Fondazione Eni Enrico Mattei

Demand Growth, Entry and Collusion Sustainability

Carlo Capuano

NOTA DI LAVORO 62.2002

SEPTEMBER 2002

PRIV – Privatisation, Regulation, Antitrust

Carlo Capuano, *University of Naples "Federico II", Italy*

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Summary

The purpose of this paper is to represent in which way a stable and no negligible growth in demand can affect the level of sustainability of collusion. For the European Commission this assumption is seen as a factor that disincentives collusion and pushes to a competitive behavior. This fact maybe is not so obvious and I have shown that what is important is the final effect on entry in the market. In fact, expected oligopolistic profits are as the Faith Morgan that attracts competitors and disappears when they have come in. Entry is profitable if it is finite, i.e. one or very few entrants, and if prices above marginal cost are still successfully sustainable. Our result is that demand growth path is not a sufficient condition to neglect the risk of collective dominance, and in order to support our analysis we consider first some trigger strategy equilibria where deviation punishment is implemented by Nash Reversion forever. After that, we consider Abreu's simple penal code (1986) and we have derived a non stationary optimal penal code that in our structural changing framework implements collusion before and after entry as a subgames perfect equilibrium. The final conclusion is that demand growth, ceteris paribus, is negatively correlated with the critical discount factor necessary to sustain collusion.

Keywords: Collusion, penal code, merger control, demand growth

JEL: L13, L4, L41

Address for correspondence:

Carlo Capuano
Dipartimento di Teoria e Storia dell'Economia Pubblica
Complesso Universitario di Monte S. Angelo
80126 Napoli
Italy
E-mail: carcapua@unina.it

The author is grateful to Patrick Rey and George Molins-Ysal, for their relevant guide in the different phases of this study. Moreover he thanks Alfredo Del Monte, Riccardo Martina, Antonio Acconcia and all the people that with their suggestions and comments have contributed to this final version. All mistakes are the author's.

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INTRODUCTION

The purpose of this paper is to represent in which way a stable and no negligible growth in demand can affect the level of sustainability of collusion. For the European Commission and in particular for the Merger Task Force, this assumption is seen as a factor that disincentives collusion and pushes to a competitive behavior. This fact maybe is not so obvious and I have shown that what is important is the final effect on entry in the market. In fact, expected oligopolistic profits are as the Faith Morgan that attracts competitors and disappears when they have come in. Entry is profitable if it is finite, i.e. one or very few entrants, and if prices above marginal cost are still successfully sustainable.

Our result is that demand growth path is not a sufficient condition to neglect the risk of collective dominance, and in order to support our analysis I consider first some trigger strategy equilibria where deviation punishment is implemented by Nash Reversion forever. After that, I consider Abreu's simple penal code (1986) and I have derived a non stationary optimal penal code that in this structural changing frame work implements collusion before and after entry as a subgame perfect equilibrium. The final conclusion is that demand growth, ceteris paribus, is negative correlated with the critical discount factor necessary to sustain collusion. This means that demand growth is a collusion plus factor and the risk of collective dominance in new markets is not negligible.

This model is preceded by an overlook on EU merger control and by a proposal of a two-phase investigation that as a perfect symbiosis between structural approach and game theory, gives a check list for a multicriteria analysis.

PART I
COLLECTIVE DOMINANCE AND EU MERGER CONTROL.

1 Collective dominance: some useful definitions.

Mergers, acquisitions, joint ventures and other concentration agreements determine an increase in firm market power and make anticompetitive behaviors more likely. According to Antitrust Authorities, it is useful to distinguish between two different kinds of anticompetitive effects. In particular we refer to unilateral effects in the cases in which mergers create a single dominant position and the combined parties can unilaterally exercise market power and raise the prices heedless of the other competitors' reactions. Differently, we refer to coordinated effects in the cases in which the new firms cannot unilaterally raise prices without being undercut by competitors but post-merger market structure might successfully support collusion.

It then follows a useful definition of **collective dominance** as *any context in which a small number of large firms is able to co-ordinate their actions and maintains prices above the competitive level.*

According with that, from a theoretical point of view, we refer to **collective dominance** considering *any situation in which firms implement a "collusive scheme" that makes them better off than repeating the short-term Nash equilibrium, which in concentrated framework is a synonymous of competition.* Successful coordination, no deviation incentives and credible punishment are necessary for the implementation of this kind of incentive-compatible equilibrium.

1.1 Ex-ante and Ex-post investigation.

Collective dominance is a clear expression of joint market power, used by coordinated firms in order to reduce the level of competition in the market and to increase profits. These anticompetitive effects can already occur given the status of the market *(present abuses)* or they can occur with some probability after a concentration agreement *(potential abuses).* This is a time distinguishing that even if it is weakly relevant in terms of the nature of the implemented equilibria and for the valuation of factors that make collusion sustainable, it would be critical in terms of antitrust enforcement and investigation approaches.

Then, we make a distinction between an ex-post and an ex-ante investigation approaches. We have an ex-post investigation when supported by evidences, some abuses of dominant position have already happened: anticompetitive behaviors, tacitly or explicitly coordinated, have already been implemented in the market. This is the case of violations of Article 82, often linked to violations of Article 81.[1]

[1]By the way, the first time that EU Commission clearly considered cases of Collective Dom-

We assist to an ex-post investigation characterized by a weak economic analysis and by a strong value of any proofs (see figure 1).

Conversely, in order to allow a concentration agreement, we assist to forward-looking analysis. The object of this analysis is represented by the post merger competitive *(collusive)* environment that potentially could support anti-competitive behaviors. We have an ex-ante valuation centered on a strong economic analysis.

This is the role of merger regulation in terms of collective dominance that, pointing out the scenario in which remnant firms will interact, plays a crucial role in competitive policy. It is an important instrument to prevent any future abuses (see figure 2).

This second kind of analysis, ex-ante investigation, in particular in a European context, will be the object of our present study .

2 EU Merger Control and Collective dominance.[2]

2.1 Legal references.

As integration of EU antitrust enforcement[3] based on *Articles 81 and 82 of Treaties of Rome (1957)*, since 1989 there has existed in Europe a merger control system that, based on the *Regulation (EEC) No 4064/89 on Merger Procedure*, in the last ten years has riddled all the cases of concentration notified to the Commission[4].

The purpose of EU merger regulation is to prevent future abuses of dominant position and to avoid any concentration that could significantly reduce the level of competition in interested markets.

In terms of collective dominance, EU Commission's position has been almost clearly expressed since 1991, in the case *Alkatel/AEG Kabel*[5] in which the *German Bundeskartellamt (BKA)* asked for an opposition to a notified merger that should have created an oligopolistic dominant position in the telecommunication and power cables markets.

inance, was about the Italian Flat Glass cartel. There was a condamne for joint violations of Articles 82 [Società Italiana Vetro Spa, Fabbrica Pisana and PPG Vernante Pennitalia Spa v. Commission, Joined Cases T-68 & 77-78/89 (1992)].

[2] For a deeper study of EU merger control and case by case analysis see Capuano(2001).

[3] EU merger control system is almost young if compared with other institutional realities. See for example the Celler-Kefauver Act of 1950 that in USA extended application of the Clayton Act not only to holding companies concentration. In Europe, mergers were first subject to control by High Authority of the ECSC, 1951, and after they also fell in the field of application of Article 81(3) of the EC Treaty of 1957. Only in the 1989, it appears the Merger Control regulation, based on Article 87 and 235 of the EC Treaty.

[4] Inside of the European Commission there exists a dedicated merger competence division, the Merger Task Force, MTF, that analizes any concentration agreements notified to the Commission.

[5] Case No IV/M.165. Date: 18.12.1991. Non-opposition

This was the first case in which the Commission explored the risk of collective dominance generated by a concentration agreement. The debate considered the acquisition by Alkatel of AEG Kabel: after the merger, on the German market, the parties' combined market share would have been about 25%, which normally would not indicate a single dominant position. However, the merging companies and two other competitors would have remained as the only relevant producers, forming a 3-firm oligopoly. The *German Act Against Restraints on Competition, ARC*[6], establishes a legal presumption of oligopolistic dominance on the basis of the aggregate market shares of the firms. The BKA pointed out that because of the fact that the three larger firms had a combined market share of about 50%, balanced by a great number of small undertakings, conscious parallelism was likely to be held. EU Commission through the MTF considered the hypothesis of collective dominance, but because differently to German Law, concentration is not a presumption of abuses, she tried to check if in all cases competition could have not been expected as an implemented equilibrium.

Coherently with these precepts, in the considered case, having proved the oligopolistic framework, other elements as a decreasing price trend, strengthens of the demand, changing in the procurement processes, have been used to reject the hypothesis of collective dominance.

This pioneeristic case represents not only a proof of the relevance of merger control on collective dominance issues, but also a proposal of a new methodological approach to case by case investigation.

The Commission's decision faced a lot of criticisms. In fact, if from the beginning a clear relationship between single dominance and anticompetitive effects was universally recognized, for a while academic position on collective dominance and on Commission's decisions was at least ambiguous.

Nevertheless, this approach and its theoretical supports got a strong legitimation by European Court of Justice (ECJ)'s decisions *Gencor vs. Commission* and *France vs. Commission* [7] only in *1996.* It confirmed Commission's position on the case *Gencor/Lonrho*[8] and *Kali und Salz/MdK./Treuhand*[9].

These statements have represented a clear and strong reference in a field characterized by years of decisions without any guideline or explanatory booklets about collusive risks. It seemed clear that, from the ECJ's point of view, collective dominance could occur when a small number of large firms in a market are able to co-ordinate, also tacitly, their actions and maintain prices above the competitive level, i.e. Cournot or Bertrand level. This mechanism do not need structural links but only economical interests and particular circumstances in which co-ordination looks like incentive-compatible.

This position, very close to our initial definitions, is nowadays well supported

[6]Sections 22(2) and 23a(2).

[7]France and Others v. Commission (1998), ECR I-1375.

[8]Case No IV/M.619. Date: 24.04.1996. Opposition.

[9]Case No. IV/M.308. Date: 14.12.1993. Non opposition.

by economic analysis.

2.1.1 Explicit or tacit collusion.

Object of merger regulation in terms of collective dominance is surely tacit collusion. In fact, explicit collusion, as any other instance of abuses, which may materialize after the merger, would have to be handled under Article 81. Indeed, it appears as reasonable that the target of Merger Regulation, in cases of coordinated effects, should be instead on whether will increase the feasibility of tacit-collusion and on preventing violations of Article 82.

This assumption is relevant from a theoretical point of view and points out a methodological interest not only on anticompetitive concerted effects, i.e. whether there exist incentives for the firms to increase the prices, but also on the sustainability of this coordination, i.e. whether there exist credible mechanisms to keep prices at that high level: collusive equilibria have to be robust with respect to unilateral deviations. We here remark the forward-looking nature of this kind of analysis. It is important to note how, in case of risk of collective dominance, Merger Control deals with ex ante conjectures and requires a deeper economic examination. Differently from cases of explicit or tacit collusion as violations of Articles 81 and 82, in terms of collective dominance enforcement , we deal with a preventive process that, departing from some structural circumstances, wants to anticipate the most probable scenario in which firms will strategically compete and checks for the eventual sustainability of collusive equilibria. Again we note how the theoretical framework of references is represented by the oligopoly analysis and the game theory's approach to repeated interactions.[10]

[10] Unfortunately, the decision of 22 September 1999 on the case Airtours/First Choice [*Case No.IV/M.*1524. *Date* : 22.07.1999. *Opposition.*] has imposed at least an extension of this almost consecrated definition. In fact, the decision of opposition to the proposed merger was born in a context where more than one economist considered dominance very hard to be proved and where the more plausible risk was of adverse welfare effects. Moreover, in this case not only for the first time we find a deep collective dominance review for more than two oligopolists, but also we face a decision of opposition merely justified by the existence of "unilateral incentives for the competitors to keep capacity tough". Even if it is diffuse the opinion that decision had the intent of avoiding collusion on capacity; we read in different points of the decision that no co-ordination was required to support voluntary capacity restraints that appeared more as unilateral effects than as coordinated ones. The thesis of collusion on capacity is weakly theoretical supported and never appears in the full text of the decision. Surely, this legal reference has introduced uncertainty in the criteria on which merger valuation's process is based.

