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Voluntary Agreements as Information Sharing Devices: Competition, Environmental Regulation and Welfare

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Abstract

Voluntary Agreements (VAs) in the environmental …eld can be an information sharing device and whereby a¤ect oligopolistic competition. We carry out a separate analysis for unilateral committments and negotiated agreements. In the case of unilateral committments we consider a duopoly model with Cournot competition where …rms aim to reduce environmental damages because consumers have green preferences. Information production and disclosure about costs eliminates production errors. Thus pro…ts always grow in the case of information sharing within unilateral commitments. As output adjustments can be "collusive", consumer surplus can be reduced by VAs.On the contrary social welfare is always positively a¤ected by them. In the case of negotiated agreements we introduce environmental regulation in the model. Even if the information sharing e¤ect continues to positively a¤ect pro…ts, in the case of negotiated agreements one must take account also the cost burden.Pro…ts gains require either loose regulatory standards and a scarce additional e¤ort in pollution abatement, or a tighter standard no matter what the additional e¤ort will be.On the contrary consumer surplus is positively a¤ected by loose regulatory standard, coupled with a signi…cant additional environemntal e¤ort required by VAs. Concerning social welfare, negotiated agreemnts increase it if industries are very e¢cient in the environemntal …eld. For less e¢cient industries, negotiated agreemnts are welfare improving either when the regulatory standard is very loose or very tight, indipendently of the additional abatement e¤ort. For intermediate levels of the regulatory standards the additional environemntal e¤ort should be quite scarce in order that VAs improve social welfare.

JEL:D43, D62, L49, Q29

1 Introduction

In recent years Voluntary Agrememnts in the environmental field (VAs from now on) have increasingly captured the attention of policy makers and social scientists, because of the opportunity they give to push the reduction of negative externalities behind regulatory standards. This behaviour is now widely known as overcompliance with respect to environmental regulation set by public agencies. A current classification distinguishes three main types of VAs: Unilateral Committments, Public Voluntary Programmes and Negotiated Agremments (Borkey, Glachant and Leveque, 1999). Unilateral committments are set by the industry acting independently without any involvment of a public authority (The "Responsible Care" program is a wellknown example of a unilateral committment made by the chemical industry in many countries). Public voluntary programmes involve commitments devised by an environmental agency and in which individual firms are invited to participate (an example is the EcoManagement and Auditing scheme - EMAS - implemented in the EU since 1993). Negotiated agreements involve committments for environmental protection developed through bargaining between a public authority and industry (they are frequently signed at the national level between an industry sector and a national authority).

Even if the anticompetitive effect of VAs has been an issue that has captured the attention of environmental agencies, antitrust authorities (European Commission, 1997) and some theorists, the fact that this effect may arise from information sharing practices has never been considered.

The information sharing function of VAs has already been the object of social policy analysis. Aggeri (1998) illustrates the evolution in theenvironmental policy approach that has made information sharing a central issue for consumers, firms and the Public Administration when they share uncertainties about environmental issues. In the past environmental policy was more a "question of combating acute, localised and identifiable pollution that could be evaluated"[1]. Oil slicks, dioxins, asbestos and toxic smoke are examples of this kind of environmental problem. At present, issues such as the greenhouse effect, the hole in the ozone layer and waste processing define the environmental policy agenda. These types of issues are characterised by uncertainty and controversy over the identity of polluters, the validity of scientific knowledge and therefore the technological solutions that should be implemented. New techonologies are frequently called upon to face these problems and neither industry nor the public administration precisely knows the costs and net social benefits associated with their use[2]. In this framework all social actors are interested in producing and sharing information in order to improve collective learning.

[1] Cfr. Aggeri, 1998, p. 5

[2] An example could be waste valorisation, a field which has seen a great diffusion of VAs. Aggeri (1998)suggests again that while at the beginning of the nineties there was a general agreement on the fact that dumping had to be reduced, there was also a debate on waste valorisation concerning methods and targets: is it better to promote recycling or incineration with energy recovery?Was it advisable to set different targets for different materials?

In the meantime one wonders about the impact of information sharing on the competition process. If …rms are uncertain not only about their own cost of pollution abatement but also about the cost of their competitors, a VA promoted by a trade association may be helpful in improving information about abatement costs. Provided that …rms compete in an oligopolistic setting, they will adjust their output, and in turn this can a¤ect both the distribution of output between …rms and market prices. There is some evidence in the antitrust practice that trade associations may be an implicit device in restraining competition through information sharing activities. A strand of literaure devoted to information sharing in oligopoly has also widely discussed this issue, in order to ascertain the impact of information sharing - either about market demand or …rms' costs - on expected pro…ts and, in some cases, also on expected consumer surplus and social welfare[3]. Even excluding explicit collusion by …rms, VAs may have some indirect e¤ect on the …nal oligopolistic equilibrium through the process of information sharing about pollution abatement costs. This process is probably particularly relevant in the case of shared uncertainties about the implementation of new technologies for pollution abatement. A trade-o¤ can arise between the increasing bene…ts of pollution reduction due to adjustments in output and the social costs of output restrictions to the extent that they cause a reduction in consumer surplus. Then an evaluation of social welfare and consumer surplus with and without a VA in place may be helpful from the point of view of social policy, in order to ascertain if an exemption clause may be granted by antitrust authorities to VAs that are supsected of giving rise to anticompetitive practices (European Commission, op.cit.).

In this paper we consider two main cases: information sharing within a unilateral committment (section one) and information sharing within a negotiated agreemnt (section two). In section two we consider a model without public intervention, where …rms only have private incentiuve to reduce environmental damages caused by production. In this framework, recalling the classi…cation we made at the start, the kind of VAs we consider are Unilateral Commitment set by industry. In a duopoly model, inspired by Fried (1984), …rms compete à la Cournot and aim to reduce environmental damages caused by their production activities, because consumers have green preferences as in Garvie (1997). However green technologies are stochastic, as both …rms are uncertain about the real cost of pollution abatement.We suppose that this kind of uncertainty is completely eliminated if …rms share information through a voluntary agreement for pollution reduction. Given the green preference assumption, both …rms would partly internalise the environmental externality even without any voluntary agreement in place. However setting such an agreement provides additional bene…ts to …rms because of information sharing about costs. As in-

[3] We can consider Ponssard (1979) as the seminal paper in this strand of literature. Ponssard deals with common uncertainty and the incentives for information sharing about a parameter measuring the vertical intercept of market demand, as do the subsequent papers by Novshek and Sonnenschein (1982), Clarke (1983), Vives (1984) and Kirby (1988). Parallel works of Fried (1984), Gal Or (1986) and Shapiro (1986) deal instead with information sharing about …rms'costs, i.e. private value uncertainty.

formation sharing activities a¤ect industry equilibrium, environmental damages will be a¤ected by the unilateral commitment set by …rms. The decision process is then represented as a two-stage game where …rms …rst choose to subscribe or not to the Voluntary Agreement and then choose the quantity of output to supply. Information production (knowing precisely …rm's own costs) and disclosure (revealing its cost to its opponent) about pollution abatement costs eliminates production errors and modi…es the distribution of output among …rms. In particular, each …rm will then be able to exactly counter-adjust its output to the output produced by its opponent. As we shall see the result is that pro…ts are maximised by negotiating a VA. Concerning social welfare, there can be a trade-o¤ between the advantage of VAs from the point of view of their impact on environmental damages and their social cost in terms of higher prices and lower quantities. The results already achieved in the literature point out that even if social welfare is enhanced by information sharing, consumer surplus can decreases because consumers can pro…t from production mistakes (Shapiro, 1986). Equilibrium analysis is presented in section 2.1, while section 2.2 is devoted to welfare analysis.

