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Voluntary Environmental Initiatives as Collusive Institutions

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Abstract

This paper studies industry-wide voluntary pollution prevention initiatives in repeated oligopolies. If firms commit to report emissions and emissions are linked to output, voluntary initiatives may allow firms to attain a level of collusion in the product market that would not be possible otherwise. Three initiative designs are considered to analyze what extent of industry's involvement in policy decision making can improve welfare. When firms are able to coordinate on pollution prevention and emissions, prevention levels are voluntarily set above the status quo to deter deviations from the joint-profit maximizing output. However, some degree of centralization is necessary to approximate social optimality under a voluntary initiative.

JEL Classification Numbers: C72, D21, L13, L50, Q28.
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1 Introduction

The difficulties a real-world oligopolist experiences in observing its rivals' actions undermine tacit collusion. In consequence, businesses have the incentive to develop or adopt institutions that facilitate monitoring and collusion. Hundreds of firms have engaged in collective initiatives designed to prevent pollution throughout the 1990s. Industrial organizations have developed their own environmental standards, and a considerable number of companies have joined one or more of the voluntary pollution prevention programs designed by the U.S. Environmental Protection Agency (EPA). This paper argues that voluntary pollution prevention initiatives (VIs) function as institutions that may allow firms to attain a level of collusion in the product market as long as the programs' members reports emissions and emissions are technologically linked to output.

Were collusion costless, firms would not invest in pollution prevention in order to coordinate their decisions. However, sustaining collusion requires that firms know when a defection occurs and who is responsible. In practice, such information is imperfect or unavailable. In Green and Porter (1984) when firms do not observe their rivals' output but a stochastic market price, episodes of low prices recur even in the absence of defection. Sustaining collusion is even more difficult if firms receive private signals, for example, idiosyncratic prices. Kandori and Matsushima (1998)and Compte (1998) have suggested that maintaining full collusion in such circumstances requires explicit communication between the firms to generate a shared history on which to coordinate their actions.

Given the difficulty in sustaining full collusion, firms may be willing to trade off the cost of pollution prevention with the benefits of an institution that gathers information, coordinates and monitors actions, and provides data on which firms are able to base their decisions. Voluntary environmental initiatives launched by the EPA, in many cases in conjunction with trade associations, act as this institution.[1]

The EPA states that one of the primary goals of VIs is "to invoke behavioral change" and to implement "industry cooperative projects" (USEPA, 1998). Although the EPA refers to environmental issues, VIs favor other forms of coordination as well. The members of the programs commit to submit progress and achievements reports making possible the monitoring of their emissions. As long as emissions are linked to production, VIs offer a mechanism to detect departures from an agreed-upon level of output. Voluntary programs also offer multiple occasions for contact and communication among the industry's members, and the standardization of technologies further facilitates coordination upon prices and output levels.

Although the hypothesis that firms may use VIs as collusive institutions has not been empirically investigated, there exists anecdotal and statistical evidence consistent with this hypothesis. One may expect firms that consider using a VI to facilitate collusion to decide jointly whether to participate in a program or not. Companies that are members of the Chemical Manufacturers Association are more likely to join the EPA's program 33/50[2] and *less* likely to join the pro-

[1]The fundamental role of information and coordination to sustaining implicit collusion has been documented by Genesove and Mullin (2001) in the case of the trade association of the sugar industry in the United States from 1927 to 1936. The association implemented costly explicit agreements on business practices to facilitate implicit collusion in the product market. See Vives (1999) for additional references on the role of communication and trade associations in collusion.

[2]The goal of 33/50 was the aggregate reduction of releases and transfers of 17 chemicals by 33 percent in 1992 and by 50 percent in 1995, relative to baseline 1988 levels. Once 1995 data

gram WasteWi$e[3] than nonmembers (Khanna and Damon [1999], and Videras and Alberini [1999]), and in some programs partners represent a large percent of the industry.[4] In addition, if firms use VIs to coordinate in the product-market, participation should be higher in industries with large barriers to entry. Indeed, industry-wide advertising expenditures are a positive and statistically significant predictor of participation in the program 33/50 (Arora and Cason [1996]).

The literature on VIs typically assumes that participation is the result of individual benefit-cost analysis. It is hypothesized that firms benefit from improved company image and preempting regulation. However, returns from green consumerism should also accrue to firms adopting standards independently. In fact, individual firm's benefits from increased consumer confidence dissipate as the number of members increases since demand for green products is limited. Therefore, this hypothesis does not actually explain *collective* environmental self-regulation.[5] In regard to the regulatory preemption hypothesis, in the U.S. experience companies are not penalized if they drop the programs and *no* program is publicized as an alternative to more stringent regulation.[6]

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revealed 33/50 accomplished its goals, the program ended with 1300 recognized partners.

[3]The aim of WasteWi$e is the reduction of solid waste such as office paper, corrugated containers, yard trimmings and packaging. The vague link between these pollutants and production activities may explain why CMA members are less willing to join WasteWi$e than 33/50. See Videras and Alberini (2000).

[4]For example, the Voluntary Aluminum Industry Program Partners take over 94 percent of the U.S. primary aluminum production capacity, Natural Gas Star Program Partners represent over 65 percent of the transmission company pipeline miles and over 35 percent of U.S. natural gas production, and over 50 percent of the U.S. cement manufacturing capacity have joined the Climate Wise Program.

[5]Interestingly, of six Canadian and U.S. industry associations studied by Labatt and Maclaren (1998) only in one case public image was a dominant factor for participation in VIs.

[6]Labatt and Maclaren (1998) note that among the six associations they studied only the Ontario Printing and Imaging Association considered the threat of regulations in its decision to join a VI.