Nevertheless, in the following discussion, we will consider the MTF's approach as standardized before the case Airtours/First Choice , focusing basically on price coordination, with the clear intention of returning on Airtours/First Choice implcations in the next tractation where a deeper and more complete analysis about other kinds of collusion will be presented.

3 Theoretical Approach: Two phase analysis.

In the EU Commission's approach *collective dominance* (as oligopolistic or joint one) is a legal term useful to describe any collusive equilibrium that can be better implemented after concentration agreements. Referring to the ECJ's sentence *France vs. Commission*[11], it is pointed out how the MTF in her valuations should point out whether there exist correlative factors that make *"[firms] able to adopt a common policy on the market"*.Coherently with this direction, it is clear how the approach that we propose will start from a structural analysis, very close to S-C-P literature, integrated by an incentive analysis, very close to Game Theory. In fact, even if oligopoly is not a presumption of oligopolistic dominance, surely it is a good starting point for any collective dominance investigation. Besides, tested the structure of market, only a deep study of any unilateral incentives to deviate can define collusion as a (subgame perfect) Nash equilibrium, i.e. if the collusive agreement is sustainable.

Then, we propose a two phase analysis composed by a first *"structural analysis"*, dedicated to prove if the market is an oligopolistic one, soon followed by an *"incentive analysis"* that check for coordination (collusion) sustainability (see figure 3 and 4).

3.1 Structural Analysis

. In order to describe the context in which firms operate, we start from the valuation of structural factors as (a) high market concentration ratios, (b) homogeneity, (c) transparency, (d) demand growth and fluctuation (e) elasticity of demand, (f) barriers to entry and market contestability. All these factors can well explain the level of cross dependence among the firms, the level of substitution among products and, more generally, all these factors guarantee the profitability of any price increases. In fact, in concentrated markets characterized by stagnant and stable demand, with rigidity by consumers, surely coordinations on prices above competitive levels are easier. *(coordination plus factors)*. But, if this kind of analysis is enough for affirming the risk of unilateral anticompetitive effects and abuses of single dominance, whenever we consider few large firms competition other evidences are necessary: we have to exploit the sustainability of coordination *(collusion plus factors)*. (see figure 5).

3.2 Incentive Analysis.

As soon as we prove the existence of an oligopolistic structure that guarantees a profitable coordination, we are obliged to check for collusion sustainability, i.e. to verify if no firm has a unilateral incentive to deviate from coordination. A

[11] France and Others v. Commission (1998), ECR I-1375

multi-criteria analysis is required and we look for (i) deviation incentives and for (ii) punishment instruments.

The analysis should separately consider supply and demand characteristics. Starting from the supply side, we make a distinction between leading firms and competitive fringes. In fact, leading firms are potentially involved in the collusive agreement and the interest has to be put on coordination plus factors as similarities (cost function, market shares, the level of vertical integration and), as the existence of structural (and/or commercial) links and any information sharing instruments. Furthermore, we should check for leading firms'deviation-punishment incentives: the existence of multimarket contacts and/or capacity constraints. In particular, the distribution of capacity constraints points out the feasibility of undercutting strategies. At this point of the analysis, the supply study cannot neglect the existence of a competitive fringe with or without capacity constraints, as well as it cannot ignore the presence of some maverick firms that can mine collusion sustainability (see figure 6)

In addition, deviations from collusive agreement could be inspired by the demand side. Customer countervailing power as monopsonies and oligopsonies could induce private bargaining and unilateral deviations. Furthermore, fluctuation of demand as well as growth and innovations, could determine the risk of potential competition (see figure 7).

Summarizing, we can affirm that not only the structural analysis is not sufficient to define the risk of collective dominance but, also adding an incentive analysis, there are no critical factors for collusion sustainability. This means that only a multi-criteria valuation, that weights all the considered factors, better forecasts the competitive context in which firms will operate after concentration agreements.

PART II
DEMAND GROWTH, ENTRY AND COLLUSION SUSTAINABILITY.

4 Demand growth as a collusion minus factor ?

The effect of demand growth on collusion sustainability mainly depends on the feasibility of new competitors' entry in the market. In fact, when demand is growing, market results more profitable and new competitors' entry can occur. This will reduce future collusion sustainability and by backward induction, this also reduces present collusion sustainability. Growing demand thus appears to be as a clear minus collusion factor. Free entry is the relevant assumption that supports this claim.

On the other side, when demand is growing but new competitors' entry is in someway excluded, collusion turns out to be more sustainable. In a repeated game framework, deviations pay in short time, but punishment will occur in the future when expected gains by collusion will be higher. This reduces the unilateral incentive to deviate. In this case, growing demand turns out to be a collusion plus-factor.

It follows that only the analysis of the equilibrium outcomes in the two supported frameworks will allow us to point out the relationship between demand growth and collusion sustainability.

One of the major task of Antitrust Authorities in merger control and collective dominance enforcement is that of identifying collusive plus factors: high market concentration, symmetries, inelasticity of demand and product homogeneity play a central role. The demand growth factor as independent variable on collusion sustainability is ambiguously analyzed in EU Commission's decisions: even if in cases as Holdercim/Cedest or CCIE/GTE[12] we find that with stagnant or declining demand, oligopolistic dominance was considered more likely. Contrary, in cases as Castrol/Carless/JV[13], declining demand was considered as creating incentives for price competition. Moreover in cases as GEC Alsthom/Cegelec, AGFA-Gevaert/Sterling, Sair Group/AOM, France Telecom/Orange and Rhodia/Donau Chemie/Albright & Wilson[14], it was assumed that growing demand reduced the risk of collective dominance. In particular in this last cases, entry

[12] Case No. IV/M.460. Date 04.07.1994. Non-opposition, Case No. IV/M.258. Date: 25.09.1992. Non-opposition.

[13] Case No Comp/M.1597. Date: 14.10.1999. Non-opposition

[14] Case No. IV/M.1164. Date: 15.05.1998. Non-opposition, Case No. IV/M.1432. Date: 15.04.1999. Non-opposition, Case No IV/M. 1494. Date: 03.08.1999. Non-opposition, Case No. COMP/M.2016. Date: 11.08.2000. Non-opposition, Case No.IV/M.1517. Date: 13.07.1999. Non-opposition.

was implicitly and sometimes improperly expected and incumbent's foreclosing strategy, even if profitable, were never considered.

In this paper we derive a theoretical framework for analyzing in which way collusion sustainability is related to entry profitability. We analyze the case in which in presence of sunk entry costs, new competitors find entry profitable only if the Bertrand paradox is avoided. Without collusion, expected oligopoly profits are as the Faith Morgan that attracts competitors and disappears when they have come in. Entry is profitable only if it is finite, i.e. one or very few entrants, and if prices above marginal cost are still successfully sustainable. This implies that firms go on implementing some level of collusion. Incumbents' strategies are crucial and different equilibria can characterize the growing market.

Our result is that a demand growth is not a sufficient condition to neglect the risk of collective dominance. To support our analysis we consider first some trigger strategy equilibria where deviation punishment is implemented by Nash Reversion for ever. After that, we consider a Abreu's simple penal code (1986) and we look for the optimal one supported by our framework. We derive a non stationary optimal penal code that in our structural changing framework implement collusion before and after entry as a subgame perfect equilibrium. The final conclusion is that demand growth ceteris paribus is negative correlated with the critical discount factor necessary to substain collusion. This means that demand growth is a collusion plus factor and the risk of collective dominance in new markets is not to be neglected.

5 Trigger strategies and price competition.

5.1 Model setting.

We start analyzing the simplest framework useful to describe our ideas,and in particular we consider the case of three firms, indexed by $i = 1, 2, 3$,

- $i = 1, 2$ incumbents that operate on the market
- $i = 3$ potential entrant with sunk costs of entry, $K > 0$.

that produce an homogeneous good with a CRS technology, zero marginal cost and prices are their control variables.

We assume that aggregated demand is linear, with stable, deterministic growth in its intercept

$$P_t = A_t - Q \tag{1}$$

where $A_t = \alpha^{\frac{t}{2}} A$, with $\alpha > 1$ and $t \in N$.

We make a technical restriction on the size of growth, considering that the coefficient a is defined such that in the set of relevant values we have

$$a\delta \leq 1 \tag{2}$$

Without this restriction, future profits weight more than present ones and collusion would be always sustainable .

In the first part of this paper, we consider a m-player infinitely repeated game that represents price competition in a m-firm oligopolistic market. The players at each time t simultaneously select outputs $q_{i,t}$, with $i = 1, 2$ in the duopoly case or $i = 1, 2, 3$ in the case of three-firm competition. In any period t, player i's payoffs are generated by the stage-game payoff function $\Pi_{i,t}(q_{i,t}, q_{-i,t})$. The weight placed upon next period payoffs, i.e. the discount factor, is δ, the same for each player. For simplicity, we restrict the model to a symmetric equilibria repeated game. Indeed, we consider players use trigger strategies defined as follows. Each player chooses coherently with the collusive path in the first period and so long as all players have done that in the previous periods; however, if one or more competitor defects at some time τ, all the competitors play the one-shot Nash equilibrium choice in all future periods.

5.2 No potential entrants.

We assume that whenever there is collusion, firms share symmetrically the market and maximize joint profits. considering a duopoly, we have the following.

$$\Pi_i^{Coll} = \frac{\Pi^M}{2} \qquad \text{where} \quad i = 1, 2$$

In the standard case, without demand growth, collusion is sustainable if no firm has incentive to deviate from collusive path. We consider Friedman's paradigm of supergames where firms play the same game infinite times. With price competition, collusion implement the monopolistic price p^M,and the best deviation is represented by a price $p^D = p^M - \varepsilon$, where $\varepsilon \to 0^+$. Deviator undercuts rivals and obtains monopolistic profits, $\Pi_i^D = \Pi^M = 2\Pi^{Coll}$. Deviations when detected is punished by Nash reversion for ever. We are looking for a subgames perfect equilibrium where no firm has unilateral incentive to deviate from the collusive path. Indeed, the following condition should hold.

$$\begin{aligned} \sum_{i=t}^{\infty} \delta^{i-t} \Pi^{Coll} &= \Pi^{Coll} + \delta \Pi^{Coll} + \delta^2 \Pi^{Coll} + ... \geq 2\Pi^{Coll} \\ \Pi^{Coll}\left(1 + \delta + \delta^2 + ...\right) &\geq 2\Pi^{Coll} \\ \frac{\Pi^{Coll}}{1-\delta} &\geq 2\Pi^{Coll} \\ \delta &\geq \frac{1}{2} \end{aligned} \qquad (3)$$

where δ is the discount factor that expresses firm level of patience. Without loss in generalities we can assume either that all the competitors have the same discount factor or that we refer our comparison to the less patient firm.

