Environmental Taxation and the Structure of the Eco-industry

Maia David

UMR INRA-INAPG Économie publique, Paris, France

E-mail: mdavid@grignon.inra.fr

Alain-Désiré Nimubona

Institute of applied Economics, HEC Montréal, Canada

E-mail: alain-desire.nimubona@hec.ca

Bernard Sinclair-Desgagné

École polytechnique, Paris; CIRANO, CIRAIG and HEC Montréal, Canada

E-mail: bsd@hec.ca

Preliminary draft - Do not cite without permission

Abstract

In a model where an imperfectly competitive eco-industry offers its services to a perfectly competitive polluting industry, we analyze how emission taxes influence the structure of the eco-industry (i.e., its concentration and its participating firms' output). Emissions taxes are found to increase the number of firms in the eco-industry, the equilibrium price of abatement goods and services, and the total quantity traded of abatement goods and services; their resulting effect on individual supplies of abatement goods and services, however, depends on their direct impact on the elasticity of demand for these goods and services. Optimal tax levels which deal with those features are then proposed.

Keywords: eco-industry, environmental tax, endogenous market structure

JEL Classifications: D62, H23, L11

1. Introduction

Over the last two decades, throughout Europe, North America and Asia, many firms specializing in the delivery of abatement goods and services have been created. In France, for example, of the 1200 firms that constituted the environment industry in 2002, about half did not exist in the early 90s (Alary Grall and Pijaudier Cabot, 2002). In Israel, the number of companies currently supplying environmental goods and servces is estimated at around 1,000.00, triple their number at the beginning of 1990s (Kennett and Steenblik, 2005). In Canada, recent merger activity among larger environmental firms, particularly engineering firms, has dampened somewhat the number of environment firms; but in actual fact, the number of new firms reporting environmental revenues also evolved rapidly during the last years. Indeed, in 2000, it reached 7,474, up 30% from 1996. Over the same period, the number of these establishments grew in all size categories. In sum, the rate of environmental business formation has consistently outpaced the national average (Industry Canada, 2002).

There is broad consensus that national and international environmental regulation has been the engine driving growth in the eco-industry. Clearly, an entrepreneur's decision to enter the eco-industry is largely based on the expectation that good returns should result from ever stricter environmental regulations. Also, environmental regulations are presented as the reason explaining large differences in size and structure between segments of the eco-industry across countries. This calls for considering more closely the relationship between environmental regulation and the structure of the eco-industry. One significant upshot would then be some amendments to environmental policies which enhance social welfare. In this paper, we seek to address that issue by analysing how emissions taxes influence the concentration of the eco-industry and its participating firms' output. We then look at the impact of these features on the structure of the optimal tax rule.

Our research builds on two strand of literature. The first one consists in recent developments dealing with the outsourcing of environmental goods and services and the consequent presence of an environment industry. In recent papers, Canton et al.(2005), David and Sinclair-Desgagné (2005), Nimubona and Sinclair-Desgagné (2005), and Requate (2005) already showed that some typical environmental policy instruments - such as emission taxes, quotas, design standards and voluntary agreements - have an effect on the level and price-elasticity of polluters' demand for abatement goods and services, hence on the market power of the eco-industry and the resulting cost of abatement. These analyses supposed, however, that the number of environment firms was fixed and exogenous. This paper now studies a situation where this assumption is relaxed. It thus relies on the literature on endogenous market structure too[1].

In industrial organization, in fact, there exists a well developed literature analyzing oligopolists with endogenous market structure. For example, Salop (1979), Satterthwaite (1979), Seade (1980), Novshek (1980), Rosenthal (1980), Mankiw and Whinston (1986),

[1] In the meantime, Greaker (2004) and Copeland (2005) considered an eco-industry characterized by product differentiation and monopolistic competition, thus allowing for the possibility of entry in the eco-industry. However, they did so in a context of international trade.

and Amir and Lambson (2000) investigated the effects of entry in Cournot markets. Especially, Seade (1980) examined the conditions under which preexisting firms in an industry react to the entry of new firms by lowering or augmenting their individual supplies. In the same veine, Mankiw and Whinston (1986) identified aspects of the post-entry game on which relies the efficiency of entry in homogenous product markets where firms incur fixed costs upon entry. On another hand, the papers by Salop (1979), Satterthwaite (1979), Rosenthal (1980) and Amir and Lambson (2000) suggested special settings under which the commonly-held view stating that increased number of firms in an industry has the effect of lowering price, , due to Cournot (1927), is ruled out.

