UNITE MIXTE DE RECHERCHE
EN ECONOMIE PUBLIQUE

JOINT RESEARCH UNIT IN
PUBLIC ECONOMICS

2007
CAHIERS DE RECHERCHE
WORKING PAPERS
2007/02

Environmental Taxation and the Structure of the Eco-industry

M. David, A.D. Nimubona, B. Sinclair-Desgagné

UMR Economie Publique
Avenue Lucien Brétignières – 78850 Grignon
16 rue Cl. Bernard – 75005 Paris
Tel. +33 (0)1 30 81 53 30
Fax. +33 (0)1 30 81 53 68
http://www.grignon.inra.fr/economie-publique

Environmental Taxation and the Structure of the Eco-industry

Maia David*, Alain-Désiré Nimubona† and Bernard Sinclair- Desgagné‡

Preliminary draft - Do note quote without permission

Abstract

We examine the effect of an emission tax when the abatement good or service is supplied by an imperfectly competitive eco-industry with free entry. We show that a higher tax always increases the number of firms in the eco-industry whereas it has an ambiguous effect on individual and total output in the eco-industry. We derive the condition under which total abatement may actually decrease with the emission tax. We then study the policy implications of these results in terms of optimal tax levels.

Keywords: eco-industry, environmental tax, endogenous market structure
JEL Classifications: D62, H23, L11

1 Introduction

Over the last two decades, many firms specialized in the delivery of abatement goods and services (i.e. eco-industries) have been created worldwide. In France, for example, of the 1200 firms that constituted the environment industry in 2002, about half did not exist in the early 1990s (Grall and Cabot, 2002). In Israel, the number of companies supplying environmental goods and services is currently estimated at around 1000, triple their number at

*UMR AgroParisTech-INRA Économie publique, Paris. E-mail: mdavid@agroparistech.fr

†Institute of applied Economics, HEC Montréal, Canada. E-mail: alain-desire.nimubona@hec.ca

‡École polytechnique, Paris; CIRANO, CIRAIG and HEC Montréal, Canada. E-mail: bsd@hec.ca

the beginning of the 1990s (Kennett and Steenblik, 2005). In Canada, although dampened somewhat by the growing merger activities among larger environmental firms, the number of new firms reporting environmental revenues reached 7474 in 2000, up 30% from 1996 (Industry Canada, 2002).

There is broad consensus that national and international environmental regulations have been the main stimulus for the demand side of the environmental market and, consequently, the engine driving growth in the eco-industry. However, only recently have economists analyzed the precise relationship between environmental regulation and the eco-industries.

Feess and Muehlheusser (1999, 2002) were the first to introduce explicitly an eco-industry in the analysis of environmental policies. Nevertheless, they assumed environment firms were price-takers and thus ruled out all strategic behaviors from this industry. David and Sinclair-Desgagné (2005) have shown how different policy instruments - emission taxes, design standards and voluntary agreements - affect the market power of an oligopolistic eco-industry. David and Sinclair-Desgagné (2005), Canton et al. (2005) and Nimubona and Sinclair-Desgagné (2005) have examined how the optimal rate for an emission tax deviates from the Pigovian rule when the abatement good or service is provided by an imperfectly competitive industry. Requate (2005) studied the best timing of policies when the eco-industry is responsible for the R&D and sells the clean technology to polluters.

However, a significant gap remains in this literature. In all previous papers, the number of environment firms is given exogenously. In other words, the market structure of the eco-industry is fixed. In the real world, the environmental intervention affects the number of firms and the degree of concentration in the abatement industry and we believe these effects have strong policy implications. A stricter environmental policy, for instance, affects the structure of demand for abatement. This in turn affects the incentives for firms to enter the abatement market, which may modify the optimal level of environmental protection. Our main objective is thus to examine the effects of the environmental policy on a free-entry eco-industry.

Several articles have studied the effects of demand alterations in free-entry oligopolies. Quirmbach (1988), Hamilton (1999), Cowan (2004), and Okuguchi and Szidarovszky (2005), have shown that the output and price effects of demand shifts may be ambiguous and depend on the shape of demand and marginal revenues functions. More precisely, Hamilton (1999) obtains two main results. First, if the demand function is subject to a parallel upwards shift, the industry output always expands when entry occurs. Second, when the inverse demand curve is subject to a clockwise rotation, industry output always contracts when entry occurs. Nevertheless, while Hamilton (1999) modeled separately the effects of a parallel shift and a rotation in demand, we show that a variation in the environmental policy actually induces both shifts simultaneously. We thus extend Hamilton's work to take into account these two simultaneous effects.

We consider a simple game of entry and exit in the eco-industry, where incumbent firms are symmetric and behave as Cournot oligopolists, while polluting firms are price-takers. In addition to introducing free-entry, we extend David and Sinclair-Desgagné (2005)'s framework by relaxing an assumption made on the convexity of the emission function (further details on this point are given in the paper). Last, we assume the authorities regulate pollution through an emission tax.

We show that a tax rise induces a parallel upward shift of the inverse demand for abatement - i.e. an increase of polluter's willingness to buy abatement - and a clockwise rotation of this inverse demand function - i.e. a decrease in the price sensitivity of abatement demand (section 3.1). We then show that the tax rise always increases the number of firms in the eco-industry and the price for abatement, whereas individual and total output of environment firms may increase or decrease (section 3.2). Hence, a more stringent environmental tax might actually *decrease* total abatement in the economy. The fact that, within a rather common framework[1], an environmental tax might reinforce rather than offset the pollution problem dramatically calls for attention. We derive the condition under which this perverse effect of the tax might occur.

Given these features, we extend David and Sinclair-Desgagné (2005)'s contribution on the optimal tax rate. We derive the conditions under which the tax rate should be superior, inferior or equal to the marginal damage of pollution (section 4). Our last section concludes our work (section 5).

2 Basic assumptions

Consider a representative price-taking firm selling a consumption good at a price P. It produces an output x and a negative externality e due to air pollution. Let v denote the constant marginal social damage of polluting emissions. Let the polluter's emission function be represented as $e(x, a)$, where a denotes abatement efforts. Following Barnett (1980), Katsoulacos and Xepapadeas (1995) and Farzin and Kort (2001), we assume that the polluter controls its emissions through end-of-pipe abatement. In other words, $e(x, a)$ is additively separable and can be written as $e(x, a) = w(x) - \epsilon(a)$. This function is twice continuously differentiable, with $w'(x) > 0$, $\epsilon'(a) > 0$,

[1] Most segments of the eco-industry are characterized by monopolistic or oligopolistic competition with free-entry.

