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Abstract

We show that an environmental regulation such as a tax on pollution can act as a collusive device and induce stable cartelization in an oligopolistic polluting industry. We consider a dynamic game where pollution is allowed to accumulate into a stock over time and a cartel that includes all the firms in the industry. We show that a tax on pollution emissions can make it unprofitable for any firm to leave the cartel. Moreover the cartel formation can diminish the welfare gain from environmental regulation. We provide an example where social welfare under environmental regulation and collusion of firms is below social welfare under a laisser-faire policy.

JEL classifications: H41, L51, Q58

Keywords: pollution tax, oligopoly, cartel formation, coalition formation, differential game

1 Introduction

Can stricter environmental regulation lead to anti-competitive behaviour amongst polluting firms and induce the formation of cartels? This is now a growing concern within anti-trust authorities.[1]

The question of the impact of an environmental policy on the collusive behaviour of firms is a legitimate one since it impacts firms' incentives to leave the cartel (internal stability of the cartel) and firm's incentives to join a cartel (external stability). It is well known that oligopolists can raise their profits if all firms collude and engage in price fixing. However, it is also well known that such a cartel may not be stable in the sense that a cartel member typically finds it profitable to exit the cartel and become an outsider. This is the internal stability concept introduced from the theory of cartels (see d'Aspremont et al. (1983)). D'Aspremont et al. (1983) and the substantial subsequent literature in the theory of coalition formation define a stable cartel (or coalition) as a cartel that is internally and externally stable, where external stability requires that no outsider firm finds it profitable to join the cartel. This concept of stability has also been extensively applied in the analysis of the stability of international environmental agreements, IEAs, (see e.g., Barrett (1994), Rubio and Ulph (2006), Carraro and Siniscalco (1993)). The general message of coalition theory and of the applications in IEAs is that large coalitions cannot be stable. Can this result be extended to the case of a polluting oligopoly where a regulator implements a tax on pollution emissions? Answering this question is a first goal of this paper. The second objective is to address the policy implications of the

[1] The Committee on Competition Law and Policy of the Organization for Economic Co-operation and Development (OECD) organized roundtable discussions on "Competition Policy and the Environment" and "Environmental Regulation and Competition" in 1996 and 2006 respectively. At these proceedings, each of the members presented specific national examples of environmental regulations leading to anti-competitive behaviour. Similar issues have been a source of concern also for the European Commission (EC). Community law provides that environmental considerations must be integrated into all other Community policies. This includes European competition policy. In their turn, both the national legislator and the industry have to respect competition law in putting in place environmental initiatives and should not establish forms of collaboration, rules or practices that would constitute unjustified obstacles to competition, as stated in Chapter 7 of the Guidelines on the applicability of Article 81 of the EC Treaty to horizontal cooperation agreements.

change in the collusive behaviour of firms. More precisely, we need to determine the welfare implications of the formation of a cartel. This second question is typically trivial in the context of IEA formation. In our context it is not. In the context of IEAs each country's benefit typically depends on its own consumption and countries interact only through the damage they inflict on each other. Therefore, when all countries form a coalition, they internalize each other's damage and the coalition necessarily results in a gain in welfare. In the context of an oligopoly, in the absence of pollution, the industry supplies less than the socially desirable output level. When pollution is taken into account, the impact of collusion on social welfare, defined as the sum of consumer's and producer's surplus net of the damage caused by pollution, becomes ambiguous and typically depends on the extent of the damage caused by pollution.

We show that when a tax on pollution emissions is implemented, there exists a set of parameter values such that the cartel formed by all firms in the industry is stable. We also show that the formation of such a cartel can be detrimental to welfare. We provide an example where the introduction of a tax on pollution emissions would be welfare improving compared to the laisser-faire policy, in the absence of cartel formation. However, given the tax on pollution, the comprehensive cartel, i.e. where all firms are cartel members[2], is stable and its formation results in a lower welfare than under the laisser-faire policy. Thus, setting a tax on pollution emissions, whilst good for the environment, can indeed be detrimental to overall welfare by encouraging tacit collusion or cartel formation amongst the polluting firms. This justifies some of the existing concerns of the OECD, the EC and other policy makers.

In addition to looking at collusion between polluting firms instead of coalitions between countries, our paper differs from the main steam literature in the theory of coalition formation in general and IEA formation in particular by incorporating explicitly intertemporal constraints that agents face. Exceptions include Breton et al. (2008) and de Zeeuw (2008). Breton et al (2008) consider the formation of an IEA in an international pollution game where signatory

[2] We only treat the case where all firms are cartel members. Our results extend to the cases where only a subset of firms in the industry form a cartel. Since no insight is added we omit these latter cases.

countries are assumed to be able to punish the non-signatories at a cost. They propose an evolutionary process through which countries may gradually reach a stable agreement. They adopt a replicator dynamics, under which evolutionary pressures are put in favor of the group (signatories versus non-signatories) obtaining the highest payoff. De Zeeuw (2008) considers the case where agents are "farsighted": when a country contemplates leaving an IEA, it takes into account the repercussions on other countries' adhesion to the IEA (see also Diamantoudi and Szartsetakis (2006) for the application of the farsightedness concept in IEAs in a static framework). He takes into account the dynamics of emissions adjustments and shows that large and small coalitions occur only if the costs of emissions is relatively small compared to the costs of abatement.

