Polluters and Abaters*

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To comply with laws, regulations and social demands, polluting firms increasingly purchase the needed means from specialized suppliers. This paper analyzes this relatively recent phenomenon. We show how environmental regulation, the size of the output market, the elasticity of demand for abatement goods and services, and the fact that in-house and outsourced abatement expenses are substitutes or complements can influence a polluter's make-or-buy decision. Specific features of abatement oursourcing are highlighted, qualifications and refinements of the theory of vertical integration are then proposed, and some consequences for environmental policy are briefly discussed.

KEYWORDS: Eco-industry, make-or-buy decision, outsourcing, vertical integration

JEL CLASSIFICATION: L23, L24, Q52

1. Introduction

Environmental goods and services are now being largely provided by a sizeable and fast-growing specialized industry. Over the last 40 years, this so-called "eco-industry" has come to rival the aerospace and pharmaceutical sectors in size, accounting for about 1.7% of employment and 2.2% of gross domestic product in the European Union and the United States at the present time, and totalling expected global revenue of US\$ 776 billion in 2010 and US\$ 800 billion in 2015.[1] The Organization for Economic Cooperation and Development and the Statistical Office of the European Commission [OECD/Eurostat (1999)] define the eco-industry as the set 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." Pollution abatement goods, services and technologies make up more than 80% of the industry's income [Institut Français de l'Environnement (2002)]. According to the OECD (2002), current growth is driven by demand from the private sector: the Institute of Clean Air Companies (ICAC), for example, an American nonprofit association of enterprises supplying stationary-source air pollution control technology and monitoring systems, recently projected that its United States market will hover around US\$ 7 billion a year through 2010, the largest segments remaining those for SO_2 and NOx technologies which essentially address the needs of privately-held industrial units.

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[1] For additional figures and trends concerning the eco-industry, together with a short history of the sector and a discussion of its definition, see Sinclair-Desgagné (2008).

In sum, polluters rely more and more on external suppliers for the goods, services and technologies necessary to comply with environmental laws and regulations; this especially happens in dealing with air pollutants, wastewater and solid-waste. Experts and practitioners allege that polluting firms can thereby focus on their respective core business, access leading expertise, and share risk [see, e.g., Miladin (2005), Blocki (2002), Shelley (1997)]. This paper's objective is to formally examine such rationales and dig out the circumstances in which they hold.

Our analysis draws from the early literature on vertical integration. We find, for instance, that polluting firms will do less in-house abatement and increase outside procurement of environmental goods and services as their product market expands. This corroborates Stigler (1951)'s (and Adam Smith's) well-known prediction that "the division of labor is limited by the extent of the market." It also supports the above "core-business" explanation. The result is guaranteed to hold, however, only when the production and abatement technologies meet specific conditions which are spelled out below.

Our modelling approach builds additionally on the emerging environmental economics literature which studies the eco-industry [see, e.g., David and Sinclair-Desgagné (2009, 2005), Requate (2005), Greaker and Rosendhal (2008), David et al (2008), Canton et al. (2007), Nimubona and Sinclair-Desgagné (2005), Perino (2009)].[2] This work has so far centered primarily on the policy consequences of imperfect competition between abatement suppliers. It acknowledges the existence of the eco-industry and is essentially

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[2] A survey of this literature can be found in Sinclair-Desgagné (2008).

normative in scope. By contrast, this paper chiefly constitutes an essay in positive economics that seeks to explain the *existence* of the eco-industry.

The following section will now present a simple (partial equilibrium) model of the market for abatement. On this basis, Section 3 uses comparative statics to analyze a polluting firm's decision to increment its external procurement of abatement goods and services. Section 4 outlines some policy implications. Section 5 finally highlights this paper's main findings, pointing out specific traits of abatement outsourcing that do not fit the current theory of vertical integration and would call for further investigation. All mathematical assumptions and derivations are summarized in an appendix.

2. The model

Imagine a representative firm subject to a tax on its polluting emissions. To alleviate the fiscal burden, this firm might expend in-house efforts in controlling emissions and/or procure abatement goods and services from an external supplier (the abater). Thereafter, we assume the latter is a monopoly, while the polluting firm is a price-taker on both the output and pollution abatement markets. This setting is that of a young abatement goods and services industry; paraphrasing Stigler (1951, p. 188):

> With the expansion of the [polluting] industry, the magnitude of the [emission control] function subject to increasing returns may become sufficient to permit a firm to specialize in performing it. The [polluting] firms will then abandon [at least part of] the [pollution abatement] process and a new firm will take it over. This new firm [here, the abater] will be a *monopoly* (...). With the continued expansion of the [polluting] industry, the number of [abatement supplying] firms will increase, so that the new [abatement] industry becomes competitive (...). [Italics and terms between brackets added]

It also seems to fit several stylized facts about the abatement goods and services market.

The Texas Center for Policy Studies reports, for example, that:

> "Area sources" are small, stationary sources that usually do not emit large amounts of criteria pollutants or toxics. (...) Important area sources include dry cleaners, printers, machine shops, service stations, wastewater treatment plants, auto painting, repair shops and consumers who use household consumer items. While these "small" businesses and consumer activities individually do not contribute large amounts of pollution to the atmosphere, taken collectively they emit more of some types of pollutants than do some individual large industries. In many cities in Texas, area sources contribute more VOCs to smog formation than do major stationary sources.

Meanwhile, the Institute of Clean Air Companies often displays only one supplier of certain technologies to abate volatile organic compounds (VOCs).

