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Summary

The paper studies how does the size of a cartel affect the possibility that its members can sustain a collusive agreement. I obtain that collusion is easier to sustain the larger the cartel is. Then, I explore the implications of this result on the incentives of firms to participate in a cartel. Firms will be more willing to participate because otherwise, they risk that collusion completely collapses, as remaining cartel members are unable to sustain collusion.

Keywords: Collusion, Partial cartels, Trigger strategies, Optimal punishment

JEL Classification: L11, L13, L41, D43

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1 Introduction

For many years it was widely held among economists that firms could not exercise market power collectively without some form of explicit coordination. However the theory of repeated games has cast some doubt on this approach. Stable arrangements may require little coordination between firms, and possibly none at all. This has raised a dilemma for the design of a policy towards collusion. If the legal standard focuses on explicit coordination, a large number of collusive outcomes can fall outside the prohibition, and if it tries to cover collusion without explicit coordination, it will prohibit non-cooperative practises.

Article 81(1) of the Rome Treaty stipulates that agreements or concerted practises between firms which distort competition are prohibited. What is meant by "agreements" and "concerted practises" is not further specified in the treaty. However, decisions recently taken by the Commission show that often firms behavior that do not involve a process of coordination are overlooked although they could mean an exercise of market power.

The literature about collusion, mainly deal with two different approaches. Firstly, there are the papers that investigate cartel stability in static models. They have mainly focused on the incentives of firms to participate in a cartel agreement. These papers focus on firms "participation constraints". Two different incentives play a role here. Firms face a trade off between participation and nonparticipation in the cartel: firms have an incentive to join the cartel so as to achieve a more collusive outcome, but on the other hand have an incentive to stay out of the cartel to free-ride on the cartel effort to restrict production. By their very nature, in these models cartel members do not cheat on a cartel agreement as it is assumed that agreements are sustained through binding contracts, they may, therefore, be viewed as models of *binding* collusion[1]. The seminal papers in this literature are Selten (1983) and d'Aspremont et al. (1983)

There is another strand in the literature on cartel stability, which takes a quite different route. The supergame-theoretic approach to collusion has focused on the problem

[1] A formal collusion agreement among competing firms (mostly oligopolistic firms) in an industry designed to control the market, raise the market price, and otherwise act like a monopoly is frequently also termed explicit collusion. Binding collusion refers, therefore, to an explicit collusive agreement enforceable at law.

of enforcement of collusive behavior (see for example Friedman (1971)). In these models, seemingly independent, but parallel actions among competing firms in an industry are driven to achieve higher profits. It is termed tacit or *implicit* collusion. This focuses on firms "incentive constraints"[2]. Then, what this approach leaves out, are firms' "participation constraints": it cannot explain why many real world cartels do not comprise all firms in the industry. Instead, they have studied under which circumstances collusion can be sustained as an equilibrium of the repeated game. Most research on the field has studied symmetric settings and have focused on the sustainability of the most profitable symmetric equilibrium. The reason to select this equilibrium is that it will be the one that firms will agree to play if they secretly meet to discuss their pricing plans (Mas-Colell et al (1996)).

The main point of the paper is that this argument is compelling but it does not take into account that firms may prefer not to attend this meeting in order not to participate in the coordination to a collusive agreement. This takes us back to the literature on the incentive to participate in a cartel, mentioned above. However, now the analysis is richer because one has to study how does the participation incentive interact with the incentive to maintain a collusive agreement. As a first step, I study how does the size of a cartel affect the possibility that its members can sustain a collusive agreement in a supergame theoretical framework. I obtain that collusion is easier to sustain the larger the cartel is. To obtain the result I study the sustainability of partial cartels i.e. cartels that do not include all the firms in a given industry. Partial cartels are often observed in reality, being the OPEC the most well known example.

The previous result has implications on cartel formation, because it reduces the incentives to free-ride from a cartel by defecting from it. I can illustrate the idea with the following extreme example. I find that for some discount factors, the only sustainable cartel is the cartel that comprises all firms in the industry. Then all firms have incentives to participate in the cartel, because otherwise collusion completely collapses. This completely eliminates the gains from free-riding at the participation stage.

Obviously, in practice it is easier to fight *binding* collusion than against implicit collusion. The model highlights that policy measures that induce firms to replace *binding*

[2]"Participation constraints" are firms incentives to join the cartel or the fringe; meanwhile "Incentive constraints" are the incentives to cheat on the cooperative agreement.

with implicit collusion[3] to escape antitrust prosecution may have its costs. Forbidding *binding* collusion (and forcing firms to collude tacitly) has the positive effect of weaken the incentives to maintain a collusive agreement but the negative effect of making stronger the incentives to participate in a cartel[4].