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 this context, we find that a tightening of environmental taxation does increase the number of environment firms, through the increase in the demand for abatement goods and services and that in the equilibrium price of these goods and services. Depending on the resulting demand elasticity, however, incumbent environment firms may react to the arrival of new competitors by lowering their individual output. Hence, a more stringent environmental tax might actually induce an inefficient number of firms supplying abatement goods and services. In this case, the optimal tax on polluting emissions should be set below the marginal social cost of pollution, a result which runs contrary to David and Sinclair-Desgagné (2005)'s conclusion. We also suggest a new context in industrial organization literature in which an increase in the number of competitors in an industry coexist with a higher price. This new context does not have any think to do with costs of production (Salop, 1979; Amir and Lambson, 2000), search costs (Satterthwaite, 1979) or the inability of price discrimination (Rosenthal, 1980). The result hinges instead on the ability of the eco-industry to take benefit of the decreasing sensibility of abatement demand due to the stringency of environmental taxation.

This paper unfolds as follows. The next section presents our model and spells out the impact of emission taxes on the structure of the eco-industry. Section 3 then derives the optimal pollution tax. Section 4 concludes our analysis, and suggests various topics for future research.

2. The model

Consider an upstream environment industry with free entry and exit, which comprises m identical environment firms behaving as Cournot oligopolists and a representative price-taking polluting firm producing a single consumption good. This polluting firm produces an output x, and a negative externality e due to air pollution. Let v denote the constant marginal social damage of polluting emissions, so ve represents total damages to the society. Let the polluter's emission function be represented as $e(x, a)$, where a corresponds to abatement efforts. Following Barnett (1980), Katsoulacos and Xepapadeas (1995), Farzin and Kort (2001), David and Sinclair-Desgagné (2005), and Nimubona and Sinclair-Desgagné (2005), we assume that the representative polluting firm mainly controls its polluting emissions through an end-of-pipe technology. This means that $e(x, a)$

is additively separable and can be written as $e(x,a) = w(x) - \epsilon(a)$. This function is twice continuously differentiable, with $w^{'}(x) > 0$, $\epsilon^{'}(a) > 0$, $w^{''}(x) \geqslant 0$ and $\epsilon^{''}(a) < 0$. The first two inequalities say that pollution increases with the level of production and decreases with the level of abatement efforts, respectively; the third relation states that the last unit of output pollutes more as total production increases; and the last inequality indicates decreasing returns to abatement. As in Katsoulacos and Xepapadeas (1995) and David and Sinclair-Desgagné (2005), we also suppose that the emission function is not too convex in a, that is $\epsilon^{'}(a)a$ is increasing in a.

Let $C(x)$ be the polluting firm's production cost function, where $C^{'}(x) > 0$, $C^{''}(x) \geqslant 0$ (decreasing returns to production). An environment firm j supplying an amount a_j of abatement services is in turn characterized by a cost function $G(a_j) + F$, where F represents a setup costs (identical for all environment firms), $G^{'}(a_j) > 0$ and $G^{''}(a_j) \geqslant 0$. The market for abatement is furthermore characterized by an inverse demand function $q(a)$, with a representing the total purchases of abatement goods and services.

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

$$\Pi(x^t, a^t) = Px^t - C(x^t) - qa^t - t\left[w(x^t) - \epsilon(a^t)\right],$$

where P is the current price of x^t and $a^t = \sum_{j=1}^{m} a_j^t$.

2.1. Behavior of polluting firms

To maximize profit, the representative polluter set 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.

$$P = C^{'}(x^t) + tw^{'}(x^t) \quad (1)$$

$$q = t\epsilon^{'}(a^t). \quad (2)$$

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 now imply that $\frac{dx^t}{dt} < 0$ and $\left.\frac{da^t}{dt}\right|_q > 0$; so when the emission tax increases, the representative polluter reacts by slowing down production and increasing abatement efforts.