Let us now describe formally the polluter's and the abater's respective behavior.

○ *The polluting firm*

Let the representative polluter set its production level x, internal abatement effort a and quantity of procured abatement goods and services (AGS) α from the interval $[0, \infty)$ in order to maximize the profit function

$$F(x, a, \alpha) = p \cdot x - c(x, a; r) - t \cdot e(x, a, \alpha; z) - w \cdot \alpha . \tag{1}$$

The letters p, t, and w refer respectively to the price of output, the emission tax level and the price of outsourced AGS. The function $c(x, a; r)$ gives the cost of production; it is indexed by an exogenous parameter r and is assumed to be twice continuously differentiable, increasing and convex in x and a (so the first and second-order derivatives c_x, c_a and c_{xx}, c_{aa} are positive). The expression $e(x, a, \alpha; z)$, finally, also indexed by an exogenous technical parameter z, denotes the firm's emission function; all other things remaining constant, it increases, and increases faster, with the quantity produced x (so the first and second-order derivatives e_x and e_{xx} are positive) but goes down, at a decreasing

5

rate, as the abatement expenses a and α get larger (so e_a, $e_\alpha < 0$ and e_{aa}, $e_{\alpha\alpha} > 0$).

To be optimal, x, a and α must then satisfy the necessary and sufficient first-order conditions given by

$$F_x \;=\; p - c_x - t \cdot e_x \;\lesseqgtr\; 0 \qquad (= 0 \;\; if \;\; x > 0) \tag{2}$$

$$F_a \;=\; -c_a - t \cdot e_a \;\lesseqgtr\; 0 \qquad (= 0 \;\; if \;\; a > 0) \tag{3}$$

$$F_\alpha \;=\; -t \cdot e_\alpha - w \;\lesseqgtr\; 0 \qquad (= 0 \;\; if \;\; \alpha > 0) \tag{4}$$

Expression (2) says that the emission tax t should not be so high if any production is to take place. Expressions (3) and (4), on the other hand, mean that some positive penalty ($t > 0$) is necessary to induce abatement efforts (a, $\alpha > 0$). If $e_a \lesseqgtr e_\alpha$, moreover (so the abater's technology does not curb emissions better than the polluter's own abatement expenses), AGS outsourcing does not occur (i.e. $\alpha = 0$) when the price w is greater that the marginal cost c_a of in-house abatement (for in this case: $w > c_a \gtreqless -t \cdot e_a \gtreqless -t \cdot e_\alpha$).[3]

Assuming thereafter that $e_a > e_\alpha$ (so an additional unit of outsourced AGS reduces emissions more than an additional unit of in-house abatement effort), condition (4) now yields the inverse demand for AGS:

$$w = -t \cdot e_\alpha(x, a, \alpha; z). \tag{5}$$

Demand is enhanced, naturally, by a larger emission tax t. As stressed by Canton et al (2007), it also depends on the relative effectiveness of abatement technologies, which is captured here by the second-order derivatives $e_{x\alpha}$, $e_{a\alpha}$, $e_{\alpha\alpha}$, and $e_{\alpha z}$. The curvature $e_{\alpha\alpha}$, in particular, plays a key role that we shall now spell out.

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[3] When $e_a > e_\alpha$, however, it may happen that $\alpha > 0$ while $w > c_a$. This qualifies Stigler (1951, p. 188)'s assertion that the new AGS supplier "(...) cannot charge a price for the process higher than the average cost of the process to the firms which are abandoning it."

○ *The pollution-abatement supplier*

The AGS provider's profit, on the other hand, can be written as

$$G(\alpha) = w \cdot \alpha - k(\alpha; \tau) , \tag{6}$$

where $k(\alpha; \tau)$, indexed by the exogenous parameter τ and assumed increasing and convex in α (so k_α and $k_{\alpha\alpha}$ are positive), stands for the cost of bringing an amount α of AGS to the market. Substituting the polluting firm's demand (5) in the latter expression yields

$$G(\alpha) = -t \cdot e_\alpha(x, a, \alpha; z) \cdot \alpha - k(\alpha; \tau) . \tag{7}$$

Suppose that the function $e(x, a, \alpha; z)$ is "moderately" convex in α, so the product $e_\alpha \cdot \alpha$ is decreasing in α. Necessary and sufficient conditions for a profit-maximizing delivery of AGS are then

$$G_\alpha = -t \cdot e_{\alpha\alpha} \cdot \alpha - t \cdot e_\alpha - k_\alpha \lesseqgtr 0 \quad (= 0 \ if \ \alpha > 0) . \tag{8}$$

This entails that the unit price for a positive quantity of AGS will be

$$w = k_\alpha + t \cdot e_{\alpha\alpha} \cdot \alpha ; \tag{9}$$

it is equal to the marginal cost at α plus a positive term proportional to the tax level t, the quantity α and the curvature $e_{\alpha\alpha}$. Using (9), one gets the familar expression for the markup of a monopolistic supplier:

$$\frac{w - k_\alpha}{w} = \frac{t \cdot e_{\alpha\alpha} \cdot \alpha}{w} = \frac{1}{\varepsilon_{AGS}} , \tag{10}$$

where $\varepsilon_{AGS} = \frac{w}{\alpha} \cdot \frac{1}{te_{\alpha\alpha}}$ is indeed the price-elasticity of demand for EGS. A lower elasticity, induced for instance by a higher tax t, allows therefore the abater to charge a higher markup (all other things remaining the same).

