

Environmental Policy and Coalitions in Polluting Oligopolies

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Abstract

This paper examines how the implementation of a carbon tax affects collusive behaviour amongst polluting firms. We use a dynamic scenario where pollution is allowed to accumulate into a stock over time. We determine the stability conditions of a grand coalition under the following two scenarios: (i) when the carbon tax rate is an exogenously given constant, that is, a "uniform" tax, (ii) when the carbon tax rate is dependent on the stock of pollution, that is a "Markovian" tax.

First, we find that, under a uniform tax rate, the grand coalition is never stable as long as there are more than two firms in the industry. However, given a Markovian tax rate, we show that there exists a set of parameter values such that the grand coalition is stable. In particular, if the degree to which the tax rate depends on the stock of pollution is sufficiently high, the natural rate of decay of the pollution stock is sufficiently high, and the discount rate is sufficiently low, we have that the grand coalition of any size can be stable. Previous studies using the same stability criteria as in our paper showed that the maximum number of players that can be sustained within a grand coalition is three. In this paper, by sufficiently increasing the degree of dependence of the tax rate on the stock of pollution, we show that the maximum size of a stable grand coalition is significantly increased. We provide numerical examples where this maximum reaches seven. Second, we show that, *ceteris paribus*, as the efficiency of abatement technology is increased, the grand coalition can go from being stable to unstable. Third, we show that some grand coalitions can be stable at a high pollution stock and unstable at a small pollution stock.

1 Introduction

Can stricter environmental regulation lead to anti-competitive behaviour amongst polluting firms? This is becoming a rising concern of international organizations. 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. The secretariat of the OECD summarizes some of the possible effects as follows. If dominant firms exist in the industry, they may outbid smaller firms or potential entrants when pollution permits are auctioned off or traded. If environmental regulation requires the adoption of capital-intensive abatement technology, this may increase the minimum efficient scale of the industry and consequently act as a barrier to entry. Such regulations sometimes only apply to new entrants, excusing incumbents from compliance. Once the number of firms are reduced in the industry, collusion is facilitated. Furthermore, taxes on emissions may act as a stabilizing influence on cartels by reducing the incentive of any individual firm to increase its output. Similar issues have been a source of concern also for the European Commission (EC), as stated in Chapter 7 of the Guidelines on the applicability of Article 81 of the EC Treaty to horizontal cooperation agreements.

To sum up, one of the overriding concerns of policymakers seems to be that environmental regulation has the potential to indirectly act as a stabilizing force on existing coalitions and to facilitate the formation of new

coalitions amongst firms, whether the coalitions are realized by means of tacit collusion or through hard-core collusion in the form of cartels. Within the environmental economics literature, the study of coalition stability has so far been restricted to international environmental agreements (IEAs), where countries form coalitions to jointly reduce emissions (See Barrett (2003) and Finus (2003) for surveys of this literature.) This paper approaches this issue from an industrial organization perspective. We ask whether the existing results regarding the stability conditions of IEAs can be carried over to possible coalition formations amongst polluting firms.

The main difference between country-level studies and firm-level studies arises from the fact that pollution damage is essentially a negative externality that firms impose on the rest of the country. Thus, whilst countries include pollution damage in their objective functions when deciding whether to enter a coalition with other countries, firms, in the absence of any government intervention, do not do so when deciding whether to collude with other firms. However, with the use of environmental regulatory instruments, governments are increasingly able to force firms to internalize this externality. One such policy instrument in use by several countries, including UK, Denmark, Austria, Germany, Italy, Sweden, Finland, Norway and The Netherlands, is the carbon tax. Countries currently considering the implementation of a carbon tax include New Zealand and the US. Concerns have been raised about carbon leakage which is the tendency for energy-intensive industries to migrate from nations with a carbon tax to those nations without a carbon tax where some of the receiving nations might be less energy-efficient. A possible antidote is for carbon-taxing countries to levy carbon-equivalent fees on imports from non-taxing nations. Both in the US (the Lieberman-Warner Climate Security Act) and the EU, it has recently been proposed that such a carbon tax on imports be imposed.

The objective of this paper is to examine how the implementation of a carbon tax affects the stability of a coalition amongst polluting firms. Consider a world with free trade and N identical polluting firms. We set up a differential game between the N firms which are assumed to behave *à la* Cournot. The firms' emissions are directly proportional to their output levels. Each firm is faced with a carbon tax, either in its own country or a carbon tax on imports when exporting its product. The dynamic scenario allows us to take into consideration the fact that in reality, pollution accumulates into a stock over time. We then determine the stability conditions of a grand coalition (that is, where all the firms within the oligopoly collude) under the following two scenarios: (i) when the carbon tax rate is an exogenously given constant (labeled as "uniform" tax rate), (ii) when the carbon tax rate is dependent on the stock of pollution (labeled as "Markovian" tax). We are particularly interested in the latter since it has been established in the differential game literature that a Markovian tax would be time consistent within this context whereas a uniform tax would not. That is, as the stock of pollution changes over time, a government setting the carbon tax has an incentive to adjust the tax rate rather than letting it remain constant. We use the uniform tax rate scenario to provide a benchmark against which to measure the effect of imposing the Markovian tax rate.