In section three we discuss the case of negotiated agreemnts. Given the same assumption about competition, we exclude green preferences and introduce explicitly environmental regulation in the model. Then VAs consist in setting additional pollution abatement e¤orts with repect to regulatory standard. Even if the information sharing e¤ect continues to positively a¤ect pro…ts, in the case of negotiated agreements one must take account also the cost burden in order to evaluate both pro…ts and welfare. Pro…ts gains require either loose regulatory standards and a scarce additional e¤ort in pollution abatemnt, or a tight standard coupled any additional e¤ort. On the contrary consumer surplus is positively a¤ected by loose regulatory standard, coupled with a signi…cant additional environemntal e¤ort, and cannot increase if the regulatory standard is already very tight, independently of the additional environmental e¤ort. Concerning social welfare, it is positively a¤ected by negotiated agreemnts in the case of industries that are very e¢cient in the environemntal …eld. In thecase of theses industries the regulatory standard can never considered to be optimal and any additional abatement e¤ort implied by the VA has a positive e¤ect. For less e¢cient industries, negotiated agreemnts are welfare improving either when the regulatory standard is very low or very tight, indipendently of the additional abatement e¤ort, or for intermediate levels of the regulatory standards if the additional environemntal e¤ort is quite low. Equilibrium analysis will be carried out in section 3.1 and welfare analysis in section 3.2. Some genral conclusions will follow.

2 Information sharing within unilateral commitments

We consider a market for an homogeneous good produced by two firms: firm i and firm j, that compete à la Cournot. The consumers' willingness to pay for any quantity of that good negatively depends on the environmental damage caused by production activities, so that externalities can be internalised as in Garvie (1997). Thus we suppose that market demand is linear and represented by the following expression:

$$P = a - b(q_i + q_j) - \theta D$$

with $D = D_i + D_j$ the total net environmental damage caused by this industry and θ $(0 < \theta < 1)$ a parameter measuring the extent of internalisation of environmental externalities by consumers. The assumption that consumers only partially internalise the negative externality seems to be quite reasonable for many reasons. One can invoke the "intensity" of green preferences and/or account for the fact that consumers are generally less informed than firms with respect to the amount of environmental damages caused by production. However in this model we do not concentrate on this issue[4].

We shall distinguish between gross and net environmental damage. All firms are characterised by the following net environmental damage function:

$$D_i = \delta q_i - \gamma E_i$$

where δ $(\delta > 0)$is a parameter measuring the degree of toxicity of the inputs used in production, E_i is the level of the emission control input, and γ parametrizes the efficiency of pollution abatement activities inside each firm. As $\gamma < 1$ the pollution production function is such that a unit of production increases pollution by δ units while installation of a unit of emission control input reduces pollution by less than one unit. Further we assume that $E_i = \delta q_i$: thus any firm should reduce pollution to a level equal to the gross environmental damage caused by production. A net environmental damage remains in any case because of the efficiency parameter[5]. On the basis of these assumptions we can then write the environmental net damage function as:

$$D_i = \delta(1 - \gamma)q_i$$

We assume that θ, δ and γ are equal across firms. Letting then:

$$[b + \theta\delta(1 - \gamma)] = \beta$$

the market demand function becomes:

[4] This problem is related to the credibility of environmental policies put in place by firms. Firms may be able to build an environmental reputation to supplement the asymmetry of information with respect to consumers as shown in Cavaliere (1999).

[5] Of course one should assume that it is physically impossible to eliminate all waste.

$$P = a - \beta(q_i + q_j)$$

As to technology, we suppose that each firm is characterized by constant returns to scale both in output production and pollution abatement. Further, we suppose that production costs are normalized to zero in order to concentrate just on pollution abatement costs, which are represented by the following expression

$$C(E_i) = \omega_i \delta q_i$$

with ω_i the unitary cost of pollution abatement for firm i. Now, considering $C_i = a - \omega_i \delta$, the profit funtcion of firm i becomes

$$\Pi_i = C_i q_i - \beta q_i^2 - \beta q_j q_i$$

However we assume that firms are uncertain about the exact value of pollution abatement costs, since environmental technologies are frequently stochastic, especially when they incorporate recent innovations. Uncertainty for both firms concerns the parameters C_i and C_j. Following Fried (op.cit) we assume that these parameters are random variables having a joint normal distribution with means $\overline{C_i}$ and $\overline{C_j}$, variances $V_i^2$and $V_j^2$and covariances $V_{ij} = rV_iV_j$ (where r is the correlation coefficient).

In each period nature chooses the values of C_i and C_j, before firms choose output. Strategic interaction between firms can be represented by a two stage game. In the first stage firms can choose whether or not to negotiate a VA. Negotiating a VA firms produce and disclose information about pollution abatement technologies, and thus the precise values of C_i and C_j chosen by nature become common knowledge. If firms do not negotiate a VA, they remain uncertain about these parameters, knowing only their mean values: $\overline{C_i}$ and $\overline{C_j}$. In the second stage of the game firms choose output on the basis of their information about C_i and C_j, resulting from their commitments in the first stage

2.1 Equilibrium Analysis

Solving the two stage game by backward induction one can show the following proposition

Proposition 1 In the framework of Cournot competition with shared uncertainties about environmental technologies, duopolists maximise profits sharing information about environmental costs within a unilateral committment.

Proof: Starting from the second stage of the game each duopolist on the basis of his own information will maximise expected profits. Thus we firstly distinguish the information sets resulting from the commitment of the first stage. Let $I_i = I_j = (\overline{C_i}; \overline{C_j})$; the information set of firm i and firm j when they do not enter into a VA and $I_i = I_j = (C_i; C_j)$ the information set of firm i and firm j when they enter into a VA. Then both firms will choose their output simultaneously and non-cooperatively by solving the following maximisation problem in q_i:

$$MaxE(\pi_i | I_i) = E[((C_i - \beta(q_i + q_j)) | I_i)q_i] \tag{1}$$

The first order condition is:

$$E[(C_i - \beta q_j) | I_i] - 2\beta q_i = 0 \tag{2}$$

Clearly equilibrium depends on the information set. We then distinguish case A in which $I_i = I_j = (\overline{C_i}; \overline{C_j})$ and case B, in which $I_i = I_j = (C_i, C_j)$. In case A the duopolists reaction functions are the following:

$$q_{iA} = \frac{\overline{C_i} - \beta q_j}{2\beta} \tag{3}$$

$$q_{jA} = \frac{\overline{C_j} - \beta q_i}{2\beta} \tag{4}$$

and the corresponding equilibrium outputs are then:

$$q^*_{iA} = \frac{2\overline{C_i} - \overline{C_j}}{3\beta} \tag{5}$$

$$q^*_{jA} = \frac{2\overline{C_j} - \overline{C_i}}{3\beta} \tag{6}$$

Concerning case B, we can simply substitute the precise values of C_i and C_j chosen by nature to the mean values $\overline{C_i}$, $\overline{C_j}$. Further, letting $\Delta C_i = C_i - \overline{C_i}$ and $\Delta C_j = C_j - \overline{C_j}$ it is possible to represent equilibrium output quantities in case B as an "excess" output with respect to equilibrium output quantities in case A:

$$q^*_{iB} = q^*_{iA} + \frac{2\Delta C_i - \Delta C_j}{3\beta} \tag{7}$$

$$q^*_{jB} = q^*_{jA} + \frac{2\Delta C_j - \Delta C_i}{3\beta} \tag{8}$$

In order to show that firms will commit to information production and disclosure by entering a VA in the first stage of the game, we have to verify that in equilibrium expected profits in case B are higher with respect to expected profits in case A. Using (1) and (2), and only considering firm i, we see that:

$$\pi^*_{iA} = \beta(q^*_{iA})^2 \tag{9}$$

$$\pi^*_{iB} = \beta(q^*_{iB})^2 = \beta(q^*_{iA} + \frac{2\Delta C_i - \Delta C_j}{3\beta})^2 \tag{10}$$

Further, using the expected value operator one obtains:

$$E(\Pi^*_{iB}) = E(\Pi^*_{iA}) + \frac{4V_i^2 - 4rV_iV_j + V_j^2}{9\beta} \quad (11)$$

Then $E(\Pi^*_{iB}) \geq E(\Pi^*_{iA})$ if and only if: $\frac{4V_i^2 - 4rV_iV_j + V_j^2}{9\beta} \geq 0$: We can rearrange this last condition to get the following:

$$\frac{(1 - r^2)}{9\beta}V_j^2 + \frac{\left[2 - r\left(\frac{V_j}{V_i}\right)\right]^2}{9\beta}V_i^2 \geq 0 \quad (12)$$

It is easy to check that, given the assumptions of the model about β, this condition is always verified.

Lemma 2 The private benefit of information sharing for firm i increases with V_i^2, V_j^2 and and decreases with r and β_i.