Rather than assuming that reputation and preemption factors are the driving factors in the formation of VIs, in this paper firms trade off the cost of pollution prevention with the benefits of collusion in the product market. Section 2 presents a two-stage model. In stage one (at time zero) the firms decide whether to join a VI and adopt the agreed upon level of pollution prevention. In the second stage (at time periods one and beyond), the firms compete in quantities taking pollution prevention techniques as given.

To analyze to what extent firms' self-interest can be used to improve environmental practices, sections 3, 4 and 5 consider three VI designs that vary on the degree of partnership between the agency and the industry. In a Centralized Voluntary Initiative (CVI) the agency sets both pollution prevention and emissions that are socially optimal under a VI and challenges businesses to join the initiative. Hence, a CVI is the benchmark that provides what the agency could ideally achieve (given the nature of these initiatives) were it not constrained by imperfect information and political considerations. In the second design, a Partially Centralized Voluntary Initiative (PCVI), the agency concedes some power to the firms in the decision making process. The agency sets pollution prevention techniques, invites companies to adopt the new practices and reports prevention practices and emissions of member firms. The third design explores under what circumstances the agency can forgo complete control over the initiative and improve welfare. In a Decentralized Voluntary Initiative (DVI) the firms decide on both emissions and prevention practices; and the agency reports emissions of member firms. Table 1 summarizes the scenarios and indicates the sections in which they are studied.

Table 1: Designs of Voluntary Initiatives

Initiative	Pollution prevention	Emissions	Section
Centralized	Agency	Agency	3
Partially Centralized	Agency	Firms	4
Decentralized	Firms	Firms	5

2 The model

Members of EPA's voluntary programs (1) sign a (non-binding) agreement with the agency; (2) designate a manager to oversee implementation and maintain contact with the EPA; (3) establish goals; and (4) identify cost-effective opportunities to achieve the goals. These requirements impose one-time administrative and set-up costs designated K. Goals are achieved by adopting pollution prevention techniques that lead to emissions reductions. The level of pollution prevention is denoted θ.[7] The increment in marginal cost of production at prevention level θ is denoted $t(\theta)$. It is assumed that $t_\theta(\theta) \geq 0$ and $t_{\theta\theta}(\theta) \geq 0$. It is also assumed that $t_\theta(0) = 0$, reflecting the presumption that once fixed costs are paid, initial marginal reductions of emissions occur easily.[8] Pre-participation prevention levels are normalized to zero, that is, $t(0) = 0$.

[7] For example, under the program 33/50 partners prevented emissions of chlorinated solvents through operational improvements of conventional processes, solvent substitution, recycling and recovering, and the adoption of alternative technologies.

[8] Pollution prevention can be accomplished by minor add-on improvements of conventional technologies, stewardship and training of workers. Therefore it is reasonable to presume that the first increment over the status quo in prevention efforts has a negligible impact on the firm's marginal cost once the fixed costs are paid. In the metal-finishing industry, for example, prevention efforts to reduce the use of chlorinated solvents in cleaning or degreasing can take the form of increasing the width of the tank opening where degreasing is completed.

The members' pollution prevention techniques are observable.[9] However, in order to use a VI to coordinate in the product-market the firms need to know their rivals' output. Firms can infer output if in addition to reporting θ, firms disclose emissions.[10] It is assumed that the emissions function $e(q, \theta)$ has the following properties

$$e_q(\cdot) > 0, \quad e_{qq}(\cdot) \geq 0, \quad e_\theta(\cdot) < 0, \quad e_{\theta\theta}(\cdot) \leq 0, \quad e_{q\theta}(\cdot) < 0, \quad \text{and} \quad e_\theta(q, 0) < 0.$$

Since $e_q > 0$, there exist an inverse function $q = e^{-1}(e; \theta)$, such that a firm's output can be inferred from the public and truthful disclosure of θ and e. Normalizing the monetary cost per unit of pollutant to one, damage from total emissions is $D = \sum_{i=1}^{n} e(q_i, \theta_i)$ for $i = 1, ..., n$.[11]

The product market consists of n symmetric firms that engage in a two-stage game.[12] In stage one (at time zero), the firms decide whether or not to join a VI, pay the one-time cost K, and adopt pollution prevention level $\theta \geq 0$. In the second stage (at time periods one and beyond) the firms compete in quantities taking θ as given. In a CVI and PCVI the agency reports prevention practices and emissions. In a DVI the agency only discloses emissions. The inverse market

[9] The members' prevention practices are frequently made available through videos, bulletins, handbooks, and software. In addition, the cost-effectiveness and technical feasibility of preferred technologies are demonstrated in seminars and workshops to facilitate coordination in the firms' decisions to adopt pollution prevention techniques.

[10] In the case of 33/50 this aspect was facilitated by the listing of targeted toxic substances in the Toxic Release Inventory (TRI). Although data in the TRI are believed to contain noise, the results of the model would remain unchanged so long as firms within an industry know or have a common prior probability over the distribution of noise.

[11] Although a convex damage function would be customary, I assume that damages are additive in per-firm emissions for tractability.

[12] It is assumed that there are substantial barriers to entry so that the threat of entrants is not an issue.

demand is given by $P : \mathcal{R}_+ \rightarrow \mathcal{R}_+$. Production cost is $C : \mathcal{R}_+ \rightarrow \mathcal{R}_+$, where $C(q)$ is assumed to be increasing. To guarantee the existence of an equilibrium in the second stage it is assumed that (i) marginal revenue is strictly decreasing: $P' + qP'' < 0$, and (ii) $C_{qq} - P' > 0$.

In the absence of collusion in the product market, an equilibrium for the infinite-horizon market game consists of repeating the single-period Cournot equilibrium in which each firm sets $\theta^{CN} = 0$, produces q^{CN} and earns single-period profits π^{CN}. In a collusive regime each firm produces q^* that maximizes the industry's joint-profits and solves

$$P(nq^*(\theta)) + nq^*(\theta)P'(nq^*(\theta)) - C_q(q^*(\theta)) - t(\theta) = 0, \qquad (1)$$

so that firms with a sufficiently high discount factor would participate in any initiative that allowed them to decide on the level of emissions (or output) given θ.

