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Ex-Ante vs. Ex-Post Pollution Permit Regulation under Imperfect Competition *

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Abstract

This paper analyzes the role of imperfect competition in optimal environmental regulation and compares two scenarios regarding the investment decisions of firms: ex-ante and ex-post pollution permit regulations. In the first scenario, the regulator commits itself ex ante to the future supply of permits. This commitment allows firms to plan their long-term investments. In the second scenario, firms make long-term decisions before the regulator announces the pollution cap. This paper assumes that firms are price takers in the market for permits and price makers in the market for products. The paper considers both price and quantity competition and shows that the first scenario is socially preferable. When strategic effects lead firms to invest less than the case in which firms do not invest strategically, the optimal ex-ante price is higher than the ex-post price. Otherwise, the ex-ante permit price may be higher or lower than in the ex-post regulation case.

JEL Classifications: L13, Q50, L51.

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

1 Introduction

Whether a pollution cap is announced before or after investment is important because most industrial production involves the use of inputs that can severely damage the environment. In industrial sectors that emit large amounts of pollutants, large investments are required over long periods of time. For example, it is commonly accepted that decisions concerning the renewal of the Electric Park should be made in upcoming years, and several countries have

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implemented\textsuperscript{1} or intend to implement pollution permits. This issue has several implications from a policy perspective. The credibility of the announcement of a future pollution cap depends on the incentives for the regulator to change the cap once firms have invested.\textsuperscript{2} The problem may also be formulated as a choice between a long period of regulation and a succession of shorter periods.\textsuperscript{3} However, firms typically claim that they need to know the severity of future environmental regulations to ensure optimal investment.

This paper compares two different methods of implementing pollution permits: ex-ante and ex-post regulations. The difference is relative to investment decisions. In the case of ex-ante regulation, the regulator commits himself ex ante to the future supply of permits and consequently to the permit price. This approach allows firms to plan their investments by accounting for the evolution of the supply of permits decided by the regulator. In the case of ex-post regulation, firms invest in the long term before the regulator announces the pollution cap. Ordinarily, pollution permits cover several oligopolistic sectors and various regions; consequently firms in the market for permits are numerous.\textsuperscript{4} Therefore, the paper assumes imperfect competition in the market for products and perfect competition in the market for permits. This market organization prevents firms from acting strategically with respect to the regulator when buying permits and investing. However, firms are strategic when they invest because they anticipate how they can alter competition among themselves in the markets for products.

The first contribution of this paper pertains to the proper framework for analyzing the interaction between the implementation of large pollution permits and environmental investment decisions. Ex-ante and ex-post regulations have already been analyzed in a partial equilibrium framework focusing on the presence of market power. However, this literature has been built around the idea that because an insufficient number of firms have market power in the market for permits.

\textsuperscript{1}For instance, the European Union has implemented a market for permits in Europe, known as the EU-ETS. The United States has a trading system for SO\textsubscript{2} permits. Australia, New Zealand and Japan have independently launched pollution permits for CO\textsubscript{2}.

\textsuperscript{2}For instance, the European Commission committed itself to reducing overall emissions at least 20\% below 1990 levels by 2020.

\textsuperscript{3}For instance, the EU-ETS regulation is defined as the repetition of 5-year periods, whereas the regulation of SO\textsubscript{2} was established for a period of 30 years.

\textsuperscript{4}For instance, the Waxman-Markey law was intended to regulate CO\textsubscript{2} emissions in different states. The competition in the different states in the market for electricity is considered to be imperfect.
for products, they can strategically invest to influence the regulator's decisions. For instance, Petrakis & Xepapadeas (2001) and Puller (2005) analyze the introduction of a tax and a standard, respectively. Nevertheless, in the case of large markets for permits, this strategic effect with respect to the regulator is impossible. Hence, this market organization requires specific attention. This paper assesses which method of implementing pollution permit is optimal on a social level.