The latter reaction functions of polluting firms to environmental taxation are not modified here compared to the situation where m is exogenous. On one side, the output decision x^t only depends on the tax level and does not depend on m. More precisely, when the level of the emissions tax increases, the output level decreases. Clearly, the output decision x^t does not depend on the equilibrium on the environmental goods and services market (this is due to the additive separability of the emission function). On the other side, the abatement decision depends on the price of abatement and the level of the environment tax. For a given price q, the demand for abatement increases with the tax.

However, the price q does not remain unchanged when the tax is increased. The price q is determined by the eco-industry's behavior and is studied in the next section. But before turning on to the eco-industry's behavior, let us study the sensibility to the tax of the demand elasticity for abatement. From (2), differentiating q with respect to t yields $\frac{dq}{dt} = \epsilon^{'}(a^t) > 0$. This reveals that the inverse demand function for abatement goods and services shifts upward when the emission tax goes up.

Differentiating equation (2) with respect to q and for a given t also yields $\left.\frac{da^t}{dq}\right|_t = \frac{1}{t\epsilon^{"}(a^t)} < 0$. This result shows us that the demand for abatement unsurprisingly decreases when the price q increases. This inequality, which was first derived by David and Sinclair-Desgagné (2005), also entails that when the tax on emissions increases, the price-elasticity of demand for abatement goods and services decreases (i.e. the sensibility to price of the demand for abatement decreases with the tax). As it shall be useful later on, let us rewrite this preceding result as follows: $q^{'} = \frac{1}{\left.\frac{da^t}{dq}\right|_t} = t\epsilon^{"} < 0$. Also, notice that $\frac{\partial^2 a^t}{\partial q \partial t} = -\frac{1}{t^2 \epsilon^{"}(a^t)} > 0$ or equivalently that $\frac{\partial^2 q}{\partial a^t \partial t} = \epsilon^{"}(a^t) < 0$.

2.2. Behavior of environmental firms

An emission tax does not only affect polluters. More stringent environmental taxation not only enhances the representative polluter's willingness to acquire abatement goods and services, it also allows incumbent environment firms to charge a higher price and consequently attracts potential entrants.

To get a grasp at the overall outcome, let us formalize the behavior of a typical environmental firm j. This behavior is first captured by the following program

$$\underset{a_j}{Max} \quad \Pi_j = q(a^t)a_j^t - G(a_j^t) - F \qquad\qquad j = 1, ..., m.$$

An incumbent firm's optimal level of abatement goods and services is then characterized by the following conditions

$$q(a^t) = -a_j^t q^{'}(a^t) + G^{'}(a_j^t) \tag{3}$$

$$2q_a + a_j^t q_{aa} - G^{"}(a_j^t) < 0, \tag{4}$$

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

$$\Pi_j^{fe}(a_j^t) = q(a^t)a_j^t - G(a_j^t) - F = 0. \tag{5}$$

For the moment, let us neglect the fact that the number of incumbent firms m must be an integer. Standard comparative statics (computations are in the appendix) from equations (3) and (5) then yields

$$\frac{da_j^t}{dt} = -\frac{a_j^t \left(q_a q_{at} - q_{aa} q_t\right)}{q_a \left[2q_a + a_j^t q_{aa} - G^{"}(a_j^t)\right]} \tag{6}$$

$$\frac{da^t}{dt} = -\frac{a_j^t q_a q_{at} + \left[2q_a - G^{"}(a_j^t)\right] q_t}{q_a \left[2q_a + a_j^t q_{aa} - G^{"}(a_j^t)\right]}. \tag{7}$$

We showed in the previous section that $q_t > 0$ and $q_{at} < 0$, so we have now that

$\frac{da_j^t}{dt} \gtreqless 0$ and $\frac{da^t}{dt} \gtreqless 0$ (see details in the appendix). These two relations say that when the emission tax goes up, an individual environment firm's supply as well as the eco-industry output could increase, decrease or remain constant. It is not possible to determine in general the effect of the emission tax on these levels of output. To use the terminology of Mankiw and Whinston (1986), environmental taxation can be business stealing or business augmenting. The business stealing effect appears when existing firms in the eco-industry respond to a stringent environment tax by lowering their volumes of sales. By contrast, business augmenting effect means that the strategic response of incumbent firms to environment taxation is to increase their level of production.[2]