With the demonstration of proposition one we have shown that firms have an incentive to enter a VA in order to share information about the cost of pollution abatement. The advantage for each duopolist is the elimination of production errors due to uncertainty not only about its own cost but also about the cost for its opponent,which prevent firms from reaching the Cournot equilibrium. As it is stated in lemma 2, condition (12) shows that the advantage of information sharing increases with the values of V_i^2 and V_j^2, representing the degree of ex-ante uncertainty about pollution abatement costs that is solved ex-post via the VA.

Furthermore the same condition also makes clear that the advantage of information sharing increases with the degree of divergence between $V_i$and V_j;affecting the covariance between firms.The private benefits of information sharing also decrease when the correlation coefficient increases. Again the covariance is affected. In fact the second term in (11) shows clearly that when the covariance increases the benefits of information sharing decrease. Thus the benefits of information sharing are even greater when uncertainty particularly concerns the cost of one firm with respect to the other one and when costs and output adjustments go in opposite directions. In fact any firm, disclosing information to its opponent, enables it to accomplish the necessary counter-adjustments that are necessary to attain the Cournot equilibrium.The extent of output adjustments and counteradjustments is directly observable in the model through the "excess" equilibrium output quantities that are produced by firms when a VA is in place, with respect to when it is not, as shown in (7) and (8).Thus concerning firm i we have: $\Delta q_i = \frac{2\Delta C_i - \Delta C_j}{3\beta}$ and concerning firm j: $\Delta q_j = \frac{2\Delta C_j - \Delta C_i}{3\beta}$. As these expression well illustrate we can distinguish for each firm a "direct" output adjustment given by $\frac{2\Delta C_i}{3\beta}$ for firm i and by$\frac{2\Delta C_j}{3\beta}$ for firm j and a counter-adjustment to the output produced by the other firm, represented respectively by $-\frac{\Delta C_j}{3\beta}$ and by $-\frac{\Delta C_i}{3\beta}$. As Fried (op.cit.) points out, parallel to the previous distinction, the information disclosed can also be implicitly broken down into two: components: 1)"Firm specific" cost information, yielding for example some additional knowledge to …rm i about …rm j's costs, but no additional knowledge about …rm i's own costs 2)"Common" cost information (concerning industry for example), yielding some additional knowledge to …rm i about its own costs, through the disclosure of cost information about …rm j. Firm speci…c cost information enables each …rm to make the necessary counter-adjustments to the revision of output carried out by its opponent on the basis of information sharing. These counter-adjustments are "collusive", to the extent that they lead to output decisions that are necessary to achieve non-cooperatively the Cournot equilibrium. Actually, it is easy to verify that, for each duopolist, counter-adjustments to the cost function of the opponent are in the opposite direction with respect to the direct adjustment made by the opponent himself. Any change of output by any …rm in any direction is more bene…cial when accompanied by a change made in the opposite direction by the other …rm, given the …nal e¤ect on market price. If …rms'costs are to some extent positively correlated, information production and disclosure will give rise to a revision of expected cost and to output variations that go in the same direction for both …rms. These revisions will not be "collusive" and as such will reduce the bene…cial impact of output counter-adjustments. Of course this last e¤ect is expected to be more pronounced the higher the correlation coe¢cient r is ;r measuring the degree of correlation between …rms'costs.

Further, both "direct" output adjustments and counter-adjsutments depend on ¯. Environmental parameters thus play a role in determining the extent of these adjustments. We can assume that b; ± and µ are industry and market parameters that a¤ect …rms in the same way. The positive e¤ect of information sharing on pro…ts decreases when the value of such parameters increases. For example an increaee of µ;meaning that consumers are more sensitive to wnvironmental damages, disturbs output adjustments that …rms intend to carry out for comepetitive reasons, because the impact of output on environemntal damage becomes more important. Thus the extent of output adjstment is a¤ected by ¯, via µ:The same thing can be said about an increase of ±;the toxicity of production inputs. On the contrary if ° - the e¢ciency of pollution abatment - increases, the extent of output adjustment that …rms can carry out without further a¤ecting environmental damages increases too, via the reduction of ¯.

2.2 Welfare analysis

The last section clearly established that in the framework of shared uncertainties VAs increase pro…ts thanks to information sharing about costs. In the …nal market equilibrium not only are prices and output quanities changed by information sharing, but also the net environmental damage varies. One wonders then about the social welfare e¤ects of information sharing, as output contractions due to non cooperative behaviour may be coupled with reductions in environmental damages. On the contrary output expansions can be coupled with an increase in environmental damage. Assessing the impact of social welfare may then provide criteria for public policy decisions concerning VAs.

We thus assume the existence of a social planner whose objective is to maximise social welfare. The social planner will take care of the residual production externality: the part of environmental damage not internalised by the market. The social welfare function is then given by the sum of producer and consumer surplus minus the residual environmental damages:

$$W = \int_0^q (a - \beta(q_i + q_j))dq - \delta\omega_i q_i - \delta\omega_j q_j - (1 - \theta)(D_i + D_j) \qquad (13)$$

In order to see if public policy should foster VAs or not one must compare social welfare in the case of shared uncertainties about pollution abatement costs (case A of last section) with social welfare when a VA is in place and firms share information about environmental technologies (case B in last section). Social welfare does not necessarily increase with information sharing VAs, even if profits are always enhanced by them. This may be due to a reduction in consumer surplus (net of environmental damage) that exceeds the increase of profits. However it may also be possible that even in the event of an increase in social welfare, consumer surplus as such decreases. In this last case the extent of the profit increase is such as to compensate for the decrease in consumer surplus (net of environmental damage). It is thus interesting to analyse the direct impact of information sharing VAs first on consumer surplus (net of environmental damage) and then on aggregate social welfare. This analysis is shown in the following proposition

Proposition 3 Information sharing VAs induce a decrease in consumer surplus if the covariance is negative. If the covariance is positive consumer surplus can increase only if the following inequality holds: $2r - \sqrt{(4r^2 - 1)} \le V_i/V_j \le 2r + \sqrt{(4r^2 - 1)}$.

Proof: By substracting profits from the expression for social welfare we get the following expression for consumer surplus net of environmental damage:

$$CS = \frac{\beta}{2}(q_i^2 + q_j^2) + 2\beta q_i q_j - (1 - \theta)[D_i + D_j] \qquad (14)$$

In order to compare consumers surplus in case A and case B we have to substitute in the last expression the equilibrium output quantities to get $CS(q^*_{iA}; q^*_{jA})$ and $CS(q^*_{iB}; q^*_{jB})$ respectively. After computing expected values, in order to see if consumer surplus is positively affected by information sharing VAs, we have to control if the following inequality is true:

$$E[CS(q^*_{iB}; q^*_{jB})] > E[CS(q^*_{iA}; q^*_{jA})] \qquad (15)$$

and this occurs if:

$$4rV_iV_j - V_i^2 - V_j^2 \ge 0 \qquad (16)$$

:

It is easy to check that when $r < 0$ the last inequality is never true. When $r > 0$, by rearranging (16) we can further analyse the roots of the following inequality:

$$\left(\frac{V_i}{V_j}\right)^2 - 4r\left(\frac{V_i}{V_j}\right) + 1 \leq 0 \qquad (17)$$

In this case the last inequality is true if and only if $\frac{V_i}{V_j}$; belongs to the following interval:

$$2r - \sqrt{(4r^2 - 1)} \leq V_i/V_j \leq 2r + \sqrt{(4r^2 - 1)} \qquad (18)$$

No other restriction is placed except that $r \neq \frac{1}{2}$.

We can comment on our results concerning consumer surplus. Intuition lead us to think that information sharing about pollution abatment costs can give rise to three different cases: 1) Both firms may contract output and thus reduce aggregate net environmental damage. While output contractions will negatively affect consumer surplus, the reduction in net environmental damages will have a positive effect on it. 2) Both firms may expand output and then net enviornmental damage would increase. While output expansion will positively affect consumer surplus, the increase of net environmental damage will have a negative effect on it. 3) While one firm may contract output, the other one will expand it. There will then be a "mixed" effect on consumer surplus and the final result depends on the relative magnitude of both the output expansion and the output contraction. Of course the effect on net environmental damage depends on the fact that the net effect on output will be a contraction or an expansion.