Introducing demand growth, by hypothesis the collusive profit path satisfies the following properties.

$$\begin{aligned}\Pi_t^{Coll} &= \frac{\Pi_t^M}{2} = \alpha^t \frac{\Pi_0^M}{2} = \alpha^t \Pi_0^{Coll} \\ \frac{\Pi_{t+i}^{Coll}}{\Pi_t^{Coll}} &= \frac{\Pi_{t+i}^{\mathrm{M}}}{\Pi_t^M} = \alpha^i\end{aligned}$$

Note that because of the hypothesis $\alpha\delta < 1$, we have an increasing but concave present profits path. Starting from time t, we can write the incentive-compatible constraint for collusion sustainability as follows.

$$\begin{aligned}\sum_{i=t}^{\infty} \delta^{i-1} \Pi_i^{Coll} = \Pi_t^{Coll} + \delta \Pi_{t+1}^{Coll} + \delta^2 \Pi_{t+2}^{Coll} + ... &\geq 2\Pi_t^{Coll} \\ \Pi_t^{Coll}\left(1 + \alpha\delta + \alpha^2\delta^2 + ...\right) &\geq 2\Pi_t^{Coll}\end{aligned}$$

Assuming that $\alpha\delta \leq 1$,we have

$$\begin{aligned}\frac{\Pi_t^{Coll}}{1-\alpha\delta} &\geq 2\Pi_t^{Coll} \\ \delta &\geq \frac{1}{2\alpha}\end{aligned} \tag{4}$$

In a context of no entry, growth increases collusion sustainability.

Given that $\alpha > 1$, it is easy to check that condition 3 is more restricted than condition 4.This means that with growth, the critical discount factor necessary to sustain collusion is lower than the critical value computed without growth, i.e. more impatient firms can successful collude.

5.3 With a potential entrant affected by sunk costs.

Now, we consider the existence of a potential entrant and we check for conditions for which entry is profitable. In fact, entry is feasible only if after that, collusion will be still sustainable. Otherwise, with Bertrand Nash equilibrium in each period, entrant could not cover its sunk costs. Then, considering no growth, entry occurs at the beginning if sunk costs are cover in the long period.

$$\sum_{i=t}^{\infty} \delta^{i-1} \Pi^{Coll} = \sum_{i=t}^{\infty} \delta^{i-1} \frac{\Pi^M}{3} \geq K \tag{5}$$

and collusion will be already sustainable.

$$\begin{aligned}
\sum_{i=t}^{\infty}\delta^{i-1}\Pi^{Coll} &= \Pi^{Coll}+\delta\Pi^{Coll}+\delta^2\Pi^{Coll}+...\geq 3\Pi^{Coll} \\
\Pi^{Coll}\left(1+\delta+\delta^2+...\right) &\geq 3\Pi^{Coll} \\
\frac{\Pi^{Coll}}{1-\delta} &\geq 3\Pi^{Coll} \\
\delta &\geq \frac{2}{3} \qquad (6)
\end{aligned}$$

If condition 5 and 6 hold, entry happens from the beginning, Otherwise,entry never holds.

With growth, entry may not be feasible at the beginning but may become feasible at some point in time t' such that

$$t' = min\left\{t\in N:\ \text{ if}\sum_{s=t}^{\infty}\delta^{s-t}\Pi_s^{Coll}\geq K\right\} \qquad (7)$$

Indeed, entry is feasible at time t' if the following two conditions are satisfied.

$$\sum_{i=t'}^{\infty}\alpha^i\delta^{i-t'}\Pi_0^{Coll}=\sum_{i=t'}^{\infty}\alpha^i\delta^{i-1}\frac{\Pi_0^M}{3}\geq K \qquad (8)$$

and

$$\begin{aligned}
\sum_{i=0}^{\infty}\alpha^i\delta^i\Pi_{t'}^{Coll} &= \Pi_{t'}^{Coll}+\alpha\delta\Pi_{t'}^{Coll}+\alpha^2\delta^2\Pi_{t'}^{Coll}+...\geq 3\Pi_{t'}^{Coll} \\
\Pi_{t'}^{Coll}\left(1+\alpha\delta+\alpha^2\delta^2+...\right) &\geq 3\Pi_{t'}^{Coll} \\
\frac{\Pi_{t'}^{Coll}}{1-\alpha\delta} &\geq 3\Pi_{t'}^{Coll} \\
\delta &\geq \frac{2}{3\alpha} \qquad (9)
\end{aligned}$$

The condition 9 deals with the sustainability of collusion among three firms when there is entry at time $t\prime$. The critical value computed is independent to the time $t\prime$ at which entry occurs.

The conditions 8 and 7 consider that given sustainable collusion after the entry, in the long run the sunk costs have to be covered. Condition 7defines entrant's optimal $t\prime$.

If collusion is sustainable, 9 holds, the condition 7 defines the time t' of entry.

Now, there exists for each value K a time $t\prime$ in which the condition 8 is satisfied as equality. In fact from that, we have

$$\begin{aligned} \sum_{i=0}^{\infty} \alpha^i \delta^i \frac{\Pi_{t'}^M}{3} &\geq K \\ \alpha^{t'} \sum_{i=0}^{\infty} \alpha^i \delta^i \frac{\Pi_0^M}{3} &\geq K \end{aligned}$$

Considering that $\sum_{i=0}^{\infty} \alpha^i \delta^i = D$, is a constant, independent on t', as long as $a\delta < 1$.

In logs we have

$$t' \log \alpha + \log D + \log \Pi_0^M - \log 3 \geq \log K$$

Then

$$t' \geq \frac{\log K + \log 3 - \log D - \log \Pi_0^M}{\log \alpha} \tag{10}$$

This condition explains how the length of the expected period before the entry, $t - t\prime$, would be positive related with the sunk costs and negative related with the demand growth rate. So, ceteris paribus, entry occurs earlier when demand growth is higher and it occurs later when firms have higher sunk costs to enter.

All the parameters are of common knowledge, and both incumbents and potential entrants know exactly from which period entry is feasible.

Now, we consider what happens in the market waiting for time $t\prime$ when entry is feasible and collusion result successful sustainable, i.e. 8 and9 hold. Collusion is sustainable from time $t < t'$ only if no incumbent has incentive to deviate from joint profits maximization, considering that entry occurs at time $t\prime$. The subgames perfect equilibrium condition is the following.

$$\begin{aligned} \sum_{i=0}^{t'-t} \alpha^i \delta^i \frac{\Pi_t^M}{2} + \sum_{i=t'-t}^{\infty} \alpha^i \delta^i \frac{\Pi_t^M}{3} &\geq \Pi_t^M \\ \frac{\Pi_t^M}{2} \left[\frac{1 - (\alpha\delta)^{t'-t+1}}{1 - \alpha\delta} \right] + \frac{\Pi_t^M}{3} \left[\frac{(\alpha\delta)^{t'-t}}{1 - \alpha\delta} \right] &\geq \Pi_t^M \\ \left[\frac{1 - (\alpha\delta)^{t'-t+1}}{2(1 - \alpha\delta)} \right] + \left[\frac{(\alpha\delta)^{t'-t}}{3(1 - \alpha\delta)} \right] &\geq 1 \end{aligned}$$

Considering $t = 0$, i.e. the incumbents collude from the beginning, after some algebraic steps, we obtain the following condition.

$$0 \geq (\alpha\delta)^{t'} [3\alpha\delta - 2] - [6\alpha\delta - 3] \tag{11}$$

The previous inequality, 11, is not of "easy" solution, but for our purpose is sufficient to study its sensitivity to parameters changes. We start considering the term $\alpha\delta$ that represents the discounted growth rate. It can be either larger or smaller than one. If we consider $\alpha\delta$ higher than one, i.e. $\alpha \geq \frac{1}{\delta}$, the series of discounted expected profits goes to infinity and collusion is always sustainable. When we consider moderate growth, i.e. $\frac{1}{\delta} \geq \alpha$, this term $\alpha\delta$ is lower than one and there exists a critical discount rate above of which collusion is successfully sustainable. This critical value is negative related with the lag before the entry,$t\prime$, i.e. the length of two-firm collusion periods. Moreover, keeping $\alpha\delta$ constant, an increase in α make collusion easier sustainable.

Proposition 1 *Given price competition between symmetric firms, the critical discount factor necessary to successfully sustain collusion is an increasing function of the number of the firms that collude.*

Given the structure of the inter-temporal expected profits, it is immediate to check that condition 11 dominates condition 4and is dominated by condition 9.Then, the necessary discount factor that satisfies condition 11 is higher than the one that satisfies condition 4 . and is lower than the one that satisfies condition 9.

$$\frac{1}{2\alpha} \leq \delta^{\circ} \leq \frac{2}{3\alpha}$$

where δ° is the discounting factor that satisfies condition 11 as an inequality.

5.3.1 Technical assumption

Considered that the growth is no negligible but "normal", $\alpha \in \left[1, \frac{4}{3}\right]$,we have the following ranking for critical discount factors

$$\frac{1}{2\alpha} < \frac{1}{2} < \frac{2}{3\alpha} < \frac{2}{3}$$

Moreover, given the previous assumption that $\alpha \leq \frac{1}{\delta}$, we can restrict our analysis to values of discount factors belonging to the following interval.

$$\delta \in \left[0, \frac{3}{4}\right]$$

5.4 Case by case analysis.

We check for what equilibrium is implemented at different values of the firms' discount factor trying to highlight in which way growth's assumption affect collusion sustainability.

1) Consider

$$\delta \in \left[0, \frac{1}{2\alpha}\right[\tag{12}$$

.

With or without growth collusion between two firms is not sustainable, then no entry in the market and Bertrand equilibrium hold.

2) Consider

$$\delta \in \left[\frac{1}{2\alpha}, \frac{1}{2}\right[\tag{13}$$

Without growth collusion is not sustainable. With growth collusion between the two incumbents is the only sustainable equilibrium because collusion among three firms is not sustainable then entry is not feasible. Condition 4 holds but not conditions 3 and 9 for any $t\prime$.

3) Consider

$$\delta \in \left[\frac{1}{2}, \frac{2}{3\alpha}\right[\tag{14}$$

With or without growth collusion between the incumbents is sustainable. No entry is part of the long run equilibrium in both of the cases. Conditions 3 and 4 hold but not condition 9.

4) Consider

$$\delta \in \left[\frac{2}{3\alpha}, \frac{2}{3}\right[\tag{15}$$

With growth at time $t\prime(K)$ entry occurs and collusion between three firms is sustainable. Conditions 9 and 8 hold. What happens before? Condition 11 holds, we have collusion before and after the entry. Without growth it's analogous to case 3.

5) Consider

$$\delta \in \left[\frac{2}{3}, \infty\right[\tag{16}$$

With growth , we are in a case analogous to case 4.Without growth, condition 6 holds and we consider two sub cases:

- condition 5 holds: entry is feasible from the beginning and collusion among the three firms is sustainable.
- condition 5 does not hold: entry is never feasible and collusion between the two incumbents is the only sustainable equilibrium.

5.4.1 Price competition: partial conclusion.

In our simple framework where price is the control variable and firms choose between complete colluding and tough competition, the intuitive result is that demand growth plays as collusive plus factor. Collusion sustainability is negative correlated with market concentration: the many more are the firms in the market, the higher is the critical discount factor necessary to substain perfect collusion as subgames perfect equilibrium. If collusion is sustainable after entry then is sustainable also before.