Therefore the total effect on price is uncertain. In the particular model I analyze price is higher with implicit than with *binding* collusion. The model predicts that the size of the cartels enforced can be larger in the *implicit* collusion model than in the *binding* collusion model.

We can think of several interesting cases where these results could be of interest. In several European countries, before governments moved to adapt its domestic competition policy to the European regime, agreements restricting competition among firms were not only permitted but also enforceable at law. Namely, Denmark (see OCDE (1993)) where before the Competition Act of 1990 was passed agreements were widespread in several sectors and often took the form of binding agreements and also West Germany where before 1987 hundreds of legalized cartels were enforced through a contract (see Audretsch (1989)). Switzerland and Sweden are other examples of countries where Cartels were sustained for decades by means of enforceable contracts. Therefore, the present model points out a possible consequence of banning binding collusion that perhaps has been unnoticed by antitrust authorities.

The structure of the paper is as follows. In the following section, the central model of the paper is set. The sustainability of the partial cartel is analyzed with the "trigger strategies"[5]. In the next section, the participation game is set. Firms decide first wether to

[3] "When the legal advisors of cartel members discovered that Article 85 had to be taken seriously, they had their clients throw their agreements in the waste basket. Simultaneously, the attention of DG\ IV shifted to the detection of tacit collusion, on the assumption that explicit collusion was being replaced by tacit collusion" (Phlips (1995)).

[4] "Although strict prohibition and strong sanctions probably reduce the incidence of explicit collusion, continuing cases are good evidence that firms find it profitable to engage in the practice. Firms are naturally careful not to create good evidence of such agreements. (...) It should be noted, however, that even if enforcement were 100 percent effective, this would not necessarily put an end to coordinated interaction. It could simply cause firms to opt for substitutes which are less likely to attract legal sanctions and offer the further advantages of greater flexibility and lower costs to arrange: It could be even argued that firms prefer less risky, more flexible alternatives to explicit collusion" (OECD (1999))

[5] The sustainability of partial cartels in a dynamic setting is considered by Martin (1990) in a ho-

join the cartel or not, afterwards the firms infinitely play a quantity game. The main aim of this section is to study the interaction between incentive and participation constraints. Afterwards, the sustainability of the partial cartel is analyzed using an optimal penal code to enforce collusion following Abreu (1986).

mogeneous firms context. However unlike our model, decision is sequential, that is cartel firms act as Stackelberg leaders.

2 Partial Cartels

Assume that n firms, where $n > 2$, indexed i, $i = 1, 2, 3, ..., n$ compete in a market whose demand is given by $P(Q) = 1 - Q$. Cost functions of firms are given by: $c(q_i) = \frac{q_i^2}{2}$, where q_i denotes the production of firm i. Assume firms simultaneously choose quantities [6].

A (partial) cartel will be said to be active in this market if there is a group of firms (cartel members) that maximize joint profits and the remaining firms (nonmembers or fringe firms) maximize individual profits. When a cartel of k firms is active, members (m), and nonmembers (nm), simultaneously produce respectively:

$$q_m^k = \frac{2}{nk - k^2 + 3k + 2 + n} \tag{1}$$

$$q_{nm}^k = \frac{k+1}{nk - k^2 + 3k + 2 + n} \tag{2}$$

In this situation, Profits of members and nonmembers are given respectively by π_m^k and π_{nm}^k. Observe that if $k = 1$, we have standard Cournot competition and $q_m^1 = q_{nm}^1$.

We are going to study under which conditions playing (1) and (2) in each period can be sustained as an equilibrium of a game where the one stage game described above is repeated infinite times. Firms will be assumed to discount the future at a factor of δ. Member firms are denoted with a natural number from 1 to k.

Cartel members will sustain cooperation by using "trigger strategies", that is, when cheating, firms are punished with infinite reversion to the Nash Cournot equilibrium. Trigger strategies for a partial cartel can be formulated the following way, where $q_{t,i}$ denotes the strategy played by firm i in period t:

Firm i, $i = 1, ..k$ plays

$$\begin{cases} q_{1,i} = q_m^k \\ q_{t,i} = q_m^k \text{ if } q_{l,j} = q_m^k \text{ for any } l < t \text{ for } j = 1, ..., k \\ q_{t,i} = q_m^1 \text{ otherwise.} \end{cases}$$

Firm i, $i = k+1, ...n$ plays

[6] Shaffer(1995) considers the cartel as a Stackelberg leader because of its power to impose its most preferred timing.

$$\begin{cases} q_{1,i} = q^k_{nm} \\ q_{t,i} = q^k_{nm} \text{ if } q_{l,j} = q^k_m \text{ for any } l < t \text{ for } j = 1, ..., k \\ q_{t,i} = q^1_m \text{ otherwise.} \end{cases}$$

Nonmember firms play optimally, because the future play of rivals is independent of how they play today and they maximize current profits. Member firms will behave optimally if the discount factor is high enough. To obtain the conditions on the discount factor such that using "trigger strategies" is also optimal for member firms, we have to calculate the profits of a member firm that deviates from the cartel. They will choose:

$$q^k_d = \underset{q}{\arg\max}\ P((k-1)q^k_m + (n-k)q^k_{nm} + q)q - \frac{q^2}{2}$$

and will obtain π^k_d like the profits obtained in the period of deviation.