The dynamic pollution game we consider is borrowed from a literature on the taxation in natural resource markets. Karp and Livernois (1992) consider the taxation of a non-renewable resource monopoly. Benchekroun and Long (1998) extend the model to a polluting oligopoly. It is this latter model that we use to study the impact of taxation of pollution emissions on firms' collusive behavior. We set up a differential game between N firms that compete *à la* Cournot. Firms' emissions are directly proportional to their output levels and accumulate into a stock of pollution. Each firm faces a unit tax on its emissions, say a carbon tax.[3] Following Karp (1992) and Benchekroun and Long (1998), to ensure time consistency of the tax policy, we consider the case where the tax rate is indexed on the state variable of the dynamic system, i.e. the stock of pollution in our case. Indeed, rational forward-looking governments may have an incentive to adjust the tax rate over time based on the evolution of the damage caused by pollution. To avoid time inconsistency issues we consider a tax indexed on the state variable, the stock of pollution: i.e., we consider Markovian tax rules. Indeed, in the case of a non-renewable resource monopoly, Karp and Livernois (1992) have shown that the monopoly may

[3] Countries that levy a carbon tax include Austria, Denmark, Finland, Germany, Italy, the Netherlands, Norway, Sweden and the UK. Countries currently considering the implementation of a carbon tax include New Zealand and the US (the Lieberman-Warner Climate Security Act).

strategically manipulate a regulator implementing a tax path. This manipulation is no longer a concern when the regulator adopts Markovian tax rules.

Section 2 presents the model. Sections 3 studies the stability of cartel formation. Section 4 gives a welfare analysis of the tax on pollution emissions. Section 5 presents concluding remarks.

2 The Model

Consider a Cournot oligopoly with $N \geq 3$ identical firms that produce a homogenous good. Each firm has a constant marginal cost, $c \geq 0$. Firm i's output is denoted by q_i and the industry's output is given by $Q = \sum q_i$. For notational convenience, the argument of time, t, is in general omitted throughout the paper although it is understood that all variables may be time dependent. The inverse demand is given by:

$$P(Q) = P(0) - Q \tag{1}$$

with $P(0) - c$ is normalized to 1. Production of each firm i generates pollution emissions denoted by e_i with $e_i = q_i$. Pollution accumulates over time and forms a stock, denoted by S with

$$\dot{S} = Q - \delta S \quad \text{and } S(0) = S_0 \geq 0$$

where $\delta > 0$ represents the natural rate of decay of the stock of pollution. The damage caused by pollution is denoted by $D(S)$ and is given by:

$$D(S) = \frac{\gamma}{2} S^2 \tag{2}$$

Under laisser-faire, i.e. in the absence of environmental regulation, firms ignore the damage that their production causes to the environment. The outcome under laisser-faire corresponds to the outcome of a static Cournot oligopoly equilibrium that is infinitely repeated.

We consider an environmental regulation in the form of a per unit tax on pollution emissions which, given the simple relationship between production and emissions, amounts to a per unit tax on production. Each firm i faces an environmental tax policy for its polluting activities given by:

$$\tau(S) = \eta + \alpha S \text{ with } \alpha \geq 0.$$

Thus, given a tax policy $\tau(.)$, the tax rate charged at time t is given by $\tau(S(t))$. The case where $\alpha = 0$ corresponds to the case of a 'myopic' environmental regulator that does not react to changes in the damage caused by pollution. It is highly likely that if the state of the environment evolves, the regulator would wish to revise her tax rate. It is, therefore, sensible in this context to consider a dynamic tax. To avoid time inconsistency issues, we consider a tax policy or rule that is in a feedback form: the tax depends on the state variable, the stock of pollution. Indeed, in the case of a non-renewable resource monopoly, Karp and Livernois (1992) have shown that a regulator implementing a tax path, which depends on the calendar time and the initial value of the state variable, may be strategically manipulated by the monopoly. This manipulation is no longer a concern when the regulator adopts a tax policy where the rate charged at each moment depends on the level of the state variable at that moment.