3 A Centralized Voluntary Initiative

Consider a centralized initiative in which only participation is voluntary. The environmental agency establishes specific prevention standards and emissions levels or, equivalently, prevention standards and output. The agency's objective is to maximize social welfare [13] subject to the incentive compatibility (IC) constraint

[13] It is not obvious that a VI would improve welfare. On the one hand, it results in less aggregate output and higher prices. On the other hand, the firms' profits increase and both pollution prevention efforts and the drop in output reduce emissions. Appendix B presents the conditions under which a VI does improve social welfare. Those conditions are assumed to hold throughout the following sections.

that the present value of participation for each firm is greater than or equal to the present value of not accepting the agency's scheme: $\pi(q,\theta)-(1-\delta)K \geq \pi^{CN}$.[14] A slack IC constraint would imply that the firms are strictly better off participating in the initiative. Participation gains may result from increments in price whose effect on profits is not fully offset by the greater cost of pollution prevention.

Defining social welfare as the sum of consumer and producer surplus minus the dollar value of environmental damages, the agency chooses q and θ that solve

$$\text{Max} \quad W(nq,\theta) = \int_0^{nq} P(z)dz - nC(q) - nqt(\theta) - nK - ne(q,\theta)$$
$$\text{subject to:} \quad \pi(q,\theta) - (1-\delta)K \geq \pi^{CN}.$$

The Lagrangian is:

$$\begin{aligned} L(nq,\theta) = & \int_0^{nq} P(z)dz - nC(q) - nqt(\theta) - nK - ne(q,\theta) - \\ & - \lambda[\pi(q,\theta) - (1-\delta)K - \pi^{CN}]. \end{aligned}$$

The first-order conditions of the problem are:

$$\frac{\partial L}{\partial q} \equiv n[P(nq) - C_q(q) - t(\theta) - e_q(q,\theta)] - \lambda[nqP'(nq) + P(nq) - C_q(q) - t(\theta)] = 0,$$
$$\frac{\partial L}{\partial \theta} \equiv -nqt_\theta(\theta) - ne_\theta(q,\theta) + \lambda qt_\theta(\theta) = 0,$$
$$\lambda \geq 0, \quad \pi(q,\theta) - (1-\delta)K \geq \pi^{CN}, \quad \lambda[\pi(q,\theta) - (1-\delta)K - \pi^{CN}] = 0.$$

[14] I also assume that it is not feasible to alter the structure of the market.

Let θ^o and q^o be the socially optimal levels of pollution prevention and output that solve the conditions above.[15] The following lemma states under what circumstances the agency sets the IC constraint binding.

Lemma 1 *The IC constraint is binding if and only if at the optimum the marginal impact on environmental quality of reducing output is larger than the net marginal effect on market surplus; that is,* $\lambda > 0$ *if and only if* $e_q(q^o, \theta^o) > P(nq^o) - C_q(q^o) - t(\theta^o)$.

Were marginal environmental benefits less than the reduction in market surplus, the initiative would not be implemented. If marginal environmental benefits of reducing output are larger than the marginal effect on market surplus then it is socially optimal to increase θ and extract the firms' participation gains so long as the IC constraint is not violated.

Consider the solution corresponding to a nonbinding IC constraint, that is, $\lambda = 0$. The optimal levels of output and prevention are given by

$$P(nq^o) - C_q(q^o) - t(\theta^o) - e_q(q^o, \theta^o) = 0, \tag{2}$$

$$-e_\theta(q^o, \theta^o) = q^o t_\theta(\theta^o). \tag{3}$$

Equation (2) indicates that at the socially efficient output and pollution prevention levels, the net market surplus that is lost as a result of a marginal reduction in q is equal to its marginal benefit on environmental quality. Note that if the market quantity distortion and the marginal environmental benefit of reducing q balance out at (q^o, θ^o) then condition (2) implies that q^o maximizes the industry's

[15] Socially optimality refers here to the levels that can be attained in any voluntary initiative. Note also that I assume that the equilibrium is symmetric, stationary and credible.

joint-profits given θ. Equation (3) shows that the marginal benefit of increasing θ is equal to the marginal cost borne by the firms.

Suppose now that $\lambda > 0$, that is, the firms' participation gains are entirely extracted. The optimal levels of output and prevention are given by the system of equations

$$P(nq^o)q^o - C(q^o) - t(\theta^o)q^o = \pi^{CN} + (1-\delta)K, \tag{4}$$

$$-e_\theta(q^o, \theta^o) = q^o t_\theta(\theta^o) \frac{e_q(q^o, \theta^o) + nq^o P'(nq^o)}{P(nq^o) + nq^o P'(nq^o) - C_q(q^o) - t(\theta^o)}. \tag{5}$$

Equation (4) indicates that the IC constraint is binding. Equation (5) shows that the marginal benefit of increasing θ is equal to the marginal cost borne by the firms weighed by the relative impact of a larger θ on surplus, environmental quality and profits.

Information requirements as well as political factors would imperil the success of a Centralized Voluntary Initiative. Section 4 and Section 5 study to what extent the agency can forgo control over the initiative and rely on the firms' self-interest to approximate socially efficient levels of θ and emissions under a VI. (Table 2 summarizes the necessary conditions for an optimum under each of the three scenarios.)

