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ENDOGENOUS BREADTH OF COLLUSIVE AGREEMENTS : AN APPLICATION TO FLEXIBLE TECHNOLOGICAL CHOICES

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Endogenous breadth of collusive agreements: an application to flexible technological choices

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Abstract: We study the impact of the breadth of collusive agreements on firms' technological choices. If firms collude only on quantities (semi-collusion), they invest more in flexible technologies than without collusion; whereas, if firms collude on quantities and on technologies (full-collusion), they invest less. Then, we endogenize the scope of the collusive agreements. Firms choose full-collusion when product differentiation and discount factor have intermediate values. A more severe antitrust policy incites firms to choose semi-collusion rather than full collusion and to increase their investments in flexibility.

Résumé : On étudie la possibilité pour les firmes d'étendre un accord de collusion portant sur les quantités aux choix technologiques. Dans un premier temps, l'étendue de l'accord est exogène. Les accords de semi-collusion conduisent à des investissements plus importants en flexibilité tandis que les accords de collusion totale réduisent les investissements. On endogénéise, ensuite, l'étendue des accords de collusion. Les firmes choisissent des accords de collusion étendus lorsque le degré de différenciation des biens et le facteur d'actualisation ont des valeurs intermédiaires. Un renforcement de la politique de la concurrence favorise les accords de semi-collusion au détriment des accords de collusion totale et provoque une augmentation des investissements des firmes.

Keywords: Collusion, competition policy, semi-collusion, flexibility, breadth of collusion.

JEL Codes: D20, D43, K21, L41.

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1 Introduction

Since the seminal paper of Friedman (1971), a lot of articles have studied collusion. However, in spite of this increase in the number of papers, some aspects still seem misunderstood. An important point is the breadth of collusive agreements. Conventional wisdom suggests that when firms collude on quantities or prices, competition in other strategic variables (advertising, services, R&D, investments in capacities, and so on) may become tougher. Several empirical studies support this idea (Steen and Sørgard, 1999; Röller and Steen, 2006; Ma, 2008). Some theoretical papers had shown that this more aggressive competition with respect to these other variables may lead to lower overall profits (Fershtman and Gandal, 1994; Jacques, 2006). So it seems natural to wonder why firms do not collude on these other variables as well. It is often put forward that these variables are difficult to monitor. But, generally, the scope of collusive agreement is exogenous. Authors do not try to endogenize it. In addition, the assumption chosen is not the same in all models. Some papers assume that firms first choose not cooperatively a first strategic variable and second collude on quantities or prices.[1] In the opposite, other papers assume that collusion agreements can be extended to the choice of the first strategic variable and that a deviation from this variable triggers reversion to competition in all variables including quantities and prices.[2] Linkage between prices collusion and cooperation in other variables can be different. For example, Martin (1995) shows that firms can increase the possibilities to sustain monopoly prices by threatening to dissolve a common R&D joint venture if a firm infringes the collusion agreement. So papers diverge on assumptions made on the possibility to extend collusion to other variables than quantities or prices. If collusive arrangements breadth depends on the firms possibilities to monitor competitors' behavior on these other variables, it probably differs according to industries. They probably exist semi-collusive and full collusive agreements in real life. So it seems desirable to study semi-collusion and full collusion models. However the simultaneous study of these two types of models should be completed with research to establish in which situations each model is the most relevant.

In this paper, we study the impact of the breadth of collusive agreements on the firms' technological choices of flexibility. Flexibility is an important factor of firms' strategy. The firms' level of flexibility acts upon the possibilities to adapt the production rate to demand's fluctuations, to switch to other product specification at a low cost, to increase the range of products, to substitute one input by an other, to incorporate quickly a process innovation, and so on. This level depends on the firms' technological and organizational choices. The adoption of flexible manufacturing systems allows firms to produce a larger range of products on the same production line. The firms' degree of flexibility also depends on the firms' internal organization and on the design of contracts written with inputs' suppliers. Flexibility is a multidimensional concept.[3] In this paper, we focus on the increase of the range of products when a firm adopts a flexible manufacturing

[1] For example, these assumptions are chosen by Davidson and Deneckere (1990), Fershtman and Gandal (1994) and Paha (2017), in which firms choose non cooperatively production capacites, by Jehiel (1992), Friedman and Thisse (1993), Ecchia and Lambertini (1997), Rath and Zhao (2003) and Matsumura and Matsushima (2011), in which firms choose non cooperatively their product location, by Brod and Shivakumar (1999), in which firms choose R&D expenditures and by Jacques (2006), in which firms choose non cooperatively between a flexible technology and a dedicated one.