$w''(x) \geq 0$ and $\epsilon''(a) < 0$. The first two inequalities state that pollution increases with the level of production and decreases with the level of abatement efforts; according to the third relation, the last unit of output pollutes more as total production increases; and the last inequality indicates decreasing returns to abatement. Let $C(x)$ be the polluting firm's production cost function, where $C'(x) > 0$ and $C''(x) \geq 0$ (decreasing returns to production).

The abatement good or service is supplied by an eco-industry with free entry and exit, which initially comprises m identical firms behaving as Cournot oligopolists. An eco-industrial firm j supplying an amount a_j of abatement is characterized by a cost function $G(a_j)+F$, where F represents setup costs. We have that $G(0) = 0$, $G'(a_j) > 0$ and $G''(a_j) \geq 0$ (decreasing returns to abatement).

The abatement demand from the polluting firm is represented by an inverse demand function $q(a)$, where q is the price of the abatement service. Its first and second derivatives are respectively denoted as q_a and q_{aa}. We assume that the following expression is always verified:

$$2q_a + aq_{aa} - G''(a_j) \leq 0 \tag{1}$$

which ensures the existence and unicity of the Cournot-Nash equilibrium in the eco-industry.

3 The impact of an emission tax

3.1 Behavior of polluting firms

In the presence of an emission tax t, the polluting firm's profit is given by:

$$\pi(x, a) = Px - C(x) - qa - t\left[w(x) - \epsilon(a)\right] \tag{2}$$

To maximize its profit, the representative polluter sets the marginal return on output and the marginal cost of abatement respectively equal to the marginal cost of production and the marginal benefit of abatement, i.e.

$$P = C'(x^t) + tw'(x^t) \tag{3}$$
$$q = t\epsilon'(a^t) \tag{4}$$

Straightforward comparative-statics from these first-order conditions (computations are given in the appendix) yield $\frac{dx^t}{dt} = -\frac{w'(x^t)}{C''(x^t)+tw''(x^t)}$ and $\left.\frac{da^t}{dt}\right|_q = -\frac{\epsilon'(a^t)}{t\epsilon''(a^t)}$. The above assumptions thus imply that $\frac{dx^t}{dt} < 0$ and $\left.\frac{da^t}{dt}\right|_q > 0$.

In other words, when the tax increases, polluters' output decreases whereas their abatement decision increases for a given price q.

Given equation (4), the inverse demand function for abatement is

$$q(a,t) = t\epsilon'(a)$$

The slope of this inverse demand function is $q_a = t\epsilon''(a) \leq 0$. Unsurprisingly, the inverse demand function for abatement is decreasing.

We have that:

$$q_t = \left.\frac{\partial q(a,t)}{\partial t}\right|_a = \epsilon'(a) > 0$$

That is, when the tax is increased the price q increases for a given a. In other words, in the (a,q) graph, a tax rise induces a parallel upwards shift of the inverse demand function (see Figure 1).

We also note that, as the tax is increased, the inverse demand function becomes steeper, i.e. the demand for abatement becomes less price elastic. Analytically, we have:

$$q_{at} = \left.\frac{\partial q_a}{\partial t}\right|_a = \epsilon''(a) \leq 0$$

Graphically, this implies that a tax increase generates a clockwise rotation of the inverse demand function in the (a,q) graph. As a result:

Lemma 1. *An increase in the emission tax induces some combination of a parallel upwards shift ($q_t > 0$) and a clockwise rotation ($q_{at} \leq 0$) of the inverse demand curve for abatement.*

Figure 1 shows the combination of both effects in the (a,q) graph.

Note that, given that for each price q the demand for abatement is increased with a tax (i.e. $\left.\frac{da^t}{dt}\right|_q > 0$), each point of the new inverse demand curve (in bold) is located on the right of the initial demand curve, as shown on Figure 1.

According to Hamilton (1999), these two effects on demand have opposite consequences in an industry with free-entry. The parallel shift increases total equilibrium output whereas the clockwise rotation has an opposite effect. The effect of environmental taxation on the behavior of a free-entry eco-industry is thus ambiguous and is examined in the coming section.

3.2 Behavior of eco-industrial firms

The program of a firm j in the eco-industry is written:

$$\max_{a_j} \Pi_j = q(a,t)a_j - G(a_j) - F \tag{5}$$

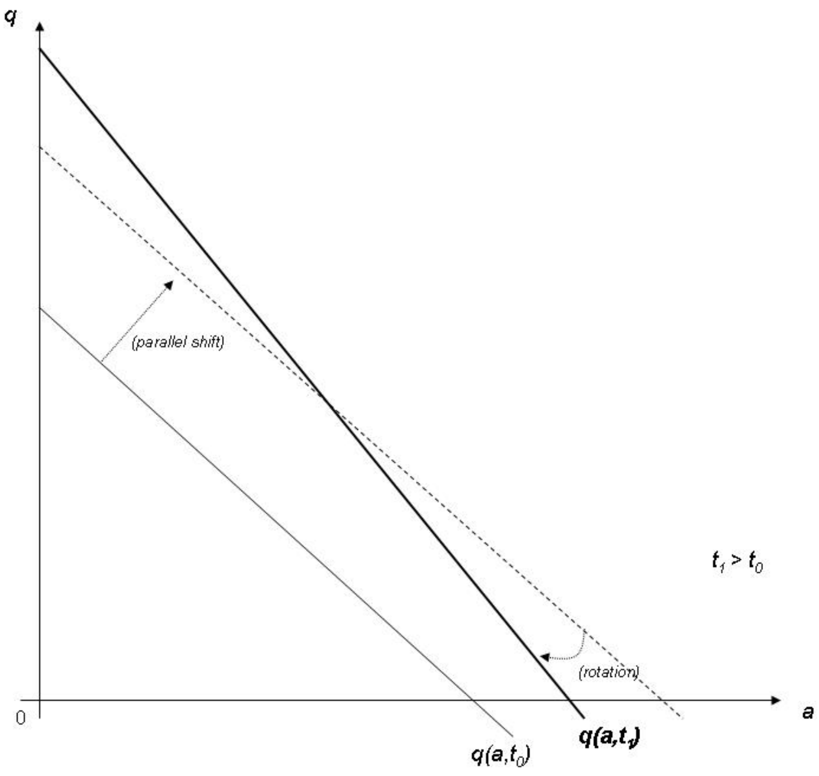

Figure 1: Impact of a tax on the abatement demand curve

where $a = \sum_{j=1}^{m} a_j$. A firm's optimal output given a tax t is then given by the following first order condition:

$$q(a^t, t) + a_j^t q_a(a^t, t) - G'(a_j^t) = 0 \tag{6}$$

while entry in the industry is determined by the following zero-profit condition[2]:

$$\Pi_j = q(a^t, t)a_j^t - G(a_j^t) - F = 0 \tag{7}$$

3.2.1 Individual output and entry decision

Standard comparative statics (computations are in the appendix) from equations (6) and (7) then yield

$$\frac{da_j^t}{dt} = -\frac{a_j^t(q_a q_{at} - q_{aa}q_t)}{q_a\left(2q_a + a_j^t q_{aa} - G''(a_j^t)\right)} \tag{8}$$

$$\frac{dm}{dt} = \frac{-q_t(2q_a + a^t q_{aa} - G''(a_j^t)) + (a^t - a_j^t)q_a q_{at}}{a_j^t q_a(2q_a + a_j^t q_{aa} - G''(a_j^t))} \tag{9}$$

From section 2, we have that $q_t > 0$ and $q_{at} \leq 0$. Moreover, from our assumption that $2q_a + a^t q_{aa} - G''(a_j^t) \leq 0$ we have $2q_a + a_j^t q_{aa} - G''(a_j^t) \leq 0$. As a result, the sign of $\frac{dm}{dt}$ is unambiguously positive whereas the sign of $\frac{da_j^t}{dt}$ is ambiguous. That is, the number of firms in the eco-industry always increases with a tax whereas the individual eco-industrial firm's supply may increase, decrease or remain constant, according to the following condition:

$$\frac{da_j^t}{dt} \gtreqless 0 \qquad \textit{if and only if} \qquad q_a q_{at} \lesseqgtr q_{aa} q_t \tag{10}$$

The intuition associated to condition (10) is the following. q_a indicates the steepness of the inverse demand function for abatement, which is related to the elasticity of abatement demand and thus to the eco-industry's market power. The greater $|q_a|$, the greater the eco-industry's market power. q_{at} indicates on how the tax affects the eco-industry's market power. The greater $|q_{at}|$, the more the tax amplifies the eco-industry's market power. q_t indicates on how much the tax increases the polluters' willingness to acquire abatement for a given price. Last, q_{aa} indicates on the degree of convexity/concavity of the inverse demand function. The impact of a tax rise on the individual

[2] To address entry in the model, the number of firms is treated as a continuous variable following Besley (1989), Mankiw and Whinston (1986) and Seade (1980).

output a_j^t results from two effects. On the one hand, the abatement demand for a given price q is increased which rather induces environmental firms to increase their output[3]. On the other hand, the price elasticity of abatement demand is reduced, which gives eco-industrial firms incentive to strategically increase the price through output restriction. Moreover, the eco-industry's stronger market power induces the entry of new firms, which may result in a "business-stealing effect" decreasing the individual output (see Mankiw and Whinston, 1986). As a result, if the market power effect of the tax (left-hand side of condition (10)) is superior to its demand effect (part of the right-hand side of condition (10)), then the individual output decreases. Else, the individual output increases. Note that when the inverse demand function $q(a)$ is linear or concave ($q_{aa} \leq 0$), the individual output always decreases with the tax.

Figures 2 and 3 illustrate the abatement decision of a firm j in the eco-industry. Figure 2 focuses on the case when at an equilibrium, the higher tax induces a lower individual output and Figure 3 on the opposite case.

As shown in these figures, the output decision of a firm j is given at the point where the firm's marginal cost $G'(a_j)$ equals its marginal revenues[4] Rm. Note that the firm takes its decision considering the other firms' decisions as given (Cournot-Nash equilibrium), i.e. $a = a_j + \sum_{i \neq j} \bar{a}_i$ where $\bar{a}_i$ is fixed.

3.2.2 Total output

At the aggregate level, since environment firms are identical, then at an equilibrium we have that $a^t = ma_j^t$ and $\frac{da^t}{dt} = a_j^t \frac{dm}{dt} + m\frac{da_j^t}{dt}$. From (8) and (9), we obtain

$$\frac{da^t}{dt} = -\frac{a_j^t q_a q_{at} + [2q_a - G''(a_j^t)]q_t}{q_a[2q_a + a_j^t q_{aa} - G''(a_j^t)]} \tag{11}$$

Given our assumptions, the denominator in (11) is always positive. Therefore, $\frac{da^t}{dt} \gtreqless 0$ according to the following expression:

$$\frac{da^t}{dt} \gtreqless 0 \qquad \textit{if and only if} \qquad q_a q_{at} a_j^t \lesseqgtr [G''(a_j^t) - 2q_a]q_t \tag{12}$$

In other words, total abatement at the market equilibrium may increase, decrease or remain equal with a tax rise. The intuition for condition (12) is similar to the one for condition (10). When the market power effect of

[3]The shift in demand induces an excess in demand on the abatement market which leads to an increase in price and supply.

[4]Firm j's marginal revenues are: $Rm_j = q_a a_j + q(a)$.