4 A Partially Centralized Voluntary Initiative

Consider now an initiative in which the agency sets pollution prevention techniques and invites companies to adopt the new practices. The firms that join the initiative decide on that level of emissions that maximizes joint-profits taking θ as given. The agency observes prevention practices and emissions of member firms and chooses θ that solves

$$\text{Max} \quad W(nq^*(\theta), \theta) = \int_0^{nq^*(\theta)} P(z)dz - nC(q^*(\theta)) - nq^*(\theta)t(\theta) - nK - ne(q^*(\theta), \theta),$$

where $q^*(\theta)$ maximizes joint-profits given θ. The first-order condition

$$-e_\theta(q^*(\theta), \theta) - q^*(\theta)t_\theta(\theta) + \frac{dq^*(\theta)}{d\theta}[P(nq^*(\theta)) - C_q(q^*(\theta)) - t(\theta) - e_q(q^*(\theta), \theta)] = 0 \tag{6}$$

indicates that the marginal benefit of increasing θ and reducing emissions is equal the marginal costs borne by the firms plus the net effect on social welfare weighed by the impact of θ on the industry's output.

Let $\hat{\theta}$ be the level of pollution prevention that solves (6). To facilitate the comparison with the CVI, rearrange (6) as follows:

$$-e_\theta(q^*(\hat{\theta}), \hat{\theta}) = q^*(\hat{\theta})t_\theta(\hat{\theta}) + \frac{dq^*(\hat{\theta})}{d\theta}[nq^*(\hat{\theta})P'(nq^*(\hat{\theta})) + e_q(q^*(\hat{\theta}), \hat{\theta})], \tag{6'}$$

where I have used condition (1) to express the net effect on social welfare of reduced output as the sum of environmental benefits plus the market quantity distortion.

4.1 Partially Centralized versus Centralized Initiative

Comparing conditions (1) and (6′) with (2)-(3) and (4)-(5), the following proposition follows:

Proposition 1 *A Partially Centralized Voluntary Initiative can approximate the socially optimal levels of both θ and emissions if and only if the market quantity distortion and marginal environmental benefits balance out at the optimum.*

If marginal environmental benefits and market quantity distortion balance out, then the agency's interest and the industry's coincide, that is, conditions (2) and (1) are identical and $q^o(\theta) = q^*(\theta)$ given θ. Furthermore, the net cost of increasing θ that it is borne by society as a whole is zero, while social optimality requires the marginal benefit of increasing θ to be equal to the marginal cost borne by the firms. In that case, $(3) = (6')$ and $\hat{\theta} = \theta^o$ and $q^o = q^*(\hat{\theta})$.

If the agency's interest and the industry's differ then a PCVI is likely to provide less output than a CVI. Moreover, if the firms planned to reduce output by a large amount then the agency would set $\hat{\theta}$ larger than otherwise to obtain benefits from pollution prevention that are sufficient to balance out the reduction in net market surplus (that is, prevention efforts per unit of output will tend to be higher the larger the output reduction intended by the industry). Consequently, a PCVI would result in lower emissions than a CVI but the market quantity distortion would be larger than it would be socially acceptable under perfect information and no political constraints.

5 A Decentralized Voluntary Initiative

Firms that join a decentralized VI are able to coordinate their decisions on both pollution prevention level and emissions (or, alternatively, output). Regarding the choice of pollution prevention techniques, the agency, firms and industry associations collaborate to gather information that provides a common benchmark that allows businesses to coordinate their choices. The disclosure by the agency of per-firm emissions allows firms to identify deviations from the agreement.

The next subsection uses the solution concept of subgame perfection to calculate the equilibria in the infinite-horizon quantity game.[16] Subsection 5.2 determines the Nash equilibrium in θ.

5.1 Equilibria in the repeated market game

Let $\pi^*(\theta)$ be single-period profits earned by each individual firm at q^* that solves equation (1); and $\pi^d(\theta)$ the single-period payoff for a firm when cheating optimally against the cartel. Note that $d\pi^*(\theta)/d\theta$ is less than or equal to 0,[17] and $d\pi^d(\theta)/d\theta \geq 0$.[18] There exits a $\overline{\theta}$ such that $\pi^*(\overline{\theta}) = \pi^{CN}$. That is, at $\overline{\theta}$ cartel profits would not be large enough to cover the fixed cost K so that firms would choose the business-as-usual equilibrium.

In case of defection participants of a VI resort to a "grim trigger" strategy.[19] Suppose $K \geq \pi^d(\theta) - \pi^{CN}$, for $\theta \in [0, \overline{\theta})$. Then, the discount factor at which profit-maximizing firms can support an agreement is $\delta(\theta) \geq 1 - \frac{\pi^*(\theta) - \pi^{CN}}{K}$. Suppose now that $K < \pi^d(\theta) - \pi^{CN}$, for $\theta \in [0, \overline{\theta})$. Then, the discount factor that supports an agreement is $\delta(\theta) \geq \frac{\pi^d(\theta) - \pi^*(\theta)}{\pi^d(\theta) - \pi^{CN}}$.

In both cases $d\delta(\theta)/d\theta > 0$. The more intensive pollution prevention is, the

[16]Subgame perfection guarantees that a collusive outcome is self-enforcing.

[17]Using the Envelope Theorem, $\frac{d\pi^*(q^*(\theta),\theta)}{d\theta} = \frac{\partial \pi^*(q^*(\theta),\theta)}{\partial \theta} = -q^* t_\theta(\theta)$, that is less than or equal to zero.

[18]Given the nature of the investment in pollution prevention, production processes are not affected irreversibly. In this case, a deviator sets $\theta = 0$. Since the partners' output decreases with θ, defection profits increase in the rivals' prevention costs.

[19]Appendix A presents the details of a "grim trigger" strategy and the derivation of the minimum discount factor that sustains collusion.

larger is the minimum discount factor at which collusion in the product market is feasible. Also, the larger the administrative and set-up costs of participation, the less likely is that firms will join a VI. This result captures the observed fact that the funding of start-up costs by large firms and the agency is necessary for the success of the initiative and participation of small businesses (Reinhardt [2000]).

