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M. David, 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 Regulation

and the Eco-Industry*

MAIA DAVID

Laboratoire d'économétrie, École polytechnique, Paris; maia.david@shs.polytechnique.fr

BERNARD SINCLAIR-DESGAGNÉ

École polytechnique, Paris; CIRANO, CIRAIG, and HEC Montréal, Canada; bsd@hec.ca

Abstract

This paper re-examines environmental regulation, under the assumption that pollution abatement technologies and services are provided by an imperfectly competitive environment industry. It is shown that each regulatory instrument (emission taxes and quotas; design standards; and voluntary agreements) has a specific impact on the price-elasticity of the polluters' demand for abatement services, hence on the market power of the eco-industry and the resulting cost of abatement. This implies that the optimal pollution tax will be higher than the marginal cost of pollution damage, while a voluntary approach to pollution abatement may fail unless the eco-industry itself is properly regulated.

Key words: pollution regulation, end-of-pipe pollution abatement, environment industry

JEL Classification: H23, L13, Q58

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1. Introduction

Pollution abatement goods and services are now largely supplied by a number of specialized firms. In 1997, these firms totalled earnings of $350 billions, and this figure has been projected to double by 2010.[1] In some countries, such as Germany, France and the Netherlands, their activities account for as much as 2% of the annual GDP (Barton 1997). Unsurprisingly, the "eco-industry" has then become a major topic for industrial policy and international trade discussions.[2] It is also central to most government bodies and institutions concerned with environmental regulation. Yet, someone will hardly find in the environmental economics literature an acknowledgement that there even exists such an industry: pollution abatement is consistently assumed to be set only by polluters, based in turn on relevant technological, regulatory or output market considerations, but absent any explicit market or bilateral relationship with actual suppliers. This paper represents a first attempt to fill this gap.

The basic (textbook) framework to analyze pollution abatement can already be viewed as a partial equilibrium model involving a representative price-taking polluter who may procure the needed goods and services on a perfectly competitive market (under no uncer-

[1] For additional data, see the reports by the European Commission (1999), the Organization for Economic Cooperation and Development (1992, 1996), and the World Trade Organization (1998).

[2] In order to collect reliable data and stimulate rigorous analyses, the OECD and the Statistical Office of the European Commission (Eurostat) have recently developed the following definition of the environment industry (Organization for Economic Cooperation and Development/Eurostat 1999): *"The environment industry consists of activities which produce goods and services to measure, prevent, limit, minimize or correct environmental damage to water, air, and soil, as well as problems related to waste, noise and eco-systems. These include cleaner technologies, products and services which reduce environmental risk and minimize pollution and resource use."* Note that pollution abatement accounts for more than 80% of the industry's income (Institut Français de l'Environnement 2002).

tainty, asymmetric information, or capacity constraints). In two companion articles that focus on trade and environmental policy and that first bring in the eco-industry, Feess and Muehlheusser (1999, 2002) similarly leave out all strategic actions on the part of environmental service providers.[3] Several empirical studies reveal, however, that significant segments of the eco-industry, such as waste management, are now dominated by a small number of large suppliers (Barton 1997; Baumol 1995; Davies 2002). These environment firms certainly enjoy some market power and matter to each other. To capture such features, this paper amends the basic framework with the alternative assumption that pollution abatement goods and services are delivered by a Cournot oligopoly.[4] In this context, we find that the particular public policy approach chosen to regulate pollution has a definite influence on the market power of environment firms and on the resulting market price of abatement, through its direct impact on the price-elasticity of demand for pollution-abating services. As a consequence, an optimal pollution tax should be set higher than the marginal social cost of damage (otherwise, the elasticity of demand for pollution abatement would be such that the relatively higher prices reached under imperfect competition would generate too little abatement), and a voluntary approach to pollution

[3] These papers' objective is to examine whether tighter environmental regulation may benefit a trading nation. Current wisdom about strategic environmental policy (see, for instance, Barrett 1994) recommends that a tax on emissions be smaller than the marginal social cost of pollution damages (as long as countries compete in quantities and the commodities sold on international markets are strategic substitutes). Feess and Muehlheusser show that the opposite conclusion may hold, however, in the presence of an eco-industry where the production of environmental services is subject to a learning curve.