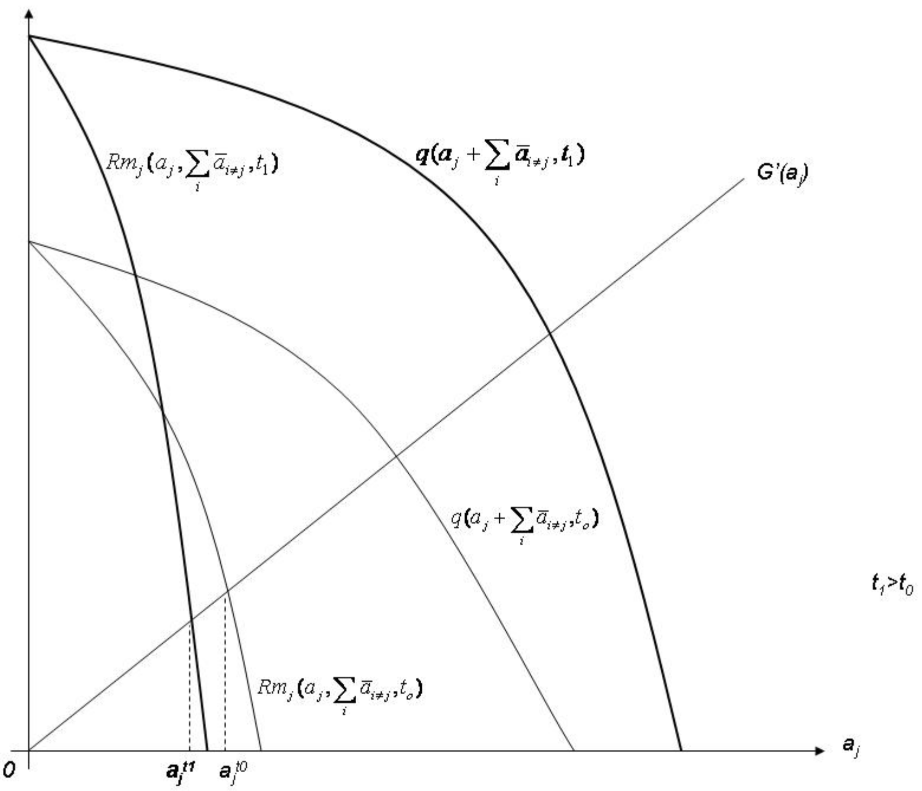

Figure 2: Individual output of the eco-industry decreases with the tax

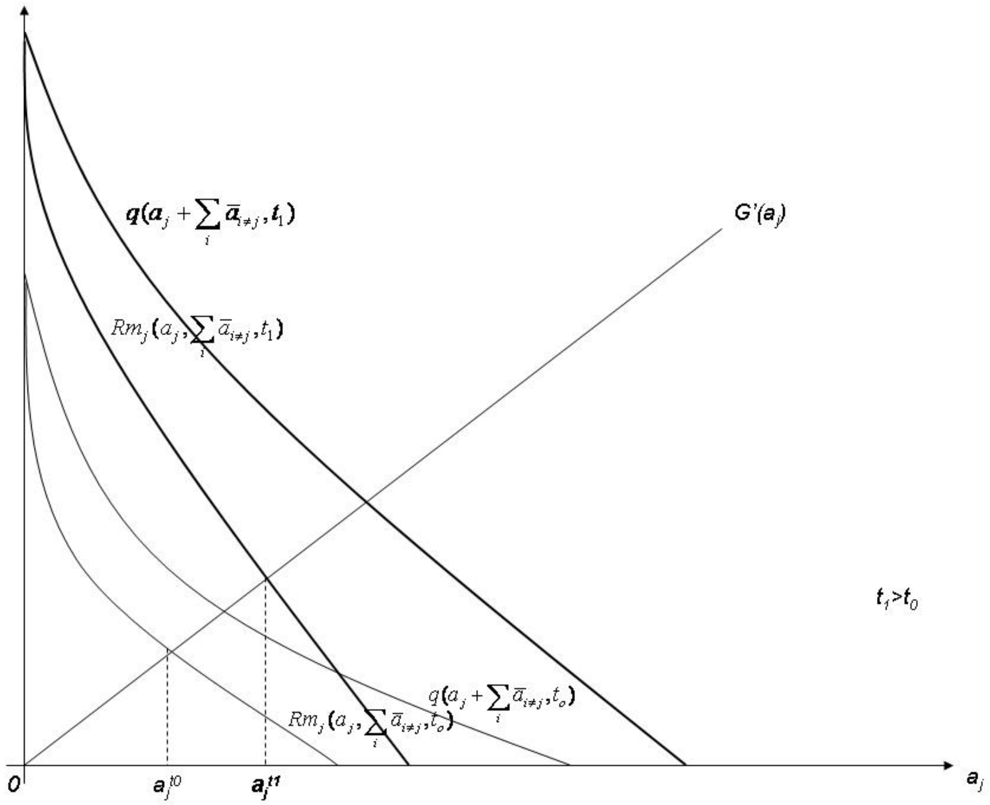

Figure 3: Individual output of the eco-industry increases with the tax

the tax is significant (left-hand side of (12)), the eco-industry strategically restricts output in order to increase its price. When the demand effect of the tax is preponderant (q_t on the right-hand side of (12)), then the eco-industry increases its supply in order to satisfy the demand. To sum up, the ultimate effect of environmental taxation on the global output depends on the specific combination of level and rotation effects of the demand function for abatement.

Note that the price for abatement always increases at an equilibrium when the tax increases. This can be shown graphically on Figure 4. According to Lemme 1, a tax increase induces a rotation and a parallel shift of the inverse demand function and each point of the new demand curve is on the right hand of each point of the initial curve (at an equilibirum $\left.\frac{da^t}{dt}\right|_q > 0$). The supply curve is given by the sum of eco-industrial firm's individual behaviour. Note that at an equilibrium, as firms in the eco-industry are identical, each chooses the same output. We then show easily that the supply curve goes through the origin and is increasing. Moreover, we can show that when the tax increases, the new supply curve still goes through the origin and has a greater slope. Figure 4 then shows the equilibrium before and after the tax increase. Given the shifts of the demand and supply curves, we see that the equilibrium price necessarily increases whereas the equilibrium output may increase or decrease.

The previous results lead to the following proposition:

Proposition 1. *Following an increase of the emission tax in an economy, the number of firms in the eco-industry always increases whereas the eco-industry's individual and total output may increase, decrease or remain unchanged. In particular, total output decreases if the tax's impact on the eco-industry's market power is strong compared to its impact on the polluters' willingness to abate. The price for abatement always increases with a tax rise.*

We thus face this surprising result according to which the total level of abatement in the economy may actually decrease with the emission tax[5]. It results from the strategic behavior that an imperfectly competitive eco-industry may adopt when facing an increase in its market power. This result

[5]Note that this result is independent from the fact that the number of firms in the eco-industry is endogenous. It is due to the generalized framework of our model compared to David and Sinclair-Desgagné (2005) where some specific assumption is made regarding the convexity of the emission function. More precisely, David and Sinclair-Desgagné assume that $\epsilon^{'}(a)a$ is increasing in a, which is a sufficient condition for $\frac{da^t}{dt}$ to be always positive. We relax this assumption.