If firms are indeed being made to internalize the pollution damage they cause through the implementation of instruments such as the carbon tax, then, are there any differences remaining between the scenarios faced by polluting countries and by polluting firms when they decide to form coalitions amongst themselves? In other words, can the existing results derived in the literature on IEAs be directly applied to the case of collusion amongst polluting firms? We argue that this is not the case. The majority of the IEA literature

uses a static framework or a repeated game framework to analyze the conditions under which a coalition achieves stability. Amongst the few existing dynamic models of IEAs, it has been assumed that pollution damage depends only on current emission levels (Breton et al (2006) and de Zeeuw (2007)). Exceptions include Rubio and Ulph (2007) where damage depends only on the stock of pollution. In this paper, on the other hand, the cost of polluting faced by firms depends not only on current emissions, but also on the stock of pollution accumulated over time, as in the case of the Markovian tax rate. The objective is to compare conditions under which the grand coalition is stable given the uniform and the Markovian tax rates. We say that the grand coalition is stable if no member has a unilateral incentive to leave the coalition (also known as the internal stability condition). Let us now turn to a discussion of the main results.

First, we find that, under a uniform tax rate, the grand coalition is never stable as long as there are more than two firms in the industry. However, given a Markovian tax rate, for any $N > 1$, we show that there exists a set of parameter values such that the grand coalition is stable. In particular, if the degree to which the tax rate depends on the stock of pollution is sufficiently high, the natural rate of decay of the pollution stock is sufficiently high, and the discount rate is sufficiently low, we have that the grand coalition of any size is stable. The more dependent the tax rate is on the stock of pollution, the more likely is the grand coalition to be stable. This is due to the following feedback mechanism which is set into motion by the implementation of a Markovian tax. As firms produce more, they add to the stock of pollution. Since the tax rate is increasing in the stock of pollution, there is a direct relationship between the level of current output of each firm and its future tax bill. This acts as an extra channel through which to restrict the firms' current output levels, and thereby, to ensure that the grand coalition is stable.

Having said this, however, we show that, at any given combination of values of the discount rate and the natural rate of decay of the pollution stock, there is a maximum industry size, N , such that the grand coalition is stable. Previous studies where the stability criterion is defined using the internal stability criterion, as in our paper, the maximum number of players that can be sustained within a grand coalition has been shown to be three. In this paper, by sufficiently increasing the degree of dependence of the tax rate on the stock of pollution, we show that the maximum size of a stable grand coalition is significantly increased. We provide numerical examples where, given a sufficiently high degree of dependence of the tax rate on the pollution stock, this maximum reaches seven.

Second, we show that, *ceteris paribus*, as the efficiency of abatement technology is increased, the grand coalition can go from being stable to unstable. This implies that if the government invests in R&D to improve the abatement technology in the hope of reducing pollution, its efforts could be counteracted by the destabilization of an existing coalition amongst the firms, which would result in an increase in the industry output level. Thus, we identify a scenario where it becomes imperative to take into account the resulting changes in industry structure whilst formulating the optimal R&D policy regarding abatement technology.

Third, we show that some grand coalitions can be stable at a high pollution stock and unstable at a small pollution stock. The higher the stock of pollution, the higher the tax rate at which the firms must pay for polluting. Hence, the lower the incentive to increase output by deviating from the coalition. This implies that, given the imposition of a Markovian tax within a polluting oligopoly, collusive behaviour might be thought of as "self-correcting" over time. If a stable coalition is formed at a high stock of pollution, this

results in a decrease in industry output. This, in turn, reduces the stock of pollution and thereby destabilizes the coalition under specific conditions which are identified in the paper.

2 A flow of pollution: The Static Model

Let us begin by presenting a static version of our model, which is analytically more tractable than the dynamic version, and serves as a benchmark against which to compare the dynamic version. Consider a Cournot oligopoly with N identical firms that produce a homogenous good. Each firm has a constant marginal cost, $c \geq 0$ and produces an output of q_i . Industry output is given by $Q = \sum q_i$ and the inverse demand function is $P = P(Q)$ with $P' < 0$ and $P(0) > c$. The firm i is assumed to emit pollution of $e_i = \theta q_i$. Firms are able to choose their own output levels. However, they have to pay a pollution tax. We consider the case where each firm's tax bill depends on its level of output. Specifically, we consider tax rules which are linear in output. Since the firms are identical, we restrict our study to the case where all firms face the same tax rule. Thus, firm i 's tax bill is given by:

$$T_i = \tau \theta q_i$$

Each firm maximizes its profits, given by:

$$\pi_i = P(q_i + Q_{-i})q_i - (c + \tau \theta)q_i$$

The first order condition is given by:

$$P - c + P'q_i - \tau \theta = 0 \tag{1}$$

We consider only symmetric equilibria where all firms behave identically. If τ is positive then we have

$$P - c + P' \frac{Q}{N} - \tau \theta = 0 \tag{2}$$

We consider the following specific case. The demand function is linear: $P(Q) = P(0) - bQ$, $P(0) - c \equiv a > 0$. The damage function is quadratic: $D(Q) = (\gamma/2)Q^2$.