The following proposition summarizes this partial result.

Proposition 2 *With price competition and sunk cost to entry, demand growth increase collusion sustainability.*

In fact, under our hypothesis entry occur only if collusion is sustainable. The condition necessary to implement collusion among m firms dominates the conditions necessary to sustain collusion among m-1 firms. Demand growth positively affects no-deviation payoffs path but does not affect defector's deviation profits. Of course unilateral deviation is less profitable for any discount factor.

Proposition 3 *When collusion before and after merger is sustainable, while incumbents obtain positive profits, entrant obtain zero profits.*

This fact depend from the fact that new competitor enter at the time he must cover his sunk cost. Can be profitable to late the entry in order to obtain positive profits?

The answer is negative and we offer the following explanation. In fact when we assume s > 1 potential competitors characterized by the same technology, if a firm does not enter in the market at time t', surely there will be another one that decide to anticipate entry. If the potential entrants have different sunk cost, the t' is computed on the second most efficient entrant. In that case the entrant obtain positive profits equal to At the moment we have the first entry, why there not occur others? Condition on sunk cost covering, consider that entrant obtain zero profit if perfect collusion is implemented. This means that at the same time surely no other firm can entry without obtaining negative profits. Than second entry will be post pone until collusion between 4 firms will be not sustainable. But as proved before n+1 collusion sustainable ask for higher minimum discount fact. That means that will be the case in which this not implementable.

6 Finite but continuous entries.

We consider now the case in which we have more than one potential entrants and, given the growing trend of demand, they enter in the market at different points in time until collusion is sustainable and sunk costs are covered. We assume that there are many symmetric potential entrants that compete to enter as soon as entry is feasible and profitable.

The purpose of this part of the paper is to compute the maximum number of firms that can profitable enter and stay in the market given a constant demand path. We indicate with $m = n + 2$, the total number of firms operating in the market where n is the number of new competitors.

6.1 Without demand growth.

We start considering a simple framework without growth, i.e. $a = 1$. As in the previous case, we look at two conditions. The first one is about the relation between collusion sustainability and number of firms in the market.

$$\begin{aligned} \frac{1}{m}\sum_{i=0}^{\infty}\delta^{i-1}\Pi^M &= \frac{1}{m}\left(\Pi^M + \delta\Pi^M + \delta^2\Pi^M + ...\right) \geq \Pi^M \\ \frac{1}{m}\Pi^M\left(1+\delta+\delta^2+...\right) &\geq \Pi^M \\ \frac{\Pi^M}{m\,(1-\delta)} &\geq \Pi^M \\ \delta &\geq \frac{m-1}{m} \end{aligned}$$

Indeed, for a given value of the discount factor the number of firms that can successfully collude in the market will be the following.

$$m = \frac{1}{1-\delta} \tag{17}$$

The second condition is about entry feasibility, i.e. sunk cost will be covered.

$$\sum_{i=0}^{\infty}\delta^{i-1}\frac{\Pi^M}{m} = \sum_{i=t_n}^{\infty}\delta^{i-1}\frac{\Pi^M}{m} \geq K$$

From this condition we derive that the maximum number of competitors in the market, m, satisfies the following constraints.

$$m = \frac{1}{1-\delta}\frac{\Pi^M}{K} \tag{18}$$

Then considering both conditions 17 and 18, we claim that without growth the maximum number of competitors, in the market m^{NG} is determined as follows.

$$m^{NG} = \min\left(\frac{1}{1-\delta}, \frac{1}{1-\delta}\frac{\Pi^M}{K}\right) \tag{19}$$

With demand growth.

With growth, nthentry can occur at a time t$_n$ if collusion is still sustainable and sunk cost will be covered.

Considering collusion sustainability. among m firms, we have the following condition.

$$\begin{aligned} \frac{1}{m}\sum_{i=0}^{\infty}\alpha^i\delta^i\Pi^{\mathrm{M}}_{t_n} &\geq \Pi^{\mathrm{M}}_{t_n} \\ m &= \frac{1}{1-\alpha\delta} \end{aligned} \tag{20}$$

Considering that also the nth entrant will cover its sunk cost, we have the following condition.

$$\begin{aligned} \frac{1}{m}\sum_{i=t_n}^{\infty}\alpha^i\delta^{i-t_n}\Pi^{M}_0 &\geq K \\ m &= \frac{1}{1-\alpha\delta}\frac{\Pi^M}{K} \end{aligned} \tag{21}$$

Note that if these conditions are satisfied for the nth entrant, implicitly they are satisfied for all the entrants before, and collusion is sustainable from the beginning.

In this case, the maximum number of firms that operate in the market, m^G, satisfies the following condition.

$$m^{G} = \min\left(\frac{1}{1-\alpha\delta}, \frac{1}{1-\alpha\delta}\frac{\Pi^M}{K}\right) \tag{22}$$

The values of the minimum functions of conditions 19 and 22 depend simply on the ratio between the static monopoly profits and the sunk costs. We can consider two cases: one with relatively high sunk cost i.e.$\Pi^M < K$, another with relatively low sunk cost , $\Pi^M \geq K$.

When we consider low sunk cost, $\Pi^M \geq K$, we have the following results.

$$\begin{aligned} m^{NG} &= \frac{1}{1-\delta} \\ m^{G} &= \frac{1}{1-\alpha\delta} \end{aligned}$$

where

$$m^G > m^{NG} \tag{23}$$

This means that growth increases the number of firms that can operate in the market.

When we consider high sunk cost, $\Pi^M < K$, we have the following results.

$$\begin{aligned} m^{NG} &= \frac{1}{1-\delta}\frac{\Pi^M}{K} \\ m^G &= \frac{1}{1-\alpha\delta}\frac{\Pi^M}{K} \end{aligned}$$

where again

$$m^G > m^{NG} \tag{24}$$

This means that also in this case growth increases the number of firms that can operate in the market.

Proposition 4 *With price competition, demand growth increases the number of firms that can perfectly collude in the market. This fact has a negative impact on social welfare.*

We can infer that with growth, much more firms can successfully enter in the market and successfully collude. The amount of sunk cost is relevant for determining the number of entrants only if it is high enough, i.e. when the barrier to entry is more restraining. In general we have a no ambiguous impact on welfare. In fact, even if the number of competitors increases, the outcome is always the monopoly price. This is increasing with respect to the demand growth and independent on the number of producers. Moreover, in this particular case reducing concentration has a negative welfare impact by duplication of entry costs.

At this point, it can be reasonable to ask which is the optimal number of competitors from a social welfare point of view. The answer is trivial. In fact with CRS technology and no capacity constraints, the incumbents are able to satisfied all the demand generated at the competitive price, $p = c = 0$ and each entry implies only duplication of sunk costs.

7 Cournot Competition and demand Growth.

Until now we have assumed that entry would be feasible only if collusion would be still sustainable and this is because of price competition. Now, we introduce quantity competition and we are going to show how with high demand entry is profitable also without collusion and this will change drastically the previous results in terms of welfare analysis. We start considering the simple case with two incumbents and one potential entrants.

With Cournot competition at time t the static profit would be the following.

$$\Pi_t^{CC} = \left(\frac{A_t}{\mathrm{m+1}}\right)^2 = \alpha^t \left(\frac{A_0}{\mathrm{m+1}}\right)^2$$

As before, we indicate with m the number of firms operating in the market.

Then, we define Π_t^D as the deviation profits obtained by a firm that anticipate the fact that the others play the collusive strategy.

$$\Pi_t^D = \Pi_{i,t}\left(q_i\left(q_{-i}\right), q_{-i}\right) = \left[\frac{(2m-1)\,A_t}{4m}\right]^2 = \alpha^t \left[\frac{(2m-1)\,A_0}{4m}\right]^2$$

The perfect collusion's profits as standard are the following.

$$\Pi_t^{Coll} = \frac{(A_t)^2}{4m} = \frac{\alpha^t (A_0)^2}{4m}$$

It is easy to check that the following properties hold.

$$\frac{\Pi_{t+i}^{CC}}{\Pi_t^{CC}} = \alpha^i$$

$$\begin{aligned} \frac{\Pi_t^{CC}}{\Pi_t^{Coll}} &= \frac{4m}{(m+1)^2} \leq 1 \\ \frac{\Pi_t^{D}}{\Pi_t^{Coll}} &= \frac{(2m-1)^2}{4m} \geq 1 \end{aligned}$$

7.1 No growth.

We start considering no demand growth. Perfect collusion is sustainable if no firm has unilateral incentive to deviate from collusive path. We assume as previously that punishment would be Nash Reversion for ever. Now, deviation profits are lower than monopolistic ones because using quantity as control variable it is impossible to undercut the rivals that always obtain positive profits. The following condition should hold when $m = 2$.

$$
\begin{aligned}
\Pi^{Coll} + \delta\Pi^{Coll} + \delta^2\Pi^{Coll} + ... &\geq \Pi^{D} + +\delta\Pi^{CC} + \delta^2\Pi^{CC} + \delta^3\Pi^{CC}... \\
\Pi^{Coll}\left(1+\delta+\delta^2+...\right) &\geq \Pi^{D} + \delta\Pi^{CC}\left(1+\delta+\delta^2+...\right) \\
\frac{\Pi^{Coll}}{1-\delta} &\geq \Pi^{D} + \frac{\delta\Pi^{CC}}{1-\delta} \\
\frac{\Pi^{Coll}}{1-\delta} &\geq \frac{9}{8}\Pi^{Coll} + \frac{8}{9}\frac{\delta\Pi^{Coll}}{1-\delta}
\end{aligned}
$$

then

$$
\delta \geq \frac{9}{17} \tag{25}
$$

This value is higher than the corresponding one computed for Bertrand competition. This depends on the fact that Cournot reversion is a weak punishment that gives always positive profits.

When we introduce demand growth we can write the incentive-compatible constraint for collusion sustainability. as follows.

$$
\begin{aligned}
\sum_{i=t}^{\infty}\delta^{i-1}\Pi_i^{Coll} = \Pi_t^{Coll} + \delta\Pi_{t+1}^{Coll} + \delta^2\Pi_{t+2}^{Coll} + ... &\geq \Pi_t^{D} + \delta\Pi_{t+1}^{CC} + \delta^2\Pi_{t+2}^{CC} \\
\Pi_t^{Coll}\left(1+\alpha\delta+\alpha^2\delta^2+...\right) &\geq \Pi_t^{D} + \alpha\delta\Pi_t^{CC}\left(1+\alpha\delta+\alpha^2\delta^2+...\right) \\
\Pi_t^{Coll}\left(1+\alpha\delta+\alpha^2\delta^2+...\right) &\geq \Pi_t^{D} + \frac{4m}{(m+1)^2}\alpha\delta\Pi_t^{Coll}\left(1+\alpha\delta+\alpha^2\delta^2+...\right)
\end{aligned}
$$

$$
\begin{aligned}
\frac{\Pi_t^{Coll}}{1-\alpha\delta} &\geq \frac{9}{8}\Pi_t^{Coll} + \frac{8}{9}\frac{\alpha\delta\Pi_t^{Coll}}{1-\alpha\delta} \\
\frac{1}{1-\alpha\delta} &\geq \frac{9}{8} + \frac{8}{9}\frac{\alpha\delta}{1-\alpha\delta}
\end{aligned}
$$

$$
\delta \geq \frac{9}{17\alpha} \tag{26}
$$

.