[4] It might actually have been even more realistic to model the eco-industry as an oligopoly with a competitive fringe, for in most market segments many small and medium enterprises (SMEs) still provide specific equipment and services (World Trade Organization 1998). This would have complicated the presentation, however, without changing our qualitative conclusions.

abatement may be doomed to failure unless some limitations on the eco-industry's market behavior (such as the prohibition of price discrimination) are enforced.

The following section will now present our model. Section 3 next contains a brief discussion of what first-best production and abatement levels would be. Section 4 - this paper's main section - then turns to environmental regulation and successively considers and compares the two main types of policy instruments - emission-based (i.e., emissions taxes and quotas) and abatement-based (i.e., design standards and voluntary agreements). Section 5 concludes the paper with some topics for future research.

2. The Model

Before spelling out our model, it is worth recalling a few stylized facts. The eco-industry can be divided into three broad segments: pollution management, cleaner technologies and products, and resources management (WTO 1998; OECD/Eurostat 1999). The first group is by far the most significant in terms of income; it comprises mostly end-of-pipe activities, such as (in decreasing order of importance) solid waste management, waste water treatment, air pollution control, and contaminated soil and groundwater remediation (European Commission 1999). Competition naturally varies within industry segments and countries, but in the United States and Germany for instance, environment firms are generally of a larger size than the national firm average (Barton 1997).[5] One rationale for this is that these firms must currently rely heavily on R&D to compete globally and

[5] Ten years ago, for example, *Waste Management Technologies* already accounted for about 10% of total eco-industry earnings in the United States and rivaled the aircraft manufacturer *Lockheed* in size (Karliner 1994).

keep abreast of rapidly evolving environmental regulations. These pieces of information should now fix intuition for the model that follows.

2.1. Basic Assumptions

Consider a representative price-taking firm that produces one consumption good while emitting one pollutant. The current price of the consumption good is P, and the production cost associated with an output level x is denoted as $C(x)$. This cost function is assumed twice differentiable, strictly increasing and convex.

The firm's emission level is given by the function $e(x, w)$, where w represents abatement effort. This emission function is twice continuously differentiable and such that $e_x > 0$ (production generates pollution), $e_w < 0$ (abatement effort reduces pollution), $e_{xx} \geq 0$ (the more the firm produces, the more the last unit delivered pollutes), and $e_{ww} > 0$ (there are decreasing returns to abatement). In a manner similar to Barnett (1980), Katsoulacos and Xepapadeas (1995), and Farzin and Kort (2001), for instance, we shall focus on end-of-pipe pollution abatement. We therefore assume that $e(x, w)$ is also additively separable, i.e., $e_{xw} = 0$, for an investment in end-of-pipe abatement does not modify the production process and so does not affect the amount of pollution imputable to each unit produced. Like Katsoulacos and Xepapadeas (1995), let us suppose, furthermore, that the function $e_w(w)w$ is decreasing in w, which means that the emission function is not too convex in w. All these assumptions would be satisfied if, for example, $e(x, w) = kx - \sqrt{Lw}$, where k and L are positive real numbers.[6]

[6]Formally, the function $e(x, w)$ could take negative values. However, the quantity of pollution gener-

2.2. Enters the Eco-Industry

Now, let the abatement goods and services be delivered by an eco-industry. An individual supplier i incurs a cost $G(w_i)$ for producing a quantity w_i of abatement goods and services, where $G(\cdot)$ is twice differentiable, strictly increasing, convex, and such that $G'(0) = 0$.