David and Sinclair-Desgagné (2005) first noted that the price-elasticity ε_{AGS} goes down with t, so a bigger emission tax grants the AGS supplier more market power.[4] This assertion remains on the whole valid here, but the possibility polluters have to abate their emissions in-house calls for some qualifications.[5]

3. Results

Let us now investigate how in-house abatement efforts a and the amount of outsourced AGS α respectively vary when circumstances are different. We assume that no situation causes a firm to exit; in other words, $x > 0$ and $\alpha > 0$ throughout the current exercise. We also suppose that polluters always perform some (even tiny) emission control themselves, so $a > 0$. Conditions (2), (3), (4) then hold as equalities. Total differentiation of these conditions, taking into account that the price w of AGS is set via formula (9), gives

$$
\begin{bmatrix}
-(c_{xx} + t \cdot e_{xx}) & -(c_{xa} + t \cdot e_{xa}) & -t \cdot e_{x\alpha} \\
-(c_{xa} + t \cdot e_{xa}) & -(c_{aa} + t \cdot e_{aa}) & -t \cdot e_{a\alpha} \\
-(e_{x\alpha} + w_x) & -(t \cdot e_{a\alpha} + w_a) & -(t \cdot e_{\alpha\alpha} + w_\alpha)
\end{bmatrix}
\begin{pmatrix} dx \\ da \\ d\alpha \end{pmatrix}
$$

$$
=
\begin{bmatrix}
-1 & 0 & c_{xr} & e_x & t \cdot e_{xz} \\
0 & 0 & c_{ar} & e_a & t \cdot e_{az} \\
0 & w_\tau & 0 & e_\alpha + w_t & t \cdot e_{\alpha z} + w_z
\end{bmatrix}
\begin{pmatrix} dp \\ d\tau \\ dr \\ dt \\ dz \end{pmatrix}
\qquad (11)
$$

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[4] David and Sinclair-Desgagné (2005, p. 141) actually made a more general statement: "(...) 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."

[5] Qualifications are also necessary if other suppliers can enter the market for AGS. This case was recently examined by David et al (2008).

Following standard comparative statics practice, the respective impact on x, a, and α of a change in the output market price p, the abater's and the polluter's respective cost parameters τ and r (to be given precise meaning below), the emission tax t and the emission control index z, which is captured by the derivatives $\frac{dx}{dp}$, $\frac{da}{dp}$, $\frac{d\alpha}{dp}$, $\frac{dx}{d\tau}$,..., $\frac{d\alpha}{dz}$, can now be assessed using Cramer's rule. Note beforehand that concavity of the polluting firm's objective requires that the determinant of the 3x3 matrix on the left-hand side, noted H_3, be negative, and the determinant

$$
H_2 = \begin{vmatrix} -(c_{xx} + t \cdot e_{xx}) & -(c_{xa} + t \cdot e_{xa}) \\ -(c_{xa} + t \cdot e_{xa}) & -(c_{aa} + t \cdot e_{aa}) \end{vmatrix} = (c_{xx} + t \cdot e_{xx})(c_{aa} + t \cdot e_{aa}) - (c_{xa} + t \cdot e_{xa})^2
$$

be positive. This completes the mathematical preliminaries to investigate some commonly stated rationales for outsourcing AGS.

3.1 *More outsourcing of abatement makes compliance cheaper*

An obvious reason to switch from in-house to externally provided AGS is that the latter are less expensive. Suppose indeed that an increase in the technical parameter τ indicates that the marginal cost of making AGS is lower; i.e. $k_{\alpha\tau} < 0$. Formula (9) implies, then, that $w_\tau < 0$; in other words, the market price of AGS goes down. By Cramer's rule and the above remark, it follows that

$$
sign\frac{d\alpha}{d\tau} = -sign\left[w_\tau \cdot H_2\right] > 0 , \tag{12}
$$

so the quantity of procured AGS increases, as expected.

Cramer's rule and the fact that $H_3 < 0$ imply, moreover, that

9

$$sign\frac{da}{d\tau} = -sign\left[-w_\tau((c_{xx} + t \cdot e_{xx})te_{a\alpha} - te_{x\alpha}(c_{xa} + t \cdot e_{xa}))\right] .$$ (13)

One might reasonably assume that e_{xa} and $e_{x\alpha}$ are negative, so taking more abatement measures (in-house or outsourced) reduces the environmental impact of production, and that $c_{xa} > 0$, so raising in-house abatement efforts increases the marginal cost of production (because managerial time and attention, say, are scarce resources). The sign of $\frac{da}{d\tau}$ then depends on that of the sum $c_{xa} + t \cdot e_{xa}$ and the cross-derivative $e_{a\alpha}$.

A positive $e_{a\alpha}$ would mean that internal and outsourced AGS are *substitutes*: more of the latter renders the former less effective (recall that e_a, $e_\alpha < 0$). In this case, if the marginal benefit of in-house abatement in terms of tax reduction $-t \cdot e_{xa}$ does not compensate for its cost c_{xa} (i.e. $c_{xa} + t \cdot e_{xa} > 0$), then $\frac{da}{d\tau} < 0$, so in-house abatement certainly decreases when procured AGS are cheaper. A negative $e_{a\alpha}$, on the other hand, portends *complementary* instruments: more of one enhances the other's performance at reducing emissions. If, additionally, the opportunity cost of internal resources is relatively small compared to fiscal benefits (i.e. $c_{xa}+t\cdot e_{xa} < 0$), then $\frac{da}{d\tau} > 0$. In other circumstances, the sign of $\frac{da}{d\tau}$ is ambiguous.