Proposition 5 *In a context of no entry, with quantity competition, demand growth increases collusion sustainability.*

Given that $\alpha > 1$, it is easy to check that condition 25 is more restrictive than condition 26. This means that with growth, the critical discount factor necessary to sustain collusion is lower than the critical value computed without growth, i.e. more impatient firms can successfully collude.

Now we consider a potential entrant. Entry is feasible only if the sum of expected profit covers the sunk costs. The scenario can be either of collusion, or of Cournot competition.

Considering entry with collusion, $m = 3$, this is possible if the sum of expected profits by collusion covers the sunk costs.

$$\sum_{i=t}^{\infty} \delta^{i-1} \Pi^{Coll} = \sum_{i=t}^{\infty} \delta^{i-1} \frac{\Pi^M}{3} \geq K \tag{27}$$

Complementary condition is about sustainability.

$$\begin{aligned}
\sum_{i=t}^{\infty} \delta^{i-1} \Pi^{Coll} = \Pi^{Coll} + \delta \Pi^{Coll} + \delta^2 \Pi^{Coll} + ... &\geq \Pi^D + \delta \Pi^{CC} + \delta^2 \Pi^{CC} ... \\
\Pi^{Coll} \left(1 + \delta + \delta^2 + ...\right) &\geq \Pi^D + \delta \Pi^{CC} \left(1 + \delta + \delta^2 + ...\right) \\
\Pi^{Coll} \left(1 + \delta + \delta^2 + ...\right) &\geq \Pi^D + \frac{3}{4} \delta \Pi^{Coll} \left(1 + \delta + \delta^2 + ...\right)
\end{aligned}$$

$$\begin{aligned}
\frac{1}{1-\delta} &\geq \frac{25}{12} + \frac{3}{4} \frac{\delta}{1-\delta} \\
\delta &\geq \frac{13}{16}
\end{aligned} \tag{28}$$

If conditions 27 and 28 hold, then entry happens from the beginning and collusion between three firms is sustainable. Otherwise we have to check if the Cournot competition make entry feasible.

$$\sum_{i=t}^{\infty} \delta^{i-1} \Pi^{CC} \geq K \tag{29}$$

If condition 29 holds, entry happens from the beginning and market is characterized by Cournot competition.

It is clear that even if condition 29is stronger than 27, this is not correlated to condition 28.

7.2 Demand growth.

Now, we introduce demand growth:again entry is feasible only if the sum of expected profit covers the sunk cost. As in the previous paragraph, the scenario can be either of collusion, either of Cournot competition.

Considering entry with collusion. This is possible if the sum of expected profits by collusion covers the sunk costs,

$$\sum_{i=t}^{\infty} \delta^{i-t} \Pi_t^{Coll} = \sum_{i=t}^{\infty} \delta^{i-t} \frac{\Pi_t^M}{3} \geq K \tag{30}$$

and collusion will be already sustainable.

$$\sum_{i=0}^{t'-1}\delta^i\Pi_i^{Coll}(m=2)+\sum_{i=t'}^{\infty}\delta^i\Pi_i^{Coll}(m=3)\geq$$

$$\Pi_i^D(m=2)+\sum_{i=1}^{t''-1}\delta^i\Pi_i^{CC}(m=2)+\sum_{i=t''}^{\infty}\delta^i\Pi_i^{CC}(m=3) \tag{31}$$

Condition 31 considers that no firms has incentive to unilateral deviation from a collusive path before and after entry that it is feasible from time t'. In fact, the entry by collusion period t' is determined as follows.

$$t'=min\left\{t\in N:\ \text{ if }\sum_{s=t}^{\infty}\delta^{s-t}\Pi_s^{Coll}\geq K\right\} \tag{32}$$

The right side of the condition considers deviation profits path. After deviation incumbents play two-firm Cournot until time t'' At this time Cournot profits in a three-firm market are so high to make entry feasible. The entry by Cournot time t'' is defined by the following condition.

$$t''=min\left\{t\in N:\ \text{ if }\sum_{s=t}^{\infty}\delta^{s-t}\Pi_s^{CC}\geq K\right\} \tag{33}$$

In particular

$$\sum_{i=t''}^{\infty}\delta^{i-t''}\Pi_i^{CC}=\alpha^{t''}\Pi_0^{CC}\sum_{i=0}^{\infty}\alpha^i\delta^i\geq K$$

Considering again that $\sum_{i=0}^{\infty}\alpha^i\delta^i=D$, is a constant, independent on t", in logs we have

$$t''\log\alpha+\log D+\log\Pi_0^{CC}\geq\log K$$

Then

$$\begin{aligned} t'' &\geq \frac{\log K-\log D-\log\Pi_0^{CC}}{\log\alpha}\\ t'' &\geq \frac{\log K-\log D-\log 3+\log\Pi_0^{M}}{\log\alpha}+\frac{\log 4-\log 3}{\log\alpha}\\ t'' &\geq t'+\frac{\log 4-\log 3}{\log\alpha}=t'+R \end{aligned} \tag{34}$$

Given that , condition 31 is equivalent to the following

$$\begin{array}{l} \Pi_0^{Coll}(m=2)\left[\frac{1-(\alpha\delta)^{t'+1}}{1-\alpha\delta}\right]+\Pi_0^{Coll}(m=3)\left[\frac{(\alpha\delta)^{t'}}{1-\alpha\delta}\right] \\ \geq \\ \Pi_0^{D}(m=2)+\alpha\delta\Pi_0^{CC}(m=2)\left[\frac{1-(\alpha\delta)^{t'+R+1}}{1-\alpha\delta}\right]+\Pi_0^{CC}(m=32)\left[\frac{(\alpha\delta)^{t'+R}}{1-\alpha\delta}\right] \end{array}$$

$$\left[\frac{1-(\alpha\delta)^{t'+1}}{1-\alpha\delta}\right]+\frac{2}{3}\left[\frac{(\alpha\delta)^{t'}}{1-\alpha\delta}\right]\geq\frac{9}{8}+\frac{8}{9}\alpha\delta\left[\frac{1-(\alpha\delta)^{t''+R+1}}{1-\alpha\delta}\right]+\frac{1}{2}\left[\frac{(\alpha\delta)^{t''+R}}{1-\alpha\delta}\right] \tag{35}$$

Considering high values of the growth coefficient α , i.e. higher than $\frac{2}{9}$, the value of $R\in[0,1]$, integer $(t'')\rightarrow$ integer (t') and condition 35 is approximated as follows.

$$\left[\frac{1-(\alpha\delta)^{t'+1}}{1-\alpha\delta}\right]+\frac{2}{3}\left[\frac{(\alpha\delta)^{t'}}{1-\alpha\delta}\right]\geq\frac{9}{8}+\frac{8}{9}\alpha\delta\left[\frac{1-(\alpha\delta)^{t'+1}}{1-\alpha\delta}\right]+\frac{1}{2}\left[\frac{(\alpha\delta)^{t'}}{1-\alpha\delta}\right] \tag{36}$$

We can verify ex post that equation 36 is dominated by condition 37, necessary to sustain collusion between three firms.

$$\sum_{i=0}^{\infty}\delta^i\Pi_i^{Coll}(n=3)\geq\Pi_i^D(n=3)+\sum_{i=1}^{\infty}\delta^i\Pi_i^{CC}(n=3) \tag{37}$$

$$\begin{aligned} \Pi_t^{Coll}\left(1+\alpha\delta+\alpha^2\delta^2+...\right) &\geq \Pi_t^D+\alpha\delta\Pi_t^{CC}\left(1+\alpha\delta+\alpha^2\delta^2+...\right) \\ \Pi_t^{Coll}\left(1+\alpha\delta+\alpha^2\delta^2+...\right) &\geq \frac{4}{3}\Pi_t^{Coll}+\frac{3}{4}\alpha\delta\Pi_t^{Coll}\left(1+\alpha\delta+\alpha^2\delta^2+...\right) \end{aligned}$$

$$\begin{aligned} \frac{\Pi_t^{Coll}}{1-\alpha\delta} &\geq \frac{25}{16}\Pi_t^{Coll}+\frac{3}{4}\frac{\alpha\delta\Pi_t^{Coll}}{1-\alpha\delta} \\ \delta &= \frac{13}{16\alpha} \end{aligned} \tag{38}$$

It is easy to check that condition 36 is satisfied for value not higher than solution 38, $\forall t'\in N$.

7.2.1 Quantity competition: partial result.

Proposition 6 *In a context with quantity competition and demand growth, entry always occurs.*

If condition 38 holds, analogously to price competition case, there exist a period t', determined by condition 32, from which entry happens and collusion is still feasible. Collusion is sustainable before and after the entry. Otherwise, If condition 38does not hold, at period t" entry occurs. Cournot Nash equilibrium is implemented from entry for ever.

Proposition 7 *In a context where perfect collusion among incumbents and new entrant is not successfully sustainable, entry will occur supported by Cournot profits. Moreover, collusion is not sustainable before entry.*

Given that collusion between three firms is not sustainable it is not obvious that collusion between two firms is sustainable in the first t" periods given that, after this period, Cournot competition would hold. The two incumbents know that after t" period collusion will be not sustainable any more. Indeed, surely at period t"-1, both of them have incentive to deviate from every collusive agreements, given that Nash reversion will happen independently on their choices. By backward induction, it is immediate to affirm that collusion is not sustainable at all, and the Cournot competition would characterized the market, before and after the entry. In fact this case is analogous to trying to support collusion with finite horizon. Given that condition38 does not hold, with demand growth entry occurs, if condition **??** hold, and collusion is not more sustainable.

7.2.2 How many entrants there will be at equilibrium??

It is important to note that our equilibrium considers that incumbents obtain positive profits but the new competitors does not. In fact, he decide to enter at time t' such that he just obtains zero profits after covering sunk cost. Is it not reasonable? Moreover, we have considered only a potential entrant. Is it a strong assumption? The answers to both question is negative and in the following we explain the reasons

In our model at equilibrium new competitor obtains always zero profits because he enters in the market, if collusion is sustainable, at the time t' such that expected profits exactly cover sunk costs. This is true also when in the next paragraph we consider different penal codes. Why does not new competitor late his entry obtaining positive profits? If we consider more potential competitors characterized by the same technology, a sort of competition outside the market explains that entry occur as soon as possible. Which firm enters is not relevant

If we consider firms characterized by different sunk costs, entry is defined as follows. If we consider m potential competitors characterized by different sunk cost

$$K_1 < K_2 < ... < K_m \tag{39}$$

the firm with the lowest sunk cost will enter as first in the market and entry time t' is defined in function of second lowest sunk cost firm.

$$t' = min\left\{t \in N : \sum_{s=t}^{\infty} \delta^{s-t} \Pi_s^{Coll} \geq K_2 \right\} \qquad (40)$$

In this case, new competitor obtains in equilibrium positive profits equal to the difference between second lowest and lowest sunk cost, $K_2 - K_1$.

.In general, conclusions of section 6 are still useful for the computation of the maximum number of firms that can profitably operate. What is relevant in our analysis is the claim that if entry is supported by collusion sustainability, conditions that guarantee n+1 firm collusion are stronger that conditions that guarantee n-firm collusion.[15]

This means that if collusion is sustainable after entry, surely a collusive equilibrium before and after entry is still sustainable.