Then trigger strategies are optimal for member firms if:

$$\frac{1}{1-\delta}\pi^k_m \geq \frac{\delta}{1-\delta}\pi^1_m + \pi^k_d$$

If we let $\delta_k = \dfrac{\pi^k_d - \pi^k_m}{\pi^k_d - \pi^1_m}$, the previous condition can be written in the following way.

If $\delta_k \geq 1$ the cartel of size k can not be sustained for any δ. If $\delta_k < 1$, the cartel can be sustained for $\delta \geq \delta_k$.

Although it may be surprising at first sight that some cartel sizes can not be sustained in equilibrium, it comes from the well-known result in the literature that with Cournot competition, mergers (or any other collusive agreement) of a small number of firms reduces profits because non-participating firms react by increasing their production (see Salant et al.(1983)).

Next proposition shows that the previous intuition extends to any cartel size in the sense that whenever a cartel of size k is sustainable, cartels of larger size are also sustainable[7].

Proposition 1 *The cutoff discount factor* (δ_k) *that sustain the strategies described above, is strictly decreasing in the size of the cartel.*

[7]Remark the similarity with the result in Salant et al.(1983) that if a merger of k firms is profitable, a merger with more firms is also profitable.

We have that δ_k can be rewritten like :

$$\delta_k = \frac{1 - \frac{\pi_m^k}{\pi_d^k}}{1 - \frac{\pi_m^1}{\pi_d^k}}$$

Therefore variations of k have two different effects. First, $\frac{\pi_m^k}{\pi_d^k}$ decreases when k increases because deviation profits increase more than profits from being in the cartel of k firms. This would increase δ_k. Second, as k increases, $\frac{\pi_m^1}{\pi_d^k}$ also decreases because π_m^1 does not depend on k, and deviation profits increase with k. Thus punishment becomes proportionally more painful. This second effect would decrease δ_k.

The result from the Proposition 1 comes from the fact that the second effect dominates the first one.

3 The participation game.

In the previous Section we have obtained conditions on the discount factor under which cartels of different sizes are active. In this Section, we will allow firms to coordinate in the different outcomes by showing their willingness to participate in a collusive agreement. Those decisions will not affect the payoff of firms, but they will only be used as a coordination device: if k firms decide to participate in a cartel agreement, only cartels of size k can be observed in the repeated game.

This pre-communication play is modelled as a stage prior to market competition. The decision of each firm relates to selecting a zero-one variable w_i where:

$$\begin{aligned} w_i \quad : \quad & 1 \text{ iff firm } i \text{ joins the cartel} \\ & 0 \text{ iff firm } i \text{ joins the fringe} \end{aligned}$$

If k firms announce joining the cartel , the future play is only modified if the discount factor allows a cartel of k firms to be active ($\delta \geq \delta_k$). Otherwise, all firms play the Cournot quantity in all periods. In short, once a cartel of k firms is formed, we will

assume that discounted payoffs of member and nonmember firms are respectively given by the following expressions:

$$\Pi_m^k = \begin{cases} \frac{1}{1-\delta}\pi_m^k \text{ if } \delta \geq \delta_k \\ \frac{1}{1-\delta}\pi_m^1 \text{ otherwise} \end{cases} \tag{3}$$

$$\Pi_{nm}^k = \begin{cases} \frac{1}{1-\delta}\pi_{nm}^k \text{ if } \delta \geq \delta_k \\ \frac{1}{1-\delta}\pi_{nm}^1 \text{ otherwise} \end{cases} \tag{4}$$

We are going to look for the Nash equilibrium of the game.

In our model, a cartel of size k is an equilibrium configuration (stable cartel) if the following two conditions are satisfied:

-Internal stability: Either $k = 1$, or:

$$\Pi_m^k \geq \Pi_{nm}^{k-1} \tag{5}$$

Which means that no cartel firm wants to leave the cartel, as the profits that this firm would obtain by joining the fringe would be no larger than profits obtained by remaining in the cartel.

-External stability: Either $k = n$, or:

$$\Pi_m^{k+1} \leq \Pi_{nm}^k \tag{6}$$

If this condition holds no fringe firm has incentives to join the cartel, as doing so the profits obtained would be no larger than the profits obtained by staying in the fringe.