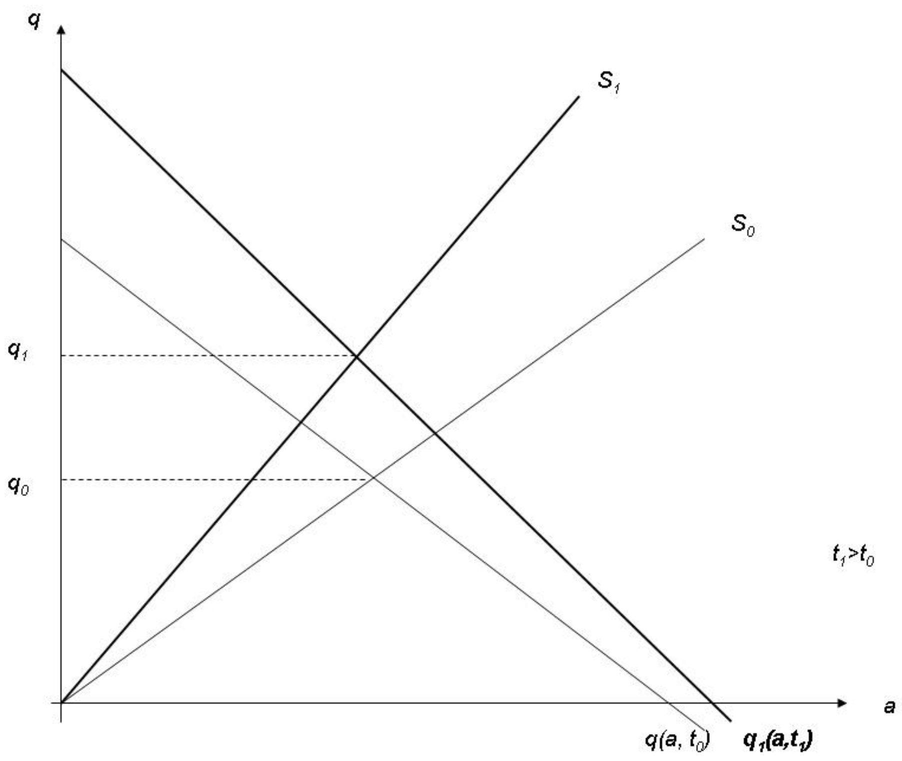

Figure 4: Equilibria on the abatement market

has strong implications on the choice of the optimal taxation, as shown in the following section.

4 Environmental taxation

Consider a benevolent regulator who chooses the emission tax in order to maximize social welfare. The latter is defined as the sum of consumers' surplus and the polluting and eco-industries' total profits, minus the total external damages imputable to the production of the final good. The regulator then solves the following program:

$$\max_t W(t) = \int_0^{x^t} P(u)du - C(x^t) - \sum_{j=1}^{m} G(a_j^t) - m(t)F - v\left[w(x^t) - \epsilon\left(a^t\right)\right]$$

At an equilibrium, all firms in the eco-industry choose the same output so social welfare can be written as:

$$W = \int_0^{x^t} P(u)du - C(x^t) - m(t)G(\frac{a^t}{m(t)}) - m(t)F - v[w(x^t) - \epsilon(a^t)] \quad (13)$$

The social welfare function can then be written as $W = W\left[x\left(t\right), a\left(t\right), m(t)\right]$ and the optimal tax is given by the following formula (computations can be found in the appendix):

$$t^* = v\left[\frac{w^{'}(x^t)\frac{dx^t}{dt} - \epsilon^{'}(a^t)\frac{da^t}{dt}}{w^{'}(x^t)\frac{dx^t}{dt} - \epsilon^{'}(a^t)\frac{da^t}{dt} - \frac{a^t}{m}\epsilon''(\frac{da^t}{dt} - \frac{a^t}{m}\frac{dm}{dt})}\right] \quad (14)$$

Compared to David and Sinclair-Desgagné (2005), this formula includes two new features. First, we now take into account the impact of the tax on the number of firms in the eco-industry, represented by the term $-\frac{a^t}{m}\frac{dm}{dt}$ in the denominator. Second, we have relaxed an assumption made in David and Sinclair-Desgagné (2005) on the convexity of the emission function (i.e. that $\epsilon^{'}(a)a$ is increasing in a). As a result, the equilibrium abatement may now be reduced with the emission tax, i.e. $\frac{da^t}{dt}$ may be negative. Consequently, the sign of both the numerator and the denominator in (14) is ambiguous. In order to understand more precisely formula (14), let us distinguish two cases.

4.1 Case when $\frac{da^t}{dt} > 0$

Let us first assume that, as in David and Sinclair-Desgagné (2005), $\epsilon^{'}(a)a$ is increasing in a, i.e. the emission function is not too convex in abatement.

Note that this condition is verified for a wide range of emission functions and, for example, for $e(x, a) = kx - \sqrt{La}$ where k and L are positive real numbers (see David and Sinclair-Desgagné, 2005). In this case, we can prove that the emission tax always increases the level of abatement in the economy ($\frac{da^t}{dt} > 0$).

The numerator in (14) is then unambiguously negative as $w' > 0$, $\frac{dx^t}{dt} < 0$ and $\epsilon' > 0$. Moreover, given that $\epsilon'' < 0$, $\frac{dm}{dt} > 0$ from Proposition 1 and given our assumption on the convexity of the emission function, we can show that the denominator in (14) is also unambiguously negative[6]. As a result, the optimal emission tax is positive. Moreover, we have that:

$$t^* \gtreqless v \qquad \textit{if and only if} \qquad \frac{da^t}{dt} - \frac{a^t}{m}\frac{dm}{dt} \gtreqless 0 \tag{15}$$

In expression (15), we can see that two opposite effects determine whether t^* should be superior or inferior to v. The first effect is represented by $\frac{da^t}{dt}$. As, in this case, $\frac{da^t}{dt}$ is positive, it plays in favor of an optimal tax above v. As in David and Sinclair-Desgagné, this effect is due to the fact that, as the eco-industry sets its price above the marginal cost of abatement, the tax must be set above the Pigovian rate in order to give incentives to polluters to abate at a sufficient level. The second effect is represented by $-\frac{a^t}{m}\frac{dm}{dt}$ and plays in favor of a tax below the Pigovian rate. It is due to the fact that the increase in m due to the emission tax has welfare decreasing consequences. As explained in Tirole (1988) for instance, the number of firms in a Cournot oligopoly with free-entry is excessive. Given that the environmental tax amplifies this distortion, it must be set at a lower level[7].