The following proposition summarizes these findings.

PROPOSITION 1: *Suppose the marginal cost of external abatement goes down (i.e. $k_{\alpha\tau} < 0$). This entails that the market price of AGS decreases, so more abatement effort will be outsourced. On the other hand (provided e_{xa}, $e_{x\alpha} < 0$ and $c_{xa} > 0$), there will be less (more) internal abatement if internal and outsourced AGS are substitutes (complements) and in-house abatement brings more (less) costs than benefits at the margin.*

The second sentence suggests that total abatement effort (external plus in-house) might actually *decrease* if the eco-industry becomes more efficient at making abatement goods and services. Indeed, with $A = a + \alpha$ denoting total abatement effort, we have after some algebra that

$$
\frac{dA}{d\tau} = \frac{da}{d\tau} + \frac{d\alpha}{d\tau}
$$

$$
= \frac{\overset{(-)}{\omega_\tau} \left[\overbrace{(c_{xa} + t \cdot e_{xa})}^{(+)} \overbrace{(t \cdot e_{x\alpha} - c_{xa} - t \cdot e_{xa})}^{(-)} + \overbrace{(c_{xx} + t \cdot e_{xx})}^{(+)} \overbrace{(c_{aa} + t \cdot e_{aa} - t \cdot e_{a\alpha})}^{(+/-)} \right]}{H_3},
$$

which is negative if and only if $c_{aa} + t \cdot (e_{aa} - e_{a\alpha}) < 0$, i.e. if $e_{a\alpha}$ is large enough (so internal and external abatement are strong substitutes). This seems to run counter to traditional wisdom, which rather expects that a lower marginal cost of abatement (all other things, in particular the emission tax, remaining the same) means greater effort will be expended at reducing pollution. What we did here, however, was to enter the "black box" of pollution abatement, considering it normally has two components - internal and outsourced - with different marginal costs; an uncompensated change in only one of the latter may then lead polluters to reallocate their abatement effort in ways that can surprise an outsider who sees only the aggregate.

3.2 *More outsourcing of abatement allows to curb emissions more effectively*

Another natural argument to justify greater outsourcing of AGS is that this provides access to leading expertise and state-of-the-art technology.[6] In the present model, the

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[6] For (albeit preliminary) evidence, the interested reader may have a look at the various case studies reported on the ICAC's website (www.icac.com).

parameter z can be used to indicate the quality of the technology available on the market: let $e_{xz} = e_{az} = 0$ and $e_{\alpha z}$, $e_{\alpha\alpha z} < 0$, so a larger z strictly means that procured AGS are more effective and experience less decreasing returns at controlling emissions. The pricing formula (9) then implies that $w_z = t \cdot e_{\alpha\alpha z} \cdot \alpha < 0$, so the market price of AGS goes down when z grows (and demand for abatement is thereby more elastic). Cramer's rule now entails that

$$sign\frac{d\alpha}{dz} = -sign\ [(t \cdot e_{\alpha z} + w_z)H_2] > 0\ . \tag{14}$$

Better returns on external abatement therefore augments AGS outsourcing, as predicted.

The effect of a greater z on in-house abatement efforts, in contrast, depends again on the relationship between t, x, a, α, and z. We have that

$$sign\frac{da}{dz} = -sign\ [-(t \cdot e_{\alpha z} + w_z)((c_{xx} + t \cdot e_{xx})te_{a\alpha} - te_{x\alpha}(c_{xa} + t \cdot e_{xa}))]\ . \tag{15}$$

In the previously mentioned scenario where $e_{a\alpha} > 0$ (in-house and outsourced abatement are substitutes) and $c_{xa} + t \cdot e_{xa} > 0$ (internal resources devoted to abatement carry a large opportunity cost), the derivative $\frac{da}{dz}$ is (rather intuitively) negative. It wears the opposite sign if $e_{a\alpha} < 0$ (in-house and outsourced abatement are complements) and $c_{xa} + t \cdot e_{xa} < 0$ (internal resources devoted to abatement give rise to a significant fiscal benefit). Its sign is ambiguous otherwise.

These developments support a second proposition.

PROPOSITION 2: *Suppose the external abatement technology improves (meaning that $e_{\alpha z}$, $e_{\alpha\alpha z} < 0$). Polluting firms will then buy more abatement goods and services. However (provided e_{xa}, $e_{x\alpha} < 0$, $c_{xa} > 0$), there will be less (more) internal abatement expenses*

12

if these are substitutes (complements) to outsourced AGS and the opportunity cost of in-house abatement is at the margin larger (smaller) than its benefits.

This proposition is analogous to the previous one and calls for the same observations. It underscores again the importance of entering the "black box" of abatement, in order to better understand and predict the efforts made by private firms to meet their environmental constraints.

3.3 *More outsourcing of abatement brings more focus*

Having an outside supplier take care of emission control clearly allows polluting firms to concentrate on their core business. This corroborating statement from Blocki (2002) is typical in the professional literature on the subject: "The primary benefit offered by an abatement contractor is focus. The plant and its staff are focused on getting the product out the door and keeping the production equipment operating. An abatement contractor has no focus on the client's production; its only focus is the abatement system." The latter sentence suggests a setting with no technical synergy between in-house and external abatement; accordingly, let's assume that $e_{a\alpha} = 0$, so $w_a = 0$ by formula (9).