[2] For example, these assumptions are chosen by Chang (1992), Häckner (1995) and Miklós-Thal (2008), in models of product design choices and by Staiger and Wolak (1992), Pénard (1997) and Knittel and Lepore (2010) in models of production capacities choices.

[3] See Jacques (2003) for a survey.

systems. Several papers have already studied this dimension of flexibility. Two important results emerge from this literature. First, the adoption of flexible manufacturing systems leads to a tougher competition with Cournot competition (Röller and Tombak, 1990) and Bertrand competition (Norman and Thisse, 1999). Second, flexible technologies promote concentration by reducing the number of firms (Eaton and Schmitt, 1994, Norman and Thisse, 1999). These results have been obtained under the assumption that firms really compete and do not collude.

Jacques (2006) began to explore the interactions between flexible technological choices and collusion. The main results of this first study are the followings. First, when firms compete in prices, collusion is easier to sustain when firms have flexible technologies than when they have dedicated ones. So flexible technologies do not necessarily increase competition, even for a given number of firms. Second, collusion may be easier to enforce when one firm has a flexible technology and the other firm has a dedicated one than when the two firms have the same technologies. Third, the area in which both firms choose flexible technologies is larger with semi-collusion than with competition. Fourth, the cost of these further investments in flexibility may dominate the benefits of collusion and cause a reduction of firms' profits.

This first study has not exhausted the problem of interactions between choices of flexibility and collusion and many questions remain. Jacques (2006) assumes that firms first choose non cooperatively their technologies and second collude on prices. He studies a semi-collusion model and does not consider full collusive agreements including technological choices. This assumption that collusive agreements cannot be extended to technological choices is crucial to obtain the third and fourth results. If the scope of collusive arrangements can include technological choices, firms will probably try to reduce their investments in flexibility to increase their profits. In this paper, we study the design and sustainability of full collusive agreements. We show that the zone in which both firms choose flexible technologies is smaller with full collusion than with competition.

Jacques (2006) does not either consider competition policy to deter collusion. Only the necessity for agreements to be self-enforcing is taken into account. In this paper, we introduce the possibility that antitrust authority detects collusive agreements and convicts firms to fine. Introduction of an antitrust authority is used to endogenize firms' choice between full collusion, semi collusion and competition. Nevertheless, to simplify the model and to shorten the paper, we make assumptions which imply that semi-collusion always dominates competition. So we focus on the choice between semi-collusion and full collusion. Full collusion allows firms to reduce their investments. But if firms reach a larger collusive arrangement, they have a higher probability to be detected by antitrust authority. So firms face a trade-off between lower fixed costs and higher conviction risk. We show that firms prefer semi-collusion when the agreement breadth has no impact on technological choices, so when product differentiation is very low or very high. For intermediate product differentiation, firms choose semi collusion when the discount factor is high and full collusion when the discount factor is lower. Semi-collusion arrangements look like an avoidance technology. First, firms have to pay higher investment expenditures, but in the following periods, the probability that their collusive arrangement is detected is lower. So it is rather intuitive that firms choose semi-collusive when they are very patient and full collusion when they are less patient. Finally, we show that a stricter competition policy (a rise of detection probability or fines) enlarges the zone where firms choose semi-collusion and causes an increase of firms' investments in flexible technologies.

The model is described in section 2. In section 3 and 4, we characterize collusive agreements according to their breadth. In section 5, we study firms' technological choices according to (exogenous) collusive arrangements scope, without antitrust authority. In section 6, we introduce antitrust authority and endogenize collusive agreement breadth. Section 7 concludes.

2 Model

We first introduce a general model, separating assumptions on firms and on the antitrust authority. Then we put more restrictive assumptions to focus on the choice between semi-collusion and collusion.

2.1 Firms

We study a two-phase model.[4] In the first phase, two firms, 1 and 2, choose simultaneously between two technologies. Firm 1 selects between a dedicated technology (D) which produces a single product A and a flexible technology (F) which allows the firm to produce the goods A and B. Firm 2 chooses between an inflexible one-product technology which limits the firm to produce product B and a flexible two-product technology producing A and B. These technological choices are irreversible. The three technologies have the same constant marginal cost c but different fixed cost. The fixed cost of the flexible technology, I_F, is higher than the one of the dedicated technologies, I_D. We denote $I \equiv I_F - I_D$, the additional cost of flexibility. In the second phase, firms will choose quantities in each of an infinite succession of time periods. In each period, the inverse demand for the two goods are:[5]

$$\begin{aligned} p^A\left(Q^A, Q^B\right) &= \max\left\{\alpha - Q^A - \lambda Q^B, 0\right\} \\ p^B\left(Q^A, Q^B\right) &= \max\left\{\alpha - Q^B - \lambda Q^A, 0\right\} \end{aligned}$$

$\lambda \in [0,1]$ is a measure of substitutability between products A and B. We note δ the discount factor. Production starts one period after the fixed costs have been paid.

