UNITE MIXTE DE RECHERCHE
EN ECONOMIE PUBLIQUE

JOINT RESEARCH UNIT IN
PUBLIC ECONOMICS

2004
CAHIERS DE RECHERCHE
WORKING PAPERS
2004/07

Regulating a Polluting Oligopoly:
Emission Tax or Voluntary Agreement?

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REVIEW OF DEVELOPMENT ECONOMICS

Regulating a Polluting Oligopoly: Emission Tax or Voluntary Agreement?*

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RRH: REGULATING A POLLUTING OLIGOPOLY

LRH: Maia David

Abstract

This paper compares, in a polluting oligopoly, an emission tax and a form of environmental policy called *voluntary agreement* (VA). There are here two ways of reducing pollution: output contraction and end-of-pipe abatement. Given the imperfect competition, firms' reaction to the tax is sub-optimal. They reduce output excessively in order to raise the price and do not abate enough. The VA is a take-it-or-leave-it contract on abatement effort, offered to the firms with the threat of a tax. It has a limited effect on output and always allows higher abatement than the tax. We find that this kind of VA may be more efficient than the tax in a concentrated industry, when pollution is not too harmful and when the abatement technology is rather efficient and cheap.

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JEL classification: H23, L13, L51, Q48

Number of figures: 3

Number of tables: 0

Date: October 7, 2004

1 Introduction

Over the last decades, global pollution issues have become increasingly worrying and the environmental protection now concerns the whole planet, including developing countries. In these countries, a large proportion of the population still lacks basic requirements to live decently[1]. The prerequisite for introducing environmental policies is then to preserve the development of the country and not to limit the population's access to basic consumers' goods. Examining the impact of environmental regulation on goods' prices and consumers' surplus is thus a priority when considering its application in developing countries. In this perspective, some environmental policy instruments applied in developed countries seem more suitable than others for less developed countries.

Environmental regulation in industrialized countries has mostly taken the form of command-and-control regulations and incentive instruments such as taxes, subsidies and tradable permits. More recently, a third generation of environmental policy instruments has emerged, namely *voluntary agreements* (VAs). VAs are commitments from polluting firms in improving their environmental performances beyond the level required by the law. They are generally implemented in combination with other instruments such as a tax or a standard that represent a threat to the firms if the VA fails. Contrary to traditional policy tools, VAs have been developed by practitioners rather than academics and they are difficult to assess formally. The small academic literature on voluntary agreements is developing rapidly[2]. In summary, VAs are known to have potential cost savings advantages over statutory regimes[3] while credibility and capture problems also exist. VAs also seem to have the potential to solve some informational problems encountered by the standard regulations when, e.g. individual emissions are costly to observe (Millock, 2000; Millock and Salanié, 2000) and/or when firms' characteristics are privately known (Chidiak, 1999; Millock, 2000).

In contrast, only few academic studies (Brau and Carraro, 1999; Conrad, 1999) have investigated the VAs' potential properties when the environmental regulator's priority is to limit the effect of her intervention on prices and consumers' surplus. Most contributions on VAs do not model the polluting firms' strategic behavior on the product market and do not take into account the polluting industry's market structure. They thus neglect the environmental policy's impact on the allocative efficiency in the economy, i.e. on the efficiency of the allocation of total surplus between firms and consumers. We offer to fill this gap by modelling a form of VA and an environmental tax within a Cournot oligopoly. This framework is relevant since many factories that emit massive pollution are owned by firms in oligopolistic industries such as steel, paper and chemicals.

In a polluting industry with imperfect competition, two sources of distortion occur. One is due to pollution, and the other is the underproduction associated with the exercise of monopoly or oligopoly power[4]. Environmental regulation reduces the generation of pollution but, by causing firms to reduce their output, it also amplifies the second source of distortion (Barnett,1980; Buchanan, 1969). Pollution is then reduced to the detriment of the consumers, whose surplus is reduced.

In this article, we assume that firms may reduce pollution either through output contraction or through an end-of-pipe abatement technology. We show that, given the imperfect competition, an emission tax does not lead to the optimal level of investment in the abatement technology. In reaction to the tax, firms act strategically by reducing output excessively in order to raise the price and they do not abate enough. They then pass the environmental policy's cost on to the consumers more than what would be socially optimal. In developing countries where people do not always have access to essential commodities, such a policy could have disastrous consequences. Given the tax's sub-optimality, we introduce and compare to the tax a second-best instrument, i.e. a VA.

Real world inspection reveals the existence of VAs that allow firms to be exempted from an environmental tax if they invest in the adoption of a clean technology. In the taxonomy offered by the OECD, this form of VA belongs to the category of public voluntary schemes with the threat of a tax. In Denmark for example a VA has been introduced in 1996 in combination with an existing tax on CO2 in order to protect firms' competitiveness in an international competition framework. This VA allows firms to reduce their tax payment by committing, through a contract, to undertake all profitable investments for energy efficiency[5]. Several articles have contributed to analyze the Danish VA[6]. Millock (2000) shows how the combined use of emission taxation and a VA can work as a mechanism to deal with the problem of asymmetric information between the regulator and industry on effective energy use. Chidiak (1999) assumes there is a maximum limit to the financial burden which can be imposed on firms, whereas the regulator faces uncertainty regarding firms' abatement costs. In this framework, the traditional emission tax implies an inefficiency and the VA may achieve lower social costs than the tax by limiting firms' financial burden. Both these models, although insightful, differ from ours on two main points. First, they focus on informational asymmetries in order to explain the use of the Danish VA. Second, they do not explicitly incorporate the firms' behavior on the consumption good's market[7].