The key ingredient of this analysis is the strategic effects in the market for products generated by investment. Indeed, environmental technology is assumed to lower the emission rates and consequently to lower the perceived marginal costs. Thus, investment alters competition between firms and induces the reactions of rivals. Strategic effects then depend on both the type of goods (substitutes or complements) and the type of competition (quantity or price). Therefore, to emphasize the role of the strategic effects, this paper considers both quantity competition and price competition. It is assumed that the regulator does not have any investment policy instruments at its disposal (neither command and control instruments nor subsidies for investment) and maximizes a social welfare function, taking into account for environmental damage. For the sake of clarity, as a first step, we consider that all sectors are identical and assume a representative sector. We relax this assumption subsequently.

The second contribution of this paper is to analyze the redistributive effects of these two methods of implementing pollution permits. This paper compares the optimal permit prices in both cases: ex-ante and ex-post regulation. This comparison is crucial to analyze the effects of both approaches to regulation on profits and on consumers. This paper shows that firms may prefer ex-post regulation in some cases and that consumers may also prefer this type of regulation.

This paper shows that ex-ante regulation is socially preferable. Indeed, in the ex-post case, the regulator cannot correct a possible distortion of the investment level but is capable of doing so in the ex-ante case. This distortion of the investment level may be derived from two effects: (i) the correction of market power in the market for products and (ii) the strategic effects of investment. When strategic effects lead firms to invest less than the case in which
firms do not invest strategically, the optimal ex-ante price is higher than the ex-post price. Otherwise, the two effects are antagonistic, and the ex-ante permit price may be higher or lower than under ex-post regulation.

The remainder of the paper is structured as follows. We start by relating the paper to the literature. Section 2 presents the modeling assumptions. In Section 3, ex-ante and ex-post regulations are described and compared. Section 4 concludes the paper.

1.1 Relation to the Literature

The paper is related to two strands of literature. First, the paper contributes to the literature on the role of imperfect competition in optimal environmental regulation. The regulator may correct an additional distortion, i.e., the market power in the market for products. In that case, the regulator does not implement a Pigovian tax. (For instance, Barnett (1980) [1] focuses on the case of a monopoly). Montero (2002)[6] shows the role of imperfect competition in incentives to invest in a less polluting technology and emphasizes the role of strategic effects in the comparison of various regulatory instruments. As in Montero (2002)[6], our paper shows that imperfect competition may impede firms from investing optimally, and we evaluate the implications of this outcome on the choice between the two types of regulation, ex-ante and ex-post regulation.

Second, since the work of Laffont & Tirole (1996)[4] showing that ex-post environmental regulation is socially preferable, there has been an ongoing debate regarding the advantages of an environmental regulator moving first. Indeed, Laffont & Tirole (1996)[4] consider the case in which there is a single innovator that develops less polluting technologies. The regulator implements a market for permits. All polluting firms buy licenses from a single innovator, and there is a strategic interaction between the innovator and the regulator. However, this paper does not focus on the interaction between an innovator sector and a polluting sector. Petrakis & Xepapadeas (2001)[8] and Puller (2005)[9] focus on a single sector and analyze the introduction of a tax and a standard, respectively. These studies consider imperfect competition in the market for products and a quadratic environmental damage function. They show that ex-post
regulation may be preferable. However, our paper considers the implementation of a wide market for permits and a linear demand function and shows that ex-ante regulation is socially preferable.

2 A Simple Model of Regulation and Investment

2.1 The Model

We assume a market for products in which \( n \) goods are sold by \( n \) firms that confront the same constant marginal cost, denoted by \( c \). Let \( p_i \) and \( q_i \) be the price and production, respectively, of firm \( i \). Consumers choose among the \( n \) goods. Firms compete in either quantities or prices. We define \( v_i \) as the strategic variable for firm \( i \), such that \( v_i \in [q_i, p_i] \). Let \( f_i(v_1, v_2, ..., v_n) \) be a function such that \( \frac{\partial f_i}{\partial v_i} < 0 \). Thus, \( f_i \) is either the demand function or the inverse demand function. Let \( g_i(v_i) \) be the function such that

\[
g_i(v_i) = \begin{cases} 
q_i & \text{if } v_i = q_i, \\
q_i(p_1, p_2, ..., p_n) & \text{if } v_i = p_i.
\end{cases}
\]

In other words, \( g_i(v_i) \) denotes the production of firm \( i \). Moreover, \( S(g_1(v_1), g_2(v_2), ..., g_n(v_n)) \) denotes the net surplus of consuming \( n \) goods in quantities \( g_1(v_1), g_2(v_2), ..., g_n(v_n) \).