The results established in proposition three help us to understand the elements that make the positive effects on consumer surplus prevail over the negative effects. First of all let us point out that the increase in consumer surplus is highly dependent on the value of the covariance rV_iV_j. For high values of the covariance, the "direct" output adjustment operated by each firm tends toexceed the "counter-adjustment"operated with respect to the disclosure of the cost of the other firm. As counter-adjustments are "collusive" they increase profits and reduce consumer surplus. Our results show that consumer surplus always decreases with information sharing if the covariance is negative ($r < 0$). If the covariance is positive, for any given value of r, consumer surplus is more likely to increase if (V_i/V_j) belongs to a given interval, meaning that the variances do not diverge too much. As this interval depends on r, one can check that the higher is r the wider is the allowed divergence between variances.

As to the case in which there is negative correlation between firms'costs, direct output adjustments tend to follow opposite directions. However if there is higher negative correlation, output adjustments by both firms tend to compensate each other.This tends to mitigate the final effects on consumer surplus. More interesting is the situation of low negative correlation, when it is likely that output reductions by one firm are followed by output increases of a greater magnitude by the other firm or viceversa. In the first case total output is thus likely to increase and environmental damage is negatively affected. In the second case total output is likely to decrease and environmental damage is positively affected. In both cases however, as stated in Proposition three, the negative effects on consumer surplus always prevail over the positive effects.

In the case of positive correlation, consumer surplus is more likely to increase if the covariance is high. Any increase in the covariance implies that V_i and V_j do not diverge too much as proposition three clearly states. Moreover the covariance increases with the correlation coefficient. If the correlation between firms'costs is higher, any information disclosed about the cost of one firm will provide useful information for the other one in making direct output adjustments. This is the case in which firms only revise expected costs and no particular profit advantage results from information sharing. This effect is more intense the higher is r, the correlation coefficient. Thus for high values of r the "collusive"effect tends to be compensated by the "direct" output adjustments that are made by firms in the same direction. For low values of r this is less likely to happen.

For example if costs are not highly correlated, then even if cost revisions are in the same direction their extent can differ substantially. As a result the firm that revises cost to a lesser extent (firm j let us suppose), even finding that its cost are lower than expected will reduce output in order to "counter-adjust" the large increase of output of its opponent (firm i), whose cost revision is wider. In this case total output increases but such an increase is lower with respect to the case in which costs are more closely correlated. Thus consumer surplus is negatively affected.

Proposition 4 Social welfare always increases with information sharing within unilateral commitments

Following the same pattern of anlysis, in order to see if VAs improve social welfare or not we must substitute in the expression of the welfare function the equilibrium output quantities respectively obtained in case A and in case B, to get $W(q^*_{iA}, q^*_{jA})$ and $W(q^*_{iB}, q^*_{jB})$ respectively:

$$W(q^*_{iA}, q^*_{jA}) = C_i q^*_{iA} + C_j q^*_{jA} - \frac{\beta}{2}(q^{*2}_{iA} + q^{*2}_{jA}) - (1-\mu)\delta\left[(1-\gamma)q^*_{iA} + (1-\gamma)q^*_{jA}\right] \quad (19)$$

$$\begin{aligned} W(q^*_{iB}, q^*_{jB}) = {} & C_i\left(q^*_{iA} + \frac{2\Delta C_i - \Delta C_j}{3\beta}\right) + C_j\left(q^*_{jA} + \frac{2\Delta C_j - \Delta C_i}{3\beta}\right) - \\ & - \frac{\beta}{2}\left(q^{*2}_{iA} + 2q^*_{iA}\frac{2\Delta C_i - \Delta C_j}{3\beta} + \frac{4(\Delta C_i)^2 - 4\Delta C_i \Delta C_j + (\Delta C_j)^2}{9\beta^2}\right) \\ & - \frac{\beta}{2}\left(q^{*2}_{jA} + 2q^*_{jA}\frac{2\Delta C_j - \Delta C_i}{3\beta} + \frac{4(\Delta C_j)^2 - 4\Delta C_j \Delta C_i + (\Delta C_i)^2}{9\beta^2}\right) - \\ & (1-\mu)\delta\left[(1-\gamma)\left(q^*_{iA} + \frac{2\Delta C_i - \Delta C_j}{3\beta} + q^*_{jA} + \frac{2\Delta C_j - \Delta C_i}{3\beta}\right)\right] \end{aligned}$$

Once the expected values are computed, the proof lies simply in controlling if the following condition is true:

$$E[W(q^*_{iB}; q^*_{jB})] > E[W(q^*_{iA}; q^*_{jA})]. \tag{20}$$

We can show that this is equivalent to solving the following:

$$7V_i^2 - 4rV_iV_j + 7V_j^2 > 0 \tag{21}$$

As to the study of the latter inequality, we can conclude that, if $r < 0$ (the covariance is thus negative) it will always be true and social welfare will always increase with information sharing. Since $r < 0$, and recalling the results already given in last proposition, this means that the magnitude of profits increase outweighs the magnitude of consumer surplus decrease that always takes place in this case. Outside of this case, rearranging the last inequality , we can have:

$$7\left(\frac{V_i}{V_j}\right)^2 - 4r\frac{V_i}{V_j} + 7 > 0 \tag{22}$$

We can show that in this case the last inequality holds for any value of $\frac{V_i}{V_j}$- i.e. social welfare always increases with information sharing

3 Information Sharing within Negotiated Agreements

We now exclude green preferences anf the partial internalisation of the social cost of pollution through the market mechanism. Thus we adopt a more traditional setting and consider a market for an homogeneous good with two firms (i and j) competing à la Cournot and facing the following market demand function

$$P = a - bQ \qquad (Q = q_i + q_j)$$

Firms produce a unit of emission z for any unit of output. Thus without any emission control we have that $z = q$. In order to induce firms to abate pollution we suppose that public intervention settles an emission standard such that any firm produces a fixed amount of emission $z \le z^{std}$. Let us call e the amount of output subject to pollution abatement, such that the amount of emission produced reduces to $z = q - \gamma e$. With respect to last section we suppose that the efficiency of pollution abatement γ differs between firms. Thus γ will be firm specific ($\gamma_i \ne \gamma_j$) and not linked to the technology adopted but to the managerial and organisational skills or to the location of the firm. We not only suppose that each firms knows its efficiency of pollution abatement but that γ_i and γ_j are also common knowledge. We suppose that standards are settled at such a level that both firms produce positive outputs and Cournot competition is viable.

In fact we would like to point out that the standard z is defined in such a way that firms could respect it either by abating polluting emissions, either by simply reducing output. We cannot a priori exclude that the efficiency in pollution abatement (γ) for some firm may be such that it won't be able to respect the standard without cutting production with respect to the best reply that that would result from Cournot competition. This would mean that the output resulting from the best reply function is simply not viable given the regulatory standard.

We continue to suppose that the pollution abatement technology can be represented by the following linear cost function:

$$c_i = \omega_i e_i$$

$$c_j = \omega_j e_j$$

and do not consider other production costs besides those due to pollution abatement. Toxic emissions will cause environmental damages that can be represented by the following damage function:

$$D = \frac{\delta}{2}(Z)^2$$

where δ represent the degree of toxicity of emissions. Being $Z = z_i + z_j$; we have that $D = \frac{\delta}{2}(z_i + z_j)^2$.

As in last section we nsuppose that firms are uncertain about the cost of controlling their toxic emissions and only know the distribution of the parameter ω: We suppose that the distribution is Normal:

$$\omega \sim N(\bar{\omega}; V):$$

In this case firms can subscribe a negotiated agreement with the public adminstration that requires them to reduce toxic emission behind the standard z settled by environmental regulation. If firms accept to negotiate their level of pollution abatement, emissions will have to be further reduced to $z \leq \alpha z^{std}$ $(0 \leq \alpha \leq 1)$, and firms will get the opportunity to share information about costs and know the exact value of the parameter ω_i and ω_j.

Our aim is still to compare firms profits, consumer surplus and social welfare when firms follow environmental regulation (case A) with respect to the case in which they participate to a negotiated agreement with the public adminstration (case B). Firsly we shall then analyse market equilibrium in case A and case B, in order to compare equilibrium profits in both cases. This analysis will enable us to discuss the private incentives to participate to a negotiated voluntary agreement implementing a tighter standard with respect to environmental regulation. Then welfare analysis will follow, in order to assess to what extent negotiated voluntary agreements also create social benefits.