8 Stick and carrot's mechanism and demand growth.

Until now, we have developed our study considering critical conditions for perfect collusion sustainability; we have used trigger strategies characterized by simple punishment as Nash Reversion from the deviation detection for ever. But, we know how Nash reversion in a context of Cournot competition would not be the most severe punishment that is implementable and moreover, how the assumption of an infinite punishment period should be a little unrealistic. Indeed, at this point of our analysis, it is a natural consequence to look for different kinds of punishments that better fit more complex strategies. I particular we look at Abreu's simple penal code.

As application of Pearce 's "stick and carrot" theory (1985), Abreu (1986) proved that in a context in which symmetric firms repeat infinity a simultaneous and static quantity game, it is possible to implement collusion as subgames perfect equilibrium supported by a symmetric and stationary penal code characterized by a finite period punishment. This mechanism, results optimal in the sense that for given level of the discount factor it implements the highest level of collusion.

In the following we are going to prove that with demand growth and quantity competition, there exist a non stationary penal code characterized by contingent punishments that given entry of a new competitor sustains perfect collusion before and after the entry.

[15] Considering either equal sunk costs or different ones, entry process consider only one firm at time. This means that there not exist case in which we pass from a n-firm market to a n+2 or n+3 firm market.

8.1 Abreu's Optimal penal code.

In order to understand the intuition necessary to construct a mechanism useful in our dynamic context, we start considering the original framework developed by Abreu.

Following Pearce's idea of stick and carrot mechanisms, Abreu's simple penal code considers a two-phase punishment profile with a first phase lasting one or more periods characterized by the most severe punishment that is implementable, q^P , and a second period during which firms implement the highest level of collusion sustainable, q^{Coll}. After starting punishment period, firms collude until no deviation occurs. If deviation occurs, all the firms come back to produce punishment output, q^P,for only one or few periods. If no firm deviates during punishment period, after that collusion is again implemented. Otherwise punishment goes on.

Formally we defines t-period i-firm out put strategy, $\mathrm{q}_{i,t}$, as follows

$$\mathrm{q}_{i,t} = \begin{cases} q^P & \begin{cases} \text{if } t=0 \quad \text{or} \\ \text{if } \exists i,i' : \mathrm{q}_{\ i,t-1} \neq \mathrm{q}_{\ i',t-1} \end{cases} \\ q^{Coll} & \text{if } \forall i,i' : \mathrm{q}_{\ i,t-1=}\mathrm{q}_{\ i',t-1} \end{cases}$$

Note that without growth and under symmetry, we have $q_{i,t}^{Coll} = q^{Coll}$ and $q_{i,t}^P = q^P$ for $i = 1,2$, and $q^{Coll} < q^P$.

The output vector $\left(q^{Coll}, q^P\right)$ describe a subgames perfect equilibrium if and only if the following constraints are satisfied.

$$\Pi_i^{DColl} - \Pi_i^{Coll} \leq \delta\left[\Pi_i^{Coll} - \Pi_i^P\right] \quad (41)$$

$$\Pi_i^{DP} - \Pi_i^P \leq \delta\left[\Pi_i^{Coll} - \Pi_i^P\right] \quad (42)$$

where for ∀ i=1,2 and ∀j=2,1

$\Pi_i^{Coll} = \Pi_i\left(q_i^{Coll}, q_j^{Coll}\right)$ is the profit obtained by collusion.

$\Pi_i^{DColl} = \Pi_i\left(q_i^d\left(q_j^{Coll}\right), q_j^{Coll}\right)$ are the profits obtained by a firm that deviates from the collusive path.

$\Pi_i^{DP} = \Pi_i\left(q_i^d\left(q_j^P\right), q_j^P\right)$ are the profits obtained by a firm that deviates from the punishment path.

$\Pi_i^P = \Pi_i\left(q_i^P, q_j^P\right)$ are the profits obtained by a firm during the most severe punishment period.

The first condition, 41, considers that unilateral deviation from equilibrium path has to be not profitable. The second one, 42, considers that if deviation happens and punishment starts, no firm has unilateral incentive to deviate from the punishment profile.

In Abreu original context, the defined penal code is symmetric, in the sense that independently on which firm deviates, all competitors in equilibrium play the same strategy. This mechanism is also stationary in the sense that strategies in equilibrium are not contingent to the time in which a particular subgame is repeated but depend only on the behavior of players in the previous periods. In particular during the collusive paths firms produce all the same quantity in each period. If deviation occurs, the most severe punishment is the same independent to the history of the game or to the period in which deviation has occurred.

Abreu has proved that under regularity assumptions on profit functions, (A1-A3), this kind of two-phase penal code is a subgame perfect equilibrium and is optimum in the sense that achieves the higher level of collusion sustainable at any value of the discount factor.

In particular defined as $\Pi(x) = \Pi(x,x) = (A-2x)x$ the no-defection profits, and as $\Pi^d(x) = \Pi(y(x),x) = \left(\frac{A-x}{2}\right)^2$ the defector's defection profits, we need of the following properties:

(A1) $\Pi(x)$ is continuous and strictly concave in x

(A2) $\Pi^d(x)$ is nonnegative, continuous, non increasing and satisfies $\Pi^d(0) > 0$

(A3) There exist an unique x^n such that $\Pi(x^n) = \Pi^d(x^n)$. ($\exists!$ Static Nash Equilibrium)

Under assumption (A1)-(A3) the existence and the optimality of s the two-phase penal code as subgames perfect equilibrium are verified (see Abreu 1986).Intuitively, the proof of the existence and the optimality of a simple penal code is articulated in two step. First, it is crucial to show that with a two-phase optimal penal code its possible to achieve the same value of discounted profits that we obtain using the worst punishment subgames perfect equilibrium (optimality). Second, it is crucial to prove that the two-phase optimal code its itself a subgames perfect equilibrium (existence). Even if more rigorous prooves exulate from our purpose, about optimality it is important to note that by participation constraint, the worst subgames perfect equilibrium that it is implementable gives non negative discounted payoffs. Otherwise players can be better off deciding not to play. It is implicit in this remark that in the effective punishment phase firms have to obtain negative profits, losses, in order to compensate the positive discounted profits that they obtain colluding during the second phase of the simple penal code. When we consider Cournot competition this is not necessary since firms can obtain positive profits also during the first period punishment but Abreu proved that in this case optimality of a symmetric penal code is only a local property.

To compute the optimal penal code, we have to identify two levels of output, $q^P$and q^{Coll}, that form the punishment profile. The first variable, q^P, is computed as the level of output that minimize the payoff of a profit maximizer deviator, during the first period of punishment. In the symmetrical case, this variable is the same independently on which firm has deviated. We assume that the first part of punishment lasts for one period after that, the second part will start and it will last for ever. The second variable, q^{Coll}, represents the highest level of collusion that firms can implement at a given discount factor. This is played by all the firms until no deviation is detected and again after the first period of punishment.

Considering our model setting, we start analyzing the case of no demand growth, i.e. $\alpha = 1$. We re-write conditions 41 and 42 in the following way where $x = q^{Coll}$and $y = q^{P}$.

$$\left(\frac{A-x}{2}\right)^2 - (A-2x)\,x = \delta\left[(A-2x)\,x-(A-2y)\,y\right] \quad (43)$$

$$\left(\frac{A-y}{2}\right)^2 - (A-2y)\,y = \delta\left[(A-2x)\,x-(A-2y)\,y\right] \quad (44)$$

Standardizing to zero marginal cost we look for symmetric quantity decision that can achieves during the effective punishment period negative equilibrium prices. This means that firms sell at a price lower than marginal cost and obtain losses. In particular we restrict strategy set in the following way. The most collusive output x is defined in the interval between the perfect collusion's outputs and the one shot Nash equilibrium . The most severe punishment y is defined in the interval between the one shot Nash equilibrium output and a limit value M.

$$x \in \left[\frac{A}{4}, \frac{A}{3}\right] \quad (45)$$

$$y \in \left[\frac{A}{3}, M\right] \quad (46)$$

where $M = M(\delta)$ is determined as the amount that give so large loss that given the discount factor δ, they can never be recouped even if the firm receive monopolistic profits forever after.

$$-\Pi(M,0) > \frac{\delta}{1-\delta}\Pi\left(\frac{A}{2},0\right)$$

$$-(A-M)M > \frac{\delta}{1-\delta}\frac{A^2}{4}$$

The system of equations 43 and 44 admits two couples of solutions,i.e. two distinct subgames perfect equilibria. The first solution, $\forall\delta \geq 0$, considers simply to play Cournot for ever.

$$y = x = q^{CC} = \frac{1}{3} \quad (47)$$

The second one is more interesting and describes the optimal penal code required.

$$y = \frac{1}{3}A + \frac{8}{27}\delta A \quad (48)$$

$$x = -\frac{1}{27}A(-9+8\delta) \quad (49)$$

It is easy to check that the conditions, 46 and 45, are satisfied for all $\delta \in [0,1]$.

Moreover, we verify that

$$y \geq q^{CC} \quad (50)$$
$$x \leq q^{CC} \quad (51)$$

and in particular

$$\frac{\partial y}{\partial \delta} \geq 0 \quad (52)$$
$$\frac{\partial x}{\partial \delta} \leq 0 \quad (53)$$

Remembering that $y = q^P$ is the worst equilibrium implementable and $x = q^{Coll}$ is the lowest collusive output sustainable at a given discount factor, it is trivial to check that the highest the discount factor, the lowest is the output, the highest are the collusive profits. What is more important for our analysis is to esplicitly describes the critical discount factor necessary to sustain a given level of collusion. From equation 49 we can derive the following equation.

$$\delta = -\frac{9}{8}\frac{3x - A}{A} \quad (54)$$

and

$$\frac{\partial \delta (x, A)}{\partial x} \leq 0 \quad (55)$$
$$\frac{\partial \delta (y, A)}{\partial A} \geq 0 \quad (56)$$

The critical discount factor is positively correlated with the level of output produced in equilibrium. It easy to check that its value is equal to zero when we consider Cournot equilibrium, i.e. the nil- level of collusion , and it's equal to

$$\delta = \frac{9}{32}$$

when the implemented collusion shares perfectly monopolistic profits. Note that the previous value is lower than the one computed considering Cournot-Nash reversion punishment for ever (trigger strategies). By simple comparison, it is immediate to affirm the following proposition.

Proposition 8 *With quantity competition and homogeneous goods, optimal penal code exists and makes perfect collusion successfully sustainable at a lower critical discount than using Nash Reversion punishment.*

8.2 Demand growth without entry.

Considering demand growth, we look for an optimal penal code that at a given level of the critical discount factor implements the highest level of collusion. As we will prove, this code is characterized by not stationary equilibrium strategies, contingent with the state of the demand at each period. Then, we are looking for a more complex strategy profiles as $\left(\left\{q_t^P\right\}, \left\{q_t^{Coll}\right\}\right)_{t=0,1,2,\ldots}^{\infty}$ and we consider a two-phase penal code characterized by the following strategies.

$$\mathrm{q}_{i,t} = \begin{cases} q_t^{\mathrm{P}} & \begin{cases} \text{if } t = 0 & \text{or} \\ \text{if } \exists i, i' : \mathrm{q}_{\ i,t-1} \neq \mathrm{q}_{\ i',t-1} \end{cases} \\ q_t^{Coll} & \text{if } \forall i, i' : \mathrm{q}_{\ i,t-1} = \mathrm{q}_{\ i,t-1} \end{cases}$$

where $i = 1, 2, 3, ..., I$ is referred to the number of producers in the market, and $t = 1, 2, 3, ...$ is the period considered.