Given a tax policy $\tau(.)$, we determine a Markov Perfect Nash equilibrium (MPNE) of this pollution game. Firm i takes the strategy of its competitors, $Q_{-i}(S)$, as given and solves the following optimal control problem:

$$max \int_0^\infty e^{-rt}[P(Q_{-i}(S) + q_i)q_i - (c + \tau(S))q_i]dt$$

subject to

$$\dot{S} = (Q_{-i}(S) + q_i) - \delta S \text{ with } S(0) = S_0$$

and

$$q_i \geq 0.$$

Let

$$V(S) \equiv \begin{cases} \frac{1}{2}AS^2 + BS + C & \text{for} \quad 0 \leq S \leq \bar{S} \equiv -\frac{1-\eta+B}{A-\alpha} \\ V\left(\bar{S}\right)\left(\frac{\bar{S}}{S}\right)^{\frac{r}{\delta}} & \text{for} \quad S > \bar{S} \end{cases} \tag{3}$$

where A, B and C are coefficients reported in the appendix. It can be checked that the N-tuple vector of strategies where each firm adopts the production strategy

$$q\left(S\right) = \frac{1 - \left(\alpha S + \eta\right) + V'\left(S\right)}{1+N}$$

constitutes a MPNE.[4] The equilibrium production strategy can be written as

$$q\left(S\right) = \begin{cases} \left(\frac{A-\alpha}{1+N}\right)\left(S - \bar{S}\right) & \text{for} \quad 0 \leq S \leq \bar{S} \\ 0 & \text{for} \quad S > \bar{S} \end{cases}$$

The function $V\left(S\right)$ in (3) corresponds to the discounted sum of profits of a firm along the MPNE.

It can be shown that $A < \alpha$ and $B < 0$ which implies that $\bar{S} > 0$ and that

$$\frac{\partial q}{\partial S} = \frac{A-\alpha}{N+1} < 0 \text{ for all } S \in [0, \bar{S}).$$

Under the MPNE above, the path of the stock of pollution is given by:

$$S\left(t\right) = S_N^{ss} + \left(S_0 - S_N^{ss}\right)e^{\beta t}$$

[4] For the details of the derivation of the MPNE of this differential game, we refer the reader to Benchekroun and Long (1998). See also Dockner et al. (2000) for a general treatment of differential games and applications in environmental economics.

where

$$S_N^{ss} = \frac{(A-\alpha)\,N}{\beta\,(N+1)}\bar{S} \tag{4}$$

and $\beta \equiv \frac{N}{N+1}(A-\alpha) - \delta$. The steady state value of the stock of pollution where N is the number of firms (and where the N firms are not colluding) corresponds to S_N^{ss} and we have $S_N^{ss} < \bar{S}$ since $\beta < \frac{N}{N+1}(A-\alpha) < 0$.

We examine the stability of cartel formation within this dynamic game. We limit our analysis of stability to the case where the cartel includes all the firms in the industry. In the terminology of coalition formation theory, we consider the stability of the grand coalition only. This case is sufficient to highlight the collusive role that an environmental tax can play. Cases where only a subset of firms in the industry form a cartel can of course be considered as well, however, we believe it will extensively lengthen the presentation of the results without adding further insight into our analysis[5].

The cartel is said to be stable for any $N > 1$, if no member has a unilateral incentive to leave the cartel, that is, if the following holds:

$$I(S) \equiv V|_{N=2}(S) - \frac{V|_{N=1}(S)}{N} < 0 \tag{5}$$

The term $V|_{N=1}(S)$ corresponds to the discounted sum of profits of a monopoly if the stock of pollution is S and the tax policy is $\tau(S)$. Since firms have the same constant marginal cost, when all the firms in the industry form a cartel, the outcome is exactly the same as if there was a single firm in the industry. The overall profits is equally split among cartel members and each firm earns $\frac{V|_{N=1}(S)}{N}$. The term $V|_{N=2}(S)$ corresponds to the discounted sum of profits of a firm in the case of a duopoly. Since firms have the same constant marginal cost, $V|_{N=2}(S)$

[5] Moreover, by focusing on the case where all the industry's firms are cartel members, we need not worry about the profitability of the cartel formation. From oligopoly theory it is known that if only a subset of the firms merge (or collude) the profit of the merged entity may be smaller than the sum of the profits of the merged firms prior to the merger: the merger is then unprofitable (see e.g., Salant, Switzer and Reynolds (1983) or Gaudet and Salant (1991)).

corresponds to the profits a firm would earn by staying out of the cartel while all the other firms in the industry are members of the cartel.

Thus, the cartel is stable to a unilateral deviation iff

$$N < \hat{N}(S) \equiv \frac{V|_{N=1}(S)}{V|_{N=2}(S)}. \tag{6}$$

The threshold $\hat{N}(S)$ gives the maximum number of firms in an industry where a cartel (in which all the firms are members) can be sustained when the stock of pollution is S and the per unit emission tax is $\tau(S) = \eta + \alpha S$. The notion of stability we use corresponds to the widely used stability concept of internal stability in the coalition formation literature and that was first introduced by d'Aspremont et al. (1983) in the case of cartel formation. In general, along with internal stability, external stability is also analyzed. A cartel is externally stable if no external member of the cartel finds it profitable to join the cartel. Since we focus on the case where all firms are cartel members, only the internal stability is relevant. In the terminology of coalition formation literature, $\hat{N}(S)$ refers to the largest stable grand coalition when the stock of pollution is S and the per unit emission tax is $\tau(S)$.