Using (2) for an interior solution, the equilibrium quantity produced by each firm is given by:

$$q = \frac{a - \tau \theta}{b(N + 1)}$$

We note that $q > 0$ iff $\tau < a$. It can be shown that equilibrium profit of each firm, which depends on the number of firms in the industry and on the emissions tax, is given by:

$$\pi(N, \tau) = b(q)^2 = \frac{1}{b} \left(\frac{a - \tau \theta}{(N + 1)} \right)^2$$

2.1 Coalition stability

In this context, we examine the stability of a coalition of M firms. Prior to the coalition formation, there exist $N \geq M > 1$ firms. A coalition of M firms is stable to unilateral¹ deviations iff (3) and (4) hold.

$$G(N, M, \tau) \equiv \pi(N - M + 2, \tau) - \frac{1}{M} \pi(N - M + 1, \tau) < 0 \quad (3)$$

$$H(N, M, \tau) \equiv \frac{1}{M + 1} \pi(N - (M + 1) + 1) - \pi(N - M + 1) < 0 \quad (4)$$

The internal stability condition, (3), ensures that no insider wants to exit the coalition, and the external stability condition, (4), ensures that no outsider wants to join the coalition.

PROPOSITION 1: *A coalition of size M , for $N > 2$ and any M such that $N \geq M > 1$, is never internally stable when pollution is a flow with no dynamic consequences.*

PROOF: From (3), we have that, under a constant tax, τ , the internal stability condition is given by:

$$\begin{aligned} G(N, M, \tau) &\equiv \frac{1}{b} \left(\frac{a - \tau\theta}{((N - M + 2) + 1)} \right)^2 - \frac{1}{M} \frac{1}{b} \left(\frac{a - \tau\theta}{((N - M + 1) + 1)} \right)^2 \\ &= (a - \tau\theta)^2 \frac{10M - 6N + MN^2 - 2M^2N + 6MN - 5M^2 + M^3 - N^2 - 9}{Mb(M - N - 3)^2(M - N - 2)^2} \end{aligned} \quad (5)$$

Given that $\frac{\partial(10M - 6N + MN^2 - 2M^2N + 6MN - 5M^2 + M^3 - N^2 - 9)}{\partial M} = -10M + 6N - 4MN + 3M^2 + N^2 + 10$, we note that the expression $(10M - 6N + MN^2 - 2M^2N + 6MN - 5M^2 + M^3 - N^2 - 9)$ has a unique local maximum at $M = \hat{M} \equiv \frac{2}{3}N + \frac{1}{3}\sqrt{N^2 + 2N - 5} + \frac{5}{3}$, where $2 < \hat{M} < N$ for all $N > 2$. This together with the fact that $G(N, 2, \tau) > 0$ and $G(N, N, \tau) > 0$ completes the proof. ■

We note that Proposition 1 holds regardless of the tax rate, τ . That is, it also holds for $\tau = 0$. Imposing the emissions tax, in this context, does not increase the potential for stabilizing a coalition.

3 A stock of pollution: The Dynamic Model

We extend our analysis to a dynamic model where pollution accumulates over time into a stock, $S(t)$ with

$$\dot{S}(t) = Q(S(t)) - \delta S(t)$$

We study the Markov Perfect Nash equilibrium (MPNE) of this model, where the strategies of all firms are functions of the payoff relevant state variable, $S(t)$. In this context, $Q(S(t)) \geq 0$ is the industry's emissions (which is equivalent to the industry's production) and $S(0) = S_0$. For notational convenience, the argument of time, t , is not mentioned explicitly in the rest of the paper. The tax rate linearly increases in the stock and is given by:

¹Given a cost of production that is linearly increasing in the quantity produced, it is straightforward to show that if unilateral deviation is not profitable, then it is also not profitable for more than one firm to deviate simultaneously by forming sub-coalitions.

$$\tau(S) = \eta + \alpha S, \quad \alpha > 0$$

Firm i 's optimal control problem is given by:

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

subject to

$$\begin{aligned} \dot{S} &= \theta(Q_{-i}(S) + q_i) - \delta S \\ q_i &\geq 0 \\ S(0) &= S_0 \end{aligned}$$

where δ represents the natural rate of decay of the stock of pollution.

We restrict our study to the linear quadratic case, where demand and damage functions are given by (6) and (7) respectively:

$$P(Q(t)) = P(0) - bQ(t) \quad (6)$$

$$D(S(t)) = \frac{\gamma}{2}(S(t))^2 \quad (7)$$

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

$$V_i(S) = \frac{1}{2}AS^2 + BS + C \quad (8)$$

²For simplicity, henceforth we set $a = 1$, $b = 1$ and $\theta = 1$, unless otherwise mentioned. The MPNE is characterized by the following values of the coefficients (A , B and C) of S in the value function given by (8).