3.1 Equilibrium Analysis

3.1.1 Case A: Cournot Competition with enviornmental regulation

In case A firms information about costs can be represented by the following information set $I = (\omega_i; \omega_j)$. Toxic emissions are given by $z_i = q_i - \gamma_i e_i \leq z^{std}$ implying that the level of emissions subject to abatement are given by $e_i \geq \frac{q_i - z^{std}}{\gamma_i}$. However, as emissions abatement is costly, firms will choose to abate the lowest amount of emissions: $e_i = \frac{q_i - z^{std}}{\gamma_i}$ and will incur the following total cost of pollution abatement:

$$c_i = \omega_i e_i = \frac{\omega_i}{\gamma_i}\left[q_i - z^{std}\right]$$

Given the espression of market demand, profit functions of firm i and firm j in this case become:

$$\pi_A^i = (a - bq_i - bq_j)\, q_i - \frac{\omega_i}{\gamma_i}(q_i - z^{std});$$

$$\pi_A^j = (a - bq_i - bq_j)\, q_j - \frac{\omega_j}{\gamma_j}(q_j - z^{std});$$

Maximising profits in q_i and q_j and solving the f.o.c. for the reaction functions, we can get the output levels that chatacterise the Cournot equilibrium in case A

$$q_{iA}^{*} = \frac{1}{3b}\left(a + \frac{\omega_j}{\gamma_j} - 2\frac{\omega_i}{\gamma_i}\right); \tag{23}$$

$$q_{jA}^{*} = \frac{1}{3b}\left(a + \frac{\omega_i}{\gamma_i} - 2\frac{\omega_j}{\gamma_j}\right) \tag{24}$$

we can then notice that equilibrium output for each firm is positively affected by firm efficiency in pollution abatement (a low ω and an high γ) but negatively affected by the efficiency of the competitor (even if to a less extent).

The corresponding equilibrium profits are then

$$\pi_{iA}^{*} = b\left(q_{iA}^{*}\right)^2 + \frac{\omega_i}{\gamma_i} z^{std} \tag{25}$$

$$\pi_{jA}^{*} = b\left(q_{jA}^{*}\right)^2 + \frac{\omega_j}{\gamma_j} z^{std} \tag{26}$$

It is easy to check that equilibrium profits are negatively affected by environmental standards. Profits grow with the quantity of toxic emissions, i.e. the quantity of output not subject to pollution abatement

3.1.2 Case B: Cournot competition with negotiated environmental agreements

In case B firms share information about pollution abatement costs. Thus their information set concerning the parameters of the cost function can be represented by $I = (\omega_i; \omega_j)$. Moreover firms negotiate with the public administration a further reduction of toxic emissions with respect to environmental standards, such that $z_i = \alpha z^{std}$, with $0 \leq \alpha < 1$. Any firm participating to the VA is then called to an additional emission abatement effort that we can represent by $(1 - \alpha)$. Thus the amount of output subject to pollution abatement will be $e_i = \frac{1}{\gamma_i}\left(q_i - \alpha z^{std}\right)$. Total cost will then amount to $c_i = \frac{\omega_i}{\gamma_i}(q_i - \alpha z^{std})$ for firm i and to $c_j = \frac{\omega_j}{\gamma_j}(q_j - \alpha z^{std})$ for firm j. Given the expression of market demand, profit functions for firm i and firm j in case B then become:

$$\pi_{iB} = (a - bq_i - bq_j)\, q_i - \frac{\omega_i}{\gamma_i}(q_i - \alpha z^{std});$$

$$\pi_{jB} = (a - bq_i - bq_j)\, q_j - \frac{\omega_j}{\gamma_j}(q_j - \alpha z^{std})$$

;

Maximising profits in q_i and q_j respectively and solving the f.o.c. for the reaction functions, we get the equilibrium Cournot outputs for case B.

$$q^*_{iB} = \frac{\left(a + \frac{\omega_j}{\gamma_j} - 2\frac{\omega_i}{\gamma_i}\right)}{3b}; \tag{27}$$

$$q^*_{jB} = \frac{\left(a + \frac{\omega_i}{\gamma_i} - 2\frac{\omega_j}{\gamma_j}\right)}{3b} \tag{28}$$

Moreover, remebering that $\omega_i = \bar{\omega}_i + \Delta\omega_i$ and $\omega_j = \bar{\omega}_j + \Delta\omega_j$; we can represent equilibrium outputs for case B as a function of equilibrium Cournot outputs for case A:

$$q^*_{iB} = q^*_{iA} + \frac{\left(\frac{\Delta\omega_j}{\gamma_j} - 2\frac{\Delta\omega_i}{\gamma_i}\right)}{3b} \tag{29}$$

$$q^*_{jB} = q^*_{jA} + \frac{\left(\frac{\Delta\omega_i}{\gamma_i} - 2\frac{\Delta\omega_j}{\gamma_j}\right)}{3b} \tag{30}$$

the corresponding equilibrium profits are then:

$$\pi^*_{iB} = b\left(q^*_{iB}\right)^2 + \alpha\frac{\omega_i}{\gamma_i} z^{std} \tag{31}$$

$$\pi^*_{j_B} = b\left(q^*_{j_B}\right)^2 + \alpha\frac{\omega_-}{\gamma_j}z^{std} \tag{32}$$

In case B we can then notice that profits still grow with the quantity of toxic emissions - as in case A - but this quantity not only depends on the standard z^{std} but also on α, the higher is α the lower is the additional abatement effort $(1-\alpha)$ required by the negotiated agreement and the higher are firms profits.

3.1.3 Private incentives to go behind regulatory standards

In order to consider the incetives for firms to join negotiated environmental agreements that impose further pollution abatement with respect to regulatory standards, we have to consider the difference in expected profits in case B and case A, for both firms. If this difference is positive we can state that the negotiated agreemnt increase firms profits and there are then private incentives to go behind regulatory standards.

$$E\left[\pi^*_{i_B}\right] - E\left[\pi^*_{i_A}\right] = \frac{1}{3b}\left(\left(\frac{V_-}{\gamma_j}\right)^2 - 4r\frac{V_-}{\gamma_i}\frac{V_-}{\gamma_j} + 4\left(\frac{V_-}{\gamma_i}\right)^2\right) - (1-\alpha)\frac{\mu_-}{\gamma_i}z^{std} \geq 0$$

$$E\left[\pi^*_{j_B}\right] - E\left[\pi^*_{j_A}\right] = \frac{1}{3b}\left(\left(\frac{V_-}{\gamma_i}\right)^2 - 4r\frac{V_-}{\gamma_i}\frac{V_-}{\gamma_j} + 4\left(\frac{V_-}{\gamma_j}\right)^2\right) - (1-\alpha)\frac{\mu_-}{\gamma_j}z^{std} \geq 0$$

Then the incentive to participate to a negotiated agreement - for firm i and firm j respectively - depends on the parameter restrictions that are necessary to verify last inequalities.

With respect to the case of unilateral committments, discussed in section 2, we cannot state that voluntary agreements always increase firms profits. In fact the difference in expected profits consists in two parts: 1) the first one - within brackets- we can call "the information sharing effect" and corresponds to difference in expected profits we have already found in the case of unilateral committments. As shown in last section, the information sharing effect always positively affect profits (see proposition 1) 2) The second part of the inequality reflects the increase in costs due to voluntary agreements. It depends on the additional abatement effort $(1-\alpha)$, and of course it negatively affects profits. In order that a firm is willing to negotiate a voluntary agreements the magnitude of the information sharing effect should be such to compensate the negative impact on profits of the additional effort concerning pollution abatement or- viceversa- this additional effort should be so tiny that the total impact on profits remains positive.

Moreover the impact of the negotiated agreement is not simmetric, as one can easily check by comparing both inequalities that differ with respect to $\frac{V_-}{\gamma_i}$; $\frac{V_-}{\gamma_j}$; $\frac{\mu_-}{\gamma_j}$ and $\frac{\mu_-}{\gamma_i}$. Concerning the efficiency parameters it is worthwhile to point out that they could be such to imply that the supplementary effort in pollution abatement required by pollution agreements could only be obtained with a reduction of output with respect to the best reply of the Cournot equilibrium.

