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Environmental regulation with and without commitment under irreversible investments *

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Abstract

This paper analyzes the long-term investment decisions of firms that are regulated by an emissions tax and that perceive a degree of market power in their respective output markets. Firms invest in abatement equipment that is fixed over the medium term (e.g., buying a new generator). This paper focuses on environmental regulation with and without commitment. In the commitment case, the government announces a long-run tax on emissions, and firms decide upon their investment levels. In the no-commitment case, the regulator announces a tax level and is free to modify it once firms have invested. This paper considers differentiated product goods and determines whether no-commitment regulation leads to more lenient or more stringent regulation than regulation with commitment.

JEL Classifications: L13, Q50, L51.

Key words: Pollution permits, imperfect competition, differentiated product goods, investment, strategic effects.

1 Introduction

Climate change is likely the most pressing challenge that is felt throughout the world. While addressing climate change requires implementation of environmental regulations worldwide, these regulations are also conditioned on the renewal of polluting production processes. Most industrial production requires irreversible investments, and substantial investments are required over long periods in many industrial sectors that emit large amounts of pollutants. For example, the average lifetimes of generators can exceed 30 years. Thus, once firms have made such an investment, they cannot modify it. The issue of commitment arises because of

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this sequentiality between environmental regulations and investment decisions. Laffont-Tirole (1996b) first emphasized that inconsistency problems may arise when environmental regulations are implemented. Focusing on irreversible investments, Gersbach and Glazer (1999) show that the regulator may have incentives to modify policies after firms have invested. In the context of firms making irreversible investment decisions, this paper determines whether a regulator who modifies the tax after firms have invested implements more lenient or more stringent regulations.

This paper compares two different methods for implementing pollution permits, i.e., commitment and no-commitment regulation. The difference in these methods relates to the regulator's behavior. With commitment regulation, the regulator commits himself ex ante to the level of tax. In the case of no-commitment regulation, the regulator first announces the level of the tax, firms invest for the long term, but the regulator may decide to change the level of tax after investments have been made. For the sake of simplicity, we assume that firms are myopic and do not consider the possible change in regulation. Ordinarily, environmental regulation covers oligopolistic sectors. Therefore, this paper assumes imperfect competition in the market for products, on one hand, and firms that are myopic regarding the regulator's behavior, on the other.

The key ingredient in this analysis is that irreversible investment generates strategic effects in the market for products. Indeed, environmental technology is assumed to reduce emission rates and – as a consequence – to lower the effective marginal cost of production (the sum of the marginal cost of production and the tax). Thus, investment alters competition among firms and leads rivals to react. Strategic effects depend on both the type of goods (substitutes or complements) and the type of competition (quantity or price). Therefore, this paper considers differentiated product goods to emphasize the role of strategic effects. Moreover, it is assumed that the regulator does not have any direct investment policy instruments at its disposal (neither command and control instruments nor subsidies for investment) and maximizes a social welfare function while accounting for environmental damage. Thus, setting the tax is a type of second-best investment policy. First, we do not consider reversible abatement. Second, we assume a linear environmental damage function. Subsequently, we relax these assumptions.

This paper thus proposes a method for generalizing the strategic effects of investment. This generalization allows us to compare the second-best taxes in both scenarios based on the strategic effects. The paper shows that when strategic effects lead firms to reduce investments, the optimal commitment tax is higher than the no-commitment tax. Otherwise, the commitment tax may be higher or lower than that under no-commitment.

This paper contributes to the literature that compares commitment and no-commitment environmental regulation. Since Laffont & Tirole (1996a) demonstrated that no-commitment environmental regulation is socially preferable, an ongoing debate has been engaged regarding the advantages of an environmental regulator moving first (Requate (2005) surveys this debate).