We purposely assume the regulator detains complete information (individual emissions and firms' abatement can be observed without cost), in order to show that when emphasizing the impact of the environmental policy on consumers, it is not necessary to introduce information asymmetries to understand the VA's potential usefulness. The VA is modelled as a take-it-or-leave-it contract offered to the firms with the threat of a tax. The offered contract is based on a level of investment in an end-of-pipe abatement technology[8]. We highlight the fact that, compared to a tax, the form of VA applied in Denmark stimulates the adoption of clean technologies, which reduces pollution for a given level of output. External damage is then reduced with a limited effect on prices and on consumers' surplus.

2 Basic Assumptions, First-Best and *Ex ante* Equilibrium

Throughout this paper we consider a partial equilibrium model with one consumption good and one pollutant generated by production. The consumption good is produced by n identical firms engaged in Cournot competition.

Following Barnett (1980), Farzin and Kort (2000) and Katsoulacos and Xepapadeas (1995, 1996) we assume pollution emissions can be abated through pollution treatment, using a filter for instance. Pollution emissions generated by a firm i are then $e(x_i, w_i)$ where x_i denotes the firm's output and w_i its abatement effort, i.e. a level of investment in the abatement technology. Polluters thus face a two variable decision problem: they choose an output level and an abatement effort. The emission function is additively separable and can be written as $e(x, w) = e_1(x) + e_2(w)$. This assumption is justified by the fact that end-of-pipe abatement does not modify the quantity of emissions generated by each unit of production. The derivatives of the emission function are: $e_1'(x) > 0$ (production generates pollution), $e_2'(w) < 0$ (abatement effort reduces pollution), $e_1''(x) \geq 0$ and $e_2''(w) \geq 0$.

Each firm i's cost function is written as $C(x_i, w_i)$. This cost function is also assumed to be additively separable in effort w and output[9], and can be written as : $C(x, w) = C_1(x) + C_2(w)$. The derivatives of the cost function are: $C_1'(x) > 0$, $C_2'(w) > 0$, $C_1''(x) \geq 0$ and $C_2''(w) \geq 0$, that is production and abatement effort exhibit non-increasing returns to scale.

Society's preferences are represented by an inverse demand function $P(X)$ and by a social damage function $V(E)$. Inverse demand $P(X)$ is concave, downward slopping and is a function of aggregate output $X = \sum_i x_i$. The social damage function depends on aggregate emissions $E = \sum_i e(x_i, w_i)$ and is increasing and linear, $V' = v$, $V'' = 0$. The regulator detains complete information on individual emissions and individual abatement effort. Observable abatement effort can be justified by the fact that, in the Danish voluntary agreement, firms signing the VA also commit to pay an independent institution to control the investments they undertake (Johannsen and Togeby, 1998).

The regulator maximizes social welfare W, measured as the sum of consumers' and producers' surplus minus external damage[10]:

$$W = \int_0^X P(u)du - \sum_i C(x_i, w_i) - v\sum_i e(x_i, w_i)$$

As a benchmark, let us present the first-best values for x and w. First-order conditions for the maximization of social welfare yield the following optimal values for each firm's output and abatement[11]:

$$P(nx^*) = C_1'(x^*) + ve_1'(x^*) \tag{1}$$

$$C_2'(w^*) = -ve_2'(w^*) \tag{2}$$

The first-best price equals marginal cost of production plus marginal social damage associated with production (equation (1)). At the optimal level of abatement effort w^*, marginal cost of abatement effort equals marginal social benefit from abatement effort (equation (2)).

Before any environmental policy, the symmetric Cournot-Nash equilibrium is denoted as (x^c, w^c). Each firm chooses its output and abatement effort so as to maximize its profit given the other firms' actions.

$$\max_{x,w} \pi = P(X)x - C(x,w)$$

which yields:

$$\begin{aligned} P(nx^c) &= C_1'(x^c) - P'(nx^c)x^c \\ w^c &= 0 \end{aligned} \tag{3}$$

Without policy implementation, firms do not abate pollution. Furthermore, whenever $-P'(nx)x \neq ve_1'(x)$, the output x^c chosen by the firms is not the first-best output x^* (compare (1) and (3)). This is due to two distortions: pollution, which implies excessive output, and imperfect competition which leads to insufficient output. If the pollution distortion dominates, $(ve_1'(x) \geq -P'(nx)x)$, then x^c is superior to x^*.

3 The Emission Tax

Let us assume that the regulator cannot restore a competitive framework and cannot, despite complete information, command on firms' output x. The regulator introduces a tax t per unit of emission. Each firm now maximizes its profit taking into account the tax payment:

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

and values for output and abatement effort are:

$$P(nx^t) = C_1'(x^t) - P'(nx^t)x^t + te_1'(x^t) \quad (4)$$

$$C_2'(w^t) = -te_2'(w^t) \quad (5)$$

The equilibrium price with the tax is higher than at the *ex ante* equilibrium (compare (3) and (4)), i.e. firms' output is lower ($x^t < x^c$). Furthermore, firms now abate pollution. Their abatement effort equalizes marginal cost of abatement effort and the marginal benefit they derive from abating by thus reducing their tax payment (equation (5)).