Suppose now that the polluting firm finds it more costly to produce when more managerial time is put on controlling emissions; i.e., in formal terms, $c_{xa} > 0$. And let a larger parameter r affect only the marginal cost of internal abatement, meaning that the marginal cost of in-house abatement has gone up; that is, $c_{xr} = 0$ and $c_{ar} > 0$. By Cramer's rule, the derivative $\frac{d\alpha}{dr}$ is such that

$$sign\frac{d\alpha}{dr} = -sign\left[c_{ar}(c_{xa} + t \cdot e_{xa})(e_{x\alpha} + w_x)\right].$$

(16)

Let c_{xa} be large enough so that $c_{xa} + t \cdot e_{xa} > 0$. If $e_{x\alpha} < 0$ as before, the sign of $\frac{d\alpha}{dr}$ depends on the value of $w_x = t \cdot e_{\alpha\alpha x} \cdot \alpha$, which captures the change in returns on outsourced AGS as output increases. A negative value, showing (rather realistically) that the returns on the abater's extra efforts are less decreasing at higher production levels, implies indeed that $\frac{d\alpha}{dr} > 0$.

In a similar fashion, we have that

$$sign\frac{da}{dr} = -sign\left[c_{ar}((c_{xx} + t \cdot e_{xx})(t \cdot e_{\alpha\alpha} + w_\alpha) - te_{x\alpha}(e_{xa} + w_x))\right] . \tag{17}$$

Assuming that $e_{\alpha\alpha\alpha} > 0$ (so returns on outsourced AGS are more decreasing as the amount α grows), which implies that $w_\alpha > 0$, this derivative is assured to be negative if $e_{x\alpha} \approx 0$.

Noting that a pure end-of-pipe abatement technology would have $e_{x\alpha} = 0$, a third proposition is now at hand.

PROPOSITION 3: *Suppose the opportunity cost of managerial attention for doing abatement in-house increases (i.e. $c_{ar} > 0$, while $c_{xr} = 0$, $c_{xa} > 0$ and $c_{xa} + t \cdot e_{xa} > 0$). Then (assuming $e_{\alpha\alpha x} < 0$, $e_{\alpha\alpha\alpha} > 0$), AGS procurement increases and internal abatement declines, the latter provided the eco-industry offers what are basically end-of-pipe solutions.*

This statement gives a rationale for the fact that, by and large, the eco-industry mostly concentrates on supplying end-of-pipe abatement devices [see Sinclair-Desgagné (2008)]. Over the last decades, iincreased competitive pressure (owing notably to globalization) and what was to become conventional wisdom across business [thanks in particular to Prahalad and Hamel (1990)'s influential article] have made managerial time even scarcer. This encouraged the externalization of abatement, especially when it is end-of-pipe and

holds therefore little synergy with a polluting firm's production.

3.4 *More outsourcing of abatement stems from "the extent of the market"*

Finally, economists have noticed some time ago that bigger markets foster specialization. Let us first examine this proposition when the output market expands, which corresponds to the Smith-Stigler's case. Throughout this subsection, we assume that $e_{a\alpha} = 0$ (which implies that $w_a = 0$), so no synergy exists between in-house and outsourced abatement, $w_\alpha > 0$ and $w_x = t \cdot e_{\alpha\alpha x} \cdot \alpha \leq 0$. A higher price p now truly indicates that the output market has increased, for we have that

$$sign \frac{dx}{dp} = sign \ [(c_{aa} + t \cdot e_{aa})(t \cdot e_{\alpha\alpha} + w_\alpha)] > 0 \ . \tag{18}$$

Consider at present the other derivatives:

$$sign \frac{da}{dp} = -sign \ [(c_{xa} + t \cdot e_{xa})(t \cdot e_{\alpha\alpha} + w_\alpha)] \ ; \tag{19}$$

$$sign \frac{d\alpha}{dp} = -sign \ [(c_{aa} + t \cdot e_{aa})(e_{x\alpha} + w_x)] \ . \tag{20}$$

The latter has the predicted positive sign if $e_{x\alpha} < 0$, i.e. if the abater does not solely offer pure end-of-pipe abatement solutions; otherwise, $\frac{d\alpha}{dp} = 0$ (for $w_x = 0$ when $e_{x\alpha} = 0$). This constitutes an interesting qualification of the Smith-Stigler theorem (one which is, furthermore, specific to this environmental context): end-of-pipe pollution abatement not being a productive input, an extension of the downstream market (everything else remaining constant) may then not affect its level.

In the same vein, the sign of $\frac{da}{dp}$ depends on that of $c_{xa} + t \cdot e_{xa}$. One may have $\frac{da}{dp} > 0$

when c_{xa} is negative (or even when c_{xa} is smaller than $-t \cdot e_{xa}$). This will happen if more in-house abatement efforts actually *decrease* the marginal cost of production. Such a situation may not be fully unrealistic, considering for instance some new evidence in support of the so-called "Porter hypothesis" [see Ambec and Lanoie (2008) for a recent assessment of this much-debated view].[7]

This yields another proposition.