Most papers have compared commitment and no-commitment environmental regulation under technology adoption and perfect competition in the product market (Laffont & Tirole

(1996), Requate & Unold (2001), Requate & Unold (2003), Amacher & Malik (2002), Kennedy & Laplante (1999), Golombeck et al. (2010)). These papers assume that a sector innovates and sells cleaner technology to firms. Firms decide to adopt – or not to adopt – this new technology. This context is completely different than the one we focus on, i.e., one in which firms make irreversible investments. All these papers have compared the two kinds of regulation from a social welfare perspective – except for Golombeck et al. (2010), which is very close to our paper and determines the cases under which the no-commitment permit price is higher than the ex-ante price. To our best knowledge, Golombeck et al. (2010) is the only paper that compares the commitment and no-commitment permit price. They show that the comparison between the two taxes depends on the value of the subsidies to innovate. We show that in a context of irreversible investment, the relative magnitudes of the commitment and no-commitment taxes depend on the strategic effects.

However, three papers focus – as we do – on irreversible investment and imperfect competition: Gersbach and Glazer (1999), Petrakis & Xepapadeas (2001) and Puller (2005). However, these papers all assume that firms are strategic, whereas we assume they are myopic relative to the regulator. Gersbach and Glazer (1999) consider the implementation of pollution permits and propose a mechanism of permit allocation that prevents the regulator from modifying its policy after to its announcement. Petrakis & Xepapadeas (2001) and Puller (2005) analyze the introduction of a tax and a standard, respectively. These studies also consider a quadratic environmental damage function and show that no-commitment regulation may be preferable. Our paper is complementary to these papers but not directly comparable.

The remainder of the paper is structured as follows. Section 2 presents the modeling assumptions. In Section 3, commitment and no-commitment regulations are described and compared. Section 4 concludes.

2 A Simple Model of Environmental Regulation and Investment

2.1 The Model

We assume that n firms produce differentiated goods and consumers choose among the n goods. All firms have the same constant marginal cost, denoted as c. Let p_i and q_i be the price and production, respectively, of firm i. $S(q_1, q_2, ..., q_n)$ denotes the gross surplus from consuming n goods in quantities q_1, q_2, ..., and q_n.

Assumption 1. The gross surplus depends on quantities but not on the identity of the firm that sells the product:

$$S(q_1, , ..., q_i, ..., q_j, ..., q_n) = S(q_1, , ..., q_j, ..., q_i ..., q_n). \tag{1}$$

This assumption is mainly technical and means that the identity of the firm does not matter.

Production involves pollution. Let α_i be the emission rate associated with the production technology of firm i. Thus, one unit of product generates α_i units of pollution.

However, assume that irreversible investment alters the production process and lowers the emission rate: $\alpha_i(y_i) = \overline{\alpha} - y_i$, where $\overline{\alpha}$ is the initial emission rate and y_i the irreversible investment of firm i. The cost of irreversible investment is denoted by $C(y_i)$ with $C' > 0$. Note that we employ a two-stage game to model irreversible investment (building a cleaner plant). As Tirole explains (1988, chapter 5), this two-stage game formalizes the assumption that investment decisions are generally made prior to price or production decisions. In other words, investment decisions are long- or medium-run choices, whereas prices or productions are fairly flexible.

We distinguish irreversible investment from reversible abatement (fuel switching). Here, we define reversible abatement as a decision to reduce emissions that is made simultaneously with price or production decisions. This distinction between irreversible investment and reversible abatement is not important under perfect competition but is crucial under imperfect competition. Indeed, due to strategic effects, abatement and investment are no longer equivalent under imperfect competition. In this model, we focus on irreversible investment and introduce reversible abatement into the discussion.

The regulator implements an emission tax to curb pollution. Let E be total emissions. Let σ be the level of the tax. We focus first on a single sector and then relax this assumption in Section 4 below. We consider a linear pollution damage function, and the marginal damage is denoted by λ. The paper addresses two externalities (market power and emissions). Therefore, we consider a social welfare function and assume that this function is defined as follows:

$$W = CS + \Sigma_1^n \pi_i - \lambda E + \sigma E, \tag{2}$$

where π denotes the firm profits, CS the consumer surplus, λE the environmental damage and $E\sigma$ the value of the tax.

The two different types of regulations considered in this paper, commitment and no-commitment regulation, are denoted by C and NC, respectively. Each type of regulation is defined by a specific sequence of decisions. In the commitment case, the regulator commits to the level of tax. This commitment allows firms to plan their long-term investments by considering the future emission tax decided by the regulator. Regulation with commitment is thus characterized by the following timing:

Stage 1: The regulator chooses the tax σ^C and announces it.