In a competitive framework in which pollution is the only distortion, a tax set at marginal social damage of pollution would lead to the first-best (Pigou, 1920). In an oligopoly, the initial level of production is sub-optimal and a Pigovian tax leads to excessive output contraction. The tax rate must then be lower than the marginal social damage in order to take into account the distortion due to imperfect competition. In a model where pollution is proportional to production and the proportionality is fixed, firms' only way to reduce pollution is to reduce their output (Baumol et Oates, 1988; Buchanan, 1969). A tax on pollution is then equivalent to a tax on production. In this case, the second-best tax rate is equivalent to the combination of a Pigovian emission tax and a subsidy on production, which corrects both distortions and leads to the first best. However, we assume here that the proportionality between pollution and production is not fixed as pollution may be abated once it is produced. In this framework, Barnett (1980) derives the optimal tax rate in a monopoly. By maximizing social welfare in the framework of our model, we show that Barnett's result can be generalized to an oligopoly[12]. The formula for the second-best tax rate, denoted as t^{**} is:

$$t^{**} = \frac{P'(nx^t)x^t \frac{dx^t}{dt}}{e_1'(x)\frac{dx^t}{dt} + e_2'(w)\frac{dw^t}{dt}} + v \tag{6}$$

See the appendix for a proof.

This rate can be split into marginal damage v and a negative term[13] which accounts for the market imperfection. We thus confirm that t^{**} is inferior to the Pigovian rate.

A Pigovian tax, set at marginal social damage (v) would lead to the optimal abatement effort w^* (see equations (2) and (5)). However, equations (1) and (4) show that, due to imperfect competition, such a tax would lead to excessive output contraction ($x^v < x^*$) and to too high a price rise. Following the same reasoning, a tax rate $\tilde{t}$ that would lead to the optimal output x^*, would lead to insufficient abatement effort ($w^{\tilde{t}} < w^*$). The second-best tax rate t^{**} then results from a trade-off between encouraging firms to abate pollution and not inducing to high an output contraction. We have: $\tilde{t} < t^{**} < v$. The second-best tax rate t^{**} thus leads to lower abatement effort than the first-best value ($w^{t^{**}} < w^*$) and insufficient output ($x^{t^{**}} < x^*$). The emission tax does not lead to the first-best anymore.

The intuition associated with this result is clear. In reaction to an emission tax, firms choose to reduce pollution in order to reduce their tax payment. They both reduce production and invest in the abatement technology. However, given the imperfect competition, their private choice between these two means of reducing pollution is not socially optimal. Firms choose to reduce output excessively as, when contracting output, they obtain a private gain by raising the price, which is not the case when they abate through pollution treatment. In other words, firms excessively pass the environmental policy's cost on to the consumers compared to what would be socially optimal.

We limit our study to the case when the rate t^{**} is positive. Formally, the second-best rate can be negative if the social damage associated to pollution is very small compared to the distortion due to the market structure. The environmental problem is then insignificant and the regulator must encourage firms to produce more. If an emission tax is the only available tool, the regulator must set a negative tax (i.e. a subsidy on pollution) to induce firms to produce more. However, an "emission subsidy" is neither realistic nor adapted to such a problem, in which regulation is a matter of antitrust policy rather than environmental policy. This case goes beyond the scope of our study. Given (6), the (positive) threshold value on marginal social damage v for t^{**} to be positive is:

$$v \geq -\frac{P'(nx^t).x^t.\frac{dx^t}{dt}}{e_1'(x).\frac{dx^t}{dt} + e_2'(w).\frac{dw^t}{dt}} \qquad (7)$$

We have seen that the emission tax does not lead to firms' optimal choice. Let us compare the tax with another second-best instrument based only on abatement effort, namely a voluntary agreement.

4 The Voluntary Agreement

The VA is modelled as a contract on abatement effort (w) and is implemented in combination with the tax. The regulator offers the firm a contract w^{VA}. Each firm can individually accept or refuse this contract. Firms refusing it must pay a tax $\hat{t}$.

Firms signing the VA choose output x^{VA} by maximizing their profit, given the VA requirement. Firms' profit with the VA is:

$$\pi^{VA} = P(X)x^{VA} - C(x^{VA}, w^{VA})$$

When all firms choose to sign the VA, each firm's output decision is given by:

$$P(nx^{VA}) = C_1'(x^{VA}) - P'(nx^{VA})x^{VA} \tag{8}$$

Comparing equations (8) and (3) and given the assumptions of the model, we obtain that $x^{VA} = x^c$. That is, when all firms sign the VA, firms' output are the same under the VA and without environmental policies.

Each firm is free to choose between the VA and the tax $\hat{t}$ and enters the VA if and only if it leads to a higher profit than the tax. The following inequality is a sufficient condition for all firms to choose individually the VA:

$$P(nx^c)x^c - C(x^c, w^{VA}) \geq P(nx^{\hat{t}})x^{\hat{t}} - C(x^{\hat{t}}, w^{\hat{t}}) - \hat{t}e(x^{\hat{t}}, w^{\hat{t}}) \tag{9}$$

In economic terms, condition (9) means that the regulator must set a threat $\hat{t}$ as high as to ensure that profits under the taxation regime are smaller than profits when all firms sign the VA. Firms' profits when all firms sign the VA are the lowest profits a firm may expect when it decides to sign the VA, because it entails the largest industry output and thus the lowest equilibrium price. As a consequence, condition (9) automatically ensures that all firms sign the VA.

Therefore, when condition (9) is satisfied, all firms sign the VA and this policy tool does not affect firm's output nor the consumers' surplus. This result remains valid for any level of w^{VA}. Note that this follows from the assumption of an additively separable cost function. Without additive separability, the VA would affect output. Nevertheless, the output contraction resulting from the VA would be inferior than with the tax as the VA lets the firms avoid the tax payment, which reduces their marginal production cost compared to the tax and therefore implies higher output.

Let us denote as $w^{\max}(\hat{t})$ the maximum level of w^{VA} for which, with a threat $\hat{t}$, condition (9) is satisfied. We find that $w^{\max}(\hat{t})$ is superior to $w^{\hat{t}}$ for all positive values for $\hat{t}$. See the appendix for a proof.