5.2 Equilibrium in the prevention level game

Since participation profits $\pi^*(\theta)$ are strictly decreasing in θ, the firms has the incentive to set prevention levels close to zero. However, it could be possible for a firm to expand output and go unnoticed by increasing, covertly, pollution prevention so that emissions are kept at the agreed-upon level. Consequently, the firms would want to set the minimum level of prevention that deters deviation. In particular, they would choose θ^* such that the increase in output needed to continue emitting $e^* = e(q^*, \theta^*)$ with more intense prevention efforts is insufficient to maintain profits at least at π^* after the increase in θ. Technically, the firms would agree upon the level of pollution prevention that equalizes the slopes of the isoemissions and isoprofits curves. The slope of the isoemissions curve is given by the marginal rate of transformation $MRT = \frac{dq}{d\theta} \mid_{e=e^*} = -\frac{e_\theta(q^*(\theta),\theta)}{e_q(q^*(\theta),\theta)}$. The increase in q that is needed to maintain profits at least at the joint-profit maximizing level after a marginal increase in θ is given by the marginal rate of substitution $MRS = \frac{dq}{d\theta} \mid_{\pi=\pi^*} = -\frac{\pi_\theta(q^*(\theta),\theta)}{\pi_q(q^*(\theta),\theta)}$.

Hence, θ^* solves:

$$-\frac{e_\theta(q^*(\theta^*),\theta^*)}{e_q(q^*(\theta^*),\theta^*)} = \frac{q^*(\theta^*)t_\theta(\theta^*)}{P(nq^*(\theta^*)) + q^*(\theta^*)P'(nq^*(\theta^*)) - C_q(q^*(\theta^*)) - t(\theta^*)} \tag{7}$$

Since I have assumed that $t_\theta(0) = 0$ and $e_\theta(q, 0) > 0$, it follows that $\theta^* > 0$, that is, the equilibrium involves prevention efforts above the status quo. The intuition behind the result is that it would be optimal for firms to defect unless θ^* was set above the level at which inexpensive operational improvements are available. Therefore, a decentralized VI that functions effectively as a collusive institution will also improve environmental practices.

Another question of interest is whether industry concentration favors or hinders collusion and the formation of VIs. In standard repeated oligopoly models as concentration rises the minimum discount factor that maintains collusion decreases (Martin [1993]). Likewise, Bruno and Carraro (1999) show that industry concentration facilitates collusion and the formation of voluntary initiatives to prevent pollution. Contrary to these analyses, in this paper collusion imposes explicit (pollution prevention investment) costs. The following proposition states that the influence of industry concentration on θ^* depends on the relative costs and benefits of defection.

Proposition 2 *Concentration is more likely to hinder collusion in the product market the larger is the rate of change of the slope of the isoemissions curve* $(\frac{e_{\theta\theta}(\cdot)}{e_\theta(\cdot)} - \frac{e_{qq}(\cdot)}{e_q(\cdot)}\frac{dq}{d\theta})$ *relative to the rate of change of the slope of the isoprofits curve* $(\frac{t_{\theta\theta}(\cdot)}{t_\theta(\cdot)} - \frac{\pi_{qq}}{\pi_q}\frac{dq}{d\theta})$.

First, note that a firm that cheats in a highly concentrated market would expand output over cartel's levels by more than a firm in a less concentrated industry would. For the benefit of intuition suppose that $e_{qq}(\cdot) = t_{\theta\theta}(\cdot) = 0$ and demand and emissions (with respect to θ) are concave. Since $e_q(\cdot)$ and $t_\theta(\cdot)$ are linear it would be relatively less expensive to deviate and adopt more intense pollution prevention practices that it would be if emissions (with respect to q) and prevention costs were convex. Therefore, the firms ought to agree upon a sufficiently high θ^* to prevent defection. Suppose on the contrary that $P''(\cdot) = e_{\theta\theta}(\cdot) = 0$ and emissions (with respect to output) and $t(\theta)$ are convex. A large increase in output is relatively less profitable and the cartel in a more concentrated market would agree upon a lower θ^*. Hence, industry concentration may either favor or hinder collusion and the formation of VIs.[20] [21]

5.3 Decentralized Voluntary Initiative versus Centralized Initiative

In order to compare these initiatives it is helpful to write condition (7) as

$$-e_\theta(q^*, \theta^*) = q^* t_\theta(\theta^*) \frac{e_q(q^*, \theta^*)}{P(nq^*) + q^* P'(nq^*) - C_q(q^*) - t(\theta^*)}. \tag{7'}$$

The next result follows.

Proposition 3 *A Decentralized Voluntary Initiative can not approximate the socially optimal levels of both emissions and θ.*

[20] Arora and Cason (1996) find that the Herfindahl index is a *negative* predictor of participation in the 33/50 program, although the estimated coefficient is not statistically significant at the conventional levels.

[21] The existence of $\theta^* < \overline{\theta}$ cannot be guaranteed. Were $\theta^* \geq \overline{\theta}$ the cartel would not form unless the partners and agency decided to monitor prevention efforts as well as emissions. In practice, EPA's programs like 33/50 require the partners to submit annual progress reports that include pollution prevention practices. The agency, nonetheless, reports only "successful" efforts. Denote $\theta^s (< \overline{\theta})$ the minimum level of prevention that is considered "successful" by the agency. The disclosure of $\theta \geq \theta^s$ implies that a firm cannot undertake efforts equal to or larger than θ^s and maintain simultaneously emissions at e^* without being detected and punished. This imposes a kink on the isoprofits curve: it is not possible to increase θ beyond θ^s and maintain the cartel payoff. In consequence, firms adopt θ^* if $\theta^* < \overline{\theta}$; otherwise they undertake pollution prevention efforts θ^s.