In the simplest setting, the eco-industry is made of n identical firms competing à la Cournot. The market for abatement is characterized by an inverse demand function $q(w)$, where w stands for total purchases of abatement goods and services. Firm i's profits are then

$$\Pi_i = q(w)w_i - G(w_i) \quad , \quad i = 1, ..., n \ ,$$

and the first-order condition for profit maximization is precisely[7]

$$\frac{\partial q}{\partial w} w_i + q(w) - G'(w_i) = 0 \quad , \quad i = 1, ..., n \ . \tag{1}$$

Since all environment firms are similar, we have that $w_i = \frac{w}{n}$ at an equilibrium.[8] Let $w' = \frac{\partial w}{\partial q}$; equation (1) can now be re-written as

$$q(w) = G'(w_i) - \frac{w}{n}.\frac{1}{w'} \quad , \quad i = 1, ..., n \ . \tag{2}$$

ated by a firm being necessarily positive or equal to zero, we only consider levels of x and w at which $e(x, w)$ is positive. This amounts to suppose that the firm never abates more than it pollutes, which is always true at an equilibrium.

[7] Given our assumptions, first-order conditions are necessary and sufficient wherever they appear.

[8] We suppose that the Cournot-Nash equilibrium exists and is unique. This is ensured when the profit functions Π_i are concave in w_i, i.e., when we have $\frac{\partial^2 q}{\partial w^2} w_i + 2\frac{\partial q}{\partial w} - G'' \leq 0$.

When the number of environment firms n is very large, the price q paid by the polluting firm for each unit of abatement approximates the marginal cost; this corresponds to the situation assumed implicitly throughout the environmental economics literature. In general, however, since w' is negative (this is proven in section 4), equation (2) reveals that $q(w) > G'(w_i)$, so the market price of abatement must exceed the marginal abatement cost. This is a well-known outcome of Cournot competition (or any form of imperfect competition). Also well-known is that the difference between $q(w)$ and $G'(w_i)$ - which reflects the environment firms market power - decreases with the price-elasticity of demand for abatement.[9] We shall soon see how various policy instruments affect this elasticity.

3. First-Best Abatement

Abatement efforts are motivated, first of all, by the negative contribution of pollution to social well-being. Without loss of generality, let the level of social prejudice D increase linearly with the amount of emissions, i.e., $D = \nu e(x,w)$ with some positive coefficient v. Social welfare is now the sum of consumers' surplus, the polluter's and the eco-industry's profits, and the social damage due to pollution:

$$W = \int_0^x P(u)du - C(x) - qw + qw - nG(\frac{w}{n}) - ve(x,w). \tag{3}$$

The first-order conditions for welfare maximization are then

[9] Note that $w' = \varepsilon \frac{w}{q}$, where ε denotes the price-elasticity of demand.

$$P(x^*) - C'(x^*) - ve_x(x^*) = 0, \quad (4)$$

$$-G'(\frac{w^*}{n}) - ve_w(w^*) = 0. \quad (5)$$

According to (4), the price of the consumption good should embed the marginal cost of producing this good plus the marginal social damage associated with it. And according to equation (5), abatement goods and services should also be delivered, up to the level w^* where the marginal cost $G'(\frac{w^*}{n})$ of the eco-industry equals the marginal benefit $-ve_w(w^*)$.

The social welfare objective given by (3), however, makes the eco-industry's revenue and the polluting firm's abatement expenses cancel. All transactions over abatement goods and services were thereby ignored. But if the polluting firm is left to maximize its profits, i.e., to solve

$$\max_{x,w} \pi = Px - C(x) - qw \ ,$$

it will surely select the output level x^0 where the marginal production cost $C'(x_0)$ equals the market price P of the consumption good, while setting its abatement orders at $w^0 = 0$. Without further intervention, there would therefore be no market for abatement.

4. Regulation

Environmental regulation not only creates a potential market for pollution-abating technologies, it also affects the structure of this market. To see this, let us now successively consider some standard policy instruments.

4.1. Emission-Based Instruments

Suppose that the regulator introduces a tax t per unit of emission. The profit-maximizing polluter now behaves as if solving

$$\max_{x,w} \pi^t = Px - C(x) - qw - te(x, w) \ ,$$

so the output and abatement levels will be such that

$$\begin{aligned} P - C'(x^t) - te_x(x^t) &= 0, \quad (6) \\ -q - te_w(w^t) &= 0. \quad (7) \end{aligned}$$

To satisfy the latter, the polluting firm is then willing to invest in abatement.