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

$$B = \frac{(a - \eta)((N^2 + 1)A - 2\alpha)}{b(r + \delta)(N + 1)^2 + \alpha(1 + N^2) - 2N^2A}$$

$$C = \frac{1}{-rb(N + 1)^2} (\eta - a - B)(a - \eta + BN^2)$$

The production strategy of a firm is given by:

$$\begin{aligned} q(S, N, \delta, r, \alpha, \eta) &= \frac{1 - (\alpha S + \eta) + V'}{1 + N} \\ &= \frac{1 - \eta + B + (A - \alpha) * S}{1 + N} \end{aligned}$$

Note that production is positive for $S < S_1$ where

$$S_1(N, \delta, r, \alpha, \eta) \equiv -\frac{1 - \eta + B}{(A - \alpha)}$$

²This is shown by Benchekroun and Long (1998) who use a similar setting to ours but do not analyze collusive behaviour within the oligopoly.

The steady state stock, S_S , is determined by

$$\dot{S} = Nq - \delta S = 0$$

We have

$$S_S(N, \delta, r, \alpha, \eta) = \frac{1 - \eta + B}{\frac{1+N}{N}\delta + \alpha - A}$$

The steady state is stable since we have the following:

$$\frac{d\dot{S}}{dS} = N \frac{dq}{dS} - \delta = N \frac{(A - \alpha)}{1 + N} < 0$$

3

In order to avoid numerous possible cases which do not change our main conclusions, we proceed by setting the following parameter values: $S = 0$, $\delta = 0.1$, and $r = 0.05$, unless otherwise mentioned. We will vary these parameters to check the robustness of our results and to discuss any cases where changing any of them affects the MPNE. For notational convenience, the arguments of the value function, N , δ , r , α , and η , are henceforth not mentioned.

3.1 Coalition Stability under a Uniform Tax

Within the dynamic context, a uniform tax refers to the case where $\alpha = 0$. That is, $\tau(S) = \eta$. We begin by examining the stability of the grand coalition, that is, when all N firms tacitly collude. The grand coalition is said to be stable for any $N > 1$, if no member has a unilateral incentive to leave the coalition, that is if (9) holds.

$$H_d \equiv V|_{N=2} - \frac{1}{N}V|_{N=1} < 0 \quad (9)$$

PROPOSITION 2: For $\delta = 0.1$ and $r = 0.05$, the grand coalition is never stable, given a uniform tax rate.

PROOF: For any S and η , we have the following:

$$H_d = \left(2.22 - \frac{5}{N}\right) (\eta - 1)^2 > 0 \quad \text{for all } N > 2$$

■

Figure 1 illustrates that (9) is never met for any $N > 2$, given these parameter values, and setting $S = 0$ and $\eta = 0.5$.

³This follows from (i) & (ii) together, where

$$(i) \frac{\partial}{\partial \alpha} \left(N \frac{(A(N, \delta, r, \alpha, \eta) - \alpha)}{1 + N} - \delta \right) = \left(-\frac{1}{2N} \right) \left(N - 1 + \frac{(N+1)(r+2\alpha+2\delta-4N\alpha+N^2r+2N^2\alpha+2N^2\delta)}{\sqrt{(N+1)^2(r+2\alpha+2\delta)(r+2Nr+2\alpha+2\delta-4N\alpha+4N\delta+N^2r+2N^2\alpha+2N^2\delta)}} \right) < 0$$

$$(ii) \left(N \frac{(A(N, \delta, r, \alpha, \eta) - \alpha)}{1 + N} - \delta \right) |_{\alpha=0} = -\delta < 0$$

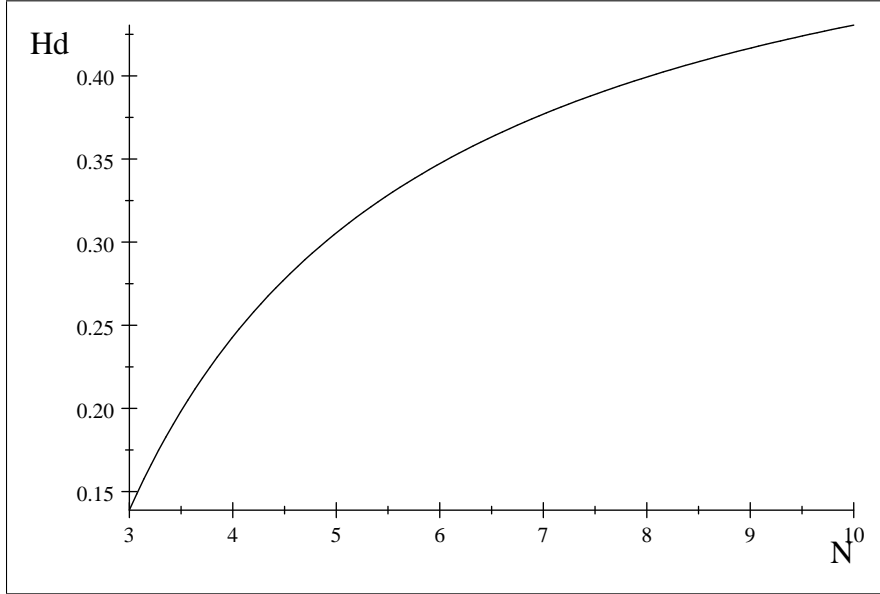


Figure 1

Given these parameter values, and setting $S = 0$ and $N = 3$, we illustrate in Figure 2 that (9) is never met for any $\eta > 0$.