The regulator chooses contract w^{VA*} that maximizes social welfare taking into account the constraint (9), and decides on the level $\hat{t}$ of the threat. Ignoring the constraint, the optimal contract is w^{*}[14]. However, whether this contract satisfies the constraint (9) depends on the threat $\hat{t}$. The level $\hat{t}$ depends on the credibility of the threat. The regulator cannot announce any threat $\hat{t}$ and still be credible. If the VA fails, the regulator will apply the tax at its optimal level t^{**}. Then if firms detain all necessary information to calculate t^{**}, the only credible threat is $\hat{t} = t^{**}$. However, firms may lack information, such as marginal social damage of pollution v. The regulator can then announce a $\hat{t}$ superior to t^{**}. In the extreme case where any threat is credible, the regulator would choose any $\hat{t}$ high enough to let the participation constraint be satisfied with contract w^*[15]. In order to keep the discussion on the credibility of the threat open, let us distinguish two cases:

- If, given the level of the credible threat $\hat{t}$, $w^* \leq w^{\max}(\hat{t})$, then the participation constraint is satisfied for the optimal contract (w^*), and the VA reaches the optimal abatement effort. $w^{VA*} = w^*$.

- If $w^* > w^{\max}(\hat{t})$, the regulator chooses a contract as close as possible to w^* but that verifies the constraint, that is $w^{VA*} = w^{\max}(\hat{t})$. In this second case, the VA reaches a sub-optimal level of abatement effort.

In all cases, we find that the abatement effort reached with the VA is superior to the abatement with the tax. Considerations made so far then lead to the following proposition:

Proposition 1. *When the participation constraint to the voluntary agreement is satisfied for all the firms, this policy tool does not affect firms' output and always implies a higher abatement effort from the firms than the optimal emission tax.*

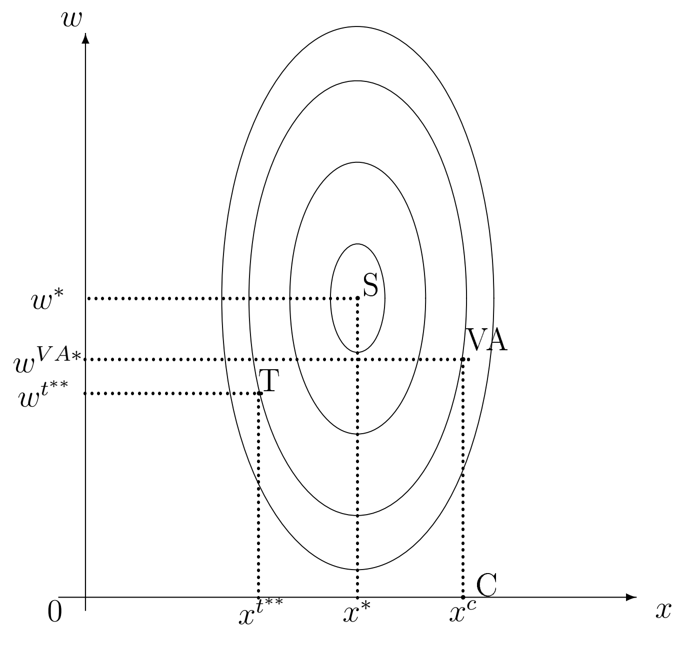
See the appendix for a proof.

The VA implies a fixed cost for the firms and thus does not affect their marginal production cost. Therefore, contrary to the emission tax, the VA does not modify the polluting firms' output decision. Moreover, firms signing the VA rather than paying the tax avoid the tax payment which, for a given level of abatement effort, lets them have a higher profit than with the tax. Hence, firms accept a contract which implies a higher abatement effort than the tax as long as the extra-cost due to the higher abatement is inferior to the extra-cost due to the tax payment.

5 Comparison of the Tax and the Voluntary Agreement

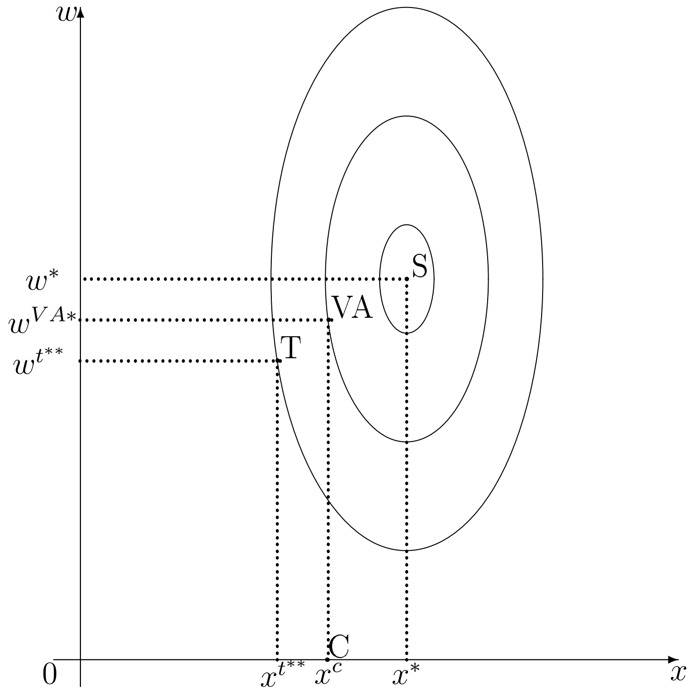
Assuming both policies may be applied at their second-best level t^{**} and w^{VA*}, let us study the conditions under which the VA is more efficient than the tax. Considering an industry with two distortions, one due to pollution and the other to imperfect competition, an emission tax applied at a second-best rate leads to insufficient abatement and insufficient output. In the same framework, we have studied a form of VA that does not affect firms' output and reaches a higher abatement than the tax. In terms of distance to the first-best values, the VA always leads to an abatement effort which is closer to the first-best level than the tax. However, the output level obtained with the VA may be closer or further from the first-best output than the output obtained with the tax. This depends on initial output x^c compared to optimal output x^*. Comparison of social welfare under the tax and the VA may therefore be ambiguous.