PROPOSITION 4: *Suppose the output market widens. Polluting firms will specialize by procuring more AGS and doing less abatement themselves if outside AGS are increasingly effective and not purely end-of-pipe ($e_{\alpha\alpha\alpha}$, $e_{\alpha\alpha x} > 0$) and if in-house abatement conveys a large opportunity cost ($c_{xa} + t \cdot e_{xa} > 0$).*

Intuitively, the AGS market should also expand, inducing less in-house abatement and more AGS outsourcing, following more stringent environmental regulation. Assume that $c_{xa} + t \cdot e_{xa} > 0$ and $e_{x\alpha} = 0$ (meaning the abatement supplier's technology is end-of-pipe, which implies that $w_x = 0$). The immediate (and commonly accepted) effect of a higher emission tax is to reduce production:[8]

$$sign\frac{dx}{dt} = -sign \ [(e_x(c_{aa} + t \cdot e_{aa}) - e_a(c_{xa} + t \cdot e_{xa}))(t \cdot e_{\alpha\alpha} + w_\alpha)] < 0 \ . \quad (21)$$

Computing the corresponding expressions for $\frac{da}{dt}$ and $\frac{d\alpha}{dt}$, moreover, gives

$$sign\frac{da}{dt} = -sign \ [(-e_x(c_{xa} + t \cdot e_{xa}) + e_a(c_{xx} + t \cdot e_{xx}))(t \cdot e_{\alpha\alpha} + w_\alpha)] > 0 \quad (22)$$

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[7]The Porter hypothesis says that certain actions commanded by stricter environmental regulation can improve both environmental performance and market competitiveness. To be fair, we must say that this situation was a priori excluded in Stigler (1951)'s argument.

[8] Indeed, the Porter Hypothesis does not hold in this case since $c_{xa} > 0$.

$$sign\frac{d\alpha}{dt} = -sign\ [(e_\alpha + w_t)H_2].\tag{23}$$

In-house abatement thus tends to increase, but the sign of $\frac{d\alpha}{dt}$ is actually uncertain since

$w_t = e_{\alpha\alpha} \cdot \alpha > 0$ and $e_\alpha < 0$. If $e_{\alpha\alpha}$ is large enough (compared to the outsourced tech-

nology's effectiveness e_α), demand for external AGS is inelastic and the abater can then

exert significant market power; in this case it may actually turn out, not unreasonably,

that $\frac{d\alpha}{dt} < 0$ so polluting firms will do less AGS outsourcing. Our last proposition now

follows:

PROPOSITION 5: *Consider an increase in the emission tax. Then (supposing $c_{xa}+t\cdot e_{xa} >$*

0 and $e_{x\alpha} = e_{a\alpha} = 0$) in-house abatement always increases, but purchases of AGS may go

down if the abater can thereby exert large market power.

This proposition means that environmental policy may not only affect the structure of the

eco-industry [David and Sinclair-Desgagné (2005)] but also the *organization* of polluting

firms [a possibility initially explored in Sinclair-Desgagné (1994)]. This and the above

have policy implications which will now be discussed.

4. Policy implications

From a public policy standpoint, the results derived in the previous section have the

following ramifications.

First, our model embeds two distinct instruments of *environmental regulation*: the

emission tax t, of course, which level can be set by a regulator who maximizes some

form of social welfare, and the quality of external abatement z that the regulator may

want to set at some level (particularly when, by comparison, the emission tax involves

high administrative or political costs). Each instrument entails specific compliance costs through its own influence on the provision of AGS. In the previous section, a higher emission tax induced higher abatement costs (since $w_t > 0$); subsection 3.2, on the other hand, showed that outsourced AGS are cheaper when they are more effective (for $w_z < 0$). As we noticed early on, a positive emission tax t is necessary to generate some control of polluting emissions in the first place. Our findings suggest, however, that compliance with environmental policy might be aided by also promoting the delivery of better AGS.

Secondly, the eco-industry is increasingly becoming - not necessarily for environmental reasons, one has to admit - an explicit target for *industrial policy* [see Ernst and Young (2006), Kojima (2008), People's Daily Online (2006), and US Department of Commerce (2001) for perspectives from Europe, Japan, China and the United States respectively]. The present analysis may shed light on the relative merits of two alternative instruments to foster environmental innovation. On the one hand, the quality standard z might correspond to the amount of resources (i.e. government subsidies) devoted to product-innovation in order to bring to the market more effective AGS; on the other hand, the parameter τ's level may be proportional to the amount of resources directed at process-innovation, which aims to reduce the cost of producing AGS. Since $\frac{d\alpha}{dz}$ are $\frac{d\alpha}{d\tau}$ are both positive, raising either z or τ will enhance the eco-industry's market.[9]

For the eco-industry to expand and prosper with minimal public help, however, one must again look at the value of outsourced AGS versus in-house abatement. As we just

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[9]As shown in David and Sinclair-Desgagné (2009), moreover, combining the emission tax t with appropriate subsidies to the eco-industry might also yield a first-best allocation of resources.

saw in the preceding section, a larger eco-industry does not fall automatically from more stringent environmental regulation. Other factors play a role as well, such as the opportunity cost of in-house abatement and whether the AGS supplier holds significant market power. Interestingly, the size of the output market can also matter: as Proposition 4 shows, when the abater offers "cleaner production" technologies (which seek to directly modify the production process, as opposed to end-of-pipe approaches), both the downstream market and that for AGS tend to grow or shrink together. This suggests that, when downstream output goes down (because the economy experiences a downturn, say), government support should aim for the cleaner-production segment of the eco-industry.