Stage 2: Firms make investment choices.

Stage 3: Firms choose productions.

In the no-commitment case, firms invest in the long term trusting what the regulator has announced in stage 1. We assume then that firms are myopic.

The timing of regulation without commitment is as follows:

Stage 1: The regulator chooses the tax and announces it.

Stage 2: Firms make investment choices.

Stage 3: After firms have invested, the regulator may decide to modify the tax by announcing σ^{NC}.

Stage 4: Firms choose productions.

Since firms are myopic relative to the regulator, firms' investment and production decisions are the same in the two timings. We now analyze the determinants of firms' irreversible investments.

2.2 A Focus on the Strategic Effects of Investment

To emphasize the role of strategic effects in optimal environmental regulation, we first examine how investment may alter competition. First, we focus on the last stage of each scenario. Profits may be represented as follows:

$$\pi_i = (p_i - c)q_i - \sigma\alpha(y_i)q_i - C(y_i). \tag{3}$$

Firm i sells its product, buys the required permits, pays the production costs and bears an investment cost.

Production stage Optimal production decisions satisfy the following:

$$q_i - c + p_i \frac{\partial q_i}{\partial p_i} = (\bar{\alpha} - y_i)\sigma. \tag{4}$$

The effective marginal cost of production is equal to the sum of the marginal cost of production plus the tax. Thus, from equation (4), we deduce that the product price increases as the effective marginal cost of production decreases.

Investment stage First, let $R_i = p_i q_i$ be the revenue of firm i. We assess how the revenue is altered by investment.

Definition 1. *Let Ry_i be the variation of firm i's revenue relative to an increase of irreversible investment such that*

$$Ry_i = \frac{\partial R_i}{\partial y_i} \tag{5}$$

The marginal revenue due to investment indicates the strategic effects of investment, i.e., the manner in which investment alters competition. Indeed, investment lowers the emission rate and, consequently, the effective marginal cost of production.

Consider for a moment the case of perfect competition. Firms are price-takers in the market for products. Thus, firms do not consider how investment modifies competition because they take product prices as exogenous. Thus, the variation in firm i's revenue relative to an increase of irreversible investment is null under perfect competition, i.e., $Ry_i = 0$.[1]

Firm i chooses its investment level y_i by maximizing profits. From the envelope theorem, the first-order condition satisfies the following:

$$Ry_i + q_i\sigma = C'(y_i). \tag{6}$$

Investment decisions clearly depend on production but are also based on the strategic effects of investment.

From equation (6), the following lemma is deduced.

Lemma 1. *Investment decisions depend on the sign of the marginal revenue due to investment.*

(i) If the marginal revenue due to investment is negative ($Ry_i < 0$), then strategic effects lead firms to reduce investments relative to perfect competition.

(ii) If the marginal revenue due to investment is positive ($Ry_i > 0$), then strategic effects lead firms to increase investments relative to perfect competition.

Investment decisions are driven by the level of tax and by strategic effects. Below, we will demonstrate that the sign of the strategic effects is crucial in addressing our issue of interest.

3 With and Without Commitment

This section compares commitment and no-commitment regulation and solves for the resulting investment decisions, tax and welfare levels. The pollution is equal to $E = \Sigma_{i=1}^{n}(\bar{\alpha} - y_i)q_i$. We then rewrite welfare as a function of the equilibrium production quantities, denoted by q_i, and the investments:

$$W(\sigma, y_1, ..., y_n) = S(q_1, q_2, ..., q_n) - \Sigma_{i=1}^{n}\left(q_i^* c + C(y_i)\right) - \lambda\left[\Sigma_1^n(\bar{\alpha} - y_i)q_i^*\right], \tag{7}$$

The equilibrium production quantities clearly depend on the tax.

Firms are myopic and trust the regulator. In the commitment case, the regulator fixes the tax before firms have invested and then reduces three distortions: environmental damage, under-production and under-investment. In the no-commitment case, the regulator reduces two distortions: environmental damage and under-production.