3 Cartel stability

We first report a straightforward result regarding the case of a uniform tax, i.e. the case where $\alpha = 0 : \tau(S) = \eta$.

PROPOSITION 1: *When $\alpha = 0$, for all $N \geq 3$, a cartel with N members is never stable.*

PROOF: When $\alpha = 0$ the outcome of the static Cournot equilibrium, where the marginal cost of firms is raised from c to $c + \tau$, is infinitely repeated and it is straightforward to check that $\hat{N}|_{\alpha=0}(S) = \frac{9}{4}$.■

This is not surprising since, under a tax rate that is independent of the stock of pollution, firms consider the tax as a simple increase in the marginal cost. The static equilibrium outcome, with a higher marginal cost than under *laisser-faire,* is just infinitely repeated. The value function of each firm is thus the present value of the discounted profits it earns in a static game.[6] Since the level of the constant marginal cost does not influence the cartel's stability, a uniform tax has no impact on the cartel's stability in our context. Competition authorities need not worry about the anticompetitive effect of a uniform tax on pollution emissions since no coalition is stable. We argue in this paper that this is not true in the case of a tax rate that evolves with the state of the game, the stock of pollution.

We refer to a tax for which $\alpha > 0$ as a Markovian tax. For simplicity and ease of exposition we set $\eta = 0$. The maximum number of firms in an industry where a cartel (in which all the firms are members) can be sustained is still given by $\hat{N}(S)$ in (6) where η is set to zero. An important result that we obtain is that, contrary to static models, $\hat{N}(S)$ can be arbitrarily large. Given the complexity of the expression of $\hat{N}(S)$ we first study the function $\hat{N}(S)$ and give an analytical proof of our statement for $S = 0$ and then treat the case for $S > 0$ through an illustrative numerical example.

3.1 Cartel stability at $S = 0$

The expression of $\hat{N}(0)$ can be obtained by determining $V|_{N=1}(0)$ and $V|_{N=2}(0)$ using (3) and substituting into $\hat{N}(S)$ in (6). We only report here its properties that are relevant to our analysis. We note that $\hat{N}(0)$ is homogenous of degree zero in (δ, r, α) and, therefore, without loss of generality we normalize one of these three parameters. We choose the following normalization: $\delta = 1$. We are unable to derive the behavior of $\hat{N}|_{\delta=1}(0)$ as a function of the parameters α and r at any positive values of α and r. However, we have the following.

[6] It can be checked that for the static game, where the damage caused by pollution is given by $D = \frac{\gamma}{2}Q^2$ and the tax rate on pollution emissions is constant, for any $N \geq 3$ no cartel is stable.

LEMMA 1:

(i) $\hat{N}|_{\delta=1}(0)$ *is a continuous function of* δ *and* r.

(ii) For any $\alpha > 0$, *we have the following:*

$$\lim_{r\to 0^+} \hat{N}|_{\delta=1}(0) = \frac{1}{4}(\alpha+9).$$

PROOF: Substituting $\delta = 1$ into $\hat{N}(S)$ in (6) gives the following:

$$\hat{N}|_{\delta=1}(0) = \frac{64(r+1)^2(3r+\omega_1)^2}{\left(\left(2r+\sqrt{(4r+8)(r+2\alpha+2)}\right)^2(13r+\omega_1+2\alpha+10)(7r-\omega_1+2\alpha+10)\right)} \tag{7}$$

with $\omega_1 \equiv \sqrt{(r+2\alpha+2)(9r+2\alpha+18)}$. Lemma 1 (i) and (ii) follow directly from (7).■

We can now state the main result of this section.

PROPOSITION 2: *For any* $N \geq 3$, *there exists* $\tilde{\alpha}_N > 0$ *and* $\tilde{r}_{\alpha_N} > 0$ *such that for any* $\alpha > \tilde{\alpha}_N$ *and* $r < \tilde{r}_{\alpha_N}$ *a cartel that includes all the* N *firms in the industry is stable.*

PROOF: Proposition 2 follows directly from Lemma 1(i) and 1(ii). Indeed, consider

$$\tilde{\alpha}_N \equiv 4N - 9$$

then choosing $\alpha = \tilde{\alpha}_N + \varepsilon$ with $\varepsilon > 0$ yields after simple but tedious calculations

$$\lim_{r\to 0^+} \hat{N}|_{\delta=1,\alpha=\tilde{\alpha}_N+\varepsilon}(0) = N + \frac{1}{4}\varepsilon > N.$$

Continuity of $\hat{N}|_{\delta=1,\alpha=\tilde{\alpha}_N+\varepsilon}(0)$ with respect to r completes the proof.■

This result is in sharp contrast with the typical result obtained within a static framework where a cartel is never stable if the total number of players exceeds 2.[7] When the dynamics of the stock of pollution is used as an indicator upon which the tax rate is based, a cartel of any size can be stable if the tax is sufficiently sensitive to the stock of pollution and the discount rate is small enough.