First, consider the case in which the market's quantity distortion and marginal environmental benefits balance out at the optimum. The agency's and the firms' solution for $q(\theta)$ given θ coincide, (2) = (1). Social optimality requires the marginal benefit of higher prevention levels to be set equal to the marginal cost to the firms of adopting those levels. In a DVI, however, the firms set θ^* such that the cost borne by the firms is less than the marginal environmental benefit of increasing θ. Therefore, (3) $\neq$ (7′). Compare now conditions (5) and (7′). The equations are identical except for the term $nq^oP'(nq^o)$ in (5) that captures the agency's concern with market quantity distortion. Were $\theta^o = \theta^*$ and $q^o = q^*$ then the left-hand side of (5) would be less than its right-hand side. In sum, either the firms agree upon a level of θ that is lower than the level that equalizes marginal benefit and marginal costs of pollution prevention or the firms exacerbate the market quantity distortion above what is socially optimal.

5.4 Decentralized Voluntary Initiative versus Partially Centralized Initiative

If social optimality is unattainable, could the agency nonetheless forgo complete control over the initiative and approximate the outcome of a PCVI? The next proposition states the conditions under which the level of pollution prevention voluntarily agreed upon by the firms can approximate $\hat{\theta}$.

Proposition 4 *A Decentralized Voluntary Initiative can approximate pollution prevention and emissions levels of a Partially Centralized Voluntary Initiative if at the optimum marginal environmental benefits are relatively less important than the market quantity distortion.*

If at $(q^*(\hat{\theta}), \hat{\theta})$, marginal environmental benefits are less important than the quantity distortion, social optimality would require the agency to set a $\hat{\theta}$ lower than otherwise by condition (5). Since the firms agree upon a level of θ such that the cost borne by the firms is less than the marginal environmental benefit of increasing θ, a DVI could result in $\hat{\theta}$ equal to θ^* while eliminating the cost of gathering information and easing political constraints.

Table 2: Optimal Conditions

CVI	$(\lambda = 0)\ P(nq^o) - C_q(q^o) - t(\theta^o) - e_q(q^o, \theta^o) = 0$ (2) $-e_\theta(q^o, \theta^o) = q^o t_\theta(\theta^o)$ (3)
	$(\lambda > 0)\ P(nq^o)q^o - C(q^o) - t(\theta^o)q^o = \pi^{CN} + (1-\delta)K$ (4) $-e_\theta(q^o, \theta^o) = q^o t_\theta(\theta^o) \frac{e_q(q^o,\theta^o) + nq^o P'(nq^o)}{P(nq^o) + nq^o P'(nq^o) - C_q(q^o) - t(\theta^o)}$ (5)
PCVI	$P(nq^*(\theta)) + nq^*(\theta)P'(nq^*(\theta)) - C_q(q^*(\theta)) - t(\theta) = 0$ (1) $-e_\theta(q^*(\hat{\theta}), \hat{\theta}) = q^*(\hat{\theta})t_\theta(\hat{\theta}) + \frac{dq^*(\hat{\theta})}{d\theta}[nq^*(\hat{\theta})P'(nq^*(\hat{\theta})) + e_q(q^*(\hat{\theta}), \hat{\theta})]$ (6′)
DVI	$P(nq^*(\theta)) + nq^*(\theta)P'(nq^*(\theta)) - C_q(q^*(\theta)) - t(\theta) = 0$ (1) $-e_\theta(q^*, \theta^*) = q^* t_\theta(\theta^*) \frac{e_q(q^*,\theta^*)}{P(nq^*) + q^* P'(nq^*) - C_q(q^*) - t(\theta^*)}$ (7′)

6 Summary

This paper considers voluntary pollution prevention initiatives in repeated oligopolies. If firms report emissions and emissions are linked to output, firms can voluntarily adopt prevention efforts above the status quo to attain a level of collusion in the product market that would not be possible otherwise. Therefore ”green” reputation and regulatory preemption factors are not necessary to explain the formation of VIs, although they may play a role in some initiatives.

Three designs are analyzed to study what extent of industry's involvement in policy decision making is welfare-enhancing. Were it possible for the agency to gather accurate information about pollution prevention technologies and verify compliance with technology standards, a Partially Centralized Voluntary Initiative would be preferred over a Decentralized Voluntary Initiative since the agency could in that instance set prevention levels that approximate those that achieve social efficiency. However, if it is believed that the firms have hidden knowledge about the availability and effectiveness of prevention technologies then a Decentralized Voluntary Initiative might be preferred over a Partially Centralized Voluntary Initiative. Not only would a DVI improve pollution prevention practices above the status quo but if the initiative took place the firms might under certain conditions set a high θ to prevent deviations (Proposition 2) and approximate pollution prevention and emissions levels of a PCVI (Proposition 3).

I assume identical firms. However, differences in production capacity and pollution prevention costs may play an important role in the use of VIs as a collusive mechanism. Firm heterogeneity would require computing a set of subgame perfect equilibria in the infinite-horizon game consisting of aggregate output and a market-sharing rule. Assuming symmetric firms also implies that firms decide unanimously whether or not to join a VI. Nonetheless, firm participation is rarely universal. An interesting extension would be to explain how the equilibrium is reached in an industry in which participants do not want to drop the program and nonparticipants do not desire to join it.

7 Appendix A: Equilibria in the repeated quantity game

The following "grim trigger" strategy supports the collusive outcome q^* for every firm i:
$S_i^1 = q^*$,
$S_i^t = q^*$ if $q_j^\tau = q^*$, $\tau \in [1, ...t-1]$
$S_i^t = q^{CN}$ otherwise.