The sign of $\frac{da_j^t}{dt}$ as well as that of $\frac{da^t}{dt}$ depends on the curvature of the environmental market demand and on the impact of environmental taxation on the demand elasticity. According to (6) and (7), we have respectively the following relations:

$$\frac{da_j^t}{dt} \gtreqless 0 \qquad \textit{if and only if} \qquad |q_{at}| \lesseqgtr \left| q_{aa}\frac{q_t}{q_a} \right| \tag{8}$$

[2] In the industrial organization literature, Seade (1980), Novshek (1980), and Mankiw and Whinston (1986) deal specifically with the effect of new entry on the output of incumbent firms.

and

$$\frac{da^t}{dt} \begin{matrix} > \\ = \\ < \end{matrix} 0 \qquad \textit{if and only if} \qquad |q_{at}| \begin{matrix} < \\ = \\ > \end{matrix} \left| \frac{\left[G^{"}\left(a_j^t\right) - 2q_a\right] q_t}{a_j^t q_a} \right| . \tag{9}$$

Hence, when the inverse demand function for abatement services is linear or concave, the level of production per environmental firm decreases as the emission tax goes up. When the inverse demand function is convex, on the other hand, the output level of individual environmental firms could decrease, increase, or remain unchanged following an increase in the emission tax rate, depending on the relative effect of the environmental taxation on demand elasticity. Relation (8) says in fact that if the weighted impact of taxation on the price of abatement services is too weak compared to its impact on the elasticity of demand for abatement, an environment firm adjusts to environmental taxation by decreasing its output. This behavior would respond to the failure of environmental taxation to increase sufficiently the polluter's willingness to buy abatement goods and services. Of course, by lowering its supply to increase prices, the environment firm also takes into account the difficulty for polluters to decrease their purchases when abatement goods and services are more expensive. Moreover, the decrease of the output of individual firms in the eco-industry may override the positive effect of higher emissions fees, through a higher number of supplies in the eco-industry, which are expected to decrease abatement goods and services prices. Clearly, $\frac{da^t}{dt} > 0$ if $\frac{da_j^t}{dt} \geqslant 0$. But when $\frac{da_j^t}{dt} < 0$, we can show that $\frac{da^t}{dt} \gtreqless 0$ depending on the level of the impact of environmental taxation on demand elasticity (see details in the appendix).

Noticing that $\frac{G''(a_j^t)-2q_a}{a_j^t} > q_{aa}$ from (4), relation (9) says, indeed, that when the impact of taxation on the elasticity of demand for abatement goods and services is sufficiently high, the decrease of the output of individual incumbent firms in the eco-industry may result in a decrease of the aggregate supply of abatement goods and services. Letting $\eta_{a_j,t}$, $\eta_{a,t}$, $\varepsilon_{q_a,t}$, and $\varepsilon_{q,t}$, denote respectively the elasticities with respect to environmental taxation of the individual environment firm supply, the eco-industry supply, the slope of abatement goods and services demand and the inverse demand while $\varepsilon_{q,a}$ and $\varepsilon_{q_a,a}$ denote the elasticities of the inverse demand and the slope of the inverse demand, we can respectively rewrite expressions (6) and (7) as follows:

$$\eta_{a_j,t} = \frac{\varepsilon_{q,t}\varepsilon_{q_a,a} - \varepsilon_{q,a}\varepsilon_{q_a,t}}{\varepsilon_{q,a}\left(2 + \frac{\varepsilon_{q_a,a}}{m} - \frac{G''(a_j^t)}{q_a}\right)}$$

and

$$\eta_{a,t} = \frac{m\left(\frac{G''(a_j^t)}{q_a} - 2\right)\varepsilon_{q,t} - \varepsilon_{q,a}\varepsilon_{q_a,t}}{m\varepsilon_{q,a}\left(2 + \frac{\varepsilon_{q_a,a}}{m} - \frac{G''(a_j^t)}{q_a}\right)},$$

These imply respectively the following relations:

$$\eta_{a_j,t} \overset{>}{\underset{<}{=}} 0 \qquad \textit{if and only if} \qquad |\varepsilon_{q_a,t}| \overset{<}{\underset{>}{=}} \left| \frac{\varepsilon_{q_a,a}}{\varepsilon_{q,a}} \right| \varepsilon_{q,t},$$

and

$$\eta_{a,t} \overset{>}{\underset{<}{=}} 0 \qquad \textit{if and only if} \qquad |\varepsilon_{q_a,t}| \overset{<}{\underset{>}{=}} m \left| \frac{\left[G^{"}(a_j^t) - 2q_a\right]}{q_a \varepsilon_{q,a}} \right| \varepsilon_{q,t}.$$