We focus on the third stage of the second timing and not on the first stage of this timing. Indeed, we compare the tax under commitment (first stage) and the tax implemented once firms have already invested. Obviously, the third stage depends on the first stage. But to compare the two optimal prices, we do not have to look at the first stage of the second timing.

[1] It should also be noted that if firms do not behave strategically, they do not consider the strategic interactions in the market for products and $Ry_i = 0$.This issue may then be formulated as a comparison between an open loop and a closed loop. See Vives (2000).

The third stage of timing under no commitment Assume there is a symmetric equilibrium. In the no-commitment case, the optimal tax satisfies the following equation:

$$\frac{\partial W^{NC}}{\partial \sigma} = \Sigma_{i=1}^{n} \left(\frac{\partial S}{\partial q_i} - \lambda \alpha y_i - c \right) \frac{\partial q_i}{\partial \sigma} = 0. \tag{8}$$

The regulator, in fixing the tax, reduces two distortions: (i) environmental externalities and (ii) demand-side distortions. However, using $\frac{\partial S}{\partial q_i} = p_i$, we rewrite equation (8) as follows:

$$\frac{\partial W^{NC}(\sigma, y^C)}{\partial \sigma} = \Sigma_{i=1}^{n} \left(p_i - \lambda \alpha y^C - c \right) \frac{\partial q_i}{\partial \sigma} = 0. \tag{9}$$

From the first-order conditions, we know that $p_i = c + (\bar{\alpha} - y_i)\sigma - q_i \frac{\partial p_i}{\partial q_i}$. Thus, equation (9) may then be written as follows:

$$\frac{\partial W^{NC}}{\partial \sigma} = \Sigma_{i=1}^{n} \left((\sigma - \lambda)(\bar{\alpha} - y_i) - q_i \frac{\partial p_i}{\partial q_i} \right) \frac{\partial q_i}{\partial \sigma} = 0, \tag{10}$$

We then deduce at the symmetric equilibrium

$$\sigma^{NC} = \lambda + \frac{q_i \frac{\partial p_i}{\partial q_i}}{(\bar{\alpha} - y_i)}. \tag{11}$$

The following lemma compares the no-commitment tax with the Pigovian tax, i.e., the marginal damage.

Lemma 2. *The tax under differentiated product goods and no commitment is lower than the marginal damage.*

Proof. Since $\frac{\partial p_i}{\partial q_i} < 0$, we conclude that $\sigma^{NC} < \lambda$. □

At first sight, this is a standard and well-known result in the literature. Even if this result is not the core of the paper, it is particularly important because it allows us to address optimal taxation and differentiated product goods.

The first stage of timing under commitment The regulator in the commitment case maximizes welfare by fixing the tax. The latter satisfies the following equation:

$$\frac{\partial W^C(\sigma, y)}{\partial \sigma} = \frac{\partial W(\sigma, y)}{\partial q_i} \left(\frac{\partial q_i}{\partial \sigma} + \frac{\partial q_i}{\partial y_i} \frac{\partial y_i}{\partial \sigma} \right) + \frac{\partial W}{\partial y_i} \frac{\partial y_i}{\partial \sigma} = 0. \tag{12}$$

Equation (12) may be divided into two parts: (i) the effect of the tax on output, and (ii) the effect of the tax on investment.

To determine whether the inconsistent regulator implements more lenient or more stringent regulations, we compare the tax under no commitment and the tax under commitment. To do so, we focus on implementation in the case of regulation with commitment with the level of tax under no-commitment regulation. When the regulator implements the no-commitment tax in the commitment case, the first part of equation (12) is null. Indeed, the no-commitment tax is such that $\frac{\partial W}{\partial q_i}\frac{\partial q_i}{\partial \sigma} = 0$. However, because $\frac{\partial q_i}{\partial \sigma}$ is obviously non-null, we deduce that it implies that $\frac{\partial W}{\partial q_i} = 0$. Thus, $\frac{\partial W}{\partial q_i}|_{\sigma^C = \sigma^{NC}} = 0$, and consequently,

$$\frac{\partial W}{\partial q_i}(\frac{\partial q_i}{\partial \sigma} + \frac{\partial q_i}{\partial y_i}\frac{\partial y_i}{\partial \sigma})|_{\sigma^C = \sigma^{NC}} = 0. \tag{13}$$