By Cramer's rule, equations (6) and (7) imply that the price-derivative of demand for abating services is precisely

$$w_t' = \frac{\partial w^t}{\partial q} = -\frac{1}{te_{ww}} \ . \quad (8)$$

Since the second-order derivative e_{ww} is strictly positive, w_t' is negative; this indicates that, as naturally expected, the polluter's abatement purchases decrease when the price of the abating goods and services goes up. The magnitude of w_t' first depends on the convexity of the emission function with respect to abatement effort: if e_{ww} increases, then w_t' decreases. This means that, as abatement measures become more effective (at the margin), the polluter's demand for abatement goods and services is less sensitive to their price. What seems important from a policy standpoint, furthermore, is that a larger tax rate t would similarly bring w_t' closer to zero. In other words: *when the tax on pollutant emissions goes up, demand for abatement becomes less price-elastic.*

Assuming the regulator is benevolent, the tax level will now be set in order to maximize the following social welfare function:

$$W^t = \int_0^{x^t} P(u)du - C(x^t) - qw^t - te(x^t, w^t) + nq\frac{w^t}{n} - nG(\frac{w^t}{n}) - ve(x^t, w^t) + te(x^t, w^t).$$

Straightforward algebra reduces this expression to[10]

$$W^t = \int_0^{x^t} P(u)du - C(x^t) - nG(\frac{w^t}{n}) - ve(x^t, w^t).$$

It can be shown (see part A.1 of the appendix) that the first-order condition for welfare maximization with respect to t then yields

$$t^* = v[\frac{e_x(x^t)\frac{dx^t}{dt} + e_w(w^t)\frac{dw^t}{dt}}{e_x(x^t)\frac{dx^t}{dt} + [\frac{w^t e_{ww}}{n} + e_w(w^t)]\frac{dw^t}{dt}}] \ . \quad (9)$$

[10]This simplification amounts, of course, to supposing that tax revenues are transfered and redistributed in a neutral way.

Standard comparative statics via equations (6) and (7) entails that $\frac{dx^t}{dt} < 0$ and $\frac{dw^t}{dt} > 0$; the latter's numerator is therefore negative. And since $e_w(w)w$ is decreasing by assumption, we have that

$$\begin{aligned} we_{ww} + e_w(w) &< 0, \\ \text{so} \quad \frac{w^t e_{ww}}{n} + e_w(w^t) &< 0, \end{aligned}$$

which implies that the denominator in (9) is also negative. The optimal tax rate is thus positive. Moreover, notice that $\frac{w^t e_{ww}}{n}\frac{dw^t}{dt} > 0$. The coefficient of ν in the above expression is then greater than 1, so $t^* > v$. This finding constitutes our first proposition.

Proposition 1: *When abatement goods and services are supplied by environment firms competing à la Cournot, the optimal pollution tax must be larger than the marginal social damage of emissions.*

Observe that, when the number of environment firms n grows, the coefficient of ν tends to one.[11] As competition within the eco-industry increases, the optimal tax on emissions then approximates the marginal prejudice caused by the polluting activity. Proposition 1 is therefore consistent with Pigou (1920)'s classical result.

The proposition nevertheless contrasts with several streams of the current literature, notably with the one that postulates an imperfectly competitive *polluting* industry. Under a polluting monopoly, or when polluting firms are identical and their number is exogenous

[11] This conclusion obtains from the presence of the term $\frac{w^t e_{ww}}{n}$ in (9). It therefore remains valid if e_{ww} goes to zero instead.