The necessary and sufficient conditions for this strategy to be a subgame perfect equilibrium are (1) the present value of single-period profits under the cartel must be larger than or equal to the present value of single-period profits under Cournot, and (2) the present value of the cooperative strategy is equal to or lager than the present value of defecting one period and reverting to the Cournot strategy in subsequent periods. Formally:

$$\frac{1}{1-\delta}\pi^*(\theta) - K \geq \frac{1}{1-\delta}\pi^{CN}$$

and,

$$\frac{1}{1-\delta}\pi^*(\theta) - K \geq \pi^d(\theta) + \frac{\delta}{1-\delta}\pi^{CN} - K,$$

where δ is the common discount factor.

The conditions above can be rewritten as:

$$\pi^*(\theta) - \pi^{CN} \geq (1-\delta)K$$

and,

$$\pi^*(\theta) - \pi^{CN} \geq (1-\delta)(\pi^d(\theta) - \pi^{CN}).$$

By inspection, one of these two conditions is redundant. Suppose $K \geq \pi^d(\theta) - \pi^{CN}$, for $\theta \in [0, \overline{\theta})$. Then

$$\delta(\theta) \geq 1 - \frac{\pi^*(\theta) - \pi^{CN}}{K}.$$

Suppose now that $K < \pi^d(\theta) - \pi^{CN}$, for $\theta \in [0, \overline{\theta})$. Then

$$\delta(\theta) \geq \frac{\pi^d(\theta) - \pi^*(\theta)}{\pi^d(\theta) - \pi^{CN}}.$$

8 Appendix B: Can VIs improve welfare?

The net impact of VIs on social welfare depends on the existing market conditions when the programs are implemented and the nature of the polluting activities covered.

A VI (CVI, PCVI or DVI) would improve welfare if and only if at the status quo

$$\frac{dW(nq,\theta)}{d\theta} |_{\theta=0} = \frac{\partial W(nq,0)}{\partial q}\frac{dq}{d\theta} + \frac{\partial W(nq,0)}{\partial \theta} > 0.$$

Since under a VI the firms are compensated for their prevention costs by reducing output (and increasing price) it follows that $\frac{dq}{d\theta} < 0$. A minimal requirement to undertake pollution prevention is that at the status quo the benefit of mitigated environmental damages after a marginal increase in θ is known to be larger than the marginal cost of pollution prevention, that is, only if $\frac{\partial W(nq,0)}{\partial \theta} > 0$. Defining social welfare as the sum of consumer and producers surplus minus the dollar value of environmental damages:

$$W(nq,\theta) = \int_0^{nq} P(z)dz - nC(q) - nqt(\theta) - nK - ne(q,\theta),$$

the next proposition follows.

Proposition 5 *For a VI to improve social welfare it is sufficient that at the initial equilibrium the marginal benefit of cutting back emissions through reduced economic activity is larger than or equal to the quantity distortion due to market concentration. Otherwise, it is necessary that the marginal benefits of cutting back emissions through reduced economic activity* plus *the marginal benefit of pollution prevention on welfare are larger than the initial quantity distortion in the market.*

The first part of the proposition indicates that if it were socially desirable to abate emissions by reducing production, then a VI that also brings in prevention efforts above the status quo would necessarily improve welfare. Indeed, the EPA acknowledges output reduction as a genuine way to prevent emissions. For example, the 33/50 program second report reveals that part of AT&T's reductions of its 33/50 chemicals were due to "decrease production levels at several of the company's plants" (USAEPA [1992]). The condition would be satisfied in a perfectly competitive market since the quantity distortion is zero. Welfare gains from reduced output levels, $\frac{\partial W(nq,0)}{\partial q}\frac{dq}{d\theta} = -ne_q(q,0)\frac{dq}{d\theta}$, are then strictly positive. However, the larger the quantity distortion in the market the more environmentally damaging production activities and the more effective pollution prevention efforts must be for a VI to increase welfare.

9 Appendix C: Proofs

Proof of Lemma 1
If $\lambda = 0$ then $P(nq^o) - C_q(q^o) - t(\theta^o) = e_q(q^o, \theta^o)$ by the first-order condition $\frac{\partial L}{\partial q} = 0$. If $P(nq^o) - C_q(q^o) - t(\theta^o) = e_q(q^o, \theta^o)$ then either $\lambda = 0$ or $P(nq^o) - C_q(q^o) - t(\theta^o) = -nq^o P'(nq^o)$ and $\lambda > 0$. Now, $P(nq^o) - C_q(q^o) - t(\theta^o) = -nq^o P'(nq^o)$ and $\lambda > 0$ would imply by equation (5) that $-e_\theta(q^o, \theta^o) = 0$ which is ruled out by the properties of the emissions function. Therefore, if $P(nq^o) - C_q(q^o) - t(\theta^o) = e_q(q^o, \theta^o)$ then $\lambda = 0$. ■

Proof of Proposition 1
Case (i): Consider the case in which $\lambda > 0$ in the CVI. Suppose that $q^*(\hat{\theta}) = q^o$ and $\hat{\theta} = \theta^o$. In that case, $P(nq^o) - C_q(q^o) - t(\theta^o) = -nq^o P'(nq^o)$ and $-e_\theta(q^o, \theta^o) = \infty$ by (5), which is ruled out by the properties of the emissions function.
Case (ii): Consider the case in which $\lambda = 0$ in the CVI. Suppose that $q^*(\hat{\theta}) = q^o$ and $\hat{\theta} = \theta^o$. Then, conditions (1) and (2) are equal. Furthermore, $-nq^*(\hat{\theta})P(nq^*(\hat{\theta})) = e_q(q^*(\hat{\theta}), \hat{\theta})$ so that conditions (3) and (6′) coincide. ■

Proof of Proposition 2
From the first-order condition of the cartel's problem, equation (1), equation (6) can be written as

$$-\frac{e_\theta(q^*(\theta^*), \theta^*)}{e_q(q^*(\theta^*), \theta^*)} = \frac{q^*(\theta^*) t_\theta(\theta^*)}{-(n-1)[q^*(\theta^*) P'(nq^*(\theta^*))]}$$