This participation game has been previously analyzed in the literature in cases where firms can sign binding contracts to sustain the outcome of the cartel[8]. In that case collusion is said to be binding, while in our model is called implicit. With binding collusion sustainability of cartels is not at issue. Then payoffs of players would be like (5) and (6) taking $\delta_k = 0$. Solving the participation game for the case of binding collusion will be both a helpful step to solve it in our case and will provide us a benchmark to compare the results.

[8]See Donsimoni (1985). The only difference is that it considers the Cartel behaves as a Stackelberg leader while in our case the cartel and nonmember firms compete à la Cournot.

The key point in the binding collusion case is that for any cartel size, internal stability is never satisfied. Firms know that the goal of the cartel is to reduce production. Then firms will have incentives to leave the cartel in order to free ride from the output reduction agreed by the remaining cartel members.

Proposition 2 *No cartel is stable when collusion is binding.*

We are ready now to determine the Nash equilibrium of the participation game. This game has many equilibria in which no cartel is active. For example all firms deciding not to join the cartel is always an equilibrium. For $\delta < \delta_n$ any choice by firms is an equilibrium because the participation decisions are irrelevant because no cartel can be sustained. To clarify the analysis I will focus on the equilibria where cartels are active whenever they exist. It turns out that when they exist, they are unique (except for a permutation of players). We state the results in the following Proposition:

Proposition 3 *No cartel is active in equilibrium if $\delta < \delta_n$. Whenever $\delta \in [\delta_k, \delta_{k-1})$ and $\delta_k < 1$, a cartel of k firms is active in equilibrium.*

The fact that for $\delta < \delta_n$ no cartel is active comes from Proposition 1. Therefore we have only to explain the second part of the Proposition. For $\delta_{k-1} > \delta \geq \delta_k$ only cartels of size greater or equal than k can be sustained. Cartels of sizes greater than k are not stable, because the result in Proposition 2 applies: internal stability does not hold.

The cartel of size k is internally stable, because firms know that quitting the cartel means that collusion fully collapses and they would obtain the Cournot profits. Therefore the cartel of size k is stable. That is, only the smallest cartel among those which can be sustained are stable in the Participation Game.

Once characterized the equilibrium of the participation game, there are two corollaries we can extract from Proposition 3.

Simply comparing Proposition 2 and Proposition 3 we get the following conclusion:

Corollary 1 *If $\delta \in [\delta_n, 1)$ the size of active cartels is bigger with* implicit *collusion than with* binding *collusion.*

Although with binding collusion cartels are always effective, because collusion consists of cartel members committing themselves to produce a certain agreement by signing

binding contracts, we can not find stable cartels. However with implicit collusion firms do not dispose of any commitment power, but when $\delta > \delta_n$ (see Proposition 3) a cartel of certain size is stable. It is precisely the success of the cartels what reduces the incentive to participate in them in explicit collusion.

In the previous Section, we checked that cartels were only active if the discount factor was high enough. Therefore, prices were increasing in the discount factor. In the present Section, the size of the cartel is determined endogenously. Then, price may decrease with the discount factor, because it reduces the size of stable cartels. The failure of small cartels to be sustainable when δ is low, induces firms to create bigger cartels. This result is recollected in the following corollary:

Corollary 2 *When the size of the cartel is endogenously determined, if* $\delta \in [\delta_n, 1)$ *price decreases with the discount factor.*

The reason is basically that as long as the cutoff of the discount factor is decreasing with k, when $\delta \geq \delta_n$, the larger the discount factor, the lower the size of the cartel that is stable. Thus as δ increases, smaller cartels associated to lower prices are enforced. However, when δ is very low ($\delta < \delta_n$), as long as no agreement is possible, the price is the Nash equilibrium price.

4 Optimal punishment.

The literature about *implicit* collusion has treated repeated game models using basically two different types of strategies to enforce subgame perfect Nash equilibria (S.P.N.E.), the "trigger strategies" and the "stick and carrot" strategies defining an optimal punishment[9]. Trigger strategies have been used in the first three sections of the model. I obtained that the cutoff of the discount factor is decreasing in the size of the cartel, and this led us to the results of the third section. I will see in this section, if it is also true when cooperation is sustained by an optimal punishment.