Let us focus on the effects of a variation in investment on welfare.

$$\frac{\partial W(\sigma, y)}{\partial y} = \Sigma_1^n \left(\frac{\partial S}{\partial q_i} - \lambda \alpha_i - c\right)\frac{\partial q_i}{\partial y} + \lambda \Sigma_1^n q_n^* - nC'(y) = 0. \tag{14}$$

By using the envelope theorem and fixing the tax at the no-commitment tax level, equation (14) may be rewritten as

$$\frac{\partial W}{\partial y}|_{\sigma^C = \sigma^{NC}} = \lambda q_i - C'(y). \tag{15}$$

We then deduce that

$$\frac{\partial W^C(\sigma, y)}{\partial \sigma}|_{\sigma^C = \sigma^{NC}} = \frac{\partial W^C}{\partial y_i}\frac{\partial y_i}{\partial \sigma}|_{\sigma^C = \sigma^{NC}} = \lambda q_i - C'(y). \tag{16}$$

Inserted into equation (6), the previous equation may be rewritten as follows:

$$\frac{\partial W^C(\sigma, y)}{\partial \sigma}|_{\sigma^C = \sigma^{NC}} = \underbrace{(\lambda - \sigma^{NC})}_{(+)} q_i - \underbrace{Ry_i}_{(+/-)} . \tag{17}$$

Two effects are at stake. First, the regulator has an incentive to increase the tax because the no-commitment tax leads to underinvestment. Second, strategic effects may encourage firms to either overinvest or underinvest. The following proposition compares the two optimal taxes.

Proposition 1. *The relative magnitude of the tax under commitment and the tax under no commitment depends on the strategic effects:*

(i) If strategic effects lead firms to reduce investments ($Ry_i < 0$), then the tax under commitment is higher than the tax under no commitment.

(ii) If strategic effects lead firms to increase investments ($Ry_i > 0$), then the tax under commitment may be higher or lower than the tax under no commitment.

When the regulator reduces under-production, it gives incentives to firms to produce less than under perfect competition. Indeed, the no-commitment tax is lower than the marginal damage. Moreover, as we noted above, strategic effects encourage firms to invest in ways that are sub-optimal. If strategic effects lead firms to invest less than they would when not behaving strategically, then the two effects are in the same direction, and the commitment tax is thus higher than the no-commitment tax. However, if the strategic effects lead firms to invest more than they would when not behaving strategically, then the two effects move in opposite directions; either effect can prevail and the commitment tax may be higher or lower than the no-commitment tax.

4 Discussion and concluding remarks

This paper demonstrates the role of imperfect competition in defining taxes on emissions for upcoming periods. A comparison of the levels of tax for the two types of regulation (i.e., with and without commitment) depends on whether strategic effects lead firms to reduce or increase investment. To conclude, the sign of strategic effects is crucial to determine whether a lack of commitment induces an increase or a decrease in stringency.

One of the main assumptions in this paper is that firms are myopic. Assume that firms are strategic and anticipate under no commitment that the regulator may modify the environmental policy. As we noted previously, the optimal tax decreases with investment. Firms then invest more than when they are myopic. In addition, the comparison between the tax under commitment and the tax under no commitment depends on the distortion in the investment level. The distortion on investment comes from the two previous effects and this latter effect that pushes firms to invest more. This effect moves in the same direction as when strategic effects lead firms to increase investments. To conclude, even when strategic effects lead firms to reduce investments, the tax under commitment may be lower than the tax under no commitment.

Until now, this paper has not considered reversible abatement technologies. Assume that firms may use reversible abatement technologies. Remember that we define reversible abatement as a decision to reduce emissions made simultaneously with price or production decisions. As abatement and production decisions are simultaneous, there is no strategic effect. Thus, there is no problem of under- or over-provision of abatement due to imperfect competition, and the introduction of abatement technologies does not alter our results.

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