We would like to point out a similarity and a difference of our result with the existing folk theorem in repeated games where firms can use strategies that allow for punishment. In the latter case it is well known that cooperation can be sustained if agents are patient enough. The difference with our result is that, in our framework, although firms' strategies do not allow for punishment or require knowledge of any part of the history of the game, the tax plays a disciplinary role. While a simple constant tax rate cannot lead to a stable cartel formation, in the case where a tax is adjusted to the stock of pollution, it can play the role of a punishment rule that helps sustain the cartel. This was not a priori straightforward since a tax negatively affects both the cartel and the potential deviator. However, since deviation from the collusive output path generates more pollution, in the case of a Markovian tax rule, the tax rate increases over time following a firm's exit from the cartel (which is not the case under a constant tax). This makes the deviation more costly than under a constant tax rate, and, thereby, helps sustain collusion.

We have, thus far, normalized δ to 1. If we normalize r to 1 instead, we obtain the following.

LEMMA 2:

(i) $\hat{N}|_{r=1}(0)$ *is a continuous function of* δ *and* α*.*

(ii) For any $\delta > 0$*, we have the following:*

$$\lim_{\alpha \to \infty} \hat{N}|_{r=1}(0) = \frac{16}{7} \frac{(\delta+1)^2}{2\delta+1}$$

[7] See footenote 6.

Proof: For $r = 1$, we have the following:

$$\hat{N}|_{r=1}(0) = \frac{64(\delta+1)^2(\sigma+3)^2}{\left(\left(\sqrt{(8\delta+4)(2\delta+2\alpha+1)}+2\right)^2(10\delta+\sigma+2\alpha+13)(10\delta-\sigma+2\alpha+7)\right)} \tag{8}$$

where

$$\sigma \equiv \sqrt{(2\delta+2\alpha+1)(18\delta+2\alpha+9)}.$$

Lemma 2(i) follows directly from (8). Lemma 2(ii) obtains by taking the appropriate limits of (8).■

The following proposition follows from Lemma 2.

Proposition 2b: *For any $N > 0$, there exists $\tilde{\delta}_N \equiv \frac{1}{4}\left(N - 4 + \sqrt{N(N-4)}\right) > 0$ and $\tilde{\alpha}_{\tilde{\delta}_N} > 0$ such that for any $\delta > \tilde{\delta}_N$ and $\alpha > \tilde{\alpha}_{\tilde{\delta}_N}$ a cartel that includes all the N firms in the industry is stable.*

Proof: This follows from Lemma 2 and the fact that

$$\frac{\partial \lim_{\alpha\to\infty} \hat{N}|_{r=1}(0)}{\partial \delta} = \frac{32}{7}\frac{(\delta+1)\delta}{(2\delta+1)^2} > 0.■$$

3.2 Cartel Stability for $S > 0$

We have shown that a cartel that includes all the firms in the industry can be stable when the initial stock of pollution is zero. We now check the stability of the cartel at positive levels of the stock of pollution.

As long as r tends to zero, we find that, the initial level of the stock does not play a role, as shown by (9). Indeed, we have

$$\lim_{r\to 0^+} \hat{N}|_{\alpha=\tilde{\alpha}_N+\varepsilon}(S) = N + \frac{1}{4}\varepsilon > N \text{ for all } S \in [0, \bar{S}|_{\alpha=\tilde{\alpha}_N+\varepsilon}) \text{ and for } \varepsilon > 0. \tag{9}$$

This is intuitive: as r tends to zero, for any initial stock of pollution, the importance of the long run benefit from collusion increases and dominates the short-run benefit from staying out of the cartel.

Next, we consider strictly positive values of r and investigate the role of S_0 on the cartel's stability. Suppose that at a given initial stock of pollution, $S_0 < S_1^{ss}$, the cartel is stable $(I(S_0) < 0)$, is it true that as the stock of pollution adjusts from S_0 to the steady state level, S_1^{ss}, we have $I(S) < 0$ over $[S_0, S_1^{ss}]$? Obviously, a similar question arises for $S_0 > S_1^{ss}$.