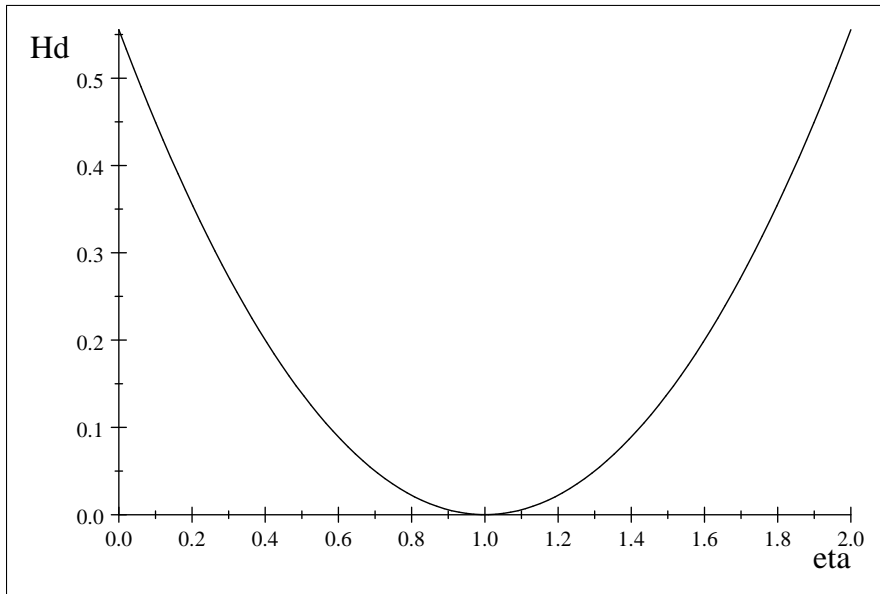


Figure 2

We have checked that varying r and δ does not change the result obtained in Proposition 2. We have also checked, for $N \in [3, 10]$, that a coalition is never internally stable for any $M < N$.

So far, we have shown that coalitions are never stable either when pollution emissions have no dynamic impact, or when pollution accumulates into a stock over time as long as a uniform tax rate is imposed. Next we illustrate that this result may be reversed, given a Markovian tax, by providing counter-examples.

4 Coalition Stability under a Markovian Tax

A Markovian tax refers to the case where $\alpha > 0$.

REMARK 1: *For any given $N > 1$, there exists $\hat{\alpha} > 0$ such that for $\alpha < \hat{\alpha}$ ($> \hat{\alpha}$) we have $H_d > 0$ (< 0).*

Remark 1 is illustrated by Figure 3 for $N = 3$.

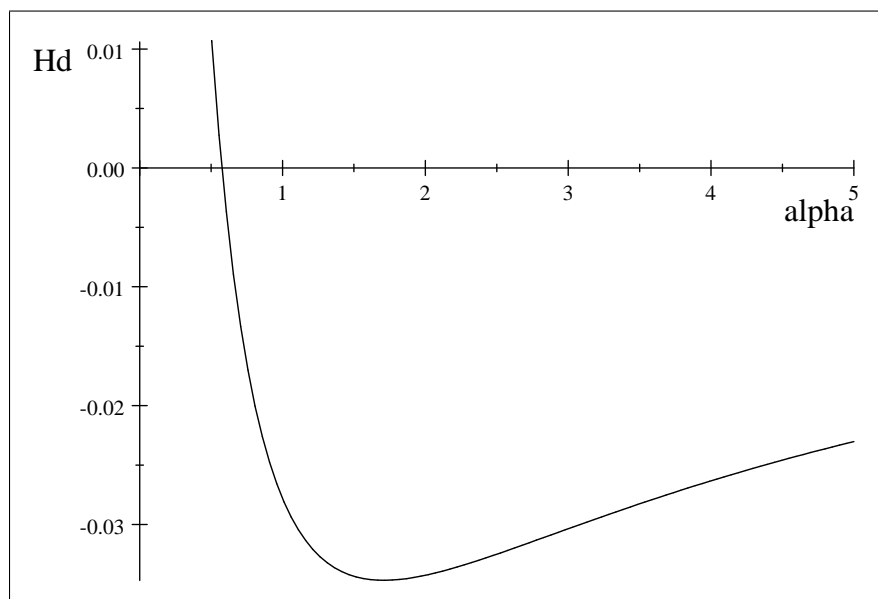


Figure 3: Stability of Grand Coalition for $N = 3$

Thus, unlike the scenarios where pollution is a flow which only affects current payoffs and where the emissions tax is uniform, for a Markovian tax, it is possible that the grand coalition is stable. The grand coalition is only stable for values of α sufficiently large. Given the specified parameter values, as $\alpha \rightarrow \infty$, $H_d \rightarrow 0$ from below. Figure 3 shows that the grand coalition is stable for all $\alpha > 0.6$. We also note that for these parameter values, a coalition of size $M = 2$ (given $N = 3$) is not internally stable, as shown in Figure 4.