(as in the actual setting), it has indeed been shown that the optimal emission tax falls short of the marginal damage cost (see Buchanan 1969; Barnett 1980; and Katsoulacos and Xepapadeas 1995).[12] The intuitive rationale for departing from these standard results runs as follows. When the eco-industry is imperfectly competitive, the price of abatement goods and services will normally be greater than their marginal cost. In this context, if the tax t was to be set equal to the marginal damage v, then the polluter would settle for an abatement level that is too small relative to the first-best w^*.[13] In order to lessen this distortion, the regulator must then tax pollutant emissions more severely.

What about the values x^{t^*} and w^{t^*} achieved with the optimal tax t^*? By (4), (5) and (7), $t = v$ would entail an efficient quantity of the consumption good, but this tax level encourages too little abatement. On the other hand, a tax level τ that implements the first-best abatement effort w^* would generate insufficient output. The optimal tax t^* balances the desire to give stronger incentives to abatement with the necessity to limit the contraction of output. It follows that $v < t^* < \tau$, so $w^{t^*} < w^*$ while $x^{t^*} < x^*$. This in turn implies that the polluter's overall environmental performance with respect to the first-best is finally ambiguous, for a relatively lower output means less pollution while a smaller abatement effort plays in the opposite direction.

The above remarks are now collected in the last proposition of this section.

[12] Otherwise, the pollution tax would exacerbate the allocative inefficiency (i.e., the under-production) due to imperfect competition. Note that this recommandation can be revised if polluting firms are different or their number is endogenous (see Katsoulacos and Xepapadeas 1995; Long and Soubeyran 1999).

[13] To see this formally, compare equations (5) and (7).

Proposition 2: *Let the abatement goods and services be supplied by environment firms competing à la Cournot. (i) The optimal emission tax leads to lower abatement effort and consumption good production than what would occur at the first-best. (ii) This phenomenon is amplified as the number of firms in the eco-industry decreases or the emission function becomes less convex in abatement. (iii) The impact of the optimal tax on total emissions relative to the first-best is ambiguous.*

It is shown in part A.2 of the appendix that, in the present context, a quota on emissions is equivalent to an emission tax, in the sense that leads to the same output level and abatement expenses. Our analysis of emission-based instruments is then complete. We shall now consider the alternative set of policy instruments.

4.2. Abatement-Based Instruments

Abatement-based regulation is sometimes preferred to an approach centered on emissions. It may be difficult, for instance, to precisely identify the polluter.[14] In this case, the regulator would rather rely on policy instruments which target the means a potential polluter is committed to take to reduce pollution. This section successively investigates two such instruments: design standards and voluntary agreements. At the end, social welfare comparisons will be made between the latter and emission-based instruments.

4.2.1 *Design Standards*

To curtail polluting emissions (of sulfure dioxide, say), the regulator can mandate some specific abatement technologies (such as a particular family of scrubbers). In the present

[14] Non-point source pollution arises in a number of contexts, such as farming and fishing.

model, this command-and-control approach amounts to impose a given abatement level $\bar{w}$. First-best abatement is then implemented when $\bar{w} = w^*$.

Suppose that the chosen design standard can be perfectly and costlessly enforced. The polluter has then no choice but to raise its abatement purchases up to the required amount $w = \bar{w}$. *Demand for abatement goods and services is now perfectly inelastic with respect to price.* In such a situation, the eco-industry enjoys unlimited market power. Unless a price ceiling on abatement goods and services is enforced, the polluting firm is thereby likely to be facing excessive abatement costs, which renders this approach unsustainable.[15]

4.2.2 *The Voluntary Agreement*

An alternative abatement-based approach that has become quite common over the last decade is the voluntary agreement. In practice, this approach can take various forms (see the OECD 1999 report). The one we shall consider here is often encountered in Europe: the regulator makes the polluter a take-it-or-leave-it offer w^V on its abatement level, while threatening to impose an emission tax τ if this proposal is rejected.

