$\mu_1 = \frac{8s}{r}(3 + \frac{s}{r}) \quad \mu_0 = \frac{4}{r^2}(4s^2 - 2s + r)$$

This fourth-degree equation in (s, r) cannot be solved analytically, and thus there is no explicit expression for the optimal precommitment emission tax. Note however that, if $4s^2 - 2s + r > 0$, then $\frac{d\widetilde{TW}}{dt}|_{t=0} > 0$, and thus $\widetilde{t} > 0$. This condition holds for all $s \geqslant 0.5$. On the other hand, if $0.25 < s < 0.5$, it holds as long as s is sufficiently large, i.e. $s > \underline{s}$, where $\underline{s}$ solves $4s^2 - 2s + r = 0$, with $\underline{s}$ decreasing in r. Finally, it never holds for $s \leqslant 0.25$. As we said above, we shall restrict attention to the cases where total welfare increases with a tax on emissions, i.e. $s > \underline{s}(r) > 0.25$.

3.3 Non-credible vs. Precommitment Policies

In this section we compare optimal time consistent and precommitment emission taxes and innovation efforts, as well as monopolist's profits and total welfare in these two cases. The following proposition compares emission taxes in the two regimes.

Proposition 1 *The optimal time consistent emission tax is always lower than the optimal precommitment emission tax, i.e.* $\widetilde{t} > t^*$.

Proof: Note first that if $\underline{s} < s < \frac{1+r}{2}$, then $t^* < 0 < \widetilde{t}$. It remains to prove that this is also true for $s > \frac{1+r}{2}$. To do this we need to evaluate $\frac{dTW}{dt}$ at $t = t^*$. First, the denominator of (26) is positive, since it can be writen as

$$2\gamma - (t^*)^2 = 2\gamma \left[1 - \frac{s(s - \frac{r+1}{2})^2}{(s - r)^2}\right] > 0$$

Thus the sign of $\frac{dTW}{dt}|_{t=t^*}$ is the same as the sign of the expression in square brackets in (26) evaluated at $t_n = \frac{t^*}{d}$. Substituting t^* from (17) and plotting the expression in square brackets for all (s, r) such that $0 < r < s \leq 1$ and $s \geq \frac{r+1}{2}$ we can see that $\frac{dTW}{dt}|_{t=t^*} > 0$. Hence, $\widetilde{t} > t^*$. Q.E.D.

We now turn to the comparison of innovation efforts under non-credible and precommitment policies. w^m is given by (16). However, to obtain $\widetilde{w}^m$, we need first to solve (26) for t_n, select the appropriate root t_n^* and then substitute t_n^* into (22). Since we cannot solve (26) analytically for the optimal precommitment emission tax, the only way to compare w^m and $\widetilde{w}^m$ is by numerical simulations. As we are able to evaluate[7] w^m and $\widetilde{w}^m$ on a fine grid $(\frac{r}{s}, s)$, simulations do not limit the generality of our results. In particular, since $0 < r < s \leq 1$, with $s > \underline{s} > 0.25$, we define a grid $(\frac{r}{s}, s)$, with $s = 0.3, 0.4, ..., 0.9$ and $\frac{r}{s} = 0.1, 0.2, ..., 0.9$.[8] Normalize $w_n^m = \frac{w^m}{v}$ and $\widetilde{w}_n^m = \frac{\widetilde{w}^m}{v}$. Then w_n^m and $\widetilde{w}_n^m$ depend only on the parameters $\frac{r}{s}$ and s. The results for the normalized values of the innovation efforts are reported in Table 1. The following summarizes the results.

Result 1: *The monopolist's environmental innovation is always higher when the government cannot credibly commit to an emission tax, i.e.* $w^m > \widetilde{w}^m$.

The intuition is straightforward. When the government selects its environmental policy after the monopolist's decision on environmental innovation, the monopolist has a strategic incentive to increase its abatement effort in order to induce a lower tax on its emissions (or even to obtain an emission subsidy). This strategic effect is absent when the government can precommit to a specific emission tax before the monopolist chooses its abatement effort. Thus, the monopolist invests more in abatement when the government policy is non-credible.