When the discount rate tends to infinity, we can show that $\lim_{r\to\infty} I(S) = 0$ with

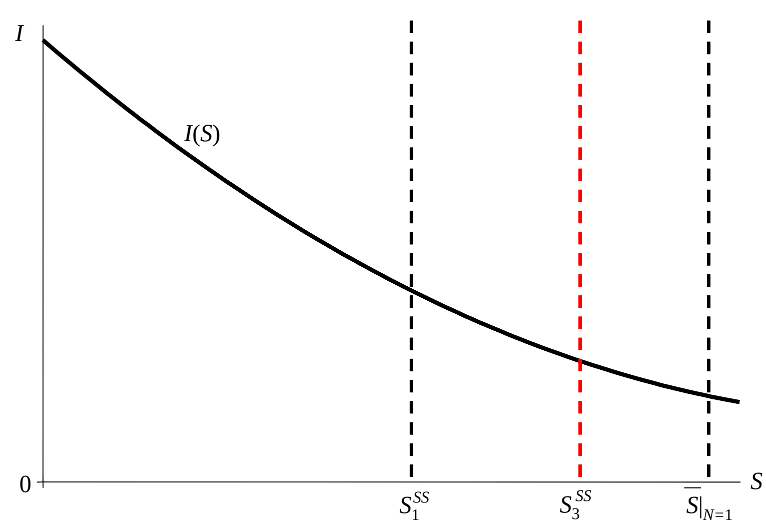
$$\lim_{r\to\infty} rI(S) = \frac{1}{36N}(4N-9)(\alpha S-1)^2 > 0.$$

Thus, for sufficiently large values of the discount rate, r, we obtain the same result as the uniform tax case. That is, a cartel is never stable for $N \geq 3$.

For $r > 0$ and finite, the expressions of $I(S)$, S^{ss} and $\bar{S}$ are too cumbersome to be tractable analytically. We, therefore, illustrate our findings through a numerical example where we fix $N = 3$, $\alpha = 3.5$ and $\delta = 1$. When $N = 3$, we have $\tilde{\alpha}_N = 3$. We have chosen α to exceed $\tilde{\alpha}_N$. This ensures that when r is small enough, the cartel is stable at $S = 0$.

We consider different values of r. Figure 1 illustrates the case where $r = 1$.

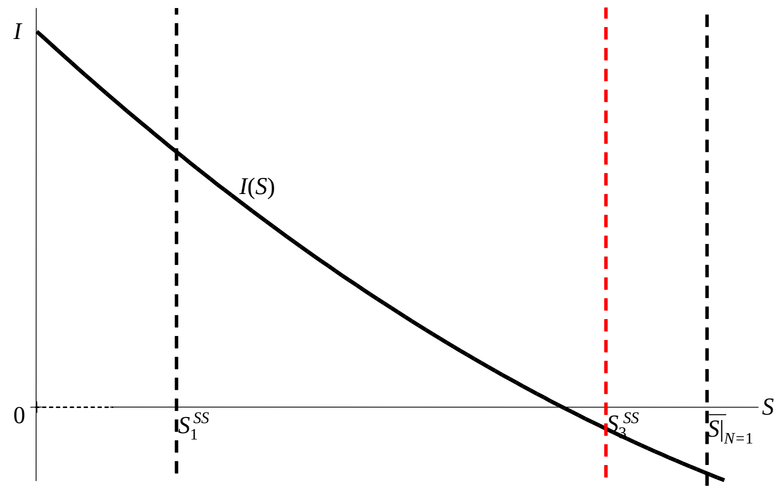
Figure 1: $I(S)$ for $r = 1$



In this case, for all $S \in [0, \bar{S}|_{N=1}]$, we have $I(S) > 0$, and thus the cartel is unstable at all stock levels.

Figure 2 illustrates the case where $r = 0.2$.

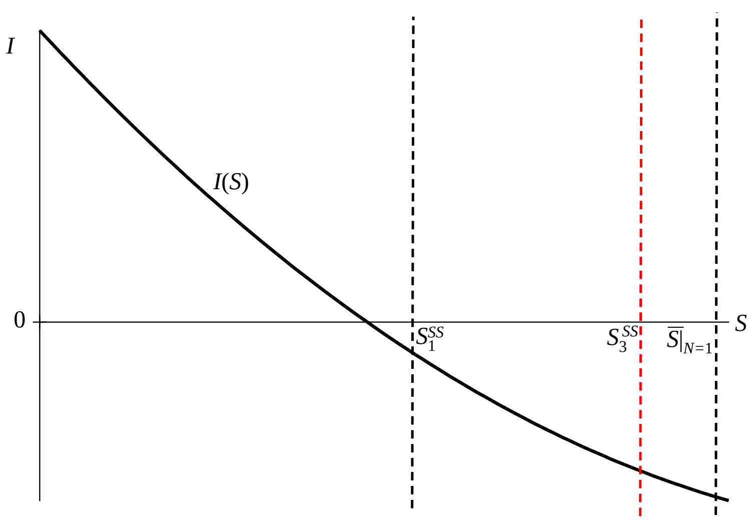
Figure 2: $I(S)$ for $r = 0.2$



At $r = 0.2$, the cartel forms at the non-cooperative steady state, S_3^{ss}, but breaks down as the stock decreases.[8]

Figure 3 illustrates the case where $r = 0.15$.