Compared with the design standard, the opportunity the polluter now has to select between a fixed abatement level w^V and one that would be determined under a given pollution tax certainly increases the price-elasticity of demand for abatement and limits the eco-industry's market power. If the market price of abatement is too high, the polluting firm can always reduce its orders and submit itself to the emission tax. This inherent

[15] To be sure, note that the derivative $w' = \frac{\partial w}{\partial q} = 0$ in this case. By condition (2), it follows that the market price q tends to ∞ . Of course, this outcome would not hold if the polluter could exit the consumption good market or a large number of firms could enter the eco-industry.

flexibility of the voluntary agreement undoubtedly justifies its growing popularity and the corresponding decline of command-and-control approaches.

However, suppose that the eco-industry can price-discriminate between a polluting firm which accepts the regulator's offer and one that prefers to be facing the pollution tax. Once a polluter enters the voluntary agreement, its demand for abatement goods and services is fixed at $w = w^V$. Clearly, the price q^V set by the eco-industry will then be the *maximum* of the price q_τ^V that yields as much profits as would be achieved under the tax τ and the largest price q_{vol}^V that makes the polluting firm still willing to adopt the proposed abatement level w^V. When $q_\tau^V > q_{vol}^V$, the eco-industry now renders the voluntary approach vacuous, since a polluter will constantly prefer the tax. This observation supports our next proposition.

Proposition 3. *If the eco-industry is allowed to price-discriminate between a polluter who agrees to the regulator's abatement proposal and one who prefers a pollution tax, then it can virtually veto any voluntary agreement.*

This statement implies that, to be workable, a voluntary approach to pollution abatement may require specific measures targetting the eco-industry. These could take the form of regulated prices for environmental goods and services, explicit incentives to enter the eco-industry (provided competition law also precludes collusion between environment firms), or direct prohibition of the current sort of price discrimination.[16]

Let us therefore suppose it is now forbidden to price-discriminate among polluting

[16] Note that the latter might be hard to enforce, however, because of the customized nature of environmental services.

firms. After accepting the regulator's offer, the representative polluter always behaves as if solving

$$\max_x \ \pi^V = Px - C(x) - q^V w^V \ .$$

The first-order condition for profit maximization is then

$$P - C'(x^V) = 0,$$

so $x^V = x^0$ and as much consumption good is produced as if there were no environmental regulation. A voluntary agreement now occurs if and only if

$$Px^0 - C(x^0) - qw^V \geq Px^\tau - C(x^\tau) - qw^\tau(q) - \tau e(x^\tau, w^\tau(q)) \ , \tag{10}$$

where the output x^τ and abatement level w^τ corresponding to the tax τ are determined by equations (6) and (7). Denote as $w^{\max}(q,\tau)$ the value of w^V which, for each price q and each tax threat τ, makes condition (10) hold as an equality. By definition,

$$w^{\max} - w^\tau(q) = \frac{1}{q}\left[Px^0 - C(x^0) - (Px^\tau - C(x^\tau)) - \tau e(x^\tau, w^\tau(q))\right] \ . \tag{11}$$

The difference on the left-hand side of (11) must be positive, since $Px^0 - C(x^0) > Px^\tau - C(x^\tau)$ and $\tau e(x^\tau, w^\tau(q)) \geq 0$. Hence, $w^{\max} > w^\tau(q)$ for all q, so the maximum abatement level the polluting firm is willing to accept is strictly superior to the abatement effort achieved under taxation. Surely, the regulator would make an offer that is as close as possible to the first-best abatement level w^* while satisfying the participation constraint (10): i.e., $w^V = \min(w^*, w^{\max})$. The only credible tax threat, furthermore, is the pollution tax t^* established in equation (9). It follows that

$$w^* \geq w^V > w^{t^*} \ . \tag{12}$$

These findings are summarized in the next proposition.