Cooperation is sustained now with strategies where cheating firms are punished with the fastest and most severe possible punishment. Abreu (1986) outlines a symmetric, two-phase output path that sustains collusive outcomes for an oligopoly of quantity setting firms. The output path considered by Abreu has a "stick and carrot" pattern. The path begins with a period of low per-firm output for cartel members (q_m^k). The strategy calls for all cartel members to continue to produce q_m^k, unless an episode of defection occurs. If some firm cheats on the agreement, all cartel firms expand output for one period (q_m^p) (stick stage) and return to the most collusive sustainable output in the following periods, provided that every player of the cartel went along with the first phase of the strategies (carrot stage). As far as fringe firms are concerned, as the future play of the other firms is independent of how they play today, they optimally maximize per period profits. The "stick and carrot" strategies for a partial cartel can be formulated in the following way, where $q_{t,i}$ denotes the strategy played by firm i in period t:

Firm i, $i = 1, ..., k$ plays:

$$(\alpha) \begin{cases} q_{1,i} = q_m^k \\ q_{t,i} = q_m^k \text{ if } q_{t-1,j} = q_m^k \text{ for } j = 1, ..., k \ \forall t = 2, 3, ..., \\ q_{t,i} = q_m^k \text{ if } q_{t-1,j} = q_m^p \text{ for } j = 1, ..., k \ \forall t = 2, 3, ..., \\ q_{t,i} = q_m^p \text{ otherwise.} \end{cases}$$

[9] The latter were firstly set in a seminal paper from Abreu (1986). These strategies became popular in the literature given their optimality and their renegotiation-proofness quality.

Firm i, $i = k+1, ..., n$ plays:

$$(\beta) \begin{cases} q_{1,i} = q^k_{nm} \\ q_{t,i} = q^k_{nm} \text{ if } q_{t-1,j} = q^k_m, \text{ for } j = 1, ..., k \quad \forall t = 2, 3, ..., \\ q_{t,i} = q^k_{nm} \text{ if } q_{t-1,j} = q^p_m, \text{ for } j = 1, ..., k \quad \forall t = 2, 3, ..., \\ q_{t,i} = q^p_{nm} \text{ otherwise.} \end{cases}$$

Following Abreu (1986), the strategies described above are considered optimal, that is, they sustain the highest range of collusive outcomes among all possible punishment phases, if continuation profits after unilateral deviation in any period, equal the Minimax value of firms. In our model it is equal to 0, as firms can always decide not to be active and get 0 profits. Therefore, (α, β) are optimal when this condition holds:

$$\pi^s_m(q^p_m) + \frac{\delta}{1-\delta}\pi^k_m = 0 \tag{7}$$

π^k_m has been defined in section two like profits obtained by cartel firms when cartel and fringe firms produce (1) and (2) respectively, and $\pi^s_m(q^p_m)$ are cartel firms profits if firms are in a punishment phase (stick stage):

$\pi^s_m(q^p_m) = (1 - kq^p_m - (n-k)q^p_{nm})q^p_m - \frac{(q^p_m)^2}{2}$

We need the conditions for the strategies (α, β) to conform a S.P.N.E. On one hand, we need that if firms are in a collusive phase (carrot stage), profits that a firm would obtain if deviates from collusion should be no bigger (given that the rest of the firms adhere to the strategies described) than the profits obtained colluding. That is given by the next condition.

$$\pi^k_d - \pi^k_m \leq \delta(\pi^k_m - \pi^s_m(q^p_m)) \text{ no deviation in the carrot stage} \tag{8}$$

π^k_d has already been defined in section two like the profits that a cartel firm obtains when unilaterally deviates from the collusive agreement.

On the other hand, if we are in a punishment phase (stick stage), we need that firms obtain higher profits in the punishment phase than deviating from it. Therefore, firms do not unilaterally deviate in the stick stage if the following condition holds:

$$\pi_d^s(q_m^p) - \pi_m^s(q_m^p) \leq \delta(\pi_m^k - \pi_m^s(q_m^p)) \text{ no deviation in the stick stage} \tag{9}$$

where we define the profits that a cartel firm obtains by unilaterally deviating in the stick stage like:

$$\pi_d^s(q_m^p) = \max_{q_i} (1 - (k-1)q_m^p - q_i - (n-k)q_{nm}^p)q_i - \tfrac{(q_i)^2}{2}.$$

We have to see how to get q_m^p, and q_{nm}^p, such that if the discount factor is high enough, collusion will be sustained with the strategies (α, β), conforming at the same time, an optimal punishment.

Regarding q_m^p, it must be such that (7) holds. From (9) and (7) we obtain that no deviation in the stick stage is only possible if $\pi_d^s(q_m^p) \leq 0$, since otherwise a firm can deviate in the first period and keep doing so every time the punishment is reimposed. Hence, the total output produced by $(k-1)$ firms must be large enough that[10] $P((k-1)q_m^p) \leq 0$. We have that:

$$P((k-1)q_m^p) \leq 0 \Longleftrightarrow q_m^p \geq x, \tag{10}$$

which sets a lower bound on the quantity produced in the stick stage. This also implies that $q_{nm}^p = 0$. To obtain the lower bound of the discount factor such that (9) and (7) hold, that we will call δ_a, we compute (7) for the lowest value of q_m^p that satisfies (10):

$$\pi_m^s(x) + \frac{\delta_a}{1-\delta_a}\pi_m^k = 0$$

what leads us to:

$$\delta_a = \frac{\pi_m^s(x)}{\pi_m^s(x) - \pi_m^k} \tag{11}$$

[10] The price $P(q)$ is interpreted as price net of marginal cost at zero.