In the following graph in the (x, w) plan, each curve is associated to a level of social welfare. At values x^* and w^*, we are located at point S which represents the first-best situation, i.e. maximal social welfare. The further is a curve from point S, the lower the associated level of welfare.



At the *ex ante* equilibrium, output produced by each firm is x^c and abatement effort is zero (point C). With the second-best tax, output $x^{t^{**}}$ is inferior to x^c and inferior to x^*. Abatement effort $w^{t^{**}}$ is positive but inferior to first-best value w^*. Point T, which represents the situation with the tax, is closer to point S than before any policy (point C). With the VA, output stays at level x^c and abatement effort w^{VA*} is between values $w^{t^{**}}$ and w^* (point VA). Point VA is also closer to the first-best (point S) than point C. The question is whether the curve on which point T is located is closer or further from point S than the curve on which point VA is located. If points T and VA are on the same curve, both policies are equivalent in terms of social welfare.

The above graph represents the case where initial output x^c is superior to x^*. In the illustrated case, points T and VA are on the same curve. The emission tax and the VA lead to the same level of social welfare. In the case where x^c is lower than first-best output x^*, the VA is always more efficient than the tax. This case is illustrated in the following figure:



In this case, any positive tax leads to output contraction and therefore to an output level $x^{t^{**}}$ further from x^* than x^c, which was already inferior to x^*. The VA avoids this undesirable output contraction and allows a higher abatement than the tax. Therefore, whenever $x^c < x^*$, i.e. whenever the distortion due to market imperfection is relatively strong, point VA is closer from S than point T. The VA is then more efficient than the tax.

Note that beyond the comparison of welfare, the tax and the VA have different effects on agents' surplus. As output is higher with the VA, consumers' surplus is always higher with the VA. Concerning the firms, there are some cases when the VA lets them have a higher profit than the tax, but this depends on the level of the threat $\hat{t}$[16]. We cannot tell whether the VA leads to higher or lower emissions than the emission tax. The higher pollution abatement associated with the VA leads to less unitary emissions than the tax. However, the higher output chosen by firms with the VA plays in favor of higher emissions. The relative effect on emissions of the VA and the tax depends on emissions elasticity with respect to output and abatement.

In order to allow further comparison between the VA and the tax, we specify the functions of the model as follows, similarly to Katsoulacos and Xepapadeas (1995): $C(x,w) = cx + gw; (0 < c < 1; g > 0)$; $e(x,w) = kx - \sqrt{Lw}; (k > 0; L > 0)$; $P(X) = 1 - X$.

Considering the case when the threat $\hat{t}$ is high enough for firms to accept contract w^*, we derive a necessary and sufficient condition on the parameters for welfare to be higher with the VA than with the emission tax set at the second-best optimal rate:

$$L(n+1)^2 v[2(1-c) - (n+2)kv] > 2kg[(n+1)kv - (1-c)]^2 \qquad (10)$$

See the appendix for a proof.

As the right-hand side in equation (10) is always positive, the above inequality may only be satisfied if the left-hand side of this equation is also positive, that is if:

$$v < \frac{2(1-c)}{(n+2)k} \qquad (11)$$

If v, the marginal social damage associated to pollution, is superior to the threshold given in (11), then the emission tax is always more efficient than the VA.

Proposition 2. *For a very harmful form of pollution, the emission tax is always more socially efficient than the voluntary agreement.*

This result can be easily interpreted. The advantage of the VA over the tax lies in the existence of a double distortion. If v is very high, the distortion due to market structure becomes insignificant compared to the distortion due to pollution. The VA then looses its potential advantage over the tax[17].

Note that condition (11) is more easily satisfied for:

- low values for n, that is for an industry composed of a small number of firms;

- low values for k, that is for a low-polluting industry[18];

Within an oligopoly composed of many firms (high n), i.e. close from a perfectly competitive industry, the misallocation resulting from the market structure is insignificant. The negative effect of the tax is therefore limited and the VA's advantage compared to the tax is reduced. Furthermore, the VA studied here leads to pollution reduction through end-of-pipe abatement only. For a very polluting industry, i.e. for a high k, the VA, which does not affect output, does not allow a significant pollution reduction. It is therefore understandable that the VA may be more efficient than the tax only for low polluting industries.

Let us now look into the interpretation of the necessary and sufficient condition (10). This condition can be written as follows:

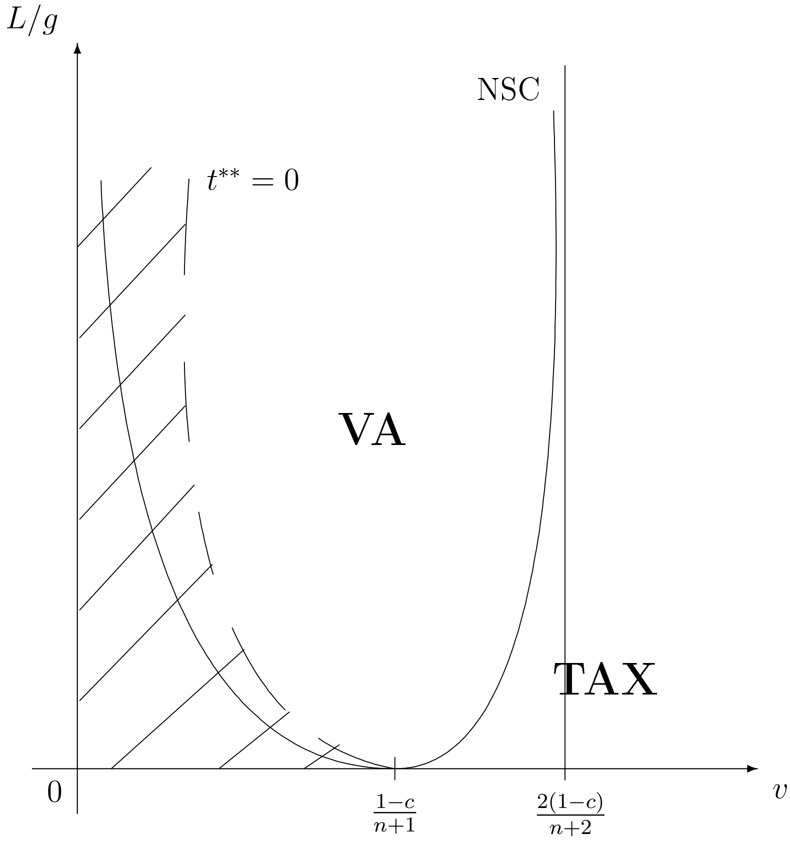
$$\frac{L}{g} > \frac{2k[(n+1)kv - (1-c)]^2}{(n+1)^2 v[2(1-c) - (n+2)kv]}$$

For high values for L, abatement effort w leads to significant emission reductions. Abatement through pollution treatment is then a relatively efficient way to reduce pollution. Variable g represents marginal cost of abatement effort. Ratio L/g then represents the efficiency of abatement effort divided by its cost. The above condition gives a minimal threshold on L/g for the VA to be more efficient than the tax.

Proposition 3. *When pollution is not too harmful, the voluntary agreement is more socially efficient than the emission tax when the abatement technology is rather cheap and efficient.*

The intuition is rather simple. For high values for L/g, it is socially optimal to reduce pollution mainly through abatement. The tax, which leads to insufficient abatement, is therefore further from the first-best than when abatement is inefficient. The VA then has a stronger advantage over the tax.

Normalizing variable k to 1[19], the necessary and sufficient condition (10) may be represented in the plan $(v, L/g)$ as follows:



In this figure, the asymptote given by the equation $v = \frac{2(1-c)}{n+2}$ represents the necessary condition (11). On the right-hand side of this asymptote (for high values for v), condition (11) is not verified and the tax is always more efficient than the VA. On the left-hand side of the asymptote, the parabola denoted as NSC, given by the equation $L/g = \frac{2[v(n+1)-(1-c)]^2}{v[2(1-c)-(n+2)v]} \cdot \frac{1}{(n+1)^2}$, represents the necessary and sufficient condition (10). Above this parabola, condition (10) is verified and the VA is more efficient than the tax. The hatched area corresponds to the case, excluded from our study, where t^{**} is negative because v is small. The equation of the dotted curve, according to condition (A2) given in the appendix, is $L/g = \frac{2}{n+1}[\frac{1-c}{v(n+1)} - 1]$. When n, the number of firms in the industry, becomes smaller, the asymptote, the parabola and the dotted curve move towards the right and the area in which the VA is more efficient than the tax becomes larger.

6 Discussion

We have shown how a form of VA as applied in Danemark can have a limited impact on consumers' surplus compared to a tax and hence have some advantages over taxation to regulate pollution in developing country. However, several points in our analysis may be subject to discussion.

First, the VA modelled in this article may be understood as a combination between two instruments (an emission tax and a contract on w). It can then seem inappropriate to compare a two-instruments policy with a one-instrument policy, namely the traditional emission tax. Moreover, if two instruments may be used at once, other two-instruments policy could be implemented that would lead to the first-best[20]. However, in this article we assume that the regulator can only regulate one variable at a time[21]. We actually compare two one-instrument policies: the tax, which regulates emissions e, and the voluntary agreement, which regulates the abatement effort

w. The VA does not imply here the use of two instruments in a simultaneous way. It uses the tax as a threat and does not regulate emissions. A command-and-control policy imposing a level of abatement effort w^* on the firms rather than letting them choose with the tax would always be equivalent or more efficient than the VA modelled above[22]. Therefore, the content of the VA (w), rather than its form as a take-it-or-leave-it contract using the tax as a threat is the crucial point in the comparison with the tax.

Second, if the comparison carried out in this article rests on the fact that the VA is based on abatement effort, independently from its form, why having modelled a VA rather than a regulatory standard on w? This choice has an empirical justification. Mandatory standards based on an abatement effort, i.e. on a level of investment in a clean technology, do not exist. Standards prescribe quantity limits on emissions or the use of a specific abatement technology rather than imposing a level of effort to adopt a clean technology. The Danish VA is the existing environmental policy that resembles the most such a standard, which explains our modelling.

Last, several extensions of the model seem relevant. First, we do not examine the cases when some firms choose the VA whereas others pay the tax. Analyzing the asymmetric equilibria of the participation game to the VA could be an interesting field for further research. Second, other forms of environmental policies may, as the VA studied here, have a limited impact on consumers' surplus. Examples are a tax in Sweden, where the revenues of the tax are distributed to the firms according to their output (Sterner and Höglund, 2000) and permit markets in which the initial allocation of permits is proportional to firms' output (Fischer, 2001). It would be relevant to include these instruments in the comparison of instruments when considering environmental policies in developing countries.