At the limit one cannot exclude that a firm could be eliminated from the market by the supplementary effort in pollution abatement required by the negotiated agreemnte while its opponent, being more efficient from the environmental point of view, can continue to sell its output. In the case of a negotiated agreemnt the less efficient firm won't be willing to subscribe it, affecting then the opportunity for all the industry to go behind environemntal regulations due to opposition inside the trade association. But in the case of public voluntary programme, whereas the less efficient firm won't particiapte to it, its competitor is not affected by this decision and can accept the proposal of the environemntal agency (see section 1, concerning the difference among VAs). In this last case the advancemnt in environmental protection is achieved at the cost of affecting competition in the market, creating a a barrier to entry for other firms. Thus voluntary agreements can potentially be sused as a strategic anticompetive weapon.

Usually voluntary agreemnts are negotiated by trade associations. We can then consider industry profits: $\Pi = \pi_i + \pi_j$ instead of single firms profits as the appropriate target to consider in order to evaluate the private benefits of voluntary agreements. Given that an increase of Π could hide a profit decrease for one firm compensated by the profit increase of the competitor, we can either consider the appropriate parameter restrictions that lead us to discuss only the case characterized by a profit increase for both firm or suppose that in any event the trade association provide side payments for those firms that could loose if a negotiated agreement is concluded with the Public Administration.Therefore to ascertain if there are private incentive to negotiate an environmental agreemnt by the industry, we must compare expected industry profits $E\left[\Pi_B^* - \Pi_A^*\right]$ and see if they increase with the negotiation. This is equivalent to check if $E\left[\Pi_B^* - \Pi_A^*\right] \geq 0$.

Comparing expected industry profits in case A and B, we are interested in analysing for what level of the environmental standards settled before (z^{std}) and after negotiations (αz^{std}), there are incentives for the trade association to join such an agreement.The results say that expected industry profits increase with a negotiated agreemnt:

- if $z^{std} > \frac{1}{9b\left(\frac{\omega_i}{\gamma_i}+\frac{\omega_j}{\gamma_j}\right)}\left(5\left(\frac{V_i}{\gamma_i}\right)^2 - 8r\frac{V_i}{\gamma_i}\frac{V_j}{\gamma_j} + 5\left(\frac{V_j}{\gamma_j}\right)^2\right)$

  $1 - \alpha \leq \frac{1}{9b\left(\frac{\omega_i}{\gamma_i}+\frac{\omega_j}{\gamma_j}\right)z^{std}}\left(5\left(\frac{V_i}{\gamma_i}\right)^2 - 8r\frac{V_i}{\gamma_i}\frac{V_j}{\gamma_j} + 5\left(\frac{V_j}{\gamma_j}\right)^2\right);$

- if $z^{std} \leq \frac{1}{9b\left(\frac{\omega_i}{\gamma_i}+\frac{\omega_j}{\gamma_j}\right)}\left(5\left(\frac{V_i}{\gamma_i}\right)^2 - 8r\frac{V_i}{\gamma_i}\frac{V_j}{\gamma_j} + 5\left(\frac{V_j}{\gamma_j}\right)^2\right)$, for any α

These results induce to think that a trade association is more likely to negotiate a voluntary agreement with the public administration in two different cases: 1) If the regulatory standards is not very tight and the additional effort in pollution abatement $(1 - \alpha)$ required by the agreement is under a given treshold

2) If the regulatory standard is already quite tight. In this second case any additional effort in pollution abatement can be accpted by the industry, as the increase in costs due to the voluntary agreement is never such to compensate the benefits of the information sharing effect.

In both cases we can observe that the standard treshold and the additional effort treshold depends on industry efficiency $\left(\frac{\delta_i}{\gamma_i}+\frac{\delta_j}{\gamma_j}\right)$. In the first case if industry efficiency grows a VA could be accepted even with a tighter standard. In the second case efficiency gains in pollution abatement induce to accept any additional effort in polution abatment for a larger set of regulatory standards than before, including looser standards.

3.2 Welfare analysis

We now aim to consider the welfare effects of negotiated agreements. Therefore we compare consumer surplus and total welfare in case A and case B in order to evaluate the social benefits of negotiated agreements with respect to regulation.Let us consider the following social welfare function:

$$W = \int_0^q (a - bq_i - bq_j)q - c_i - c_j - \frac{\delta}{2}(z_i + z_j)^2$$

>From this function we get consumer surplus as:

$$CS = W - \Pi = \frac{b}{2}(q_i^2 + q_j^2) + 2bq_iq_j - \frac{\delta}{2}(z_i + z_j)^2$$

Let us evaluate consumer surplus firstly and then total welfare both in case A and case B, to make then the comparison

3.2.1 Consumer surplus

Case A) In this case the damage function becomes

$$D = 2\delta\left(z^{std}\right)^2$$

and consumer surplus is given by:

$$CS_A^* = \frac{b}{2}\left(q_{i\,A}^*\right)^2 + \frac{b}{2}\left(q_{j\,A}^*\right)^2 + 2bq_{i\,A}^*q_{j\,A}^* - 2\delta\left(z^{std}\right)^2$$

Case B) In this case the damage function is the following:

$$D = 2\alpha^2\delta\left(z^{std}\right)^2$$

to evaluate consumer surplus we must remember that equilibrium output in case B can be represented as a function of equilibrium output in case A. Thus being consumer surplus represented by the following expression:

$$CS^*_B = \frac{b}{2}\left(q^*_{i_B}\right)^2 + \frac{b}{2}\left(q^*_{j_B}\right)^2 + 2bq^*_{i_B}q^*_{j_B} - 2\alpha^2\delta\left(z^{std}\right)^2$$

allowing for the necessary substitutions we obtain:

$$\frac{b}{2}\left(q^*_{i_A} + \frac{\left(\frac{\omega_j}{\gamma_j} - 2\frac{\omega_i}{\gamma_i}\right)}{3b}\right)^2 + \frac{b}{2}\left(q^*_{j_A} + \frac{\left(\frac{\omega_i}{\gamma_i} - 2\frac{\omega_j}{\gamma_j}\right)}{3b}\right)^2 +$$

$$+ 2b\left(q^*_{i_A} + \frac{\left(\frac{\omega_j}{\gamma_j} - 2\frac{\omega_i}{\gamma_i}\right)}{3b}\right)\left(q^*_{j_A} + \frac{\left(\frac{\omega_i}{\gamma_i} - 2\frac{\omega_j}{\gamma_j}\right)}{3b}\right) - 2\alpha^2\delta\left(z^{std}\right)^2$$

In order to evaluate the impact of the negotiated agreement on consumers we must compute the difference in expected consumer surplus in case A and case B: $E\left[CS^*_B - CS^*_A\right]$ and then consider the cases in which there is an increase in expected consumer surplus due to negotiated agreements: $E\left[CS^*_B - CS^*_A\right] \geq 0$. Last inequality can be reduced to the following one

:

$$-\frac{1}{6b}\left(\left(\frac{V_j}{\gamma_j}\right)^2 - 4r\frac{V_i}{\gamma_i}\frac{V_j}{\gamma_j} + \left(\frac{V_i}{\gamma_i}\right)^2\right) + 2\delta\left(1 - \alpha^2\right)\left(z^{std}\right)^2 \geq 0$$

$$\left(\frac{V_i}{\gamma_i}\right)^2 - 4r\frac{V_i}{\gamma_i}\frac{V_j}{\gamma_j} + \left(\frac{V_j}{\gamma_j}\right)^2 - 12b\delta\left(1 - \alpha^2\right)\left(z^{std}\right)^2 \leq 0; \qquad (33)$$

One can easily observe that the increase in consumer surplus depends ont two components: the first one is the"information sharing effect"and the second one is the reduction of the environmental damage due to the voluntary agreemnts. As in the case of unilateral committments, that we explored in last section, the information sharing effect not always benefits consumers, while, with respect to that case, environemntal damages always decrease to the advantage of comnsumers.Thus, in order to assess if a negotiated agreement induces an increase of consumer surplus, we must distinguish the following cases:

1) If $r \geq \frac{1}{2}$ and $\left(2r - \sqrt{4r^2 - 1}\right)\frac{\gamma_i}{\gamma_j} \leq \frac{V_i}{V_j} \leq \left(2r + \sqrt{4r^2 - 1}\right)\frac{\gamma_i}{\gamma_j}$ consumer surplus increases for any value of α