5. Concluding remarks

This paper offers a first attempt at explaining the widespread and growing practice of AGS outsourcing. Beyond the necessary environmental policies (an emission tax, in this case), access to cheaper and better abatement technology, and more pressure on polluters to focus on core business activities, lead polluting firms to rely further on a specialized eco-industry for the needed means of emission control. The expansion of the output market was also seen to make polluters procure more AGS and do less emission control by themselves [as originally predicted by Stigler (1951) and Adam Smith], provided such AGS are not end-of-pipe (a qualification of the Smith-Stigler's theorem which is specific to the environmental goods and services sector), the opportunity cost of in-house abatement is large and the AGS supplier's market power (which is mostly determined by the choice of environmental regulation) is limited.

The current model, however, did not allow to investigate one last important rationale for AGS outsourcing, which is the opportunity for polluters to thereby share the risk of noncompliance and legal liability. Stylized facts about the eco-industry seem to go here against transaction costs economics [as exposed, for instance, in Lafontaine and Slade (2007), Klein (2005), Whinston (2003), and Williamson (1975, 1985)]: while complying with environmental regulations often involves specific investments, intricate know-how and unforeseeable contingent actions, the current trend is clearly not towards the internalization of AGS by polluting firms. The property rights approach [Hart (1995)], on the other hand, seems particularly relevant. Take, for instance, the following statement from Blocki (2002):

> Outsourcing can make the contractor a full financial partner with contractual responsibilities for compliance, including reimbursement of any fines and penalties for non-compliance. (...) Although the contractor cannot be held responsible for any criminal liability that arises, this joint "ownership" can provide maximum benefits to the environment.

This amounts to saying that AGS outsourcing enables a polluting firm to make the abatement supplier a residual claimant in matters of environmental compliance. In agreement with the theory, "(...) the interests and motivations of the contractor can thereby be closely aligned." [Blocki (2002)]

This research could finally be extended in a number of ways. For instance, one should allow a monopolistic abatement supplier to set nonlinear prices and a regulator to use nonlinear taxes. Other typical issues of outsourcing, such as negotiation and renegotiation between parties, asymmetric information and moral hazard should be considered. And predictions should be tested empirically. Further normative considerations are also in or-

20

der, since this paper carried out what is mainly a positive analysis of the eco-industry. The optimal environmental and/or industrial policies dealing with an expanding eco-industry, for example, should be searched for. One should moreover examine a framework in which there is imperfect competition between polluters and/or between AGS suppliers; in this context, the respective incentives and bargaining power of polluting and abating firms could enter the analysis of a polluter's make-or-buy decision. Considering an oligopolistic eco-industry could ultimately highlight some key issues on the organization of environmental R&D, such as the degree of cooperation to allow between pollution abaters; as Poyago-Theotoky (2007) pointed out, this extension may not constitute a straightforward application of the actual R&D literature, since bringing in environmental externalities involves additional market failures.

Appendix

The following table summarizes our mathematical assumptions and results.

Effect of τ
$sign\frac{d\alpha}{d\tau} = -sign\left[w_\tau \cdot H_2\right] > 0$ iz $\{w_\tau = \ \ k_{\alpha\tau} < 0 \text{ and } H_2 > 0\}$
$sign\frac{da}{d\tau} = -sign\left[-w_\tau((c_{xx} + t \cdot e_{xx})te_{a\alpha} - te_{x\alpha}(c_{xa} + t \cdot e_{xa}))\right] < 0$ iz $\{e_{xa}, e_{x\alpha} < 0, c_{xa} > 0, w_\tau = \ \ k_{\alpha\tau} < 0\}$, $e_{a\alpha} > 0$, and $c_{xa} + t \cdot e_{xa} > 0$
$sign\frac{da}{d\tau} = -sign\left[-w_\tau((c_{xx} + t \cdot e_{xx})te_{a\alpha} - te_{x\alpha}(c_{xa} + t \cdot e_{xa}))\right] > 0$ iz $\{e_{xa}, e_{x\alpha} < 0, c_{xa} > 0, w_\tau = \ \ k_{\alpha\tau} < 0\}$, $e_{a\alpha} < 0$ and $c_{xa} + t \cdot e_{xa} < 0$
Effect of z
$sign\frac{d\alpha}{dz} = -sign\left[(t \cdot e_{\alpha z} + w_z)H_2\right] > 0$ iz $[\{e_{xz} = \ \ e_{az} = 0, e_{\alpha z}, e_{\alpha\alpha z} < 0, w_z = t \cdot e_{\alpha\alpha z} \cdot \alpha \text{ and } H_2 > 0\}$
$sign\frac{da}{dz} = -sign\left[-(t \cdot e_{\alpha z} + w_z)((c_{xx} + t \cdot e_{xx})te_{a\alpha} - te_{x\alpha}(c_{xa} + t \cdot e_{xa}))\right] < 0$ iz $\{e_{xa}, e_{x\alpha} < 0, e_{xz} = \ \ e_{az} = 0, e_{\alpha z}, e_{\alpha\alpha z} < 0, w_z = t \cdot e_{\alpha\alpha z} \cdot \alpha\}$, $e_{a\alpha} > 0$ and $c_{xa} + t \cdot e_{xa} > 0$
$sign\frac{da}{dz} = -sign\left[-(t \cdot e_{\alpha z} + w_z)((c_{xx} + t \cdot e_{xx})te_{a\alpha} - te_{x\alpha}(c_{xa} + t \cdot e_{xa}))\right] > 0$ iz $\{e_{xa}, e_{x\alpha} < 0, e_{xz} = \ \ e_{az} = 0, e_{\alpha z}, e_{\alpha\alpha z} < 0, w_z = t \cdot e_{\alpha\alpha z} \cdot \alpha\}$, $e_{a\alpha} > 0$ and $c_{xa} + t \cdot e_{xa} > 0$
Effect of r
$sign\frac{d\alpha}{dr} = -sign\left[c_{ar}(c_{xa} + t \cdot e_{xa})(e_{x\alpha} + w_x)\right] > 0$ iz $\left\{\begin{array}{c} c_{xa} > 0, c_{xr} = 0, c_{ar} > 0, \\ w_x = te_{\alpha\alpha x} \cdot \alpha < 0 \end{array}\right\}$, $e_{a\alpha} = 0$, $w_a = t \cdot e_{\alpha\alpha a} \cdot \alpha = 0$, and $c_{xa} + t \cdot e_{xa} > 0$
$sign\frac{da}{dr} = -sign\left[c_{ar}((c_{xx} + t \cdot e_{xx})(t \cdot e_{\alpha\alpha} + w_\alpha) - te_{x\alpha}(e_{xa} + w_x))\right] < 0$ if $\{c_{xa} > 0, c_{xr} = 0, c_{ar} > 0, w_x = \ \ te_{\alpha\alpha x} \cdot \alpha < 0, e_{\alpha\alpha\alpha} > 0, \text{and } w_\alpha > 0\}$, $e_{x\alpha} \approx 0$