For simplicity, we consider a 2-firm collusion, i.e. $i = 1, 2$, but the results are extendible at any $I \geq 2$.

The index i has been neglected by symmetric property: in fact we assume that $\forall i,\ x_t = q_{i,t}^{Coll}$ and $y_t = q_{i,t}^P$

Indeed,$(\{x_t\}, \{y_t\})_{t=0,1,2,\ldots}^{\infty}$ is a subgames perfect equilibrium if and only if ,$\forall t$, the following conditions are satisfied.

$$\left(\frac{A_t - x_t}{2}\right)^2 - (A_t - 2x_t)\, x_t \leq \delta\left[(A_{t+1} - 2x_{t+1})\, x_{t+1} - (A - 2y_{t+1})\, y_{t+1}\right] \quad (57)$$

$$\left(\frac{A_t - y_t}{2}\right)^2 - (A_t - 2y_t)\, y_t \leq \delta\left[(A_{t+1} - 2x_{t+1})\, x_{t+1} - (A - 2y_{t+1})\, y_{t+1}\right] \quad (58)$$

$$x_t \in \left[\frac{A_t}{4}, \frac{A_t}{3}\right] \quad (59)$$

$$y_t \in \left[\frac{A_t}{3}, M(\delta, a)\right] \quad (60)$$

where $M = M(\delta, a)$ is determined as the amount that give so large loss that given the discount factor δ and growth coefficient α, they can never be recouped even if the firm receive monopolistic profits forever after.

$$\begin{aligned} -\Pi_t(M, 0) &> \frac{\delta a}{1 - \delta a}\Pi\left(\frac{A_t}{2}, 0\right) \\ -(A_t - M)M &> \frac{\delta a}{1 - \delta a}\frac{A_t^2}{4} \end{aligned}$$

To model strategies along the time we impose the property of balanced growth path of quantities and prices along the equilibrium path and we derive the following restrictions.

$$x_{t+1} = \alpha^{\frac{1}{2}} x_t \tag{61}$$

$$y_{t+1} = \alpha^{\frac{1}{2}} y_t \tag{62}$$

The first condition about collusive output x_t is obvious, the second one about punishment output y_t can seem to be as a restriction in the strategy definition. But, considering the quadratic specification of profits function, it is easy to check that all the variables of our optimal penal code are homogenous of degree one with respect the demand intercept.

Then we can re-write conditions 57 and 58.as follows.

$$\left(\frac{A_t - x_t}{2}\right)^2 - (A_t - 2x_t)\, x_t = \delta' \left[(A_t - 2x_t)\, x_t - (A_t - 2y_t)\, y_t\right] \tag{63}$$

$$\left(\frac{A_t - y_t}{2}\right)^2 - (A_t - 2y_t)\, y_t = \delta' \left[(A_t - 2x_t)\, x_t - (A_t - 2y_t)\, y_t\right] \tag{64}$$

where $\delta' = \alpha\delta$ is the modified discount factor.

It is important to remark that the fact that growth effects are considered in the modified discount factor, δ', make no-deviation and defector's deviation payoffs functions, in relative terms, no contingent to the period t. Then, we have imposed a sort of stationary in relative terms and this is crucial in order to satisfy (A1)-(A3).

Proposition 9 *. With demand growth, a penal code considering strategies that satisfied balanced growth path's properties define a subgames perfect equilibrium. This equilibrium is optimum in the sense of Abreu (1986).*

It is easy to check that these two conditions are satisfied as equalities by the following discount factor and optimal punishment.

$$\delta = -\frac{9}{8}\frac{3x_t - A_t}{aA_t} \tag{65}$$

$$y_t = -x_t + \frac{2}{3}A_t \tag{66}$$

It easy to check that Cournot equilibrium is sustainable for every $\delta \geq 0$.We remind that the computed $\delta = \delta(x)$ is the minimum discount factor necessary to sustains the level of collusive output $x_{t.}$

In particular the critical discount factor and the most severe punishment necessary to successfully sustain perfect collusion between two firms will be the following

$$
\begin{aligned}
y_t &= \frac{5}{12} A_t \\
\delta &= \frac{9}{32a}
\end{aligned}
$$

In a duopoly characterized by quantity competition and demand growth, perfect collusion is sustainable throw a two-phase penal code at a discount factor lower than the one necessary when Nash reversion punishment is used.

Given that collusion will be sustainable also after, this result is good for describes collusive equilibria by the two incumbents in the pre entry period. And we come back it later

8.3 Demand growth and a potential entrant.

Coming back to our model, we remind that in notation we use $i = 1,2$ and $i = 3$, to indicate respectively the two incumbents and the potential entrant. Indeed, given the change in market structure that characterized our model, we assume that the incumbents play according to the following strategy.

$$
\mathrm{q}_{i,t} = \begin{cases} q^{\mathrm{P}}(t, m_t) & \left\{ \begin{array}{c} \text{if } \; t = 0 \qquad \text{or} \\ \text{if } \; \exists i, i' \in m_{t-1} : \mathrm{q}_{\,i,t-1} \neq \mathrm{q}_{\,i',t-1} \end{array} \right. \\ q^{Coll}(t, m_t) & \text{if } \forall i, i' \in m_{t-1} : \mathrm{q}_{\,i,t-1} = \mathrm{q}_{\,i,t-1} \end{cases}
$$

where $i = 1,2$ is referred to the two incumbents and m_t is the set of the effective producers at time t: $m_t = \{1,2\}$, before the entry and $m_t = \{1,2,3\}$ after the entry.

Before to consider potential entrant's strategy, in order to simplify the notation we define with (dd) the following condition

$$
(dd): \qquad \exists i, i' \in n_{t-1} : q_{i,t-1} \neq q_{i',t-1}
$$

Then potential entrant's strategy is the following.

$$
q_{3,t} = \begin{cases} 0 & \left\{ \begin{array}{l} \text{if} \quad \sum_{i=s}^{\infty} \delta^{s-t} \Pi_s \left(q^{\mathrm{M}}(s, m_s) \right) < K \qquad \text{or} \\ \text{if } \sum_{s=t}^{\infty} \delta^{s-t} \Pi_s \left(q^{Coll}(s, m_s) \right) \geq K \quad \text{but } \; q_{3,t-1} = 0 \;\text{ and } \; (dd) \end{array} \right. \\ q^{P}(t, , m_t) & \text{if } \sum_{s=t}^{\infty} \delta^{s-t} \Pi_s \left(q^{Coll}(s, m_s) \right) \geq K, \quad \mathrm{q}_{3,t-1} \neq 0 \;\text{ and } \; (dd) \\ q^{\mathrm{Coll}}(t, m_t) & \text{if } \sum_{s=t}^{\infty} \delta^{s-t} \Pi_s \left(q^{Coll}(s, m_s) \right) \geq K \qquad \text{but not } \; (dd) \end{cases}
$$

In order to describe a subgames perfect equilibrium $q^P(t, m_t)$ and $q^{\mathrm{M}}(t, m_t)$ have to satisfy the following conditions obtained generalizing conditions 41 and 42 .

$$\Pi_{i,t}^{DColl}(., m_t) - \Pi_{i,t}^{Coll}(., m_t) \leq \delta\left[\Pi_{i,t+1}^{Coll}(., m_t) - \Pi_{i,t+1}^{P}(., m_t)\right] \quad (67)$$
$$\Pi_{i,t}^{DP}(., m_t) - \Pi_{i,t}^{P}(., m_t) \leq \delta\left[\Pi_{i,t+1}^{Coll}(., m_t) - \Pi_{i,t+1}^{P}(., m_t)\right] \quad (68)$$

$\forall i = 1, 2, 3, \forall t$

where

$\Pi_{i,t}^{Coll}(.)$ is the profit that a firm i obtained by collusion at time t.

$\Pi_{i,t}^{DColl}(.)$ are the profits obtained by a firm i that deviates from the collusive path at time t.

$\Pi_{i,t}^{DP}(.)$ are the profits obtained by a firm i that deviates from the punishment path at time t.

$\Pi_{i,t}^{P}(.)$ are the profits obtained by a firm i during the most severe punishment period at time t.

We will show a more rigorous formalization of conditions 67 and 68 in what follows.

In our model until a time t' from which entry is feasible, we have only two firms in the market, after that if no deviation has happened, entry occurs and we have three effective producers in the market.

The entry period t' is endogenously determined and depends on the highest level of collusion that is successfully implementable.

$$t' = min\left\{t \in N : \sum_{s=t}^{\infty}\delta^{s-t}\Pi_s\left(q^{\mathrm{Coll}}(s, m_s)\right) \geq K\right\} \quad (69)$$

Computation of optimal penal code is naturally related to prove the existence of a subgames perfect equilibrium.

8.3.1 Contingent optimal penal code.

To construct our penal code, we consider a composed penal code in which(y, x) are contingent to market structure and lag to entry period. We apply a sort of backward induction and we have distinguished in the time horizontal five segments or phases. Starting from the last one, we consider a three-firm collusion phase that start from period $t = t\prime + 1$ to for ever. We call with (y_1, x_1), the strategy vector played by the firms.

$$\forall t \in [t' + 1, \infty[\quad : (y_1, x_1)$$

The second segment of time considers the period during which entry occurs, and we call with (y_2, x_2) , the strategy vector played by the firms.

$$t = t' \qquad\qquad (y_2, x_2)$$

The third and the fourth segment consider respectively one and two period before entry occurs. Considering this lags will be relevant in term of incentive to no deviate before entry both during collusive period both during of punishment one. We call with (y_3, x_3) and (y_4, x_4) ,the strategy vectors played by the firms respectively during periods $t = t\prime - 1$ and $t = t\prime - 2$.

$$t = t' - 1 \qquad (y_3, x_3)$$

$$t = t' - 2 \qquad (y_4, x_4)$$

At the end we consider as a whole segments all period from the start to two period before entry occurs. We we call with (y_5, x_5) , the strategy vector played by the firms.

$$\forall t \in [0, t' - 2[\qquad (y_5, x_5)$$

8.3.2 After entry subgames equilibria.

We start considering what happens after entry, $\forall t \in [t' + 1, \infty[$ .We have three firms producing in the market, and we look for values of (y_1, x_1) that satisfied the following constraints.

$$\left(\frac{A_t - 2x_1}{2}\right)^2 - (A_t - 3x_1)\, x_1 \leq \delta' \left[(A_t - 3x_1)\, x_1 - (A_t - 3y_1)\, y_1\right] \quad (70)$$

$$\left(\frac{A_t - 2y_1}{2}\right)^2 - (A_t - 3y_1)\, y_1 \leq \delta' \left[(A_t - 3x_1)\, x_1 - (A_t - 3y_1)\, y_1\right] \quad (71)$$

$$x_{1,t} \in \left[\frac{A_t}{6}, \frac{A_t}{4}\right]$$

$$y_{1,t} \in \left[\frac{A_t}{4}, M(\delta, a)\right]$$

where $M = M(\delta, a)$ is determined as in the duopoly case.