**Assumption 1.** The net surplus depends on quantities but not on the identity of the firm that sells a product. Then, \( S(g_1(v_1), ..., g_j(v_j), ..., g_i(v_i), ..., g_n(v_n)) = S(g_1(v_1), ..., g_i(v_i), ..., g_j(v_j), ..., g_n(v_n)) \).

Production involves pollution. Let \( \alpha_i \) be the emission rate associated with the production technology of firm \( i \). Thus, one unit of product generates \( \alpha_i \) units of pollution. However, let us assume that investment alters the production process and lowers the emission rate: \( \alpha_i(y_i) = \bar{\alpha} - y_i \), where \( \bar{\alpha} \) is the initial emission rate and \( y_i \) the investment of firm \( i \). The cost of investment is denoted by \( C(y_i) \) with \( C' > 0 \).

The regulator implements a market for permits to curb pollution. Firms should then purchase pollution permits to allow them to pollute. Let us assume that one permit is required
for one pollution unit. Let $E$ be the number of pollution permits or, in other words, the pollution cap. Let $\sigma$ be the permit price. Firms are price takers in the market for permits; thus, $\frac{\partial \sigma}{\partial y_i} = 0$. Because the market for permits covers several sectors, firms are supposed to be price takers. We initially assume that the sectors are identical, and we focus on a representative sector. We will relax this assumption in Section 4.

We consider a linear damage function of pollution, and the marginal damage is denoted by $\lambda$. The regulator considers the firm's profits ($\pi$), the consumer surplus (CS), the environmental damage ($\lambda E$) and the value of the permits sold ($E\sigma$). The social welfare function is then defined as follows:

$$W = CS + \Sigma_i^n \pi_i - \lambda E + \sigma E.$$  
However, because firms are price takers and there is no uncertainty, it is equivalent for the regulator to fix the pollution cap or the permit price (see Weitzman (1974)[12]).

The two different types of regulations considered in this paper, ex-ante and ex-post regulation, are denoted by $X_A$ and $X_P$, respectively. Each type of regulation is defined by specific timing. In the ex-ante case, the regulator commits ex ante to the future supply of permits and consequently also commits to the permit price. This commitment allows firms to plan their long-term investments by considering the future permit price decided by the regulator. Ex-ante regulation is thus characterized by the following timing:

**Stage 1:** The regulator chooses the permit price $\sigma^{X_A}$ and announces it.

**Stage 2:** Investment choices are made by firms.

**Stage 3:** The market for permits opens. Firms choose the level of the strategic variable (price or quantity) on the product market and sell or buy permits on the market for permits. In the ex-post case, firms invest in the long term before the regulator announces the pollution cap. The timing of ex-post regulation is as follows: paragraphStage 1: Investment choices are made by firms.
Stage 2: The regulator chooses the permit price $\sigma^{XP}$ and announces it.

Stage 3: The market for permits opens. Firms choose the level of the strategic variable (price or quantity) on the product market and sell or buy permits on the market for permits.

2.2 A Focus on the Strategic Effects of Investment

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

$$\pi_i(v) = v_i f_i(v_i, v_{-i}) - (c + \alpha (y_i) \sigma) g(v_i) - C(y_i).$$  \hspace{1cm} (1)

Firm $i$ sells its product, buys the required permits and bears an investment cost. Indeed, $v_i f_i$ represents the sales of firm $i$. Recall that firms choose the investment level and then determine the level of the strategic variable. The investment lowers the emission rate and consequently the marginal cost. Therefore, production decisions depend on investment decisions. Optimal production decisions satisfy the following:

$$f_i(v_i, v_{-i}) + v_i \frac{\partial f_i}{\partial v_i} = (c + (\bar{\alpha} - y_i) \sigma) \frac{\partial g_i}{\partial v_i}. \hspace{1cm} (2)$$