Figure 3: $I(S)$ for $r = 0.15$

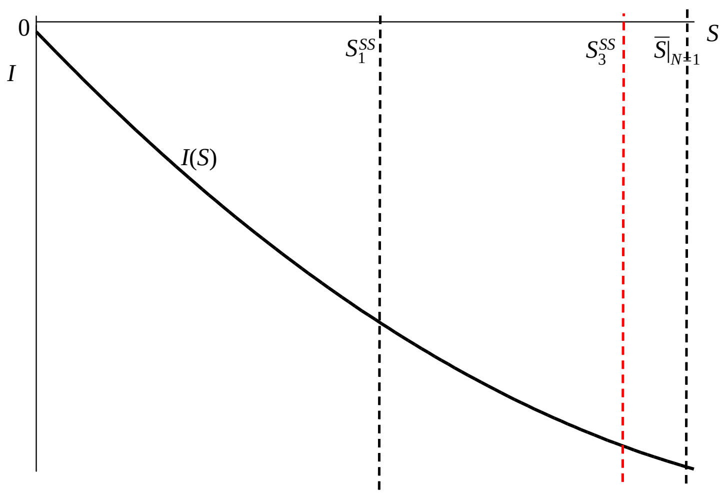


[8] There are possibly stable cartels formed by only a subset of the industry's firms.

For $r = 0.15$, the cartel is stable throughout the transition phase, that is, starting from the non-cooperative steady state, it remains stable until the steady state under collusion is reached.

Figure 4 illustrates the case where $r = 0.1$.

Figure 4: $I(S)$ for $r = 0.1$



For $r = 0.1$, the cartel is stable for all S_0.

We have checked that this behaviour of the stability of the cartel holds for several other numerical examples that we have considered.

The main policy implication of the results derived in this section is that, with a tax on pollution emissions, competition authorities cannot rely on individual firms' incentives to cheat on a collusive agreement to prevent the formation of a cartel.

4 Welfare Analysis

Since a tax on pollution emissions can render a cartel stable, it is now relevant to address the following question, in line with the concerns of the OECD and the EC: Can stricter environmental policy have a detrimental effect on welfare by encouraging anti-competitive behaviour? After all, collusion among polluters results in a reduction of industry output. Because of the negative externality generated by production it is not clear that a decrease in industry output is at the detriment of social welfare.

Instantaneous social welfare is assumed to be $w = U(Q) - cQ - D(S)$, where $U(Q)$ is the area under the demand curve:

$$w = \int_0^Q P(X)\,dX - cQ - D(S)$$

or

$$w = Q - \frac{1}{2}Q^2 - \frac{\gamma}{2}S^2.$$

The aggregate welfare over time is given by:

$$W = \int_0^\infty e^{-rt} w(t)\,dt \tag{10}$$

Given the complexity of the integral (10), it is not possible to determine a general set of conditions under which the formation of a cartel is welfare-improving. Therefore, we consider the numerical example of the previous section, setting $N = 3$, $r = 0.1$, and $\delta = 1$. We have checked that similar results hold for other parameter values. We examine welfare under three scenarios. In Scenario 1, we assume that firms behave non-cooperatively and the tax on pollution emissions is zero. This scenario corresponds to the outcome of a laisser-faire policy since, in the absence of a tax, the cartel is unstable. In Scenario 2, we assume that firms behave non-cooperatively and the regulator imposes a tax on pollution emissions with $\alpha = 3.5$. This corresponds to the outcome expected by an environmental regulator that does not anticipate the formation of the cartel. In Scenario 3, the regulator imposes a tax on pollution emissions with $\alpha = 3.5$ and firms are assumed to form a cartel. From our analysis in section 3, for $\alpha = 3.5$ the cartel is indeed stable, and therefore Scenario 3 would be the prevailing outcome if a tax is implemented. We give below, for $S_0 = 0$, in the numerical example considered, the expressions of the discounted sum of welfare as functions of the damage parameter γ for the different Scenarios 1, 2 and 3 respectively:

$$W|_{N=3,\alpha=0} = 4.688 - 2.435\gamma$$

$$W|_{N=3,\alpha=3.5} = 1.873 - 0.187\gamma$$

and

$$W|_{N=1,\alpha=3.5} = 1.136 - 0.062\gamma$$

We find that there exist γ_1, γ_2 and γ_3, where $0 < \gamma_1 < \gamma_2 < \gamma_3$, such that the following hold:

(i) For $\gamma \in [\gamma_1, \gamma_3]$, welfare under Scenario 1 is lower than that under Scenario 2. In the absence of cartelization, the imposition of a tax on pollution emissions is welfare improving.