The possibility that the total supply of the eco-industry may decrease when emissions taxes are stringent leaves room to self-defeating behaviors[3]. Therefore, to better understand the global impact of emissions taxes on the quality of the environment, we need to deepen our reflection. For that, let us focus on the effects of emissions taxes on the total quantity of abatement goods and services traded. In order to better understand the forces explaining the variation of total abatement purchases when a tax is increased ($\frac{da^t}{dt}$), we must study the equilibrium on the market for environmental goods and services. We then simultaneously study the variation of the polluters' behavior (demand side effects)

[3]It is worth noting that our ambiguous results on the effect of emissions taxes on the supply side of environment market have nothing to do with our hypothesis of an endogenous structure of the eco-industry. Requate (2005), for example, finds an ambiguous impact of emissions taxes on the supply side while considering a monopolistic setting for the eco-industry supplying a new environmentally friendly technology. He explained this as resulting from two effects of the emissions taxes on the demand side, already mentioned, that are the increase in the willingness to buy abatement goods and services and the decrease in the sensibility of the demand of these goods and services. But he managed to define the condition, dealing with the efficiency of the environmentally friendly technology, under which the output of the monopolistic eco-industry increases with the emissions tax.

and of the eco-industry's behavior (supply side effects).

Considering the above definition of q'(in the subsection 2.1), the symmetric Cournot-Nash equilibrium in the eco-industry (equation (3)), can be rewritten as[4]:

$$q^c = G^{'}(\frac{a}{m}) - \frac{a}{m} t\epsilon^{"}. \tag{10}$$

This equation shows us that the equilibrium price of the abatement service depends on the tax level, on the number of firms in the eco-industry (m) and on the level of total abatement purchases (a). On another hand, the zero profit condition (equation (5)) which define the number of firms entering the eco-industry (m) shows us that, for a given total abatement a, when the price q increases, m also increases in order that condition (equation (5)) remains valid: $\frac{\partial m}{\partial q} > 0$. Then, equation (10) can be rewritten as follows:

$$q^c = G^{'}(\frac{a}{m(q)}) - \frac{a}{m(q)} t\epsilon^{"}. \tag{12}$$

Let us now study how the price q varies when the tax t varies, for a given total abatement level. Totally differentiating (12) yields:

$$\left.\frac{dq^c}{dt}\right|_a = \frac{-\frac{a}{m}\epsilon^{"}}{1 + \frac{a}{m^2} G^{"} \frac{\partial m}{\partial q} - \frac{a}{m^2} t\epsilon^{"} \frac{\partial m}{\partial q}}. \tag{13}$$

Given that $\frac{\partial m}{\partial q} > 0$, that $\epsilon^{"} < 0$ and that $G^{"} > 0$, $\left.\frac{dq^c}{dt}\right|_a$ is unambiguously positive. That

[4] q^c denotes the Cournot-Nash equilibrium price.

is, when the emission tax is increased, the price of the abatement services rises for a given abatement level. We can now study the variation of total abatement purchases at an equilibrium when t varies.

Differentiating totally equation (2), keeping in mind that $q = q^c(a,t)$ according to the eco-industry's behavior, we obtain:

$$\frac{da^t}{dt} = \frac{\epsilon^{'}(a^t) - \frac{dq^c}{dt}\Big|_a}{-t\epsilon^{"} + \frac{\partial q^c}{\partial a}}. \tag{14}$$

From equation (10), we have $\frac{\partial q^c}{\partial a} > 0$. The denominator in (14) is then positive (recall that $\epsilon^{"} < 0$). Moreover, we have shown that $\frac{dq^c}{dt}\Big|_a > 0$ and $\epsilon^{'} > 0$. As a result, the sign of the numerator in (14), and thus the sign of $\frac{da^t}{dt}$, is ambiguous, as previously shown. In other words, total abatement purchases at an equilibrium may increase or decrease when the emission tax increases. This is due to two opposite effects. Clearly, the tax rise induces a rise in abatement demand for a given price (first term in the numerator). However, the price for abatement increases with the tax, which reduces the equilibrium demand (second term in the numerator).