Proposition 4. *Suppose environment firms cannot price-discriminate. (i) The abatement level achieved through a voluntary agreement is always higher than the one reachable via a pollution tax; it can be equal to the first-best. (ii) On the other hand, the quantity of the consumption good produced under a voluntary agreement exceeds the first-best one.*

This proposition suggests that a voluntary agreement may not always yield less social welfare than an emission-based regulation. When the market for abatement goods and services is perfectly competitive, the optimal emission tax implements the first-best, while a voluntary approach to pollution abatement remains a second-best instrument (because the output x^0 chosen by a polluter is larger than the socially optimal level). When the eco-industry is imperfectly competitive and exercises market power, however, taxing pollution also becomes a second-best policy. It is then not possible to rank an emission tax or quota above or below a voluntary agreement in terms of social welfare for all existing cases. The former measures entail a lower production of the consumption good, hence less pollution damages; but (end-of-pipe) abatement efforts are greater under a voluntary agreement, and polluters as well as consumers are better off because the consumption good is delivered at the absolute profit-maximizing level $x^0 > x^{t^*}$.[17]

4. Conclusions

Prices polluters pay to alleviate environmental damages are now largely determined on market segments dominated by a few big suppliers of abatement technologies. While this fact is widely acknowledged in environmental policy discussions, environmental economics still provides little guidance on how to precisely regulate polluting activities in this context.

This paper first seeked to convey the message that imperfect competition between environment firms does matter for environmental regulation. Accordingly, we amended the basic (textbook) setting - which involves a representative price-taking polluter and no uncertainty or asymmetric information - by now making the polluting firm acquire abatement goods and services from identical suppliers competing à la Cournot. We then showed that taxes on emissions may have to be adjusted upward, and that voluntary agreements on abatement efforts may not be doable without simultaneously putting appropriate limitations on the eco-industry's market power.

A number of valuable research directions could be taken from here. Of course, one first needs to pursue the analysis of environmental regulation in more complex settings, where there is imperfect competition between polluters as well, for instance, or when the

[17] A definite conclusion can nevertheless be reached in the following specialized version of the present model: $P(x) = 1 - x$, $C(x) = \frac{1}{2}x^2$, $G(w) = gw$ ($g > 0$), and $e(x, w) = kx - \sqrt{Lw}$ ($k > 0$, $L > 0$), where the parameter g represents the marginal production cost of the eco-industry, k is the amount of emissions generated by one unit of the consumption good, and L captures the efficiency of the available abatement goods and services. See part A.3 of the Appendix.

environment firms have private information about the cost (or the quality) of abatement services.[18] Since environment firms already play a significant role in international trade and economic growth while remaining strongly dependent upon environmental regulation, one would also want to explore further the interface between environmental policy and industrial policy.[19] Finally, important new findings might result from explicitly considering the structure of the eco-industry in regular studies of environmental innovation (such as, for example, Carraro and Soubeyran 1996; or Innes and Bial 2002).

Appendix

A.1 Equation (9): The Optimal Pollution Tax

Total differentiation of W^t yields:

$$\frac{dW^t}{dt} = [P(x^t) - C'(x^t)]\frac{dx^t}{dt} - G'(\frac{w^t}{n})\frac{dw^t}{dt} - v[e_x(x^t)\frac{dx^t}{dt} + e_w(w^t)\frac{dw^t}{dt}] \quad . \tag{A.1}$$

Since, by (5) and (6),

$$-G'(\frac{w^t}{n}) = -q(w^t) - \frac{w^t}{n}.\frac{1}{w_t'} \quad \text{and} \quad P - C'(x^t) = te_x(x^t) \ ,$$

[18]Addressing the latter topics does not seem to be a straightforward application of the actual literature on vertical relationships and outsourcing (see, for instance, Perry 1989; or Mookherjee 2003), for the abatement services provided by environment firms are meant to correct a negative externality and are usually *not* embedded in the consumption good.

[19]One starting point to enter this road might be the article by Cadot and Sinclair-Desgagné (1995).