Firms have the possibility to negotiate a collusive agreement. Firms' managers have to meet to conclude a collusive agreement. This meeting can take place at two different times. Firms can design the agreement before their technological choices. Then the agreement holds on the technology each firm has to choose and on quantities each firm has to produce. We will call this case: full collusion. Alternatively, firms can reach an agreement only after technological choices and restrict it to quantities. We will call this case: semi-collusion. There is no renegotiation possibility. If a firm defects from an agreement's clause, firms revert to the one-shot Cournot equilibrium forever. In particular, if a firm deviates from the technology stipulated by a full agreement, firms cannot afterwards negotiate a semi-collusive agreement.

[4] The model is a variant of Röller and Tombak (1990). The main difference is Röller and Tombak (1990) assume that the Cournot game is played only once so there is no collusion possibility.

[5] These functions can be interpretated as the demand functions of a representative consumer with quadratic utility function.

2.2 Antitrust authority (AA)

To formalize the working of an antitrust authority (AA), we need to do a lot of assumptions about the probabilities of detection and conviction, the level of fines, the possibility for firms to commit subsequent offences, the design of clemency programs, and so on.[6] Our selection's criterion is tractability. We assume that the probabilities of detection do not depend on firm's technological choices, prices' level or prices' moves.[7] On the other hand, we assume that the probabilities of discovery depend on the breadth of collusive agreement. We denote ρ^S the probability of detection of a semicollusive arrangement in each period and ρ^T the probability for a fully collusive agreement to be discovered. We assume that the cartel can no longer be discovered if a firm cheats. If a cartel is detected, it is automatically convicted. We assume that fines do not depend on prices' level or cartel's longevity.[8] We note F^S the fine each firm must pay if it is successfully prosecuted for a semicollusive agreement and F^T the fine for a fully collusive arrangement. Collusion cannot restart after a conviction by AA. Firstly, we assume that AA does not use leniency programs. We discuss the impact of leniency programs at the end of section 6. These assumptions dismiss a lot of potential effects but allow to focus on the main issue.

2.3 Problem's simplification

In this model, firms have three possible strategies: negotiate a full collusive agreement, negotiate a semi-collusive arrangement or not collude. To limit the length of this article, we focus on the choice between full collusion and semi-collusion. A simple way to exclude no collusion as a possible equilibrium is to assume $\rho^S = 0$. Under these assumptions, after the technological choice, semi-collusion always provides higher profits than no collusion. In addition, we assume that firms can not commit before technological choice to not choose semi-collusion after technological choice. These two assumptions imply that no collusion can not be an equilibrium of the game when discount factor is high enough. Moreover, we assume that the discount factor is high enough to sustain monopoly price. If $\rho^S = 0$, F^S becomes irrelevant. We can simplify the notations by putting $\rho^T = \rho$ and $F^T = f$.

3 Competition and semicollusion

We start by computing firms' profits in each technological configuration when firms compete and when they negotiate semi-collusive agreements.

[6] See Harrington (2017) for a survey.

[7] If the likelihood of detection depends on prices' changes, the optimal cartel price path becomes complex (Harrington, 2004a and 2005; Harrington and Chen, 2006). If the detection probability depends on price levels, firms choose prices below monopoly prices (Houba, Motchenkova and Wen, 2010, 2012).

[8] This implies that firms choose monopoly price when they collude. Firms would choose lower prices if fines were increasing with damages (Besanko and Spulber, 1989; Souam, 2001) and could choose higher prices if fines depend on firms'revenue (Bageri, Katsoulacos and Spagnolo, 2013; Katsoulacos, Motchenkova and Ulph, 2015, 2020).

This assumption also implies that prices after the cartel has been dissolved are the Cournot ones. Harrington (2004b) develops a model in which firms distort the post-cartel prices during litigation to influence the estimation by AA of the competitive price and reduce the fine.

3.1 Competition

Firms never choose to not collude in the subgame perfect Nash equilibria of the game. But we need to specify the quantities chosen in the no collusion case to describe the punishing paths and the firms' behavior after the detection of a cartel. We will also use the discount profit to study the impact of collusion on technological choices.