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

$$C'(y_i) = v_i \Sigma_{j=1}^{n-1} \frac{\partial f_i}{\partial v_i} \frac{\partial v_j}{\partial y_i} + g(v_i) \sigma. \hspace{1cm} (3)$$

Recall that firms are price takers in the market for permits ($\frac{\partial \sigma}{\partial y} = 0$). The investment decisions clearly depend on production but are also based on the strategic effects of investment, i.e., the manner in which investment alters competition. Indeed, investment lowers the emission rate and consequently the perceived marginal production cost. From equation (2), we deduce that a firm’s production increases as the marginal cost of production decreases.
It should be noted that if firms do not behave strategically,\textsuperscript{5} then they would not consider the strategic interactions in the market for products. Moreover, when \( \frac{\partial L}{\partial y_i} \frac{\partial y_j}{\partial y_i} > 0 \), firms invest more than in the case in which firms do not behave strategically; otherwise, they invest less.

2.3 Optimal Investment

Before determining the optimal investment, we rewrite the welfare function to depend on the equilibrium quantities of the third stage of the scenarios. Recall that we previously defined the social welfare function as follows:

\[
W = CS + \sum_{i=1}^{n} \pi_i - \lambda E + \sigma E.
\]

However, the pollution cap at equilibrium in the market for permits is equal to \( E = \sum_{i=1}^{n} (\bar{\alpha} - y_i)g_i(v_i) \). The net surplus is equal to the consumer surplus minus purchases. The profits are equal to the revenue earned on the product market minus all of the costs borne by firms (the cost of the permits bought and the investment costs). We then rewrite the welfare as a function of the equilibrium production quantities, denoted by \( g_i(v_i^*) \), and the investments:

\[
W = S(g_1(v_1^*), ..., g_n(v_n^*)) - \sum_{i=1}^{n} (g_i(v_i^*)c + C(y_i)) - \lambda [\sum_{i=1}^{n} (\bar{\alpha} - y_i)g_i(v_i^*)], \tag{4}
\]

where the equilibrium production quantities clearly depend on the permit price.

Let us now address the issue of identifying the socially optimal investment that maximizes welfare. The regulator can fix the investment level. Let us assume that because firms are symmetric, the regulator implements the same investment level for all firms. The optimal investment satisfies the following equation:

\[
\frac{\partial W}{\partial y} = \sum_{i=1}^{n} \left( \frac{\partial S}{\partial g_i} - \lambda \alpha_i - c \right) \frac{\partial g_i}{\partial y} + \lambda \sum_{i=1}^{n} g_i(v_i^*) - nC'(y) = 0. \tag{5}
\]

The investment policy corrects two distortions: (i) the environmental externality and (ii)\textsuperscript{5}\footnote{This issue may then be formulated as a comparison between an open loop and a closed loop. See Vives (2000) [11].}

This issue may then be formulated as a comparison between an open loop and a closed loop. See Vives (2000) [11].
the distortion on the demand side. (i) Indeed, investment lowers the emission rate and consequently reduces emissions. (ii) Moreover, the imperfect competition induces under-production. As we observed previously, production increases with investment. Thus, the optimal investment policy urges firms to produce more than in equilibrium.

3 Comparison of Ex-ante and Ex-post Regulations

Let us now analyze and compare ex-post and ex-ante regulations.

3.1 Ex-post regulation

In the case of ex-post regulation, firms invest at stage 1 and anticipate the regulator’s decisions. The optimal ex-post permits price satisfies the following:

$$\frac{\partial W^{XP}}{\partial \sigma} = \sum_{i=1}^{n} \left( \frac{\partial S}{\partial y_i} - \lambda \alpha_i - c \right) \frac{\partial g_i}{\partial \sigma} = 0.$$  

As noted previously, in fixing the optimal permit price, the regulator corrects two distortions: (i) the environmental externality and (ii) the distortion on the demand side. However, using $\frac{\partial S}{\partial y_i} = p_i$, we rewrite the equation (7) as follows:

$$\frac{\partial W^{XP}}{\partial \sigma} = \sum_{i=1}^{n} (p_i - \lambda \alpha_i - c) \frac{\partial g_i}{\partial \sigma} = 0.$$  

The following lemma compares the optimal pollution permit price with the Pigovian tax, i.e., the marginal damage.