Using the Implicit Function Theorem, $\frac{d\theta^*}{dn} = -\frac{F_n}{F_{\theta^*}}$, where

$$F_n = P'(nq^*)e_\theta(\cdot) + (n-1)q^* \frac{\partial P'(nq^*)}{\partial n} e_\theta(\cdot) > 0$$

where $\frac{\partial P'(nq^*)}{\partial n} < 0$, and

$$F_{\theta^*} = (n-1)[e_{\theta\theta}(\cdot)P'(nq^*) + ne_\theta(\cdot)P''(nq^*)dq/d\theta] - e_{qq}(\cdot)t_\theta(\theta^*)dq/d\theta - e_q(\cdot)t_{\theta\theta}(\theta^*) \gtreqless 0$$

Noting that when firms are identical market concentration is inversely related to the number of firms n, if $F_{\theta^*} > 0$ then $\frac{d\theta^*}{dn} < 0$ and the larger θ^* is as concentration rises. Manipulating the expression above, $F_{\theta^*} > 0$ if

$$(n-1)[\frac{e_\theta(\cdot)P'(\cdot)}{e_q(\cdot)t_\theta(\cdot)}][\frac{e_{\theta\theta}(\cdot)}{e_\theta(\cdot)} + n\frac{P''(\cdot)}{P'(\cdot)}dq/d\theta] > [\frac{e_{qq}(\cdot)}{e_q(\cdot)}dq/d\theta + \frac{t_{\theta\theta}(\cdot)}{t_\theta(\cdot)}]$$

Since

$$\frac{dlnMRT}{d\theta} = \frac{e_{\theta\theta}(\cdot)}{e_\theta(\cdot)} - \frac{e_{qq}(\cdot)}{e_q(\cdot)}dq/d\theta$$

and

$$\frac{dlnMRS}{d\theta} = \frac{t_{\theta\theta}(\cdot)}{t_\theta(\cdot)} - \frac{\pi_{qq}}{\pi_q}dq/d\theta$$

it follows that the larger $\frac{dlnMRT}{d\theta}$ is relative to $\frac{dlnMST}{d\theta}$ the most likely that θ^* increases as industry concentration raises. ■

Proof of Proposition 3
Note that by Proposition 1 $q^*(\hat{\theta}) = q^o$ and $\hat{\theta} = \theta^o$ if and only if $-nq^*(\hat{\theta})P'(nq^*(\hat{\theta})) = e_q(q^*(\hat{\theta}), \hat{\theta})$. By equation (6′) $-e_\theta(q^*(\hat{\theta}), \hat{\theta}) = q^*(\hat{\theta})t_\theta(\hat{\theta})$. However, by equation (7′) $-e_\theta(q^*(\theta^*), \theta^*) > q^*(\theta^*)t_\theta(\theta^*)$. Therefore, $\hat{\theta} \neq \theta^*$. ■

Proof of Proposition 4
Suppose that $-nq^*(\hat{\theta})P'(nq^*(\hat{\theta})) < e_q(q^*(\hat{\theta}), \hat{\theta})$, then $-e_\theta(q^*(\hat{\theta}), \hat{\theta}) < q^*(\hat{\theta})t_\theta(\hat{\theta})$ by equation (6′). However, by equation (7′) $-e_\theta(q^*(\theta^*), \theta^*) > q^*(\theta^*)t_\theta(\theta^*)$. Therefore, $\hat{\theta} \neq \theta^*$.

Suppose that $-nq^*(\hat{\theta})P'(nq^*(\hat{\theta})) > e_q(q^*(\hat{\theta}), \hat{\theta})$, then $-e_\theta(q^*(\hat{\theta}), \hat{\theta}) > q^*(\hat{\theta})t_\theta(\hat{\theta})$

by equation (6′). So long as $-(n-1)q^*(\theta^*)P'(nq^*(\theta^*) < e_q(q^*(\theta^*),\theta^*) < -nq^*(\theta^*)P'(nq^*(\theta^*)$, $-e_\theta(q^*(\theta^*),\theta^*) > q^*(\theta^*)t_\theta(\theta^*)$ by (7′). Therefore, $\hat{\theta}$ and θ^* could be equal. ■

Proof of Proposition 5
Defining social welfare as the sum of consumer and producers surplus minus the dollar value of environmental damages:

$$W(nq,\theta) = \int_0^{nq} P(z)dz - nC(q) - nqt(\theta) - nK - ne(q,\theta),$$

taking the total derivative of this expression, and using the first order condition from the firms' problem, a VI could improve social welfare if at the initial equilibrium either

$$\text{(i)} \quad -q^{CN}P'(nq^{CN}) \leq e_q(q^{CN},0), \quad \text{or}$$
$$\text{(ii)} \quad -e_\theta(q^{CN},0) - e_q(q^{CN},0)\frac{dq}{d\theta} > q^{CN}P'(nq^{CN})\frac{dq}{d\theta}$$

Let $\tilde{q}$ be the level of output such that $-\tilde{q}P'(n\tilde{q}) = e_q(\tilde{q},0)$. Then, if $q^{CN} < \tilde{q}$ condition (ii) must hold: the marginal benefit of cutting back emissions through prevention practices and reduced economic activity $(-e_\theta(q^{CN},0) - e_q(q^{CN},0)\frac{dq}{d\theta})$ must be larger than the marginal cost imposed on consumers $(q^{CN}P'(nq^{CN})\frac{dq}{d\theta})$. At the initial equilibrium, a marginal increase in θ does not affect producers since it has been assumed that $t_\theta(0) = 0$. If $q^{CN} \geq \tilde{q}$, the planner can always improve welfare by reducing output and setting strictly positive prevention levels. ■

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