3.1.1 Quantities competition

The table below sums up quantities, prices and profits per period for the four possible technological configurations (subscripts point out firms and exponents indicate products. The first [second] letter in the left column indicates the technology of firm 1 [firm 2]):

	Quantities	Prices	Profits
D,D	$q_1^A = \frac{\alpha-c}{2+\lambda}$ $\quad q_2^A = 0$ $q_1^B = 0$ $\quad q_2^B = \frac{\alpha-c}{2+\lambda}$	$p^A = c + \frac{\alpha-c}{2+\lambda}$ $p^B = c + \frac{\alpha-c}{2+\lambda}$	$\pi_1^{nc} = \left(\frac{\alpha-c}{2+\lambda}\right)^2$ $\pi_2^{nc} = \left(\frac{\alpha-c}{2+\lambda}\right)^2$
F,F	$q_1^A = \frac{\alpha-c}{3(1+\lambda)}$ $\quad q_2^A = \frac{\alpha-c}{3(1+\lambda)}$ $q_1^B = \frac{\alpha-c}{3(1+\lambda)}$ $\quad q_2^B = \frac{\alpha-c}{3(1+\lambda)}$	$p^A = c + \frac{\alpha-c}{3}$ $p^B = c + \frac{\alpha-c}{3}$	$\pi_1^{nc} = \frac{2(\alpha-c)^2}{9(1+\lambda)}$ $\pi_2^{nc} = \frac{2(\alpha-c)^2}{9(1+\lambda)}$
F,D	$q_1^A = \frac{\alpha-c}{2(1+\lambda)}$ $\quad q_2^A = \frac{(2-\lambda)(\alpha-c)}{6(1+\lambda)}$ $q_1^B = 0$ $\quad q_2^B = \frac{\alpha-c}{3}$	$p^A = c + \frac{(3-\lambda)(\alpha-c)}{6}$ $p^B = c + \frac{\alpha-c}{3}$	$\pi_1^{nc} = \frac{(13-5\lambda)(\alpha-c)^2}{36(1+\lambda)}$ $\pi_2^{nc} = \frac{1}{9}(\alpha-c)^2$
D,F	$q_1^A = \frac{\alpha-c}{3}$ $\quad q_2^A = 0$ $q_1^B = \frac{(2-\lambda)(\alpha-c)}{6(1+\lambda)}$ $\quad q_2^B = \frac{\alpha-c}{2(1+\lambda)}$	$p^A = c + \frac{\alpha-c}{3}$ $p^B = c + \frac{(3-\lambda)(\alpha-c)}{6}$	$\pi_1^{nc} = \frac{1}{9}(\alpha-c)^2$ $\pi_2^{nc} = \frac{(13-5\lambda)(\alpha-c)^2}{36(1+\lambda)}$

3.1.2 Present values of profits

By computing the present values of the stream of profits and substracting the fixed costs, we obtain the following pay-off matrix:

	F	D
F	$\Pi_1^{NC}(F,F) = \sum_{i=1}^{\infty}\delta^i \frac{2(\alpha-c)^2}{9(1+\lambda)} - I_F$ $\Pi_2^{NC}(F,F) = \sum_{i=1}^{\infty}\delta^i \frac{2(\alpha-c)^2}{9(1+\lambda)} - I_F$	$\Pi_1^{NC}(F,D) = \sum_{i=1}^{\infty}\delta^i \frac{(13-5\lambda)(\alpha-c)^2}{36(1+\lambda)} - I_F$ $\Pi_2^{NC}(F,D) = \sum_{i=1}^{\infty}\delta^i \frac{1}{9}(\alpha-c)^2 - I_D$
D	$\Pi_1^{NC}(D,F) = \sum_{i=1}^{\infty}\delta^i \frac{1}{9}(\alpha-c)^2 - I_D$ $\Pi_2^{NC}(D,F) = \sum_{i=1}^{\infty}\delta^i \frac{(13-5\lambda)(\alpha-c)^2}{36(1+\lambda)} - I_F$	$\Pi_1^{NC}(D,D) = \sum_{i=1}^{\infty}\delta^i \left(\frac{\alpha-c}{2+\lambda}\right)^2 - I_D$ $\Pi_2^{NC}(D,D) = \sum_{i=1}^{\infty}\delta^i \left(\frac{\alpha-c}{2+\lambda}\right)^2 - I_D$

3.2 Semi-collusion

Now we assume that firms choose their technologies non-cooperatively before negotiating a collusive agreement on the production levels. We have assumed $\rho^S = 0$, so collusion is never detected and collusion stops only if one firm cheats.

3.2.1 Quantities' choice

If one firm cheats, firms play the Cournot equilibrium forever on the punishing path. We have specified this equilibrium in the previous section. Now we need to describe the collusion path and the optimal deviation for each technological configuration.