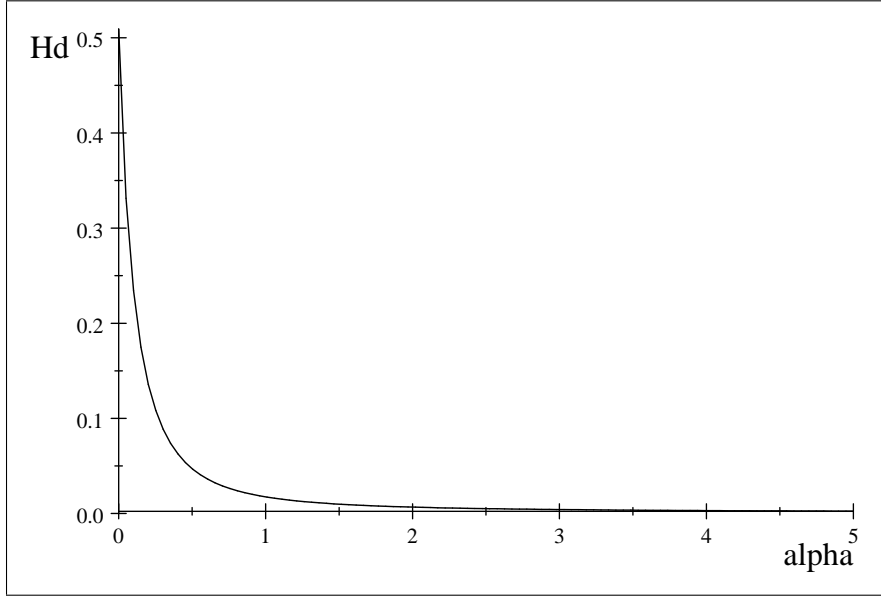


Figure 4: Stability of Coalition of size $M = 2$, given $N = 3$

REMARK 2: *We have that $\hat{\alpha}$ is increasing in N .*

Remark 2 is illustrated by Figure 5.

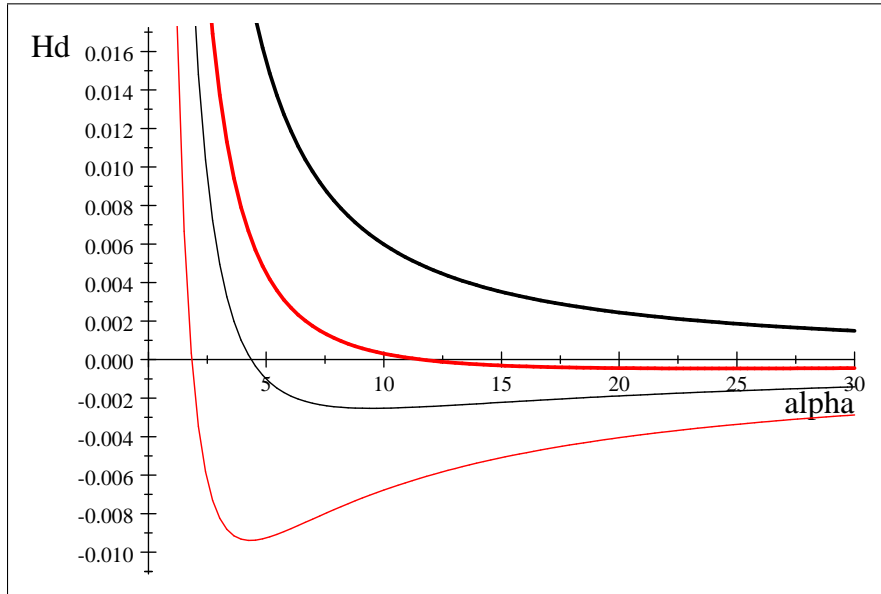


Figure 5: Coalition stability as N varies

Figure 5 illustrates that the bigger the industry size, N , the higher the value of $\hat{\alpha}$ beyond which the grand coalition becomes stable. Alternatively, this can be interpreted as the larger the α , the more likely is the stability of a grand coalition of any given size. This is due to the following feedback mechanism which is set into motion by the implementation of a Markovian tax, where $\alpha > 0$. As firms produce more, they add to

the stock of pollution. Since the tax rate is increasing in the stock of pollution, there is a direct relationship between the level of current output of each firm and its future tax bill. This acts as an extra channel through which to restrict the firms' current output levels, and thereby, to ensure that the grand coalition is stable. Having said this, however, we show that there is a limit in terms of the size of the grand coalition that can be stabilized no matter how large is α . In other words, at any given combination of values of r and δ , there is a maximum industry size, N , such that the grand coalition is stabilized as α is increased.

REMARK 3: *For any $\alpha > 0$, there exists $\hat{N} > 0$ such that for $N < \hat{N}$ ($> \hat{N}$) the grand coalition is stable (not stable).*

Previous studies where the stability criterion is defined using the internal stability criterion, as in our paper, the maximum number of players that can be sustained within a grand coalition has been shown to be three. In this paper, by sufficiently increasing the degree of dependence of the tax rate on the stock of pollution, we show that the maximum size of a stable grand coalition is significantly increased. Given our parameter values, for example, the maximum number of firms that can be stable in a grand coalition is given by:

$$\lim_{\alpha \rightarrow \infty} \left(\frac{V|_{N=1}}{V|_{N=2}} \right) = 7.2$$

Figure 6 shows the maximum size of the grand coalition that can be stabilized at any given value of α . We note that this maximum does not increase further as α rises above 20.