This leads us the the following proposition:

Proposition 2. *When abatement is provided by an imperfectly competitive eco-industry with free-entry and the emission function is not too convex in abatement, then the optimal emission tax is superior to the Pigovian rate if and only if the positive effect of the tax on abatement is strong compared to its effect on entry in the eco-industry.*

4.2 Case when $\frac{da^t}{dt} < 0$

Let us now assume that $\frac{da^t}{dt} < 0$. This case occurs when the emission function is rather convex in abatement. The sign of the numerator in (14) is now

[6] This is due to the fact that, when $\epsilon'(a)a$ is increasing in a, then $(-\epsilon'(a^t) - \epsilon''\frac{a^t}{m})\frac{da^t}{dt} < 0$.

[7] Note that increasing m also has welfare increasing consequences as it increases competition within the eco-industry, which allows a higher abatement at the equilibrium. However, this effect is already included in the value of $\frac{da^t}{dt}$.

ambiguous. Note that the sign of the numerator indicates on whether total emissions increase or decrease with the emission tax[8]. On the other hand, we show that in this case, the sign of the denominator is always negative (see Appendix D for a proof). Two main cases may then be derived.

If the numerator in (14) is negative, i.e. total emissions decrease with the tax, we obtain that the optimal tax is positive but inferior to the Pigovian rate: $0 < t^* < v$. This is due to the fact that the expression in condition (15) is now always negative as $\frac{da^t}{dt}$ is negative. The emission tax now has two negative effects: the reduction of abatement and eco-industrial firms' entry. It is therefore always inferior to the Pigovian rate. However, the tax has one positive effect (which explains why the optimal tax rate is positive) through the reduction of total emissions due to the reduction of polluters' output.

If the numerator in (14) is positive, it implies that increasing the environmental tax increases total emissions. In this case, the emission tax has the opposite effect of what is excepted. Thus, the optimal emission tax is unsurprisingly negative: $t^* < 0$, which is equivalent to a subsidy. A subsidy on polluting emissions is obviously not a realistic environmental policy. We thus assume that in this case, the tax is not the appropriate policy instrument and should not be implemented ($t = 0$).

This leads us to our last proposition:

Proposition 3. *When abatement is provided by an imperfectly competitive eco-industry with free-entry and the emission function is rather convex in abatement, then the optimal emission tax is either inferior to the Pigovian rate if total emissions decrease with the tax or equal to zero if total emissions increase with the tax.*

The fact that total emissions may increase with the tax is due to the increased market power of the eco-industry when the tax increases, which in turn increases the price for abatement and may result in a lower equilibrium abatement. This strong result demonstrates that, under certain conditions when an oligopolistic eco-industry provides the abatement good or service, an emission tax may become totally inappropriate to reduce pollution.

5 Concluding remarks

According to common wisdom, the society should benefit from higher emission taxes that put pressure on polluters. As suppliers of abatement goods

[8]Total emissions vary due to two effects: the variation of the polluters' output, which always decreases with the tax; the variation of abatement, which in this case decreases with the tax.

and services increase accordingly, the eco-industry would become more competitive which would lead to lower abatement costs. The actual outcome, however, depends crucially on the behavior of the eco-industry which, over the past decades, has considerably developed.

In this paper, we study the effect of a change in emission tax on the supply of abatement goods and services and on the number of eco-industrial firms. First, we highlight the fact that a variation in the environmental tax not only shifts the demand function for abatement up or down but also affects its slope. We then show that a more stringent environmental tax induces entry in the eco-industry. The total abatement in the economy may however be reduced with the emission tax when the tax strongly amplifies the eco-industry's market power. In this case, the environmental tax may have the opposite effect from what expected by actually increasing the pollution level. We derive the optimal emission tax rates according to the different cases.

Our analysis left out some technical aspects. As is common in the literature (see Besley (1989), Mankiw and Whinston (1986) and Seade (1980)), our derivations ignored the fact that the number of firms in the eco-industry must be an integer number. Also, we restricted to marginal analysis our study of the impact of environmental tax on the eco-industry. However, environmental taxes can be changed in a discrete way as the underlying variation of the number of firms in the eco-industry. It would thus be interesting to study the effects of non-marginal variations in environmental taxes. In this perspective, an approach based on lattice-theoretic methods - as developed by Topkis (1978, 1979), Vives (1990), Milgrom and Roberts (1990) among others - would be appropriate.

Last, the impact of environmental taxation within more realistic eco-industry structures remains to be explored. It would be interesting to introduce some asymmetry between entering firms that have to pay a fixed cost which is already sunk for incumbents. The case where entry leads to mergers - with the incumbents buying the entrants or vice-versa - also seems to characterize many segments of the eco-industry.

6 Appendix

A. Comparative-statics analysis for the polluting industry

Differentiating equations (3) and (4) with respect to t yields:

$$\begin{cases} -C''(x^t)\frac{dx^t}{dt} - tw''(x^t)\frac{dx^t}{dt} = w'(x^t), \\ -t\epsilon''(a^t)\left.\frac{da^t}{dt}\right|_q = \epsilon'(a^t). \end{cases}$$

Solving this set of equations by Cramer's rule gives us the following results:

$$\begin{cases} \frac{dx^t}{dt} = -\frac{w^{'}(x^t)}{C^{"}(x^t)+tw^{"}(x^t)}, \\ \left.\frac{da^t}{dt}\right|_q = -\frac{\epsilon^{'}(a^t)}{t\epsilon^{"}(a^t)}. \end{cases}$$