**Lemma 1.** When the regulation is ex-post, the permit price is lower than the marginal damage.

**Proof.** Consider first $v_i = q_i$. Equation (3) may then be rewritten as $p_i - c + q_i \frac{\partial p_i}{\partial q_{it}} = (\bar{\alpha} - y_i)\sigma$, and we obtain $p_i = c + (\bar{\alpha} - y_i)\sigma - q_i \frac{\partial p_i}{\partial q_{it}}$. Now consider $v_i = p_i$. Equation (3) may then be rewritten as $q_i + (p_i - c - (\bar{\alpha} - y_i)\sigma) \frac{\partial q_{it}}{\partial p_i} = 0$, and we obtain, as shown previously, $p_i$ =
\[ c + (\bar{\alpha} - y_i)\sigma - q_i \frac{\partial q_i}{\partial y_i}. \]
The first optimal condition may then be written as follows:

\[
\frac{\partial W^{XP}}{\partial \sigma} = \sum_{i=1}^{n} \left((\sigma - \lambda)(\bar{\alpha} - y_i) - q_i \frac{\partial p_i}{\partial q_i}\right) \frac{\partial q_i}{\partial \sigma} = 0,
\]

which implies \( \sigma^{XP} = \lambda + \frac{\sum_{i=1}^{n} q_i \frac{\partial p_i}{\partial q_i}}{\sum_{i=1}^{n} (\bar{\alpha} - y_i) \frac{\partial q_i}{\partial \sigma}}. \)

However, \( \frac{\partial q_i}{\partial \sigma} < 0; \) moreover, \( \frac{\partial p_i}{\partial q_i} < 0. \) We then conclude that \( \sigma^{XP} < \lambda. \)

This result is standard and well known in the literature. Under perfect competition, the optimal permit price is equal to the Pigovian tax. However, under imperfect competition, the regulator should implement a lower permit price to decrease the market power of firms in the market for products \( (\frac{\partial p_i}{\partial q_i} < 0). \)

Let us then focus on the first stage of the game. Firm \( i \) determines the investment level \( y_i \) by maximizing profits. From the envelope theorem and based on \( \frac{\partial \sigma}{\partial y_i} = 0, \) the investment decision is given by the following:

\[
C'(y_i) = v_i \sum_{j=1}^{n-1} \frac{\partial f_i}{\partial v_j} \frac{\partial v_j}{\partial y_i} + g(v_i)\sigma^{XP}.
\]

We deduce that because firms are symmetric, they invest in the same manner and consequently that their production is the same. We then deduce the following lemma.

**Lemma 2.** Under imperfect competition, in the ex-post case, the level of investment is not optimal.

**Proof.** From the envelope theorem, when the regulator fixes the permits price equal to \( \sigma^{XP}, \)

\[
\sum_i \left( \frac{\partial S}{\partial q_i} - \lambda \alpha_i - c \right) \frac{\partial q_i}{\partial y_i} = 0.
\]

Moreover, investments and production are symmetric. The optimal investment is given by \( C'(y) = \lambda g(v), \) which is different from equation (5). \( \square \)

The distortion of the investment level comes from both (i) the correction of the distortion on the demand side and (ii) the existence of strategic effects. (i) The regulator fixes an optimal permit price lower than the marginal damage, which reduces the incentives for firms to invest. The most interesting point here is that the regulator generates a distortion (of the investment)
by correcting the distortion of the demand side. (ii) Moreover, firms may also overinvest or underinvest for strategic reasons.

3.2 Ex-ante regulation

We assume that the regulator announces the permit price before firms invest. Therefore, firms make their investment decisions once they know the degree of severity of the environmental regulation. The regulator maximizes the welfare by fixing the optimal permit price. The latter satisfies the following equation:

\[
\frac{\partial W}{\partial \sigma} = \frac{\partial W}{\partial v} \left( \frac{\partial v}{\partial \sigma} + \frac{\partial v}{\partial y} \frac{\partial y}{\partial \sigma} \right) + \frac{\partial W}{\partial y} \frac{\partial y}{\partial \sigma} = 0.
\] (9)

The equation (9) may be divided into two parts: (i) the first part is the same expression as in equation (7), and (ii) the second part refers to the effect of the permit price on investment. Indeed, in the ex-post case, the regulator acts once the investment has already been realized. However, in the ex-ante case, the regulator may correct the distortion on the investment level. The following proposition compares the two types of regulation in terms of welfare.