When $\delta > \delta_a$, you need a harsher punishment such that (7) is satisfied.

As far as deviation in the carrot stage is concerned, we have that from (8) and (7), we obtain that firms do not deviate if:

$$\frac{1}{1-\delta}\pi_m^k \geq \pi_d^k \tag{12}$$

This gives us the lower bound of the discount factor such that (8) and (7) are satisfied:

$$\delta \geq \frac{\pi_d^k - \pi_m^k}{\pi_d^k} = \delta_b$$

Finally, we have that (7), (8) and (9) are satisfied if the following condition on the discount factor holds:

$$\delta \geq \max\{\delta_a, \delta_b\} = \delta_k \tag{13}$$

On the one hand, δ_a is decreasing in k. When the number of firms in the cartel increases, it is possible to dissuade unilateral deviations without the need of expanding so much total output. Then profits in the stick stage ($\pi_m^s(x)$) are increasing in k what given (11) implies the result.

On the other hand, δ_b increases in k, because $\delta_b = 1 - \frac{\pi_m^k}{\pi_d^k}$ and deviation profits increase in k more than cartel profits. This make δ_b increase in k.

Analyzing the behavior of δ_k in (13), we obtain the following result:

Proposition 4 *: The cutoff discount factor that sustain the strategies (α, β) as a S.P.N.E. and define an optimal punishment, is strictly decreasing in the size of the cartel (k), if $k \leq \min\{n, f(n)\}$.*

where $f(n) = \frac{13+3n+\sqrt{(9n^2+138n+249)}}{10}$ and strictly increasing otherwise.

If k is small compared to n, the decreasing effect over δ_a dominates the increasing effect over δ_b(see fig. 1 for a graphic representation). The result is no so tight as in

Proposition 1, because the cutoff is always decreasing only if $n \leq 8$ ($n < f(n)$). However, the fact that is decreasing for low enough values of k (observe that $f(n) > \frac{n}{2}$) will allow us to obtain similar results as far as the participation game is concerned.

We proceed to solve the participation game, as we did in section three. Firms show their willingness to participate in a collusive agreement in a stage previous to play the "stick and carrot" strategies. The payoffs are given by (3) and (4) where now δ_k is the one in (13). For the result, we need to define $\overline{\delta} = \min_k \ \delta_k$

Proposition 5 *: If $\delta < \overline{\delta}$ or $\delta \geq \delta_2$, no cartel is active in equilibrium. Otherwise, a cartel of k firms is active in equilibrium if $\delta_{k-1} > \delta \geq \delta_k$.*

This result is analogous to the result in Proposition 3. For $\delta_{k-1} > \delta \geq \delta_k$ only the smallest cartel among those which can be sustained is stable in the participation game. That is because in the smallest sustainable cartel, if firms do not remain in the cartel, it means that collusion fully collapses and they would obtain the Nash-Cournot profits which is worse for them if the cartel enforced has a size greater than two. If $\delta < \overline{\delta}$ collusion is not sustainable and if $\delta \geq \delta_2$ firms are better off with the Nash-Cournot profits than with the cartel of size two (see fig. 1).

Given that for $\delta \in [\overline{\delta}, \delta_2)$ cartels are active, similar results to the ones in Corollaries 1 and 2 can be derived from Proposition (7).

Corollary 3 *: If $\delta \in [\overline{\delta}, \delta_2)$ the size of active cartels is bigger with* implicit *collusion than with* binding *collusion.*

Corollary 4 *: When the size of the cartel is endogenously determined, if $\delta \in [\overline{\delta}, \delta_2)$ price decreases with the discount factor.*

This means that we have exactly the same result we obtained for the case of the "trigger strategies" when δ belongs to the interval $[\overline{\delta}, \delta_2)$.

Again, it is the success of the cartels what reduces the incentive to participate in them with binding collusion. Meanwhile, although firms do not dispose of any commitment

power in implicit collusion, it is the threat to the collapse of collusion what provokes the existence of stable cartels.

Corollary 4 says that, if $\delta \in [\overline{\delta}, \delta_2)$, the larger the discount factor, the lower the size of the cartel that is stable. Thus, as δ increases, smaller cartels associated to lower prices are enforced.