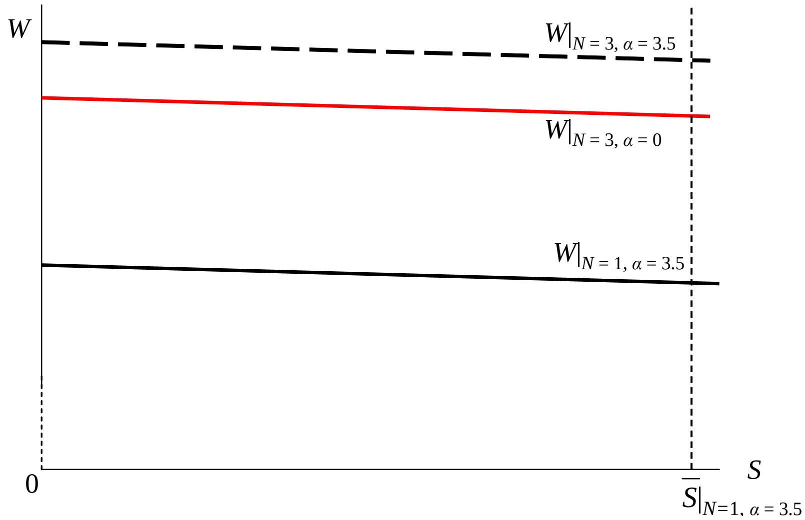
(ii) For $\gamma \in [0, \gamma_3]$, welfare under Scenario 3 is lower than under Scenario 2. Given the imposition of a tax on pollution emissions, the cartel formation induced through environmental regulation is welfare reducing for all $\gamma \in [0, \gamma_3]$.

(iii) For $\gamma \in [\gamma_1, \gamma_2]$, welfare under Scenario 3 is lower than under Scenario 1. The decrease in welfare due to cartelization of the industry can lower welfare below its level under laisser-faire.

For $S_0 = 0$, in the numerical example considered, we have $\gamma_1 = 1.252$, $\gamma_2 = 1.497$ and $\gamma_3 = 5.903$. For $\gamma \in [\gamma_1, \gamma_2]$, the environmental regulator would expect the imposition of the tax to be welfare improving (since $W|_{N=3,\alpha=3.5} > W|_{N=3,\alpha=0}$), if it did not take into consideration the possibility of cartelization of the industry. However, if the tax triggered the formation of the cartel, which is stable for this range of γ, welfare would fall below the laisser-faire level (since $W|_{N=1,\alpha=3.5} < W|_{N=3,\alpha=0}$).

For $S_0 > 0$, we provide an example illustrated in Figure 5, where for all $S_0 \in \left[0, \bar{S}|_{N=1,\alpha=3.5}\right]$ we have that the imposition of the tax on pollution emissions results, through the formation of the cartel, in a level of welfare smaller than that under the laisser-faire policy.

Figure 5: W as a function of S for $\gamma = 1.3$



5 Conclusion

We have shown that the implementation of a tax on pollution emissions can modify substantially the collusive behaviour amongst polluting firms. It is particularly important to understand the implications of having a Markovian tax since environmental policies are likely to be more tied to some index of aggregate pollution levels, such as the stock of pollution. Under a uniform tax rate, the cartel is never stable as long as there are more than two firms in the industry. However, if the tax rate evolves with the state of the pollution damage and is indexed on aggregate pollution levels such as the stock of pollution, we showed that the cartel that includes all the firms in industry can be stable.

The collusive behavior induced by the tax on pollution emissions can reduce the gain in welfare that the environmental regulation is supposed to achieve. The decrease in welfare from cartelization can even lead to a level of welfare that is lower than under the laisser-faire policy. Therefore, when designing regulatory interventions in the context where pollution can have a lasting effect, such as carbon emissions, it is important to take into account the impact of the intervention on the market structure and the behaviour of firms.

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Appendix:

The value function of each firm for the linear quadratic case is given by:

$$V_i(S) = \frac{1}{2}AS^2 + BS + C \tag{11}$$

where A, B and C are computed using the undetermined coefficient technique (see Dockner et al. (2000) for a general treatment of differential games and Benchekroun and Long (1998) for the derivation of the MPNE of this differential game). The coefficients A, B and C are given by:

$$A = \frac{1}{4N^2}\left(\omega + 2\alpha\left(1+N^2\right) - \sqrt{(N+1)^2(r+2\delta+2\alpha)\left(\omega+2\alpha(N-1)^2\right)}\right)$$

$$B = \frac{(\eta-1)\left(2\alpha - A - AN^2\right)}{\omega - 2AN^2 + \alpha\left(1+N^2\right)}$$

$$C = \frac{\left(\eta - BN^2 - 1\right)(\eta - B - 1)}{r(N+1)^2}$$

where

$$\omega \equiv (r+2\delta)(N+1)^2 .$$