Finally, we compare the monopolist's profits and the total welfare under non-credible and precommitment environmental policies. We again use numerical simulations to compare TW^* and $\widetilde{TW}^*$. TW^* is given in (20), while to obtain $\widetilde{TW}^*$ we substitute t_n^* into (25). Normalize $TW_n^* = \frac{TW^*}{A^2}$ and $\widetilde{TW}_n^* = \frac{\widetilde{TW}^*}{A^2}$. Then TW_n^* and $\widetilde{TW}_n^*$ depend only on the parameters $\frac{r}{s}$ and s. Using a similar procedure we can compare the monopolist's profits in the two cases: π^m is given by (19) and $\tilde{\pi}^m$ is obtained by substituting t_n^* into (24). The results for the normalized total welfare are reported in Table 2.[9] The following summarizes the results.

[7] All calculations were performed using Mathematica.

[8] Of course, if $s = 0.3$, then r/s can only take the value of 0.9; and if $s = 0.4$, $r/s = 0.5, 0.6, ...0.9$.

[9] The numerical results for the monopolist's profits are available from the authors upon request.

Result 2: *Total welfare is always lower, and monopolist's profits always higher, when the government cannot precommit to a specific emission tax.*

Since the monopolist overinvests in abatement to obtain a lower tax on its emissions, the environmental innovation expenditures are excessive for the society. On the other hand, a lower emission tax (or an emission subsidy) leads to a higher level of output, and thus an increase in consumer surplus. In addition, it often leads to higher aggregate emissions, and thus increases the environmental damages. The negative effect dominates the positive effect, hence total welfare is lower when the government is unable to precommit to an emission tax. In fact, total welfare can even be negative under optimal non-credible policies. This could happen when both s and $\frac{r}{s}$ take rather high values (see Table 2: e.g. for $s = .8$ and $r = .8$, $TW^* = -.043A^2$). On the other hand, the monopolist has the first mover advantage when the government is unable to precommit to a policy. The monopolist is then able to increase its net profits by appropriately choosing its abatement effort to manipulate the government's choice of emission tax.

4 Conclusions

The question addressed in this paper is whether a government's precommitment to an environmental policy promotes environmental innovation. We show that the government's ability to precommit to an emission tax leads the monopolist to lower its abatement effort relative to the case where the environmental policy is at the government's discretion. However, under precommitment, total welfare is always higher than under non-credible policies.[10] The monopolist overinvests in abatement effort to induce the government to decrease the tax on its emissions, or even receive an emissions subsidy. As a result, the optimal time consistent emission tax is always lower than the optimal tax under precommitment.

In this paper we have restricted attention to the monopoly case. It is worth exploring whether the same results apply when there are more firms in the industry. For instance, oligopolists would have the same strategic incentive to increase their environmental efforts in order to induce the government to decrease the tax on their emissions. However, as this tax decrease

[10] This result is in line with the the literature. See e.g. Leahy and Neary (1996), Herguera *et al.* (1997).

will benefit not only the firm under consideration, but also all its rivals, the firm will have less incentive to overinvest in abatement effort. The latter effect will not be present if all firms in the industry participate in an Environmental Research Joint Venture to reduce their unitary emissions. In the latter case, our conjecture is that all the above results will apply. It is also worth exploring the international dimension of our problem. An emissions tax weakens the competitiveness of the domestic firms in the international arena and governments are, thus, reluctant to adopt such a policy. Our analysis suggests that a government, by not precommitting to a policy, not only induces domestic firms to increase their abatement efforts, but also harms their international competitiveness less as the tax on their emissions is lower in this case.