Both firms have dedicated technologies: In each period, we have:

	Collusion	Deviation
Quantities	$q_1^A = q_2^B = \frac{\alpha-c}{2(1+\lambda)}$	$q_i^{dX} = \frac{2+\lambda}{4(1+\lambda)}(\alpha-c)$
Prices	$p^A = p^B = c + \frac{1}{2}(\alpha-c)$	$p^{dX} = c + \frac{2+\lambda}{4(1+\lambda)}(\alpha-c)$
Profit	$\pi^c = \frac{1}{4(1+\lambda)}(\alpha-c)^2$	$\pi^d = \frac{(2+\lambda)^2}{16(1+\lambda)^2}(\alpha-c)^2$

Perfect collusion is sustainable between two dedicated firms if and only if (π^{nc} is the one-shot game profit):

$$\delta \geq \frac{\pi^d - \pi^c}{\pi^d - \pi^{nc}} = \frac{(2+\lambda)^2}{\lambda^2 + 8\lambda + 8}$$

This critical discount factor is an increasing function of λ on $]0,1]$. It tends towards 0.5 when λ tends towards 0 and it is equal to $\frac{9}{17}$ when the two goods are perfect substitutes. Sustaining collusion is easier when products are more differentiated.

Both firms have flexible technologies: In each period, we have:

	Collusion	Deviation
Quantities[9]	$q_1^A = q_1^B = q_2^A = q_2^B = \frac{\alpha-c}{4(1+\lambda)}$	$q_i^{dA} = q_i^{dB} = \frac{3(\alpha-c)}{8(1+\lambda)}$
Prices	$p^A = p^B = c + \frac{1}{2}(\alpha-c)$	$p^{dA} = p^{dB} = c + \frac{3}{8}(\alpha-c)$
Profit	$\pi^c = \frac{1}{4(1+\lambda)}(\alpha-c)^2$	$\pi^d = \frac{9}{32(1+\lambda)}(\alpha-c)^2$

Perfect collusion between two flexible firms is sustainable if and only if:

$$\delta \geq \frac{\pi^d - \pi^c}{\pi^d - \pi^{nc}} = \frac{9}{17}$$

Asymmetric technological configuration: The collusive agreement characterization when firms have different technologies is a more difficult task. We have to select one equilibrium in an infinity. When firms have the same technologies, a symmetric equilibrium is a natural focal point. When firms have different technologies, the selection rule is less natural. We choose the bargaining solution of Nash (1950). Denoting H the set of possible profits' sharing, we have:

$$\begin{aligned} (\pi_1^c, \pi_2^c) \quad &\in \quad \arg\max_H \left(\pi_1 - \pi_1^{nc}\right)\left(\pi_2 - \pi_2^{nc}\right) \\ s/t \quad \delta \quad &\geq \quad \frac{\pi_i^d - \pi_i^c}{\pi_i^d - \pi_i^{nc}} \quad i = 1,2 \end{aligned}$$

In a first step, we solve the problem without the self-enforcing constraints. Then we calculate the discount

[9] An equal sharing of the two markets minimizes the gain of cheating.

factors for which the solution is self-enforcing.

$$\left(\pi_1^c, \pi_2^c\right) \in \arg\max_H \left(\pi_1 - \pi_1^{nc}\right)\left(\pi_2 - \pi_2^{nc}\right) \Rightarrow \begin{Bmatrix} \pi_1^c = \frac{1}{2}\left(\pi^m + \pi_1^{nc} - \pi_2^{nc}\right) \\ \pi_2^c = \frac{1}{2}\left(\pi^m - \pi_1^{nc} + \pi_2^{nc}\right) \end{Bmatrix}$$

with $\pi^m = \frac{(\alpha-c)^2}{2(1+\lambda)}$ the profit of a monopoly producing the two goods. We assume that the flexible firm is firm 1. We have:

$$\pi_1^c = \frac{3-\lambda}{8\left(1+\lambda\right)}\left(\alpha - c\right)^2 \quad \text{and} \quad \pi_2^c = \frac{1}{8}\left(\alpha - c\right)^2$$

From these values, we can deduce the firms' production quotas:[10]

$$q_1^A = \frac{\alpha - c}{2\left(1+\lambda\right)} \quad ; \quad q_1^B = \frac{\left(1-\lambda\right)\left(\alpha - c\right)}{4\left(1+\lambda\right)} \quad ; \quad q_2^A = 0 \quad ; \quad q_2^B = \frac{1}{4}\left(\alpha - c\right)$$

Reporting these quotas in the firms' best reply functions, we obtain the firms' optimal deviations:

	Quantities	Prices	Deviation profit
Firm 1	$q_1^{dA} = \frac{\alpha-c}{2(1+\lambda)}$ $q_1^{dB} = \frac{(3-\lambda)(\alpha-c)}{8(1+\lambda)}$	$p^{dA} = c + \frac{(4-\lambda)(\alpha-c)}{8}$ $p^{dB} = c + \frac{3}{8}\left(\alpha-c\right)$	$\pi_1^d = \frac{25-7\lambda}{64(1+\lambda)}\left(\alpha-c\right)^2$
Firm 2	$q_2^{dB} = \frac{3}{8}\left(\alpha-c\right)$	$p^{dB} = c + \frac{3}{8}\left(\alpha-c\right)$	$\pi_2^d = \frac{9}{64}\left(\alpha-c\right)^2$