However, using common sense, we can argue that the total quantity traded of abatement goods and services will never decrease following a tighening of emissions taxes. Indeed, one has to notice that, while increasing price, the eco-industry takes account of its impact on the demand according to the level of demand elasticity. When the demand is still highly sensitive following a tighening of emissions tax, the price will increase sligthly. Conversely, the price will increase considerably if the effect of the tax on the demand sensibility is too consistent. Consequently, the second effect is likely to be always dominated by the first effect. More formally, we can show that a sufficient condition for total abatement to increase with the tax is our assumption that $\epsilon^{'}(a)a$ be increasing in a, which means that the emission function is not too convex in a. This assumption 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)).

Therefore, assuming that we are in the situation when total abatement at the market equilibrium increases with a tax increase ($\frac{da^t}{dt} > 0$), the price q always increases ($q(a, t)$ is increasing in both its terms): $\frac{dq}{dt} > 0$. Consequently, the number of firms m in the eco-industry also increases, for the zero-profit condition to remain valid: $\frac{dm}{dt} > 0$. Let us now study the effect on individual, a_j^t, output at the equilibrium. Since environment firms are identical, we have that $a^t = ma_j^t$. We can thus easily study the effect on individual output at the equilibrium $a_j^t = \frac{a^t}{m}$. We immediately get:

$$\frac{da_j^t}{dt} = \frac{1}{m} \left[\frac{\partial a^t}{\partial t} - a_j^t \frac{\partial m}{\partial t} \right]. \tag{15}$$

The sign of the variation of a_j^t is ambiguous as the first term in (15) is positive whereas the second term is negative. Also, the tax has no effect on the individual profit of the firms in the eco-industry as profits always remain equal to zero due to free entry and the following zero profit condition. All these findings can be summarized in our first proposition.

Proposition 1. *When entry in the eco-industry is free, a tightening of environmental taxation increases the number of environmental firms in that industry, the total quantity traded, as well as the equilibrium price of abatement goods and services. However, the level of production per environmental firm might decrease, increase or remain unchanged.*

The upshot of this analysis for environmental policy is that, if a regulator introduces a tax per unit of emission of a polluting industry, the eco-industry, which supplies the polluting firms with abatement services, reacts strategically. Clearly, as emphasized already in the literature (Canton et al. (2005); David and Sinclair-Desgagné, 2005; Nimubona and Sinclair-Desgagné, 2005; Requate, 2005), this strategic adjustment affects the effectiveness and efficiency of environmental policy. In the next section, we then study how the regulator should take the eco-industry into account while setting up a tax on polluting emissions.

3. 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 x. The regulator then solves the following program:

$$\underset{t}{Max} \quad W(t) = \int_0^{x^t} P(z)dz - C(x^t) - \sum_{j=1}^{m(t)} G\left(\frac{a^t}{m(t)}\right) - m(t)F - v\left[w(x^t) - \epsilon\left(a^t\right)\right].$$

While choosing the optimal rate for environmental taxation, the regulator takes into account the behavior of environment firms and the structure of the eco-industry. Denote as $m(t)$ the number of environment firms that meet the zero profit condition in the presence of an environmental tax t. The social welfare function can then be written as $W = W\left[x\left(t\right), a\left(t\right), m(t)\right]$.

One can show that the optimal tax will be given by the following formula (computations can be found in the appendix):

$$t^{*} = v\left[\frac{w'(x^{t})\frac{dx^{t}}{dt} - \epsilon'(a^{t})\frac{da^{t}}{dt}}{w'(x^{t})\frac{dx^{t}}{dt} - \left[\epsilon'(a^{t}) + \frac{a^{t}}{m}\epsilon''(a^{t})\right]\frac{da^{t}}{dt} + \left(\frac{a^{t}}{m}\right)^{2}\epsilon''(a^{t})\frac{dm}{dt}}\right]. \tag{16}$$