**Proposition 1.** Ex-ante regulation is socially preferable to ex-post regulation.

**Proof.** It is always possible to replicate the ex-post permit price in the ex-ante case. □

The following logic is employed. When the regulator acts first, it simultaneously corrects the three distortions. By implementing the ex-post price, the regulator achieves at least the same welfare ex ante as ex post. Indeed, the second part of equation (9) is positive. Therefore, ex-ante regulation is socially preferable. However, to compare the two optimal permit prices, we focus on the ex-ante implementation of the ex-post permit price. If the regulator fixes the permit price equal to the optimal ex-post price, then the first part of equation (9) is null. We then analyze the second part of equation (9). However, from equations (5) and (7) and using the envelope theorem, we obtain the following:

\[
\frac{\partial W}{\partial y} \bigg|_{\sigma_{XA} = \sigma_{XP}} = \lambda g(v_i) - C'(y).
\]
We deduce then that
\[
\frac{\partial W^{X_A}}{\partial \sigma} \bigg|_{\sigma_{X_A} = \sigma_{X_P}} = \frac{\partial W^{X_A}}{\partial y_i} \frac{\partial y_i}{\partial \sigma} \bigg|_{\sigma_{X_A} = \sigma_{X_P}} = \lambda g(v_i) - C'(y). \tag{10}
\]

Inserted in equation (5), the previous equation may be rewritten as follows:
\[
\frac{\partial W^{X_A}}{\partial y_i} \frac{\partial y_i}{\partial \sigma} \bigg|_{\sigma_{X_A} = \sigma_{X_P}} = (\lambda - \sigma_{X_P}) g(v_i) - v_i \sum_{j=1}^{n-1} \frac{\partial f_i}{\partial v_j} \frac{\partial v_j}{\partial y_i}. \tag{11}
\]

Two effects are at stake. First, the regulator has an incentive to increase the permit price because the ex-post permit price leads to underinvestment. Second, the strategic effects may urge firms either to overinvest or to underinvest. The following proposition compares the two optimal permit prices.

**Proposition 2.** The comparison between ex-ante and ex-post permit prices depends on the strategic effects:

(i) If the strategic effects lead firms to invest less than in the case in which firms do not behave strategically \((\frac{\partial f_i}{\partial v_j} \frac{\partial v_j}{\partial y_i} < 0)\), then the ex-ante permit price is higher than the ex-post price.

(ii) If the strategic effects lead firms to invest more than in the case in which firms do not behave strategically \((\frac{\partial f_i}{\partial v_j} \frac{\partial v_j}{\partial y_i} > 0)\), then the ex-ante permit price may be higher or lower than the ex-post price.

Consider the situation in which firms do not behave strategically. The second part of equation (??) is null, and firms always underinvest because the regulator corrects the distortion on the demand side. Indeed, the ex-post permit price is lower than the marginal damage. The regulator corrects the distortion generated by the correction of market power in the ex-ante case.

Assume now that firms do behave strategically. As we previously noted, the strategic effects urge firms to invest in ways that are not optimal. If the strategic effects lead firms to
invest less than in the case in which firms do not behave strategically, then firms underinvest, and the two effects are in the same direction. The ex-ante permit price is then higher than the ex-post price. However, if the strategic effects lead firms to invest more than in the case in which firms do not behave strategically, then firms overinvest, and the two effects are in turn opposite. Moreover, each effect can prevail. Thus, the ex-ante permit price may be higher or lower than the ex-post price.