Effect of p
$sign\frac{dx}{dp} = sign\ [(c_{aa} + t \cdot e_{aa})(t \cdot e_{\alpha\alpha} + w_\alpha)] > 0$ $if\ \{w_\alpha > 0, w_x = \ t \cdot e_{\alpha\alpha x} \cdot \alpha < 0\},\ e_{a\alpha} = 0$ and $w_a = t \cdot e_{\alpha\alpha a} \cdot \alpha = 0$
$sign\frac{da}{dp} = -sign\ [(c_{xa} + t \cdot e_{xa})(t \cdot e_{\alpha\alpha} + w_\alpha)] < 0$ $if\ \{w_\alpha > 0, w_x = \ t \cdot e_{\alpha\alpha x} \cdot \alpha < 0\},\ e_{a\alpha} = 0, w_a = t \cdot e_{\alpha\alpha a} \cdot \alpha = 0$, and $c_{xa} + t \cdot e_{xa} > 0$
$sign\frac{da}{dp} = -sign\ [(c_{xa} + t \cdot e_{xa})(t \cdot e_{\alpha\alpha} + w_\alpha)] > 0$ if $\{w_\alpha > 0, w_x = \ t \cdot e_{\alpha\alpha x} \cdot \alpha < 0\}, e_{a\alpha} = 0, w_a = t \cdot e_{\alpha\alpha a} \cdot \alpha = 0, w_\alpha > 0$, and $c_{xa} < 0$
$sign\frac{d\alpha}{dp} = -sign\ [(c_{aa} + t \cdot e_{aa})(e_{x\alpha} + w_x)] > 0$ if $\{w_\alpha > 0, w_x = \ t \cdot e_{\alpha\alpha x} \cdot \alpha < 0\}$, $e_{a\alpha} = 0$, and $w_a = t \cdot e_{\alpha\alpha a} \cdot \alpha = 0.$
$sign\frac{d\alpha}{dp} = 0$ if $e_{a\alpha} = 0, w_a = \ t \cdot e_{\alpha\alpha a} \cdot \alpha = 0$, and $e_{x\alpha} = 0$ $(w_x = t \cdot e_{\alpha\alpha x} \cdot \alpha = 0)$
Effect of t
$sign\frac{dx}{dt} = -sign\ [(e_x(c_{aa} + t \cdot e_{aa}) - e_a(c_{xa} + t \cdot e_{xa}))(t \cdot e_{\alpha\alpha} + w_\alpha)] < 0$ if $e_{a\alpha} = \ e_{x\alpha} = 0$, $w_a = t \cdot e_{\alpha\alpha a} \cdot \alpha = 0, c_{xa} + t \cdot e_{xa} > 0, e_{x\alpha} = 0$ $(w_x = t \cdot e_{\alpha\alpha x} \cdot \alpha = 0)$, and $w_\alpha = te_{\alpha\alpha a} > 0$
$sign\frac{da}{dt} = -sign\ [(-e_x(c_{xa} + t \cdot e_{xa}) + e_a(c_{xx} + t \cdot e_{xx}))(t \cdot e_{\alpha\alpha} + w_\alpha)] > 0$ if $e_{a\alpha} = \ e_{x\alpha} = 0$, $w_a = t \cdot e_{\alpha\alpha a} \cdot \alpha = 0, c_{xa} + t \cdot e_{xa} > 0, e_{x\alpha} = 0$ $(w_x = t \cdot e_{\alpha\alpha x} \cdot \alpha = 0)$, and $w_\alpha = te_{\alpha\alpha a} > 0$
$sign\frac{d\alpha}{dt} = -sign\ [(e_\alpha + w_t)H_2] < 0$ if $e_{a\alpha} = 0, w_a = \ t \cdot e_{\alpha\alpha a} \cdot \alpha = 0, e_{x\alpha} = 0$ $(w_x = t \cdot e_{\alpha\alpha x} \cdot \alpha = 0), e_{\alpha\alpha} > \frac{|e_\alpha|}{\alpha}$

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