7 Conclusion

This paper examines the choice of the environmental policy instrument in an imperfect competition framework. There are two ways of reducing pollution: output contraction and end-of-pipe abatement. In this context, the second-best emission tax leads to insufficient output and insufficient abatement. We then model a form of voluntary agreement which induces pollution reduction only through abatement. This VA is a take-it-or-leave-it contract offered to the firms with the threat of the emission tax. It has no impact on output and always leads to higher abatement than the tax. Given the framework and assumptions of the model, we derive a necessary and sufficient condition on the parameters of the model for which the VA is more efficient than the optimal emission tax. According to this condition, the tax is always more efficient to regulate a very harmful type of pollution and/or in a low-concentrated industry. Otherwise, the VA may be more efficient than the tax when the abatement technology is rather efficient and cheap.

Beyond the comparison of social welfare, the VA and the tax have different distributive impacts, which constitutes a significant criterion in the environmental policy choice within developing countries. More precisely, the VA is always preferred to the tax from the consumers' point of view since it avoids output contraction and thus a rise in prices.

Previous analysis of the Danish VA have focused on explaining the specific form of this policy when informational asymmetries occur. In contrast, the present article has highlighted the potential properties of the Danish VA's content when regulating pollution in developing countries. Explaining at once the content of the Danish VA and its take-it-or-leave-it form offers scope for further research.

8 References

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Notes

[1]Some 2.8 billion people still survive on less than $2 a day and one in six people in the world lack sufficient food to fulfill their basic daily requirements.

[2]See Alberini and Segerson (2002) and Lyon and Maxwell (2001) for literature surveys.

[3]There is however no systematic evidence to show how widely this claim might hold true.

[4]Consumers' surplus is insufficient compared to an optimal allocation of total surplus.

[5]Firms must invest in projects to improve energy efficiency until the pay-back period of such investments reaches a given level, that is four years for heavy processes and six years for light processes.

[6]See Johannsen and Togeby (1998) for a general description of this VA.

[7]Lyon and Maxwell (2003) also analyze a VA with the threat of a tax. However these authors do not either model the firms' production activity.

[8]End-of-pipe abatement technologies are common as more than 60% of the investments in favor of the environment undertaken by polluting firms concern pollution treatment (http://www.belspo.be/belspo/home/).

[9]Investment in a clean technology is a fixed cost, it does not modify marginal pro-

duction costs. This assumption is realistic and common in the literature (for example in Katsoulacos and Xepapadeas, 1995).

[10]As is common in the literature, the environmental damage directly enters social welfare and not consumers' utility.

[11]Given our assumptions, second-order conditions are satisfied throughout the model.

[12]Katsoulacos and Xepapadeas (1996) obtain a similar result.

[13]Differentiating (4) and (5), we show easily that $\frac{dx^t}{dt} < 0$ and $\frac{dw^t}{dt} > 0$.

[14]This result is due to an additively separable cost function and is easily proven by maximizing the welfare.

[15]$w^{\max}(\hat{t})$ is increasing in $\hat{t}$.

[16]If the threat of the tax is set at level $\hat{t} = t^{**}$, then, given the participation constraint, the variation of firms' profit between the tax t^{**} and the VA is positive.

[17]Note that when v is small, the second-best tax rate t^{**}, and thus the credible threat $\hat{t}$, are also small. w^{max} is then low and the VA reaches a low abatement effort, which may be thought to deteriorate the efficiency of the VA. However, for low values of v, the optimal abatement effort w^* is also small. Therefore, a small v does not necessarily reduce the efficiency of the VA compared to the tax in terms of distance to the first-best.

[18]k represents the quantity of emissions generated by each unit produced.

[19]Each unit of output generates one unit of emissions.

[20]For instance, it is easily shown that the combination of a subsidy on abatement effort and an emission tax reaches the first-best.

[21]This can be explained by the duplication of administrative costs when using two instruments or by acceptability problems towards the regulated firms.

[22]Such a regulatory standard would reach the optimal level of abatement effort whereas the VA may reach a sub-optimal abatement effort: $w^{VA*} \leq w^*$.

9 Appendix

Proof of(6):

Assuming that the tax revenue is redistributed in a neutral way in the economy, social welfare with the emission tax is:

$$W^t = \int_0^{nx^t} P(u)du - nC_1(x^t) - nC_2(w^t) - vn[e_1(x^t) + e_2(w^t)]$$

Differentiating totally W^t and equalizing to zero we obtain:

$$\frac{dW^t}{dt} = [P(nx^t) - C_1'(x^t) - ve_1'(x^t)]\frac{dx^t}{dt} - [C_2'(w^t) + ve_2'(w^t)]\frac{dw^t}{dt} = 0 \qquad \text{(A1)}$$

From (4) we have:

$$P(nx^t) - C_1'(x^t) = -P'(nx^t)x^t + te_1'(x^t)$$

From (5) we have:

$$C_2'(w^t) = -te_2'(w^t)$$

Therefore, (A1) is equivalent to:

$$-P'(nx^t)x^t.\frac{dx^t}{dt} + (t-v)e_1'(x^t).\frac{dx^t}{dt} + (t-v)e_2'(w^t).\frac{dw^t}{dt} = 0$$

which yields equation (6).