Equations (1) and (2) now imply that $\frac{dx^t}{dt} < 0$ and $\frac{da^t}{dt} > 0$. Given the above assumptions, this means that the numerator is always negative. Also, we have that $\frac{dm}{dt} > 0$, from subsection 2.2 and proposition 1, and that $\epsilon^{'}(a) + \epsilon^{''}(a)a > 0$, from our assumptions. So, recalling that $\epsilon^{''}(a) < 0$, $\epsilon'(a^t) + \frac{a^t}{m}\epsilon''(a^t) > 0$ and thus the denominator in (16) is also negative. However, since $\left(\frac{a^t}{m}\right)^2 \epsilon''(a^t)\frac{dm}{dt} - \frac{a^t}{m}\epsilon''(a^t)\frac{da^t}{dt}$ can not be signed unambiguously, the coefficient of v may be greater, equal, or less than 1. Hence, the optimal emission tax could be less than, equal to, or greater than marginal external damages. In actual facts, the adjustment to the Pigouvian tax to correct externalities depends on the reaction of the environmental market as specified in the following relation:

$$t^* \begin{matrix} > \\ = \\ < \end{matrix} v \qquad if \qquad \frac{da^t}{dt} - \frac{a^t}{m}\frac{dm}{dt} \begin{matrix} > \\ = \\ < \end{matrix} 0. \tag{17}$$

Notice that the expression $\frac{da^t}{dt} - \frac{a^t}{m}\frac{dm}{dt}$ represents the impact of the emission tax on the output of incumbent environment firms. On the one hand, it says that when environmental taxation induces incumbent firms in the eco-industry to increase their output, the optimal level of taxation should be greater than marginal social damage. On the other side, it entails that when incumbent environment firms reduce their output after a higher emission tax is imposed, the reverse should hold. This finding now gives a second proposition.

Proposition 2. *When abatement technologies and services are provided by an imperfectly competitive eco-industry with free-entry, the optimal emission tax may be greater than, equal to, or lower than the marginal social damage of pollution, depending on the strategic reaction of incumbent environmental firms to environmental taxation.*

This proposition generalizes the conclusions of David and Sinclair-Desgagné (2005). These authors argued that the optimal pollution tax must be larger than the marginal social damage of pollution when abatement goods services are supplied by a Cournot oligopoly. However, they kept the number of environment firms exogenous. Our actual framework now brings in a new distortion in the economy, which is the possibility of reaching a socially inefficient number of environment firms following a new emission tax. When an entrant in the eco-industry causes incumbent firms to reduce their production of abatement services, for instance, entry is more desirable for the entrant than it is to society. This tends to decrease the optimal level of taxation.

Therefore, what our results say is that when duplicating fixed costs in the eco-industry through entry does not serve to increase competition in this industry, it is necessary to correct for the distortion related to an inefficient number of environmental firms which can arise from free entry in the case of an increasing emission tax. Indeed, the increase of abatement services' supply through the entrance of new firms in the eco-industry which, from proposition 1, follows an increase of the emission tax might be dampened due to the decrease of the output of incumbent environment firms. This could neutralize or make problematic demand side effects of a stringent environmental regulation on the environmental market. Thus, the optimal level of taxation should be lower than social marginal damage.

4. Concluding remarks

Common wisdom says that the society should benefit from higher emissions taxes that put pressure on polluters. As suppliers of abatement goods 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 developed considerably.

Our first objective was to study the effect of a change in emission tax on the supply of abatement goods and services and on the number of environment firms. Our results show that a more stringent environmental tax induces new firms to enter the eco-industry. However, although the total quantity of abatement goods and services traded is reasonably supposed to increase following any tigthening of emissions taxes, this does not induce a reduction of the equilibrium price of abatement services. Interestingly, if those newcomers cause incumbent firms to reduce output, the regulator might prefer to set the pollution tax below the marginal social cost of pollution damages.

Our derivations ignored the fact that the number of firms in the eco-industry must be an integer number. More importantly, the impact of environmental taxation for more realistic eco-industry structures remains to be explored. Stylized facts about the eco-industry suggest to concentrate on the following market structures. First of all, it would be worthwhile to consider an eco-industry characterized by product differentiation and monopolistic competition (a situation already considered by Greaker (2004) and Copeland 2005 in the context of international trade), some dominant firms with a competitive fringe, or some asymmetry between entering firms that have to pay a fixed cost which is already sunk from the point of view of incumbents. Secondly, a multiproduct polluting oligopoly which can also make and trade abatement goods and services, in competition with the eco-industry, would constitute a more realistic setting. Thirdly, the case where entry leads to mergers - with the incumbents buying the entrants or vice-versa - seems to characterize many segments of the eco-industry (such as solid waste management).