B. Comparative-statics analysis for the eco-industry

Differentiating equations (6) and (7) with respect to the level of taxation t yields:

$$\begin{cases} q_t + q_a\left(m\frac{da_j^t}{dt} + a_j^t\frac{dm}{dt}\right) + a_j^t q_{at} + q_a\frac{da_j^t}{dt} + a_j^t q_{aa}\left(m\frac{da_j^t}{dt} + a_j^t\frac{dm}{dt}\right) - G^{"}(a_j^t)\frac{da_j^t}{dt} = 0, \\ q(a^t,t)\frac{da_j^t}{dt} + a_j^t q_t + a_j^t q_a\left(m\frac{da_j^t}{dt} + a_j^t\frac{dm}{dt}\right) - G^{'}(a_j^t)\frac{da_j^t}{dt} = 0. \end{cases}$$

This is also equivalent to

$$\begin{cases} \left[(m+1)\,q_a + m a_j^t q_{aa} - G^{"}(a_j^t)\right]\frac{da_j^t}{dt} + \left[a_j^t q_a + \left(a_j^t\right)^2 q_{aa}\right]\frac{dm}{dt} = -\left(q_t + a_j^t q_{at}\right), \\ \left[q(a^t,t) + m a_j^t q_a - G^{'}(a_j^t)\right]\frac{da_j^t}{dt} + \left(a_j^t\right)^2 q_a\frac{dm}{dt} = -a_j^t q_t. \end{cases}$$

Using Cramer's rule, we obtain the following equations:

$$\begin{cases} \frac{da_j^t}{dt} = -\frac{a_j^t(q_a q_{at} - q_{aa} q_t)}{q_a\left(2q_a + a_j^t q_{aa} - G^{"}(a_j^t)\right)}, \\ \frac{dm}{dt} = \frac{-q_t(2q_a + a^t q_{aa} - G''(a_j^t)) + (a^t - a_j^t) q_a q_{at}}{a_j^t q_a(2q_a + a_j^t q_{aa} - G''(a_j^t))}. \end{cases}$$

C. The optimal pollution tax

Total differentiation of $W(t)$ with respect to t yields:

$$\frac{dW}{dt} = \frac{\partial W}{\partial x}\frac{dx^t}{dt} + \frac{\partial W}{\partial a}\frac{da^t}{dt} + \frac{\partial W}{\partial m}\frac{dm}{dt} = 0,$$

where

$$\frac{\partial W}{\partial x}\frac{dx^t}{dt} = \left[P(x^t) - C^{'}(x^t) - vw^{'}(x^t)\right]\frac{dx^t}{dt},$$

$$\frac{\partial W}{\partial a}\frac{da^t}{dt} = \left[-G^{'}\left(\frac{a^t}{m(t)}\right) + v\epsilon^{'}(a^t)\right]\frac{da^t}{dt},$$

and

$$\frac{\partial W}{\partial m}\frac{dm}{dt} = \left[-G\left(\frac{a^t}{m(t)}\right) + \frac{a^t}{m(t)}G^{'}(\frac{a^t}{m(t)}) - F\right]\frac{dm}{dt}.$$

Thus,

$$\frac{dW}{dt} = \left[P(x^t) - C^{'}(x^t)\right]\frac{dx^t}{dt} - G^{'}\left(\frac{a^t}{m(t)}\right)\frac{da^t}{dt} - G\left(\frac{a^t}{m(t)}\right)\frac{dm}{dt} - F\frac{dm}{dt}$$
$$+\frac{a^t}{m(t)}G^{'}\left(\frac{a^t}{m(t)}\right)\frac{dm}{dt} - v\left[w^{'}(x^t)\frac{dx^t}{dt} - \epsilon^{'}(a^t)\frac{da^t}{dt}\right] = 0. \qquad \text{(C-1)}$$

Substituting (3) and (6) into (C-1) yields:

$$tw^{'}(x^t)\frac{dx^t}{dt} - \left[q(a^t) + \frac{a^t}{m(t)}q_a(a^t)\right]\frac{da^t}{dt} - G(a_j^t)\frac{dm}{dt} - F\frac{dm}{dt} + \frac{a^t}{m(t)}\left[q(a^t) + \frac{a^t}{m(t)}q_a(a^t)\right]\frac{dm}{dt}$$
$$= v\left[w^{'}(x)\frac{dx^t}{dt} - \epsilon^{'}(a^t)\frac{da^t}{dt}\right]$$

After some computations, we have

$$tw^{'}(x^t)\frac{dx^t}{dt} - q(a^t)\frac{da^t}{dt} - \frac{a^t}{m(t)}q_a(a^t)\frac{da^t}{dt} - G(a_j^t)\frac{dm}{dt} - F\frac{dm}{dt} + \frac{a^t}{m(t)}q(a^t)\frac{dm}{dt} + \frac{(a^t)^2}{m^2(t)}q_a(a^t)\frac{dm}{dt}$$
$$= v\left[w^{'}(x^t)\frac{dx^t}{dt} - \epsilon^{'}(a^t)\frac{da^t}{dt}\right] \qquad \text{(C-2)}$$

Substituting (4) and (7) into (C-2), we then get:

$$tw^{'}(x^t)\frac{dx^t}{dt} - t\epsilon^{'}(a^t)\frac{da^t}{dt} - \frac{a^t}{m(t)}q_a(a^t)\frac{da^t}{dt} + \frac{ta^2\epsilon^{''}(a^t)}{m^2(t)}\frac{dm}{dt}$$
$$= v\left[w^{'}(x^t)\frac{dx^t}{dt} - \epsilon^{'}(a^t)\frac{da^t}{dt}\right] \qquad \text{(C-3)}$$

Given that $q_a = t\epsilon''(a^t)$, solving equation (C-3) with respect to t yields expression (14).

D. Demonstration that the denominator in (14) is negative when $\frac{da^t}{dt} < 0$

When $\frac{da^t}{dt} < 0$, we necessarily have that $\epsilon'(a)a$ is not increasing in a, for any a. In other words, we have that:

$$-\epsilon'(\frac{a^t}{m}) - \epsilon'' \frac{a^t}{m} \geq 0 \tag{16}$$

Given that $a^t > \frac{a^t}{m}$, that $-\epsilon'(a) < 0$ for any a and that $\epsilon'(a)$ is decreasing in a, equation (16) implies that:

$$-\epsilon'(a^t) - \epsilon'' \frac{a^t}{m} \geq 0$$

which is equivalent to:

$$-\epsilon'(a^t)\frac{da^t}{dt} - \epsilon'' \frac{a^t}{m}\frac{da^t}{dt} \leq 0$$

As a result, given that $w'(x^t) > 0$, $\frac{dx^t}{dt} < 0$ and $\frac{dm^t}{dt} > 0$, the denominator in (14) is always negative when $\frac{da^t}{dt} < 0$.