2) If $r \leq \frac{1}{2}$ and $\frac{V_i}{V_j} \leq \left(2r - \sqrt{4r^2 - 1}\right)\frac{\gamma_i}{\gamma_j} \cup \frac{V_i}{V_j} \geq \left(2r + \sqrt{4r^2 - 1}\right)\frac{\gamma_i}{\gamma_j}$ consumer surplus increases for $\alpha \leq \sqrt{1 - \frac{1}{6b}\frac{1}{2\delta\left(z^{std}\right)^2}\left(\left(\frac{V_j}{\gamma_j}\right)^2 - 4r\frac{V_i}{\gamma_i}\frac{V_j}{\gamma_j} + \left(\frac{V_i}{\gamma_i}\right)^2\right)}$, given that $\left(z^{std}\right) > \sqrt{\frac{1}{12b\delta}\left(\left(\frac{V_j}{\gamma_j}\right)^2 - 4r\frac{V_i}{\gamma_i}\frac{V_j}{\gamma_j} + \left(\frac{V_i}{\gamma_i}\right)^2\right)}$

3) If $r \leq \frac{1}{2}$ and $\frac{V_i}{V_j} \leq \left(2r - \sqrt{4r^2 - 1}\right)\frac{\gamma_i}{\gamma_j} \cup \frac{V_i}{V_j} \geq \left(2r + \sqrt{4r^2 - 1}\right)\frac{\gamma_i}{\gamma_j}$; but $\left(z^{std}\right) < \sqrt{\frac{1}{12b\delta}\left(\left(\frac{V_j}{\gamma_j}\right)^2 - 4r\frac{V_i}{\gamma_i}\frac{V_j}{\gamma_j} + \left(\frac{V_i}{\gamma_i}\right)^2\right)}$ there is no value of α that could lead to an increase of consumer surplus.

In case 1) the information sharing e¤ect is positive for consumers. Thus consumers surplus will increase independently of the additional abatement e¤ort required to the industry. One can easily check that this case corresponds to the one in which consumers surplus increases even with a unilateral committment, as shown in section 2.2 (see proposition 3) and due to the value of the covariance between …rms costs that reduces the "collusive" e¤ect. The only di¤erence with resepct ot section 2.2 is that the interval that limits the divergence between …rms variances is here also conditioned by $\frac{\gamma_i}{\gamma_j}$: As in the case we are considering …rm e¢ciency in pollution abatemnt is di¤erent between …rms, output adjustments and environmental damges are also a¤ected by this di¤erence.

But with negotiated agreements consumer surplus can increase also in case 2, given that environmental standards settled by regulation are not very tight and the additonal e¤ort in pollution abatement required to …rm by the agreemnt is signi…cant. In fact in this case the information sharing e¤ect negatively affects consumers sutplus (the "collusive e¤ect" is greater because the covariance is lower). Therefore consumer surplus can increase only if the reduction of environmental damages is so signi…cant that it can compensate the "information sharing e¤ect". Of course if the environemntal standard is already very tight - as it happens in case 3 - there is no additonal pollution abatement e¤ort that could compensate consumer for the negative information sharing e¤ect.

3.2.2 Social welfare

Concerning social welfare we follow the same analytical methodology, evaluating W both in case A and case B and then computing the di¤erence in expected social welfare, to …nd then the appropriate restrictions on parameters that guarantee that this di¤erence is positive and there is then an increase of social welfare due to a negotiated voluntary agreement. We recall the expression of social welfare: $W = \int_0^q (a - bq_i - bq_j)\, q - c_i - c_j - \frac{\delta}{2}(z_i + z_j)^2$

Case A) $I = (\bar{\omega}_i; \bar{\omega}_j)$

$z_i = z_j = z^{std} \Rightarrow D = 2\delta\left[z^{std}\right]^2$

$$W^*_A = a\left(q^*_{iA} + q^*_{jA}\right) - \frac{b}{2}\left(q^*_{iA}\right)^2 - \frac{b}{2}\left(q^*_{jA}\right)^2 - \left(\frac{\bar{\omega}_i}{\gamma_i} q^*_{iA} - \frac{\bar{\omega}_i}{\gamma_i} z^{std}\right) - \left(\frac{\bar{\omega}_j}{\gamma_j} q^*_{jA} - \frac{\bar{\omega}_j}{\gamma_j} z^{std}\right) - 2\delta\left[z^{std}\right]^2$$

Case B) $I = (\omega_i; \omega_j)$

$z_i = z_j = \alpha z^{std} \Rightarrow D = 2\alpha^2\delta\left[z^{std}\right]^2$

$$W^*_B = aq^*_{iB} + aq^*_{jB} - \frac{b}{2}\left(q^*_{iB}\right)^2 - \frac{b}{2}\left(q^*_{jB}\right)^2 - \left(\frac{\omega_i}{\gamma_i} q^*_{iB} - \alpha\frac{\omega_i}{\gamma_i} z^{std}\right) - \left(\frac{\omega_j}{\gamma_j} q^*_{jB} - \alpha\frac{\omega_j}{\gamma_j} z^{std}\right) - 2\alpha^2\delta\left[z^{std}\right]^2 =$$

$$a\left(q^*_{iA} + q^*_{jA} - \frac{\left(\frac{\Delta\omega_i}{\gamma_i} + \frac{\Delta\omega_j}{\gamma_j}\right)}{3b}\right) - \frac{b}{2}\left(q^*_{iA} + \frac{\left(\frac{\Delta\omega_j}{\gamma_j} - 2\frac{\Delta\omega_i}{\gamma_i}\right)}{3b}\right)^2 - \frac{b}{2}\left(q^*_{jA} + \frac{\left(\frac{\Delta\omega_i}{\gamma_i} - 2\frac{\Delta\omega_j}{\gamma_j}\right)}{3b}\right)^2$$

$$-\frac{\omega_i}{\gamma_i}\left(q_{iA}^* + \frac{\left(\Delta\frac{\omega_i}{\gamma_i} - 2\Delta\frac{\omega_j}{\gamma_j}\right)}{3b} + \alpha\frac{\omega_i}{\gamma_i}z^{std}\right) - \frac{\omega_j}{\gamma_j}\left(q_{jA}^* + \frac{\left(\Delta\frac{\omega_j}{\gamma_j} - 2\Delta\frac{\omega_i}{\gamma_i}\right)}{3b} + \alpha\frac{\omega_j}{\gamma_j}z^{std}\right) - 2\alpha^2\delta\left(z^{std}\right)^2$$

$E[W_B - W_A] \geq 0$ if

$$7\left(\frac{V_i}{\gamma_i}\right)^2 - 4r\frac{V_i}{\gamma_i}\frac{V_j}{\gamma_j} + 7\left(\frac{V_j}{\gamma_j}\right)^2 + 36b\delta\left(1-\alpha^2\right)\left(z^{std}\right)^2 - 18b(1-\alpha)\left(\frac{\omega_i}{\gamma_i}+\frac{\omega_j}{\gamma_j}\right)z^{std} \geq 0; \quad (34)$$

One can check that the expected increase of social welfare due to a negotiated environmental agreement depends on three components: 1) the first one is the "information sharing effect" that will always positively affect W (even if it can negatively affect consumers surplus, the impact on profits dominates) 2) the second component is the additional pollution abatement effort that causes a reduction of environmental damages (depending on α and z^{std}) and therefore positively affects social welfare3) the third component is a negative one and relates to the cost burden that society faces to reduce toxic emissions (depending not only on α and z^{std};but also on the efficiency of pollution abatement, represented by $\frac{\omega_i}{\gamma_i}$ and $\frac{\omega_j}{\gamma_j}$).

Given that a negotiated agreement mainly consist in setting α, the additonal pollution abatement effort that the industry is called to carry out to further reduce environmental damages with respect to regulation, it is interesting to find the conditions that should be sarisfied in order that α be welfare improving, given the regulatory standard and industry environmental efficiency. The analysis of last inequality leads to state the following results:

1) If $\left(\frac{\omega_i}{\gamma_i}+\frac{\omega_j}{\gamma_j}\right) < \sqrt{4\delta\frac{1}{9b}\left(7\left(\frac{V_i}{\gamma_i}\right)^2 - 4r\frac{V_i}{\gamma_i}\frac{V_j}{\gamma_j} + 7\left(\frac{V_j}{\gamma_j}\right)^2\right)}$ no value of z^{std} can be optimal and W can increase for any value of α.