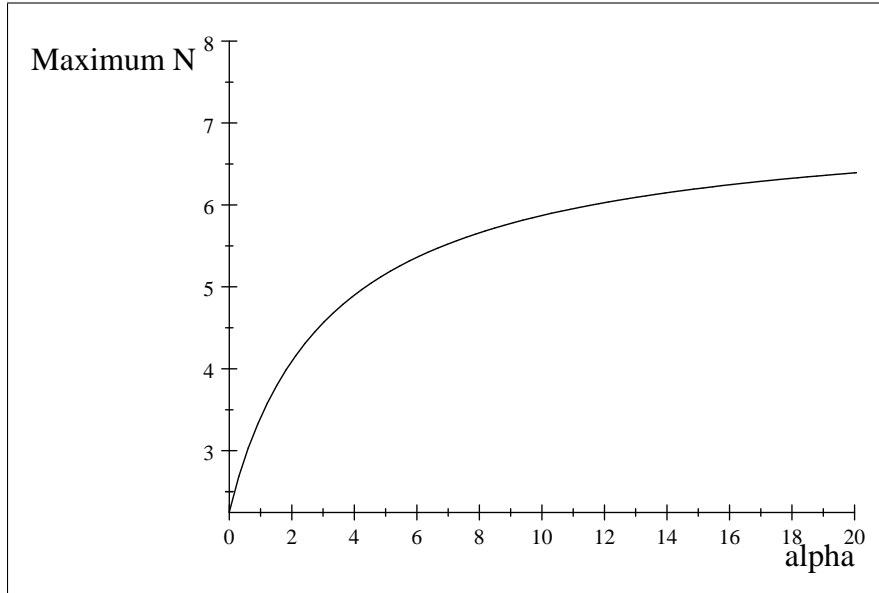


Figure 6: Maximum size of stable grand coalition

We now determine the factors, other than α , which influence the stability of the grand coalition.

REMARK 4: *For any $\alpha > 0$, there exists $\hat{S} \in [0, S_1]$ such that for $S \in [0, \hat{S}]$ the grand coalition is not stable, and for $S \in [\hat{S}, S_1]$ the grand coalition is stable.*

Remark 4 states that some grand coalitions can be stable at high pollution stock and unstable at small pollution stock. Figure 5 shows that for $\alpha = 1$, we have $H_d < 0$ for all $S \in [0, S_1]$, where $S_1 = 0.98546$. For $\alpha = 0.5$, we have $\hat{S} = 0.58$ with $H_d < 0$ for all $S \in [\hat{S}, S_1]$, where $S_1 = 0.96774$.

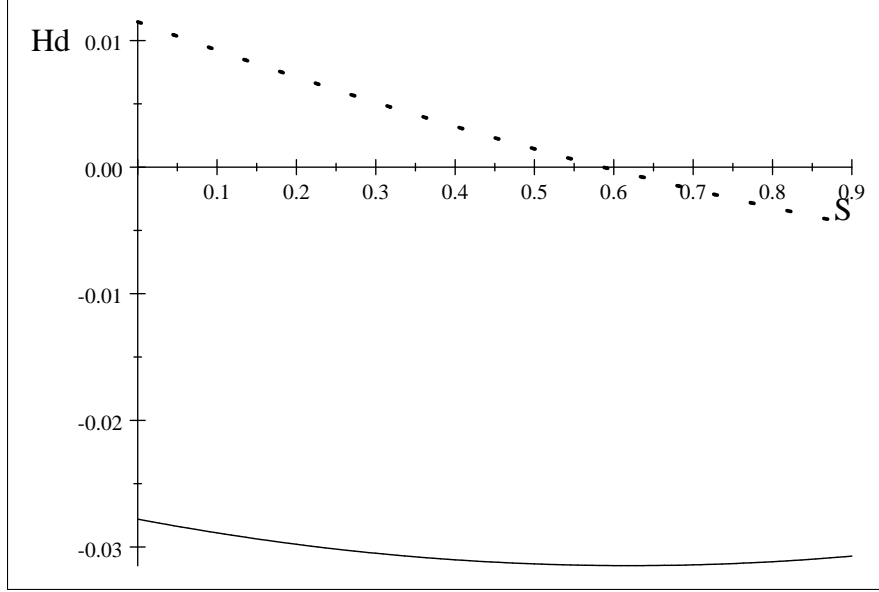


Figure 7: — alpha = 1, alpha = 0.5

The intuition for this result is straightforward. Given any $\alpha > 0$, the tax burden of the polluting firms is increasing in S . Therefore, at high values of S , each firm has less of an incentive to further add to their tax bills by deviating from the grand coalition (and thereby increasing S further). This implies that, given the imposition of a Markovian tax within a polluting oligopoly, collusive behaviour might be thought of as “self-correcting” over time. If a stable coalition is formed at a high stock of pollution, this results in a decrease in industry output. This, in turn, reduces the stock of pollution and thereby destabilizes the coalition, as shown in Figure 7 for $\alpha = 0.5$.