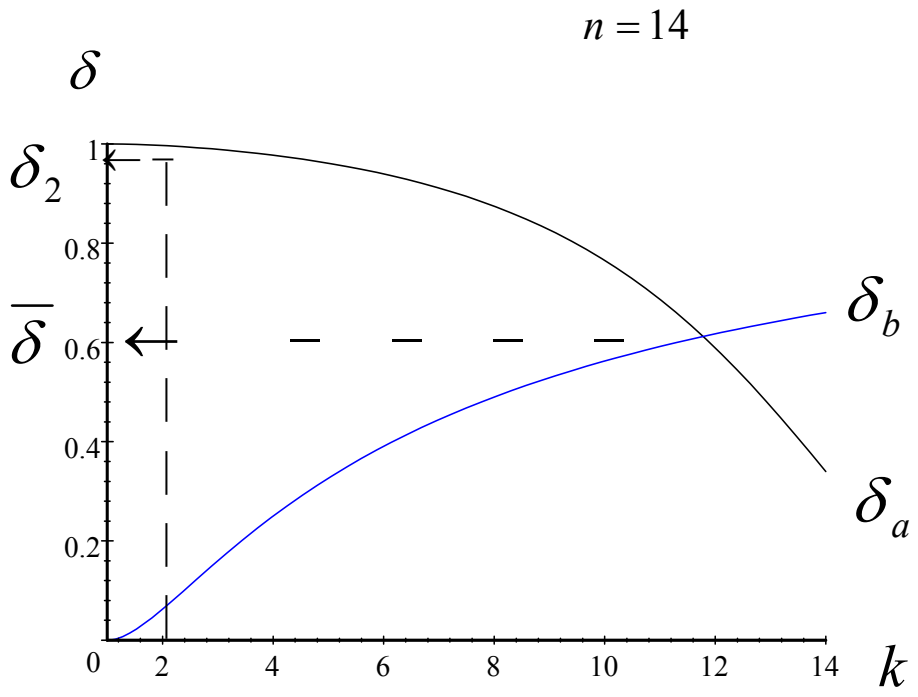

Figure1

5 Conclusions

The main aim of the paper has been basically to analyze a model of partial collusion under two different approaches. The implicit collusion model approach with two different types of strategies to enforce collusion, showed that the larger the cartel, the easier is to sustain the cartel. When collusion is binding, that is, firms can somehow meet and sign a binding contract, it has been proved that the incentives to free ride the cartel play a central role, therefore only very small cartels can be enforced.

To be able to compare both models, a participation game has been set. In this model, an interaction between the incentive and the participation constraints, takes place. The main conclusion is that implicit collusion can enforce larger cartels than binding collusion, becoming therefore perhaps of greater concern for antitrust authorities, especially those countries, namely Holland, Denmark, Switzerland, etc., who moving to adapt its domestic competition policy to the European regime banned binding collusion.

6 Appendix

Proof of Proposition 1: We have $\delta(k) = \frac{\pi^d - \pi^k}{\pi^d - \pi^1}$. If we calculate $\frac{\partial \delta(k)}{\partial k}$, we have that it is the following expressions in our model:

$$-24\frac{28n-60k-84nk+48k^2+24n^2k^2-12nk^3+60nk^2-39n^2k+30n^2-12k^3+2n^4+13n^3-3n^2k^3+3n^3k^2-6n^3k+8}{(9k^3-18nk^2-45k^2+5n^2k+2nk-16k+28+28n+7n^2)^2}$$

It is tedious but straightforward to show that, as long as $k \leq n$, we obtain that the derivative is negative. ■

Proof of Proposition 2: The conditions for stability are the following:

Internal stability:

$$2\frac{2k+1}{(nk-k^2+3k+2+n)^2} \geq \frac{3}{2}\frac{k^2}{\left(n(k-1)-(k-1)^2+3k-1+n\right)^2}$$

External stability:

$$(k+1)\,\frac{\frac{3}{2}k+\frac{3}{2}}{(nk-k^2+3k+2+n)^2} \geq 2\frac{2k+3}{\left(n(k+1)-(k+1)^2+3k+5+n\right)^2}$$

We can show that the expression of Internal stability is decreasing in k. Therefore showing that the condition does not hold at $k = 3$ also proves that coalitions of $k \geq 3$ are not stable. When $k = n = 2$, cooperation is sustainable. For $k = 2$, we can see in the internal stability that if $n \geq 3$ there are incentives to leave the cartel. ■

Proof of Proposition 3: If $\delta < \delta_n$, no collusive agreement is sustainable, therefore looking at (3) and (4) we can see that firms profits are the Nash equilibrium profits and no cartel can be active in equilibrium.