Proof of $w^{\max}(\hat{t})$ superior to $w^{\hat{t}}$ for all $\hat{t}$:

$w^{\max}(\hat{t})$ is the maximum level of w^{VA} for which the constraint (9) is satisfied, with threat $\hat{t}$:

$$P(nx^c)x^c - C(x^c, w^{max}(\hat{t})) = P(nx^{\hat{t}})x^{\hat{t}} - C(x^{\hat{t}}, w^{\hat{t}}) - \hat{t}e(x^{\hat{t}}, w^{\hat{t}})$$

The cost function being additively separable, this can be written as:

$$P(nx^c)x^c - C(x^c, w^{\hat{t}}) - C(0, w^{max}(\hat{t})) + C(0, w^{\hat{t}}) = P(nx^{\hat{t}})x^{\hat{t}} - C(x^{\hat{t}}, w^{\hat{t}}) - \hat{t}e(x^{\hat{t}}, w^{\hat{t}})$$

Then:

$$C(0, w^{max}(\hat{t})) - C(0, w^{\hat{t}}) = P(nx^c)x^c - C(x^c, w^{\hat{t}}) - [P(nx^{\hat{t}})x^{\hat{t}} - C(x^{\hat{t}}, w^{\hat{t}})] + \hat{t}e(x^{\hat{t}}, w^{\hat{t}})$$

The above expression is positive because $\hat{t}e(x^{\hat{t}}, w^{\hat{t}}) \geq 0, \forall \hat{t} > 0$ and

$$P(nx^c)x^c - C(x^c, w^{\hat{t}}) - [P(nx^{\hat{t}})x^{\hat{t}} - C(x^{\hat{t}}, w^{\hat{t}})] > 0, \forall \hat{t}$$

as $x^c = arg\max_x \pi = P(X)x - C(x, w)$. Therefore: $C(0, w^{max}(\hat{t})) - C(0, w^{\hat{t}}) > 0, \forall \hat{t} > 0$. And, given the assumptions on C, we have: $w^{max}(\hat{t}) > w^{\hat{t}}, \forall \hat{t} > 0$

Proof of Proposition 1:

Comparing equations (8) and (3) and given the assumptions of the model, it is straightforward that: $x^{VA} = x^c$. When all firms choose to sign it, the VA does not affect firms' output.

Moreover, we have found that either $w^{VA} = w^*$ or $w^{VA} = w^{max}(\hat{t})$. From section 3, we know that the abatement effort reached with the second-best emission tax is sub-optimal: $w^{t^{**}} < w^*$. Moreover, the regulator always announces a threat such that: $\hat{t} \geq t^{**}$. As w^t is increasing in t, we obtain: $w^{\hat{t}} \geq w^{t^{**}}$. Moreover, we have demonstrated that: $w^{max}(t) > w^t, \forall t$. We thus obtain that: $w^{max}(\hat{t}) > w^{\hat{t}} \geq w^{t^{**}}$. We can then conclude that in all cases:

$w^{VA} > w^{t^{**}}$. That, is, the VA always implies a higher abatement effort from the firms than the optimal emission tax.

Proof of condition (10):

Given that $C(x,w) = cx + gw; (0 < c < 1; g > 0)$; $e(x,w) = kx - \sqrt{Lw}; (k > 0; L > 0)$ and $P(X) = 1 - X$, values for output and pollution treatment are:

- at first-best: $x^* = \frac{1-c-kv}{n}; w^* = L(\frac{v}{2g})^2$

- before any environmental policy: $x^c = \frac{1-c}{n+1}; w^c = 0;$

- with the emission tax t: $x^t = \frac{1-c-kt}{n+1}; w^t = L(\frac{t}{2g})^2$

- with the VA: $x^{VA} = x^c = \frac{1-c}{n+1}; w^{VA} = w^* = L(\frac{v}{2g})^2$

The second-best tax rate is:

$$t^{**} = \frac{v(n+1)[k^2 + (n+1).\frac{L}{2g}] - k(1-c)}{k^2 n + (n+1)^2.\frac{L}{2g}}$$

t^{**} is positive if and only if:

$$v \geq \frac{k(1-c)}{(n+1)[k^2 + (n+1)\frac{L}{2g}]} \qquad \text{(A2)}$$

Variation of welfare between the tax and the VA is:

$$\Delta W = W^{VA} - W^t = \Delta CS + n\Delta\pi - nv\Delta e - nte(x^t, w^t)$$

where ΔCS, $\Delta\pi$ et Δe respectively denote variation of consumers' surplus, variation of firms' profits and variation of firms' emissions. The last term represents the tax revenues. We wish to study the sign ofΔW at the optimal tax rate t^{**}. W^t reaches its maximal value in t^{**}. ΔW thus reaches its minimal value in t^{**}. Therefore, for ΔW to be positive in t^{**}, it must always be positive.

$$\Delta CS = \frac{n^2}{2}[\frac{2(1-c)kt-(kt)^2}{(n+1)^2}]$$

Note that ΔCS is always positive (consumers are always better off with the VA than with the tax).

$$\Delta \pi = \frac{(1-c)(1-n)kt+n(kt)^2}{(n+1)^2} - \frac{L(v^2-t^2)}{4g} + te(x^t, w^t)$$

$$\Delta e = \frac{k^2 t}{n+1} - \frac{L(v-t)}{2g}$$

Which yields, after simplification:

$$\Delta W = n[\frac{2(1-c)kt+n(kt)^2-2(n+1)k^2tv}{2(n+1)^2} + \frac{L(v^2+t^2-2vt)}{4g}]$$

The sign of ΔW is the same as the sign of the following polynomial, denoted as Q:

$$Q = \{(n+1)^2L+2ngk^2\}t^2 - \{2v(n+1)^2L+4kg[(n+1)kv-(1-c)]\}t+(n+1)^2Lv^2$$

Therefore, for ΔW to be positive in t^{**}, Q must be positive in all t. Q is a second degree polynomial in t and its first coefficient is always positive. Therefore, Q is always positive if and only if its discriminant is negative. D

denotes the polynomial Q's discriminant. Simplificating D yields:

$$D = 8gkv(n+1)^2L[(n+2)kv - 2(1-c)] + \{4gk[(n+1)kv - (1-c)]\}^2$$

The necessary and sufficient condition for the VA to be more efficient than the tax is then that discriminant D be negative, which leads to condition (10):

$$L(n+1)^2v[2(1-c) - (n+2)kv] > 2kg[(n+1)kv - (1-c)]^2$$