REMARK 5: *There exists $\hat{\theta} \geq 0$ such that for $\theta > \hat{\theta}$ ($< \hat{\theta}$) we have that the grand coalition is stable (unstable).*

Remark 5 shows that, ceteris paribus, as the efficiency of abatement technology is increased, the grand coalition can go from being stable to unstable. This implies that if the government invests in R&D to improve the abatement technology in the hope of reducing pollution, its efforts could be counteracted by the destabilization of an existing coalition amongst the firms, which would result in an increase in the industry output level. Thus, we identify a scenario where it becomes imperative to take into account the resulting changes in industry structure whilst formulating the optimal R&D policy regarding abatement technology.

PROPOSITION 2: *For any $N > 0$ and $S = \eta = 0$, there exists $\tilde{\delta}_{r,N}$ such that for any $\delta/r > \tilde{\delta}_{r,N}$, there exists α_N such that for $\alpha > \alpha_N$ the grand coalition is stable.*

PROOF: At $S = \eta = 0$, we have that

$$\lim_{\alpha \rightarrow \infty} \left(\frac{V|_{N=1}}{V|_{N=2}} \right) = 2 \frac{\delta}{r} + \frac{1}{1 + 2 \frac{\delta}{r}} + 3$$

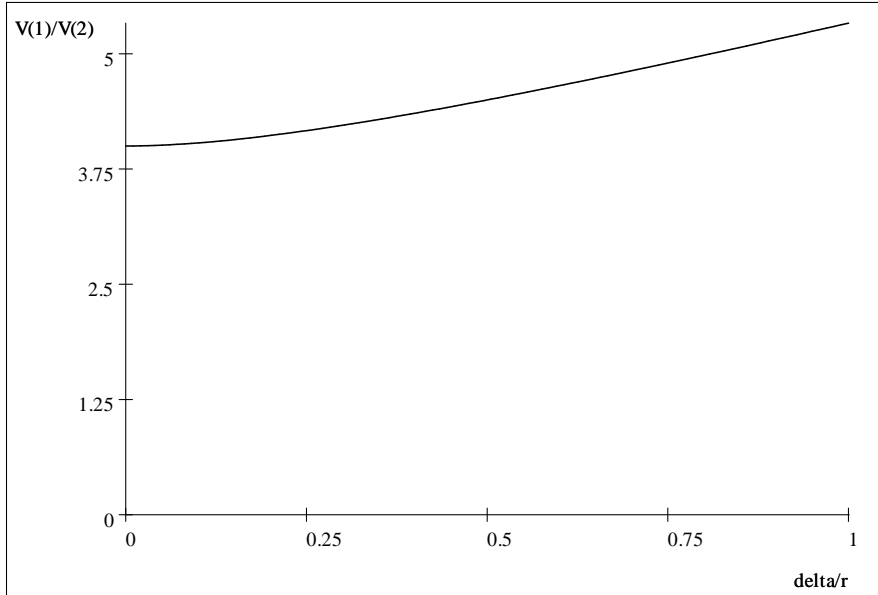


Figure 8

Figure 8 shows that for all $\frac{\delta}{r} > 0$, we have $\lim_{\alpha \rightarrow \infty} \left(\frac{V|_{N=1}}{V|_{N=2}} \right) \geq 4$. Thus the maximum size of the grand coalition given any $\frac{\delta}{r} > 0$ is at least 4. Since $\lim_{\alpha \rightarrow \infty} \left(\frac{V|_{N=1}}{V|_{N=2}} \right)$ is monotonically increasing in $\frac{\delta}{r}$, we have that for higher values of $\frac{\delta}{r}$, the maximum size of the grand coalition is larger. ■

We, therefore conclude that as long as α is sufficiently large, there exist a set of parameter values such that the grand coalition is stable.

5 Conclusion

This paper examined how the implementation of a carbon tax affects collusive behaviour amongst polluting firms. A dynamic scenario was analyzed, where pollution is allowed to accumulate into a stock over time. The stability conditions of a grand coalition were determined under the following two scenarios: (i) when the carbon tax rate is an exogenously given constant, that is, a "uniform" tax, (ii) when the carbon tax rate is dependent on the stock of pollution, that is a "Markovian" tax.

First, it was shown that, under a uniform tax rate, the grand coalition is never stable as long as there are more than two firms in the industry. However, given a Markovian tax rate, we showed that there exists a set of parameter values such that the grand coalition is stable. In particular, if the degree to which the tax rate depends on the stock of pollution is sufficiently high, the natural rate of decay of the pollution stock is sufficiently high, and the discount rate is sufficiently low, we have that the grand coalition of any size can be stable. Previous studies using the same stability criteria as in our paper showed that the maximum number of players that can be sustained within a grand coalition is three. In this paper, by sufficiently increasing

the degree of dependence of the tax rate on the stock of pollution, it was shown that the maximum size of a stable grand coalition is significantly increased. We provided numerical examples where this maximum reaches seven. Second, we showed that, ceteris paribus, as the efficiency of abatement technology is increased, the grand coalition can go from being stable to unstable. Third, we showed that some grand coalitions can be stable at a high pollution stock and unstable at a small pollution stock.

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