TABLE 1
Environmental Innovation Efforts

s $\frac{r}{s}$	.3	.4	.5	.6	.7	.8	.9	
.1			.0526 .0019	.0426 .0069	.0323 .0086	.0217 .0076	.011 .0046	w_n^m $\widetilde{w}_n^m$
.2			.1111 .0061	.0909 .0142	.0698 .0172	.0477 .0155	.0244 .0096	w_n^m $\widetilde{w}_n^m$
.3			.1764 .0118	.1463 .0218	.1139 .0258	.0789 .0237	.0411 .015	w_n^m $\widetilde{w}_n^m$
.4			.25 .0184	.2105 .0296	.1667 .0344	.1176 .0320	.0625 .0208	w_n^m $\widetilde{w}_n^m$
.5		.375 .0063	.333 .0257	.2857 .0378	.2308 .0431	.1667 .0405	.0909 .027	w_n^m $\widetilde{w}_n^m$
.6		.4737 .0137	.4286 .0337	.375 .0461	.3103 .0518	.2308 .0492	.1304 .0338	w_n^m $\widetilde{w}_n^m$
.7		.5833 .0221	.5385 .0422	.4828 .0547	.4118 .0606	.3182 .058	.1892 .041	w_n^m $\widetilde{w}_n^m$
.8		.7059 .0312	.6667 .0512	.6154 .0637	.5454 .0695	.4444 .067	.2857 .0488	w_n^m $\widetilde{w}_n^m$
.9	.863 .0103	.8438 .0411	.8182 .0606	.7826 .0728	.7297 .0785	.6429 .076	.4737 .0571	w_n^m $\widetilde{w}_n^m$

TABLE 2
Total Welfare

s $\frac{r}{s}$	.3	.4	.5	.6	.7	.8	.9	
.1			.1246 .1252	.080 .0813	.0447 .0463	.0199 .0208	.0050 .0052	TW_n^* $\widetilde{TW}_n^*$
.2			.1235 .1258	.0785 .0827	.0438 .0476	.0193 .0216	.0048 .0055	TW_n^* $\widetilde{TW}_n^*$
.3			.1211 .1266	.0761 .0841	.0418 .0490	.0180 .0225	.0043 .0058	TW_n^* $\widetilde{TW}_n^*$
.4			.1172 .1275	.072 .0855	.0382 .0504	.0156 .0234	.0034 .0061	TW_n^* $\widetilde{TW}_n^*$
.5		.1688 .1751	.1111 .1284	.0653 .087	.032 .0518	.0111 .0244	.0017 .0064	TW_n^* $\widetilde{TW}_n^*$
.6		.1621 .1755	.102 .1295	.0547 .0884	.0214 .0533	.0030 .0254	$-.002$ .0068	TW_n^* $\widetilde{TW}_n^*$
.7		.1528 .176	.0888 .1307	.0381 .090	.0035 .0548	$-.012$ .0265	$-.010$ .0072	TW_n^* $\widetilde{TW}_n^*$
.8		.1401 .1766	.0694 .1319	.0118 .0915	$-.028$ .0563	$-.043$ .0277	$-.028$ .0077	TW_n^* $\widetilde{TW}_n^*$
.9	.2115 .2251	.123 .1773	.0413 .1331	$-.030$ .093	$-.085$ .0579	$-.112$ .0289	$-.086$ .0082	TW_n^* $\widetilde{TW}_n^*$

References

[1] Barnett, A.H. (1980):"The Pigouvian Tax Rule under Monopoly", *American Economic Review,* 70, 1037-41.

[2] Herguera, I., P. Kujal, and E. Petrakis (1997): "Non credible Policies and Leapfrogging in Vertically Differentiated Industries", Universidad Carlos III Working Paper 97-73.

[3] Koujianou Goldberg, P. (1995): "Strategic Export Promotion in the Absence of Government Precommitment", *International Economic Review,* Vol. 36, No 2, 407-26.

[4] Leahy, D., and J.P. Neary (1996):"International R&D Rivalry and Industrial Strategy without Government Commitment", *Review of International Economics,* 4:3, Oct. 1996, 322-38.

[5] Leahy, D., and J.P. Neary (1995):"Learning by Doing, Precommitment and Infant- Industry Protection", Centre for Economic Performance Discussion Paper No 251, LSE, July 1995 (*forthcoming, Review of Economic Studies).*

[6] Leahy, D., and J.P. Neary (1997):"Public Policy Towards R&D in Oligopolistic Industries", *American Economic Review,* Vol. 87, No 4, pp.642-62.

[7] Maskin, E., and D. Newbery (1990): "Disadvantageous Oil Tariffs and Dynamic Consistency", *American Economic Review,*Vol. 80, 143-56.

[8] Persson T. and G. Tabellini (1997): "Political Economics and Macroeconomic Policy', CEPR Discussion paper No 1759.