If $\delta \in [\delta_n, \delta_k]$ cartels of size $k^{'}$, for all $k^{'} \in [k, n]$ are sustainable. Using Proposition 2 we can see that no cartel is stable in the explicit game. However, looking again at (3) and (4), we can see that $\Pi_m^{k^{'}} \geq \Pi_{nm}^{k^{'}-1}$ is hold if $k^{'} = k$ with $k^{'} \geq 3$. This is true as the profits of a cartel of size equal or bigger than 3 are larger than Cournot equilibrium profits. At the same time, $\Pi_m^{k^{'}+1} \leq \Pi_{nm}^{k^{'}}$ also holds. Therefore, for every discount factor, only the smallest cartel among those which are sustainable is stable and will be active in equilibrium. ■

Proof of Corollary 2: This is straightforward to show, only seeing that the price of the market is decreasing with k. Therefore, as the configuration enforced in the market involves smaller cartels, prices decrease. ■

Proof of Proposition 4: We obtain the cutoff δ for both stages of the punishment phase, where the envelope of both will be the significative cutoff that sustain the strategies.

It is easy to show that $\delta_a = 3\frac{\left(-nk+k^2-3k-2-n\right)^2}{16+36k+3k^2+12n+30nk+3n^2k^2-6nk^3+12nk^2+6n^2k+3n^2+3k^4-10k^3}$ and $\delta_b = \frac{k^2-2k+1}{(k+2)^2}$ are respectively strictly decreasing and strictly increasing with k. Therefore the minimum value of the decreasing δ will be at $k = n$. So we just have to calculate up to which value the decreasing part is above the increasing part.. Thus the envelope from above of both cutoffs is decreasing with k. If we construct the function $\delta_a - \delta_b$. We have that this is 0 whenever $k = \frac{13+3n+\sqrt{(9n^2+138n+249)}}{10}$. We can see that for smaller k, $\delta_a > \delta_b$ therefore the envelope is decreasing. ■

Proof of Proposition 5: If we see δ_a and δ_b we can check that for every (k, n) whenever $\delta_b = \delta_a = \overline{\delta}$, this $\in (0, 1)$. That is, the envelope $\max(\delta_b, \delta_a)$ is never increasing with k for all range of k. We know from Proposition 2 that no cartel is stable in the binding collusion model. Therefore if we look at which are the stable cartels in the implicit collusion model we see that if $\delta < \overline{\delta}$, no cartel is either stable with implicit collusion because $\overline{\delta} = \min(\max(\delta_b, \delta_a))$ and represents the minimum discount factor from which a cartel of any size can be sustainable. When $\delta > \delta_2$ all sizes of cartels are sustainable but as no cartel is stable in the participation game, if we apply to the argument of Proposition 3 this fails because Nash-Cournot profits are larger than cartel of size 2 profits. Therefore no cartel configuration is stable. Whenever $\delta \in (\overline{\delta}, \delta_2)$ if we check the stability of those which are sustainable we can apply exactly the same argument of proposition 3, and the Corollary 1, and the smallest sustainable cartel is stable. ■

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(lix) This paper was presented at the ENGIME Workshop on "Mapping Diversity", Leuven, May 16-17, 2002
(lx) This paper was presented at the EuroConference on "Auctions and Market Design: Theory, Evidence and Applications", organised by the Fondazione Eni Enrico Mattei, Milan, September 26-28, 2002
(lxi) This paper was presented at the Eighth Meeting of the Coalition Theory Network organised by the GREQAM, Aix-en-Provence, France, January 24-25, 2003
(lxii) This paper was presented at the ENGIME Workshop on "Communication across Cultures in Multicultural Cities", The Hague, November 7-8, 2002
(lxiii) This paper was presented at the ENGIME Workshop on "Social dynamics and conflicts in multicultural cities", Milan, March 20-21, 2003
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(lxv) This paper was presented at the EuroConference on "Auctions and Market Design: Theory, Evidence and Applications" organised by Fondazione Eni Enrico Mattei and sponsored by the EU, Milan, September 25-27, 2003
(lxvi) This paper has been presented at the 4th BioEcon Workshop on "Economic Analysis of Policies for Biodiversity Conservation" organised on behalf of the BIOECON Network by Fondazione Eni Enrico Mattei, Venice International University (VIU) and University College London (UCL) , Venice, August 28-29, 2003
(lxvii) This paper has been presented at the international conference on "Tourism and Sustainable Economic Development – Macro and Micro Economic Issues" jointly organised by CRENoS (Università di Cagliari e Sassari, Italy) and Fondazione Eni Enrico Mattei, and supported by the World Bank, Sardinia, September 19-20, 2003
(lxviii) This paper was presented at the ENGIME Workshop on "Governance and Policies in Multicultural Cities", Rome, June 5-6, 2003
(lxix) This paper was presented at the Fourth EEP Plenary Workshop and EEP Conference "The Future of Climate Policy" , Cagliari, Italy, 27-28 March 2003

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