Firm 1 (the flexible one) has no incentive to deviate if:

$$\delta \geq \frac{\pi_1^d - \pi_1^c}{\pi_1^d - \pi_1^{nc}} = \frac{9}{17}$$

Firm 2 (the dedicated one) has no incentive to defect if:

$$\delta \geq \frac{\pi_2^d - \pi_2^c}{\pi_2^d - \pi_2^{nc}} = \frac{9}{17}$$

If $\delta > \frac{9}{17}$, these two constraints are satisfied. The collusive agreement described above is a Nash perfect equilibrium. If $\delta = \frac{9}{17}$, the two constraints are binding. It is not possible to sustain the monopoly price for δ below that value. Below this threshold, firms can maintain quantities lower than Cournot but higher than monopoly ones. We choose to not study these cases of partial collusion and to focus on perfect collusion by assuming that δ is high enough to sustain monopoly behavior.

3.2.2 Profits' present values

We can now construct the first stage pay-off matrix. For $\delta \geq \frac{9}{17}$, we have the following matrix:

	F	D
F	$\Pi_1^S(F,F) = \sum_{i=1}^{\infty}\delta^i \frac{(\alpha-c)^2}{4(1+\lambda)} - I_F$ $\Pi_2^S(F,F) = \sum_{i=1}^{\infty}\delta^i \frac{(\alpha-c)^2}{4(1+\lambda)} - I_F$	$\Pi_1^S(F,D) = \sum_{i=1}^{\infty}\delta^i \frac{(3-\lambda)(\alpha-c)^2}{8(1+\lambda)} - I_F$ $\Pi_2^S(F,D) = \sum_{i=1}^{\infty}\delta^i \frac{1}{8}\left(\alpha-c\right)^2 - I_D$
D	$\Pi_1^S(D,F) = \sum_{i=1}^{\infty}\delta^i \frac{1}{8}\left(\alpha-c\right)^2 - I_D$ $\Pi_2^S(D,F) = \sum_{i=1}^{\infty}\delta^i \frac{(3-\lambda)(\alpha-c)^2}{8(1+\lambda)} - I_F$	$\Pi_1^S(D,D) = \sum_{i=1}^{\infty}\delta^i \frac{(\alpha-c)^2}{4(1+\lambda)} - I_D$ $\Pi_2^S(D,D) = \sum_{i=1}^{\infty}\delta^i \frac{(\alpha-c)^2}{4(1+\lambda)} - I_D$

[10] The profit of firm 1 in market A is equal to: $\frac{(\alpha-c)^2}{4(1+\lambda)}$. So its profit on market B must be equal to: $\frac{(3-\lambda)(\alpha-c)^2}{8(1+\lambda)} - \frac{(\alpha-c)^2}{4(1+\lambda)} = \frac{(1-\lambda)(\alpha-c)^2}{8(1+\lambda)}$. We can find the firms' quotas by dividing these profits by the mark-up: $p - c = \frac{1}{2}\left(\alpha - c\right)$.

4 Full collusion

In this section, we assume that firms can collude on quantities and on technological choices. They will use this possibility to try to reduce their investments in flexibility. We delimit the area in which each technological configuration is sustainable.

4.1 Both firms have dedicated technologies

Agreement's design: To maximize their joint profits, firms have to minimize their first stage investments. The collusive agreement which maximize firms' profits is the following. The two firms choose the dedicated technology. In each period where the agreement is in force, firms produce: $q_1^A = q_2^B = \frac{\alpha - c}{2(1+\lambda)}$ and $q_2^A = q_1^B = 0$, and earn a profit equal to: $\frac{(\alpha-c)^2}{4(1+\lambda)}$. If one firm cheats or if the AA detects the collusion, the agreement stops and firms play the one-shot Cournot equilibrium forever.

Firms' present profits with this agreement are equal to:

$$\begin{aligned}\Pi_i^T(D,D) &= \sum_{i=1}^{\infty} \delta^i \left\{ (1-\rho)^{i-1} \left[\frac{(\alpha-c)^2}{4(1+\lambda)} - \left(\frac{\alpha-c}{2+\lambda}\right)^2 - \rho f \right] + \left(\frac{\alpha-c}{2+\lambda}\right)^2 \right\} - I_D \\ &= \frac{\delta}{1-\delta(1-\rho)} \left[\frac{\lambda^2(\alpha-c)^2}{4(1+\lambda)(2+\lambda)^2} - \rho f \right] + \frac{\delta}{1-\delta}\left(\frac{\alpha-c}{2+\lambda}\right)^2 - I_D\end{aligned}$$

Agreement's sustainability: To check if this agreement is sustainable, we must verify two incentive constraints. First, firms do not have incentive to produce more. Second, firms can not increase their profits by choosing a flexible technology in the first stage.