The value of effective punitive output y_1 and the modified discount factor δ'necessary to substain the collusive output x_1 are the following.

$$\begin{aligned} y_1 &= \frac{A_t}{2} - x_1 \\ \delta' &= -\frac{4x_1}{A_t} - 1 \end{aligned}$$

For value of the modified discount factor close to zero repeated Cournot -Nash is equilibrium of the game. The values necessary to substain perfect collusion, i.e. $x_1 = \frac{A_t}{6}$, are the following

$$\begin{aligned} y_1 &= \frac{A_t}{3} \\ \delta' &\geq \frac{1}{3} \end{aligned}$$

8.3.3 Entry period subgames equilibrium.

Knowing that after entry three-firm will be sustainable for discount factors not lower than one third, at time $t'$the potential entry begins to produce. We have that firms face the following constraints where $(x_{2,t}, y_{2,t})$ define the strategy played at that period.

$$\left(\frac{A_t - 2x_2}{2}\right)^2 - (A_t - 3x_2)\,x_2 \leq \delta'\left[(A_t - 3x_2)\,x_2 - (A_t - 3y_2)\,y_2\right] \quad (72)$$

$$\left(\frac{A_t - 2y_2}{2}\right)^2 - (A_t - 3y_2)\,y_2 \leq \delta'\left[(A_t - 3x_2)\,x_2 - (A_t - 3y_2)\,y_2\right] \quad (73)$$

It easy to check that when we consider perfect collusive equilibria, conditions 72 and 73 are satisfied for the same values that satisfy conditions 70 and 71. In particular we have that for $\delta' \geq \frac{1}{3}$,

$$x_2 = x_1 = \frac{A_t}{6}$$

$$y_2 = y_1 = \frac{A_t}{3}$$

Again, for discount factors not lower than one third perfect collusion is sustainable, entry is profitable and no deviations occur in equilibrium for ever.

8.3.4 Pre-entry periods subgames equilibria.

Now, we focus our attention to period $t' - 1$.When we consider time $t' - 1$, if no deviation occurs in the next period players pass from a two-firm collusive equilibrium to a three firm collusive equilibrium. Otherwise, a two-firm punishment phase starts. In that case, i.e. deviations from collusion occurs at time $t'-1$, at time $t\prime$ we have a punishment phase. Entry is shifted at the first period in which the most collusive output is implementable, i.e. no deviations from punishment occur.

Then, if we want that the period before entry two-firm collusion is sustainable, the following conditions have to be satisfied.

$$\left(\frac{A_t - x_3}{2}\right)^2 - (A_t - 2x_3)\, x_3 \leq \delta' \left[(A_t - 3x_2)\, x_2 - (A_t - 2y_3)\, y_3\right] \quad (74)$$

$$\left(\frac{A_t - y_3}{2}\right)^2 - (A_t - 2y_3)\, y_3 \leq \delta' \left[(A_t - 3x_2)\, x_2 - (A_t - 2y_3)\, y_3\right] \quad (75)$$

If deviation occurs at time $t'-2$, at $t'-1$ the most severe punishment between two firms holds, at time t'if no deviation from the punishment path is observed, entry occurs and players implement the higher level of three-firm collusion that it is sustainable. Note that if we observe deviation from the punishment path, ongoing punishment involves only incumbents. In fact, the third firm will enter in the market only when a symmetric path holds. With entry, the structural of the market changes as the form of the no deviation and the defector's deviation payoffs functions. This assumption gives the following conditions.

$$\left(\frac{A_t - x_4}{2}\right)^2 - (A_t - 2x_4)\, x_4 \leq \delta' \left[(A_t - 2x_4)\, x_4 - (A_t - 2y_4)\, y_4\right] \quad (76)$$

$$\left(\frac{A_t - y_4}{2}\right)^2 - (A_t - 2y_4)\, y_4 \leq \delta' \left[(A_t - 3x_2)\, x_2 - (A_t - 2y_4)\, y_4\right] \quad (77)$$

Now its easy to check that considering perfect collusive equilibria,

$$x_4 = x_3 = \frac{A_t}{4}$$

$$x_2 = \frac{A_t}{6}$$

condition 76 is dominated by condition 74: ceteris paribus collusion between two firms is more profitable than collusion between two firms. Otherwise each firm can chooses to play as two distinct entities.

Conditions 77 and 75 admit exactly the same solutions,

$$y_4 = y_3.$$

As previously we look for the minimum critical discount factor that successfully sustain perfect collusion. Then we look only at conditions 74 and 75. By computation we obtain the following solutions.

Considering

$$\delta' \geq \frac{1}{3}$$

and

$$y_4, y_3 \in \left[\frac{A_t}{4}, \frac{A_t}{2}\right]$$

we have the following optimal punishment output.

$$y_4 = y_3 = \frac{A_t}{4} + \frac{A_t}{48}\sqrt{102}$$

In this paragraph we have operatively proved that there exists a feasible output strategy that make collusion between incumbents sustainable in periods just before entry.

8.3.5 Two firms collusive equilibrium.

When we consider period $t \in [0, t' - 3]$, conditions to implement perfect collusion as subgames perfect equilibrium are the ones previously derived when we have introduced the case of duopoly with demand growth.

$$\begin{aligned} y_5 &= \frac{5}{12}A_t \\ \delta &= \frac{9}{32a} \leq \frac{1}{3a} \end{aligned}$$

The principal result of this section is summarized by the following proposition.

Proposition 10 *With demand growth and quantity competition, there exist a penal code characterized by punishment contingent with the period, that given entry of a new competitor ,at any discount factor not lower than* $\frac{1}{3}a$ *sustains perfect collusion before and after the entry.*

For

$$\delta \geq \frac{1}{3\alpha}$$

the optimal penal code is defined as follows:

$$\forall t \in [t' + 1, \infty[\qquad : \left(y_1 = \frac{A_t}{3}, x_1 = \frac{A_t}{6}\right)$$

$$t = t' \qquad \left(y_2 = \frac{A_t}{3}, x_2 = \frac{A_t}{6} \right)$$

$$t = t' - 1 \qquad \left(y_3 = \frac{A_t}{4} + \frac{A_t}{48}\sqrt{102}, x_3 = \frac{A_t}{4} \right)$$

$$t = t' - 2 \qquad \left(y_4 = \frac{A_t}{4} + \frac{A_t}{48}\sqrt{102}, x_4 = \frac{A_t}{4} \right)$$

$$\forall t \in [0, t' - 2[\qquad \left(y_5 = \frac{5A_t}{12}, x_5 = \frac{A_t}{4} \right)$$

8.4 Conclusion

The purpose of this paper is to represent an analytical framework for describing collusive incentive in market characterized by demand growth. The idea is to prove that even if profitability attracts new competitors, this is no a clear collusion-minus factor as considered in many EU Merger task Force's decisions.

We have proved as considering simple framework, with some cost to entry, demand growth reduces the critical discount factor necessary to substain collusion.

In the last part of the paper we have constructed a non stationary but symmetric penal code that applies stick and carrots strategies in a context characterized by demand growth and variation in market concentration. This is useful to implement collusive equilibria at lower critical discount factor than using trigger strategies.

Again, we have proved than in our framework also by using more sophisticated punishment approach, collusive equilibria, characterized by perfect collusion before and after entry, are easier substainable and .demand growth, decreasing critical discount factor, plays as a sure collusive plus factor. This result give robustness to our initial idea about a positive relation between demand growth and collusion sustainability.

To tell the truth, until now we have only considered condition for implementing collusive equilibria but they are not the only ones.. We know that incumbents can choose other foreclosing strategies and implement no entry equilibria if they results more profitable in terms of discounted long run payoff. The profits obtained considering a two firms perfect collusion for a longer period can be higher than the ones obtained implementing a three firm perfect collusion profits. The subgames perfect equilibrium implemented is defined by incumbents expected payoffs comparison in the different scenarios. This development is the base for our next studies.

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(xlii) This paper was presented at the International Workshop on "Climate Change and Mediterranean Coastal Systems: Regional Scenarios and Vulnerability Assessment" organised by the Fondazione Eni Enrico Mattei in co-operation with the Istituto Veneto di Scienze, Lettere ed Arti, Venice, December 9-10, 1999.

(xliii)This paper was presented at the International Workshop on “Voluntary Approaches, Competition and Competitiveness” organised by the Fondazione Eni Enrico Mattei within the research activities of the CAVA Network, Milan, May 25-26,2000.

(xliv) This paper was presented at the International Workshop on “Green National Accounting in Europe: Comparison of Methods and Experiences” organised by the Fondazione Eni Enrico Mattei within the Concerted Action of Environmental Valuation in Europe (EVE), Milan, March 4-7, 2000

(xlv) This paper was presented at the International Workshop on “New Ports and Urban and Regional Development. The Dynamics of Sustainability” organised by the Fondazione Eni Enrico Mattei, Venice, May 5-6, 2000.

(xlvi) This paper was presented at the Sixth Meeting of the Coalition Theory Network organised by the Fondazione Eni Enrico Mattei and the CORE, Université Catholique de Louvain, Louvain-la-Neuve, Belgium, January 26-27, 2001

(xlvii) This paper was presented at the RICAMARE Workshop “Socioeconomic Assessments of Climate Change in the Mediterranean: Impact, Adaptation and Mitigation Co-benefits”, organised by the Fondazione Eni Enrico Mattei, Milan, February 9-10, 2001

(xlviii) This paper was presented at the International Workshop “Trade and the Environment in the Perspective of the EU Enlargement ”, organised by the Fondazione Eni Enrico Mattei, Milan, May 17-18, 2001

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(l) This paper was presented at the Workshop “Growth, Environmental Policies and Sustainability” organised by the Fondazione Eni Enrico Mattei, Venice, June 1, 2001

(li) This paper was presented at the Fourth Toulouse Conference on Environment and Resource Economics on “Property Rights, Institutions and Management of Environmental and Natural Resources”, organised by Fondazione Eni Enrico Mattei, IDEI and INRA and sponsored by MATE, Toulouse, May 3-4, 2001

(lii) This paper was presented at the International Conference on “Economic Valuation of Environmental Goods”, organised by Fondazione Eni Enrico Mattei in cooperation with CORILA, Venice, May 11, 2001

(liii) This paper was circulated at the International Conference on “Climate Policy – Do We Need a New Approach?”, jointly organised by Fondazione Eni Enrico Mattei, Stanford University and Venice International University, Isola di San Servolo, Venice, September 6-8, 2001

(liv) This paper was presented at the Seventh Meeting of the Coalition Theory Network organised by the Fondazione Eni Enrico Mattei and the CORE, Université Catholique de Louvain, Venice, Italy, January 11-12, 2002

(lv) This paper was presented at the First Workshop of the Concerted Action on Tradable Emission Permits (CATEP) organised by the Fondazione Eni Enrico Mattei, Venice, Italy, December 3-4, 2001

(lvi) This paper was presented at the ESF EURESCO Conference on Environmental Policy in a Global Economy “The International Dimension of Environmental Policy”, organised with the collaboration of the Fondazione Eni Enrico Mattei , Acquafredda di Maratea, October 6-11, 2001

(lvii) This paper was presented at the First Workshop of “CFEWE – Carbon Flows between Eastern and Western Europe”, organised by the Fondazione Eni Enrico Mattei and Zentrum fur Europaische Integrationsforschung (ZEI), Milan, July 5-6, 2001

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SUST	*Sustainability Indicators and Environmental Evaluation* (Editor: Carlo Carraro)
KNOW	*Knowledge, Technology, Human Capital* (Editor: Dino Pinelli)
PRIV	*Privatisation, Regulation, Antitrust* (Editor: Bernardo Bortolotti)
MGMT	*Corporate Sustainable Management* (Editor: Andrea Marsanich)
ETA	*Economic Theory and Applications* (Editor: Carlo Carraro)