3.3 Discussion

First, let us discuss the strategic effects. We can divide these effects into three types of effects: (i) the effect of the investment of one firm on its own strategic variable, (ii) the relation between the firm’s strategic variable and the rivals’ strategic variables and (iii) the relation between the rivals’ strategic variables and the function $f$. (i) The first relation is well known in the literature and depends on the nature of competition. Indeed, if firms compete in prices, then they decrease the perceived marginal cost when they invest and consequently decrease their own price. However, if they compete in quantities, then they decrease the perceived marginal cost when they invest and consequently decrease their own production. (ii) The second relation depends on whether the strategic variables are strategic substitutes or strategic complements, which depends on the types of goods and the type of competition. For instance, if demand is linear, firms compete in quantities and goods are substitutes, then quantities are then strategic substitutes. However, if demand is linear, firms compete in prices and goods are substitutes, then prices are strategic complements. When demand is not linear, the situation is more complicated. (iii) The relationship between the rivals’ strategic variables and the function $f$ depends on the type of competition. When firms compete in prices, the function $f$ decreases with the rivals’ strategic variables. However, when firms compete in quantities, the function $f$ increases with the rivals’ strategic variables. We can then conclude that the result is straightforward if and only if demand is linear.

Now consider that the markets for products covered by the market for permits are not identical. We then relax the assumption of a representative sector. Let us assume $n$ markets
for products covered. We show that for ex-post regulation, the optimal permit price is also lower than the marginal damage because the regulator reduces the market power in all of the markets for products (see Appendix 4). For the ex-ante regulation, the results depend on the sum of all strategic effects. As we noticed, strategic effects may be positive or negative. Some negative strategic effects may offset some positive effects, and the permit price may then be higher than the marginal damage. However, if the types of goods and the type of competition are the same in all markets and if demand is linear, then the result is trivial.

Ordinarily, profits decrease with the permit price. In this case, firms prefer ex-post regulation when quantities are strategic complements because the ex-ante permit price is higher than the ex-post price. In the other case, when the ex-ante permit price is lower than the ex-post price, firms prefer ex-ante regulation. However, profits may increase with the introduction of an environmental regulation. This phenomenon results from the characteristics of the demand (see Seade (1985))[10]. If profits increase with environmental regulation, then firms prefer ex-ante regulation when the strategic effects lead firms to invest more than in the case under in which firms are do not behave strategically; otherwise, firms may prefer ex-post regulation. The firm perspective may then be antagonistic to that of the regulator. However, the consumer surplus always decreases with environmental regulation. Thus, consumers prefer the type of regulation that leads to a lower permit price. Therefore, consumers may also prefer ex-post regulation.

In this paper, the regulator is assumed to commit itself ex ante to fixing the permit price. However, the issue of commitment credibility arises. In the ex-ante case, the regulator has incentives to change the pollution cap after firms have invested. Indeed, once the distortion on investment is corrected, the regulator has incentives to increase the permit price to further curb pollution. The regulator is thus time-inconsistent. Therefore, modifying the environmental regulation should be costly. For instance, as in Laffont & Tirole (1996)[4], the regulator may give free allowances conditionally to demonstrate its commitment. Another solution is to delegate the environmental regulation to an independent authority, as in Helm et al. (2003)[3].

This paper does not consider the existence of abatement technologies. However, because
abatement and production decisions are simultaneous, there is no strategic effect. The introduction of abatement technologies does not alter our results.

4 Conclusion

This paper demonstrates the role of imperfect competition defining pollution caps for upcoming periods. It is optimal for the regulator to act first when the market for products is imperfect and when the market for permits is perfect. However, the comparison of permit prices for the two types of regulation (i.e., ex-ante and ex-post) depends on whether firms invest more or less than in the case in which they do not behave strategically. Surprisingly, firms may benefit from ex-post regulation.

The paper’s main assumptions are a lack of time to build, symmetry, certainty and a linear damage function. It would be interesting to examine the effect of relaxing the symmetry assumption. One aspect that we leave for future research is the time to build. Pacheco-de-Almeida & Zemsky (2003)[7] show that an investment needs several years to be operative. Given this time to build, the analysis should account for uncertainty about the future context in which the investment will be available. Finally, a quadratic damage function plays a crucial role in Puller (2005)[9] and Petrakis & Xepapadeas (2001)[8]. Therefore, introducing such an assumption may be a promising extension.