References

[1] Alary-Grall, L. and F. Pijaudier-Cabot (2002), Éco-Industries: Des Enjeux de Taille, *Cahier Industries*, 75: 13-21.

[2] Amir, R. and V.E. Lambson (2000), "On the Effects of Entry in Cournot Markets", *The Review of Economic Studies*, 67(2): 235-54.

[3] Besley, T.J. (1989), "Commodity Taxation and Imperfect Competition: a Note on the Effects of Entry", *Journal of Public Economics*, 40: 359-367.

[4] Canton, J., Soubeyran, A. and H. Stahn (2005), "Optimal Environmental Policy, Vertical Structure and Imperfect Competition", Working paper, GREQAM.

[5] Copeland, B. (2005), "Pollution Policy and the Market for Abatement Services", Mimeo, University of British Columbia.

[6] Cournot, A. (1927), *Mathematical Principles of the Theory of Wealth*, English translation by N. O. Bacon, New York, The Macmillan Company.

[7] Cowan, S. (2004), "Demand Shifts and Imperfect Competition", *Economics Working Paper*, n°188, Oxford University.

[8] David, M. and B. Sinclair-Desgagné (2005), "Environmental Regulation and the Eco-Industry", *Journal of Regulatory Economics*, 28(2): 141-55.

[9] Dixit, A. (1986), "Comparative Statics for Oligopoly", *International Economic Review*, 27: 107-22.

[10] Denicolo, V. (1999), "Pollution-Reducing Innovations under Taxes or Permits", *Oxford Economic Papers*, 51: 184-99.

[11] Feess, E., and G. Muehlheusser. (2002), "Strategic Environmental Policy, Clean Technologies and the Learning Curve", *Environmental and Resource Economics*, 23: 149-166.

[12] Feess, E., and G. Muehlheusser (1999), "Strategic Environmental Policy, International Trade and the Learning Curve: The Significance of the Environmental Industry", *Review of Economics*, 50 (2): 178-194.

[13] Frank, C.R. (1965), "Entry in a Cournot Market", *The Review of Economic Studies*, 32(3): 245-50.

[14] Greaker, M. (2004), "Industrial Competitiveness and Diffusion of New Pollution Abatement Technology- a New Look at the Porter-Hypothesis", Discussion Paper n°371, Statistics Norway.

[15] Hamilton, S. F. (1999), "Demand Shifts and Market Structure in Free-Entry Oligopoly Equilibria", *International Journal of Industrial Organization*, 17: 259-75.

[16] Industry Canada (2002), *Canada's Environment Industry: an Overview*, Environmental Affairs Branch, Ottawa, Canada.

[17] Katsoulacos, Y. and A. Xepapadeas (1995), "Environmental Policy under Oligopoly with Endogenous Market Structure", *Scandinavian Journal of Economics*, 97(3): 411-20.

[18] Kennett, M. and R. Steenblik (2005), "Environmental Goods and Services: a Synthesis of Country Studies", *Trade and Environment Working paper*, n°2005 − 03, Organization for Economic Cooperation and Development, Paris, France.

[19] Lanjouw, J. O. and A. Mody (1996), "Innovation and the International Diffusion of Environmental Responsive Technology", *Research Policy*, 25: 549-71.

[20] Lee, S.H. (1999), "Optimal Taxation for Polluting Oligopolists with Endogenous Market Structure", *Journal of Regulatory Economics*, 15: 293-308.

[21] Mankiw, N.G. and M.D. Whinston (1986), "Free Entry and Social Inefficiency", *Rand Journal of Economics*, 17(1): 48-58.

[22] Nimubona, A.D. and B. Sinclair-Desgagné (2005), "The Pigouvian Tax Rule in the Presence of an Eco-Industry", Working paper n°57-05, *FEEM.*

[23] Novshek, W. (1980), "Cournot Equilibrium with Free Entry", *Review of Economic Studies*, 47: 473-87.

[24] Okuguchi, K. and F. Szidarovszky (2005), "Changes in Demand Function in Cournot Oligopoly", *Pacific Economic Review*, 10(3): 371-78.

[25] Parry, I. (1995), "Optimal Pollution Taxes and Endogenous Technologies Progress", *Resource and Energy Economics*, 17: 69-85.

[26] Quirmbach, H. C. (1988), "Comparative Statics for Oligopoly: Demand Shift Effects", *International Economic Review*, 29(3): 451-59.

[27] Requate, T. (1997), "Green Taxes in Oligopoly if the Number of Firms is Endogenous", *Finanzarchiv*, 54 (N.F.): 261-80.

[28] Requate, T. (2005), "Timing and Commitment of Environmental Policy, Adoption of New Technology, and Repercussions on R&D", forthcoming in *Environmental and Resource Economics.*

[29] Rosenthal, R.W. (1980), "A Model in which an Increase in the Number of Sellers Leads to a Higher Price", *Econometrica*, 48(6): 1575-80.

[30] Salop, S.C. (1979), "Monopolistic Competition with Outside Goods", *The Bell Journal of Economics*, 10(1): 141-56.

[31] Satterthwaite, M.A. (1979), "Consumer Information, Equilibrium Industry Price, and the Number of Sellers", *The Bell Journal of Economics*, 10(2): 483-502.

[32] Seade, J. (1980), "On the Effects of Entry", *Econometrica*, 4: 479-90.

[33] Skea, J (2000), "Environmental technology", in *Principles of Environmental and Resource Economics*, Cambridge, MA: Edward Elgar Publishing.

[34] Steenblik, R., Drouet, D., and G. Stubbs (2005), "Synergies between Trade in Environmental Services and Trade in Environmental Goods", Trade and Environment Working paper n°$2005-01$, Organization for economic Cooperation and Development, Paris, France.

[35] Tirole, J. (1988), *The Theory of Industrial Organization*, Cambridge, MA: The MIT Press.