Firms have no incentive to cheat in the production phase if:[11]

$$\delta(1-\rho) \geq \frac{\pi^d - \pi^c}{\pi^d - \pi^{nc}} \Leftrightarrow \delta \geq \frac{(2+\lambda)^2}{\lambda^2} \frac{\lambda^2 + \rho 16 (1+\lambda)^2 \frac{f}{(\alpha-c)^2}}{(1-\rho)\left(8+8\lambda+\lambda^2\right)}$$

Firms have no incentive to deviate in the technological choice stage if:

$$\Pi_1^T(D,D) \geq \Pi_1^{NC}(F,D) \Leftrightarrow$$

$$I + \delta\left[Y(\alpha-c)^2 - (2-\rho)I - \rho f\right] - \delta^2\left[Z(\alpha-c)^2 - (1-\rho)I - \rho f\right] \geq 0 \Leftrightarrow \delta \leq \delta_{DD}^T$$

with $Y = \frac{\left(-16+4\lambda+16\lambda^2+5\lambda^3\right)}{36(1+\lambda)(2+\lambda)^2}$ and $Z = \frac{\left[9\lambda^2-(1-\rho)(1-\lambda)\left(16+12\lambda+5\lambda^2\right)\right]}{36(1+\lambda)(2+\lambda)^2}$. See appendix for the expression of δ_{DD}^T.

This agreement can be not sustainable even if δ is near 1. Indeed, if the goods' differentiation is very high, one firm can increase its profit by choosing a flexible technology. The agreement is cancelled, but the retaliation possibilities of the other firm are very low. In fact, if the differentiation is very high, the dedicated firm produces more on the collusion path (when the two firms have chosen dedicated technologies) than on the punishment path (when the other firm had chosen a flexible technology). A firm can deter the other firm to deviate and choose a flexible technology only if it can credibly commit to increase its production after the deviation, so only if the differentiation is low enough.

[11] Deviation profit, π^d, has the same value than in the semi-collusion case.

4.2 Both firms have flexible technologies

Agreement's design: Both firms choose flexible technologies and produce, in each colluding period, the quantities: $q_1^A = q_1^B = q_2^A = q_2^B = \frac{\alpha - c}{4(1+\lambda)}$.

The value of firms' present profits is:

$$\Pi_i^T(F,F) = \frac{\delta}{1-\delta(1-\rho)}\left[\frac{(\alpha-c)^2}{36(1+\lambda)} - \rho f\right] + \frac{\delta}{1-\delta}\frac{2(\alpha-c)^2}{9(1+\lambda)} - I_F$$

Agreement's sustainability: Firms do not have incentive to chisel in the production phase if:

$$\delta \geq \frac{9}{17(1-\rho)}\left[1 + 32\rho\frac{(1+\lambda)f}{(\alpha-c)^2}\right]$$

They do not have incentive to deviate in the technological choices stage if:

$$\Pi_1^T(F,F) \geq \Pi_1^{NC}(D,F) \Leftrightarrow$$

$$I - \delta\left[\frac{5-4\lambda}{\frac{36(1+\lambda)}{(\alpha-c)^2}} - \rho f + (2-\rho)I\right] + \delta^2\left[\frac{5-4\lambda-4\rho(1-\lambda)}{\frac{36(1+\lambda)}{(\alpha-c)^2}} - \rho f + (1-\rho)I\right] \leq 0 \Leftrightarrow \delta \geq \delta_{FF}^T$$

See appendix for the expression of δ_{FF}^T. We always have $\delta_{FF}^T \leq \delta_{DD}^T$. This implies that if a firm has incentive to deviate from a (F,F) configuration in the technological choice stage, then it has not incentive to deviate from a (D,D) configuration in the first stage. Similarly, if firms have incentives to deviate from (D,D), then they have not incentive to deviate from (F,F). In addition, there exists a zone (with intermediate product differentiation) where the configurations (D,D) and (F,F) are both sustainable. Firms may have difficulties to sustain the (F,F) configuration in the technological choices stage only if product differentiation is low, but in this case they can maintain the (D,D) configuration and prefer it.