(A.1) is equivalent to:

$$\frac{dW^t}{dt} = te_x(x^t)\frac{dx^t}{dt} + [-q(w^t) - \frac{w^t}{w'_t}.\frac{1}{n}]\frac{dw^t}{dt} - v[e_x(x^t)\frac{dx^t}{dt} + e_w(w^t)\frac{dw^t}{dt}]. \qquad \text{(A.2)}$$

Recalling from (7) and (8) that

$$-q(w^t) = te_w(w^t) \quad \text{and} \quad -\frac{w^t}{w'_t} = w^t te_{ww} \ ,$$

equation (A.2) now becomes

$$\frac{dW^t}{dt} = te_x(x^t)\frac{dx^t}{dt} + [e_w(w^t) + \frac{w^t e_{ww}}{n}]t\frac{dw^t}{dt} - v[e_x(x^t)\frac{dx^t}{dt} + e_w(w^t)\frac{dw^t}{dt}] \ .$$

Setting the latter equal to 0 gives equation (9).

A.2 Emission Taxes and Quotas Are Equivalent Policy Instruments

Suppose the regulator imposes a quota on emissions, noted $\bar{e}$. The polluting firm now behaves as if solving

$$\begin{cases} \max_{x,w} \pi^e & = Px - C(x) - qw \\ e(x,w) & \leq \bar{e} \end{cases}$$

and the corresponding first-order conditions are precisely:

$$\begin{aligned} P - C'(x^e) - \lambda e_x(x^e) &= 0, & \text{(A.3)} \\ -q - \lambda e_w(w^e) &= 0, & \text{(A.4)} \\ e(x^e, w^e) &= \bar{e}, & \text{(A.5)} \end{aligned}$$

where λ is the Lagrange multiplier associated with the constraint on emissions.

Comparing (6) and (7) with (A.3) and (A.4), we notice that the two systems of equations are identical but, for the former's tax rate t being replaced by the shadow price λ in the latter. Since our assumptions imply that the respective solutions of these systems are unique, we have that $\lambda = t^*$, $x^e = x^{t^*}$ and $w^e = w^{t^*}$.

A.3 When an emission tax is more efficient than a voluntary agreement.

The social welfare levels associated with an emission tax and a voluntary agreement are given respectively by:

$$W^t = \int_0^{x^t} P(u)du - C(x^t) - nG(\frac{w^t}{n}) - ve(x^t, w^t), \text{ and} \quad \text{(A.6)}$$

$$W^V = \int_0^{x^0} P(u)du - C(x^0) - nG(\frac{w^V}{n}) - ve(x^0, w^V) \; . \quad \text{(A.7)}$$

A necessary condition for $W^V \geq W^t$ for some abatement level w^V is that it is the case when $w^V = w^*$. Let therefore $\Delta W = W^V(w^*) - W^t$.

Consider now the following specialized version of the present model: $P(x) = 1 - x$, $C(x) = \frac{1}{2}x^2$, $G(w) = gw$, and $e(x, w) = kx - \sqrt{Lw}$, with g, k, L strictly positive. In this context, the polluter's preferred quantity of the consumption good is $x^0 = 1/2$. When an emission tax t applies, however, this quantity goes down to $x^t = \frac{1-tk}{2}$ (by equation (6)) and demand for abatement goods and services is given by $w^t(q) = L(\frac{t}{2q})^2$ (by equation (7)). The latter entails that

$$w^t = \frac{Lt^2(2n-1)^2}{16(ng)^2} \ ,$$

while the first-best abatement level is

$$w^* = L(\frac{v}{2g})^2 \ .$$

Insert these expressions in (A.6) and (A.7). After some straightforward algebra, we obtain:

$$\Delta W = t^2[\frac{k^2}{4} + \frac{L(2n-1)^2}{16n^2 g}] - t[\frac{vk^2}{2} + \frac{vL(2n-1)}{4ng}] + \frac{v^2 L}{4g} \ .$$

This quadratic polynomial is non-negative at its minimum (which it reaches at the socially optimal tax level) only if its discriminant D is non-positive. This would mean that:

$$D = [\frac{vk^2}{2} + \frac{vL(2n-1)}{4ng}]^2 - \frac{v^2 L}{g}[\frac{k^2}{4} + \frac{L(2n-1)^2}{16n^2 g}] = k^2 + \frac{L}{g}(\frac{n-1}{n}) \leq 0 \ .$$

But the latter is impossible within the assumed range of parameter values. ■

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