2) If $\left(\frac{\omega_i}{\gamma_i}+\frac{\omega_j}{\gamma_j}\right) > \sqrt{4\delta\frac{1}{9b}\left(7\left(\frac{V_i}{\gamma_i}\right)^2 - 4r\frac{V_i}{\gamma_i}\frac{V_j}{\gamma_j} + 7\left(\frac{V_j}{\gamma_j}\right)^2\right)}$;let us consider the following treshold values of the regulatory standard and for α:

- $$\left(z^{std}\right)^- = \frac{1}{36\delta b}\left(9b\left(\frac{\omega_i}{\gamma_i}+\frac{\omega_j}{\gamma_j}\right) - \sqrt{9b\left(9b\left(\frac{\omega_i}{\gamma_i}+\frac{\omega_j}{\gamma_j}\right)^2 - 4\delta\left(7\left(\frac{V_i}{\gamma_i}\right)^2 - 4r\frac{V_i}{\gamma_i}\frac{V_j}{\gamma_j} + 7\left(\frac{V_j}{\gamma_j}\right)^2\right)\right)}\right)$$

- $$\left(z^{std}\right)^+ = \frac{1}{36\delta b}\left(9b\left(\frac{\omega_i}{\gamma_i}+\frac{\omega_j}{\gamma_j}\right) + \sqrt{9b\left(9b\left(\frac{\omega_i}{\gamma_i}+\frac{\omega_j}{\gamma_j}\right)^2 - 4\delta\left(7\left(\frac{V_i}{\gamma_i}\right)^2 - 4r\frac{V_i}{\gamma_i}\frac{V_j}{\gamma_j} + 7\left(\frac{V_j}{\gamma_j}\right)^2\right)\right)}\right)$$

- $$\alpha^\delta = \frac{1}{12b\delta\left(z^{std}\right)}\left(3b\left(\frac{\omega_i}{\gamma_i}+\frac{\omega_j}{\gamma_j}\right) - \sqrt{b\left(b\left(3\left(\frac{\omega_i}{\gamma_i}+\frac{\omega_j}{\gamma_j}\right) - 12\delta\left(z^{std}\right)\right)^2 + 4\delta\left(7\left(\frac{V_i}{\gamma_i}\right)^2 - 4r\frac{V_i}{\gamma_i}\frac{V_j}{\gamma_j} + 7\left(\frac{V_j}{\gamma_j}\right)^2\right)\right)}\right)$$

2.1) If z^{std} · $(z^{std})^{i}$ [z^{std} ¸ $(z^{std})^{+}$, then W can increase for any value of ®.

2.2) If $(z^{std})^{i}$ · z^{std} · $(z^{std})^{+}$;then W can increase only for ® **>** $®^{±}$.

If costs are very low as in case 1, it is always optimal to go behind the regulatory standard, further reducing toxic emission. Thus any negotiated agreemnt will induce an increase of social welfare. Actually what happens is that the aggregate social bene…ts of the VA - due to information sharing and to the reduction of environmental damages- will easily compensate environmental costs from the social point of view. Concerning, information sharing the net e¤ect is always positive, as the positive e¤ect on pro…ts always compensate the negative e¤ect on consumer surplus. Concerning environmental damages, even accounting for cases in which its reduction may not be wide - an high value of ® with respect to a tight z^{std}- one must always consider that cost are always low enough to induce a positive net e¤ect on W. On the contrary for signi…cant additional pollution abatement levels - a tight value of ® with respect to a loose level of z^{std}- the reduction of environmental damages will easily compensate the increase of environmental costs, as cost are low.

When costs become higher, as in case 2.1, either the environmntal standard is already tight and then the cost burden can never be such to exceed the environmental bene…ts, given that the additional pollution abatement e¤ort is bounded, or the environmental standard is loose and there can be additional environmental e¤orts that imply a heavy cost burden for society, but in the meantime a great reduction of environmental damages that bene…t consumers.For intermediate levels of the regulatory standards (case 2.2), the additonal pollution abatement e¤orts cannot imply a further reduction of emissions above the treshold $®^{±}$ as going behind this tresholf would imply too heavy a cost burden with resepct to the ben…ts of information sharing and of enevironmental damages reduction.

4 Conclusions

The results that we have presented add to the past literature in providing explanations for the fact that …rms may be willing to subscribe to VAs in spite of the fact that any commitment to overcompliance with respect to mandatory standards implies an increase in environmental costs that …rms incur voluntarily. Not only have we supposed the existence of green preferences that drive …rms to reduce the environmental impact of their activities, but we have also shown that any VA has an important information sharing function that a¤ects competition in such a way to let …rms'pro…ts increase in any case. Thus even if …rms would be willing to accept an increase in their environmental costs, in order to satisfy consumer preferences, even without subscribing to a VA, they prefer to enter into such a negotiation with their competitor and the public administration especially when they face a situation of shared uncertainties with respect to environmental technologies. The examples that we have given in our introduction show that this situation characterises some important environmental issues that are on the policy agenda. The environmental effectiveness of new technologies or their actual cost are often uncertain not only for consumers and for public adminstration officers but also for firms that are directly involved in their use. That is why in the environmental field shared uncertainty may be as relevant as asymmetric information between firms and consumers or between firms and public authorities.

Even if information sharing about environmental technologies may be justified on these grounds, we have shown that it can also affect competition in an oligopolistic market. Imperfect knowledge about environmental costs prevents firms from achieving the Cournot equilibrium, as firms cannot properly adjust their output level to their own cost and to the cost of their opponent. On the contrary, entering a VA and sharing information gives firm this opportunity. Even excluding that firms will collude, the output adjustments that are carried out to reach a Cournot equilibrium are partly "collusive" to the extent that any firm adjusts its own production to the production that its opponent is expected to choose. Thus information sharing changes the distribution of output between firms and while profits are always enhanced by this effect consumer surplus may on the contrary suffer a contraction. Except when firms costs are highly correlated. In this last case either information sharing lead both firms to expand output or to contract it. In fact consumer surplus can increase even with a contraction of output, because such a contraction implies lower environmental damages and an higher willingness to pay by consumers. On the contrary total welfare always increases with information sharing as the positive impact on profits is always such to compensate the contraction of consumer surplus when the covariance between costs is low or negative.

When we come to consider the case of negotiated agreement within firms and the public administration we can see that firms are incited to go behind regulatory standards, either when these standards are not very tight and the additional pollution abatement effort remains under a given treshold, or when regulatory standards are already very tight. Our intuition for this result is that in the case of tighter standards firms are already bearing a significant cost burden to comply with regulation. Therefore the perspective of a negotiated agreemnt is good news for them, as they can get the benefits of information sharing with only a modest increase of environmental costs. Concerning the impact of negotiated agreemments on consumers, we can see that not only consumers benefit from a VA when the "collusive" effect is reduced (as we already noticed in the case of unilateral committments), but they can get further due to the reduction of environmental damages even when the "collusive" effect dominates. However these benefits benefits should be substantial as in this cases ana increase of consumer surplus requires that the regulatory standard be loose and the additional effort in pollution abatement be significant. Let us then notice that if the regulatory standard is already very tight, firms can still benefit from a negotiated agreement, while the net effect on consumers would be negative. On the contrary with a loose standard both consumers and firms can benefit from a negotiated agreement, but their interests are in conflict for what concerns the extent of the additional effort concerning pollution abatement. That is why we see a relevant bargaining issue concerning the level of this effort.

As far as social welfare is concerned, negotiated agreements contribute to increase it the cost of pollution abatement is not too high. We find that if the industry is very efficient from th point of view of pollution abatemnt, no regulatory standard can be considered optimal and any additional effort to reduce emissions positively affects social welfare. For less efficient industries the optimality of negotiated agreements depends on the regulatory standards. If regulatory standards are either very tight or very loose a negotiated agreement is welfare improving no matter what is the level of the additional pollution abatement effort required. For intermediate levels of the regulatory standard, welfare increases only if the additional effort is scarce. In this last case consumer surplus is not increasing (with the exception of the case in which the "collusive" effect is not relevant). Therefore, in order to obtain a welfare improvement, there should be a huge profit increase, that in turn will be connected to a relevant "information sharing effect" and to a tiny additonal effort in pollution abatement.

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