Appendix

A. Comparative-statics analysis for the polluting industry

Differentiating equations (1) and (2) with respect to t yields:

$$\begin{aligned} -C^{"}(x^t)\frac{dx^t}{dt} - tw^{"}(x^t)\frac{dx^t}{dt} &= w^{'}(x^t) \\ -t\epsilon^{"}(a^t)\frac{da^t}{dt} &= \epsilon^{'}(a^t). \end{aligned}$$

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

$$\frac{dx^t}{dt} = -\frac{w^{'}(x^t)}{C^{"}(x^t) + tw^{"}(x^t)}$$

$$\left.\frac{da^t}{dt}\right| = -\frac{\epsilon^{'}(a^t)}{t\epsilon^{"}(a^t)}.$$

B. Comparative-statics analysis for the eco-industry

Given the result in subsection 2.1, stating that the emission tax exogenously affects the pricing of abatement services, we can rewrite the profit function of each environmental firm as follows:

$$\Pi_j(a_j^t, t) = q(a^t, t)a_j^t - G(a_j^t) - F \qquad j = 1, ..., m.$$

Differentiating equations (3) and (5) with respect to the level of taxation t, keeping in mind this small change in the expression of the profit of environmental firms, yields

$$\begin{aligned} q_t + q_a \frac{da^t}{dt} + a_j^t q_{at} + q_a \frac{da_j^t}{dt} + a_j^t q_{aa} \frac{da^t}{dt} - G^{"}(a_j^t) \frac{da_j^t}{dt} &= 0 \\ q(a^t, t) \frac{da_j^t}{dt} + a_j^t q_t + a_j^t q_a \frac{da^t}{dt} - G^{'}(a_j^t) \frac{da_j^t}{dt} &= 0, \end{aligned}$$

which is also equivalent to

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

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

$$\begin{aligned} \frac{da_j^t}{dt} &= -\frac{a_j^t \left(q_a q_{at} - q_{aa} q_t\right)}{q_a \left[2q_a + a_j^t q_{aa} - G^{"}(a_j^t)\right]} \\ \frac{\partial a^t}{\partial t} &= -\frac{a_j^t q_a q_{at} + \left[2q_a - G^{"}(a_j^t)\right] q_t}{q_a \left[2q_a + a_j^t q_{aa} - G^{"}(a_j^t)\right]}. \end{aligned}$$

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,

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

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

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

After some computations, we have

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

Substituting (2) and (5) into (C-2), and recalling that $q^{'}(a^t) = t\epsilon^{"}(a^t)$, we then get:

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

Solving equation (C-3) with respect to t gives expression (16).

D. Summary of our results

D.1. Effect of the curvature of the abatement services demand

q is concave ($q_{aa} < 0$)	q is convex ($q_{aa} > 0$)	q is linear ($q_{aa} = 0$)
$\frac{da_j^t}{dt} < 0$	$\frac{da_j^t}{dt} \gtreqless 0$	$\frac{da_j^t}{dt} < 0$
$\frac{da^t}{dt} \gtreqless 0$	$\frac{da^t}{dt} \gtreqless 0$	$\frac{da^t}{dt} \gtreqless 0$

D.2. Effect of the impact of environmental taxation on the level of the elasticity of abatement services demand

$q_{at} < A$	$q_{at} = A$	$A < q_{at} < B$	$q_{at} = B$	$q_{at} > B$
$\frac{da_j^t}{dt} < 0$	$\frac{da_j^t}{dt} < 0$	$\frac{da_j^t}{dt} < 0$	$\frac{da_j^t}{dt} = 0$	$\frac{da_j^t}{dt} > 0$
$\frac{da^t}{dt} < 0$	$\frac{da^t}{dt} = 0$	$\frac{da^t}{dt} > 0$	$\frac{da^t}{dt} > 0$	$\frac{da^t}{dt} > 0$

With: $A = \frac{\left[G^{"}(a_j^t) - 2q_a\right] q_t}{a_j^t q_a}$ and $B = \frac{q_{aa} q_t}{q_a}$.

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

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

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

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

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

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

[9] 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.

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

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

[12] Kennett, M. and R. Steenblik (2005), "Environmental Goods and Services: a Synthesis of Country Studies", Trade and Environment Working paper n°2005/3, Organization for Economic Cooperation and Development, Paris, France.

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

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

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

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

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

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

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

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

[21] 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.

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

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

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

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