References


Appendix

Several and various market for products covered by the same market for products

We relax from now on the assumption such that all the market for products are identical. Consider, from now on, \( m \) sectors included in the same market for permits. Inside each market,
firms are symmetric. A sector $l$ is characterized by demand $q_l$, marginal cost $c_l$, number of firms $n_l$ and emission rate $\alpha_l$. First of all, the welfare function aggregates the surplus coming from the different sectors, and may be written such as:

$$W(\sigma) = \sum_{l=1}^{m} S(g_1(v_{l1}), \ldots, g_d(v_{ld})) - \sum_{l=1}^{m} \sum_{d=1}^{n} (g_d(v_{ld})c + C(y_{ld})) - \lambda \sum_{l=1}^{m} \left[ \sum_{d=1}^{n} (\bar{\alpha} - y_{ld})g_d(v_{ld}) \right].$$

(12)

As previously, we determine firms’ decisions in each market. The profits may be written as:

$$\pi_i(v_i) = v_i f_i - (c_l + \sigma \alpha(y_i))g(v_i) - C(y_i).$$

(13)

Optimal production decisions satisfy,

$$f_d(v_{id}) + v_{id} \frac{\partial f_d}{\partial v_{id}} = (c_l + (\bar{\alpha}_l - y_{id})\sigma) \frac{\partial g_{id}}{\partial v_{id}}.$$

(14)

Firms choose the investment level by maximizing profits. The first order condition satisfies:

$$v_{id} \sum_{j=1}^{n} \frac{\partial f_d}{\partial v_{jd}} \frac{\partial v_{jd}}{\partial y_{id}} + \sigma g(v_{id}) - C'(y_{id}) = 0.$$

(15)

**Ex-ante regulation.** We assume that the regulator announces the permits price before firms invest. Therefore, the firms take their investment decisions knowing the degree of severity of the environmental regulation. The regulator maximizes the welfare by choosing the permits price. The optimal ex-ante permits price satisfies:

$$\frac{\partial W_{XA}}{\partial \sigma} = \sum_{l=1}^{m} \left( \frac{\partial W_{XA}}{\partial v_{il}} \left( \frac{\partial v_{il}}{\partial \sigma} + \frac{\partial v_{il}}{\partial y_{il}} \frac{\partial y_{il}}{\partial \sigma} \right) + \frac{\partial W_{XA}}{\partial y_{il}} \frac{\partial y_{il}}{\partial \sigma} \right),$$

$$= \sum_{l=1}^{m} \left( \frac{\partial W_{XA}}{\partial v_{il}} \frac{\partial v_{il}}{\partial \sigma} + \frac{\partial W_{XA}}{\partial y_{il}} \frac{\partial y_{il}}{\partial \sigma} \right) + \sum_{l=1}^{m} \left( \frac{\partial W_{XA}}{\partial y_{il}} \frac{\partial y_{il}}{\partial \sigma} \right), = 0.$$  

(16) 

(17)
When the regulator implements the ex-post permits price, the first part of the previous equation is null. Moreover, however, we know that \( \frac{\partial W^{XA}}{\partial \sigma} = (\lambda g_{il}(v_{il}) - C'(y_{il})) \). We conclude then that

\[
\left. \frac{\partial W^{XA}}{\partial \sigma} \right|_{\sigma^{XA} = \sigma^{XP}} = \left. \frac{\partial W^{XA}}{\partial y_{il}} \right|_{\sigma^{XA} = \sigma^{XP}} = \lambda g_{il}(v_{il}) - C'(y_{il}).
\]

Plugging back equation (15) in the previous expression, we conclude that:

\[
\left. \frac{\partial W^{XA}}{\partial y_{il}} \right|_{\sigma^{XA} = \sigma^{XP}} = \left( \lambda - \sigma^{XP} \right) \Sigma_{l=1}^{m} g_{il}(v_{il}) - \Sigma_{l=1}^{m} \Sigma_{j=1}^{n_{l}-1} v_{il} \Sigma_{j=1}^{n_{l}} \frac{\partial f_{il}}{\partial v_{jl}} \frac{\partial v_{jl}}{\partial y_{il}}.
\]

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