4.3 Mixed technological configuration

Agreement's design: As in the semi-collusion case, we have to define a sharing rule to allocate production quotas between firms when they have different technologies. In the semi-collusion case, the firms are asymmetric when the bargaining begins (they had already chosen their technologies). In the full-collusion case, firms are symmetric when they negotiate the collusive agreement (technological choices are made later). So it seems natural to look for an agreement with equal profits for the two firms: $\Pi_1^T(F,D) = \Pi_2^T(F,D)$.

But firms' profits are higher in the (D,D) configuration than in the (F,D) one. So firms choose (F,D) configuration only if (D,D) is not sustainable. But, if firms cannot maintain (D,D) configuration, they cannot sustain a (F,D) configuration with $\Pi_1^T(F,D) = \Pi_2^T(F,D)$. Indeed, we have $\Pi_1^T(F,D) + \Pi_2^T(F,D) < \Pi_1^T(D,D) + \Pi_2^T(D,D)$. This inequality and the equality $\Pi_1^T(F,D) = \Pi_2^T(F,D)$ imply $\Pi_1^T(F,D) < \Pi_1^T(D,D)$. In the zone where (D,D) is not sustainable, we have $\Pi_1^T(D,D) < \Pi_1^{NC}(F,D)$. Then, in this area, we have $\Pi_1^T(F,D) < \Pi_1^{NC}(F,D)$. So if firms choose a market shares' allocation with $\Pi_1^T(F,D) = \Pi_2^T(F,D)$, the flexible firm has incentive to defect from the agreement by increasing its production. This implies that in a (F, D) agreement we must have $\Pi_1^T(F, D) > \Pi_2^T(F, D)$. So the market shares' allocation binds one of the two incentive constraints of the flexible firm.[12]

However, in the area where (D, D) cannot be supported, the flexible firm has no incentive to change its technology. This constraint is verified if $\Pi_1^T(F, D) > \Pi_1^{NC}(D, D)$. This is always true if (D, D) is not sustainable. If (D, D) cannot be maintained, we have $\Pi_1^{NC}(F, D) > \Pi_1^T(D, D)$. If (F, D) is sustainable, we must have $\Pi_1^T(F, D) \geq \Pi_1^{NC}(F, D)$ and $\Pi_1^T(D, D) \geq \Pi_1^{NC}(D, D)$. Therefore if (F, D) is sustainable and (D, D) is not, we necessary have: $\Pi_1^T(F, D) > \Pi_1^{NC}(D, D)$.

Therefore, if firms choose a (F, D) configuration, they choose a market shares' allocation which binds the flexible firm's constraint to not cheat during the production phase. So production quotas and profits are the followings (see appendix):

$q_1^A = \frac{1}{2(1+\lambda)}(\alpha - c)$	$q_1^B = \frac{x}{1+\lambda}(\alpha - c)$	$\pi_1^c = \frac{1+2x}{4(1+\lambda)}(\alpha - c)^2 - \rho f$
$q_2^A = 0$	$q_2^B = \frac{1-2x}{2(1+\lambda)}(\alpha - c)$	$\pi_2^c = \frac{1-2x}{4(1+\lambda)}(\alpha - c)^2 - \rho f$

with:

$$\begin{aligned} x &= \frac{1 + \delta(1-\rho)(1+2\lambda) - \sqrt{[1 + \delta(1-\rho)(1+2\lambda)]^2 - X}}{2[1 - \delta(1-\rho)]} \\ X &= [1 - \delta(1-\rho)] \left\{ \frac{\delta(1-\rho)\left(7 - 4\lambda - 20\lambda^2\right) + 9}{9} + \frac{16(1+\lambda)^2 \rho f}{(\alpha - c)^2} \right\} \end{aligned}$$

Firms' present profits are equal to:

$$\begin{aligned} \Pi_1^T(F, D) &= \frac{\delta}{1 - \delta(1-\rho)}\left(\pi_1^c - \pi_1^{nc}\right) + \frac{\delta}{1-\delta}\pi_1^{nc} - I_F \\ \Pi_2^T(F, D) &= \frac{\delta}{1 - \delta(1-\rho)}\left(\pi_2^c - \pi_2^{nc}\right) + \frac{\delta}{1-\delta}\pi_2^{nc} - I_D \end{aligned}$$

Agreement's sustainability: By construction, the flexible firm has no incentive to defect from the agreement. So we just need to check the incentive constraint of the dedicated firm. Firm 2 does not deviate in the technological choice stage if:

$$\Pi_2^T(F, D) \geq \Pi_2^{NC}(F, F) \Leftrightarrow$$

$$\delta^2 [18x - 1 - 4(1-\lambda)\rho + K(2-\rho)] + \delta\left[1 - 18x - K\left[\frac{\rho f}{I} + (2-\rho)\right]\right] + K \geq 0 \Leftrightarrow \delta \leq \delta_{FD}^T$$

with $K \equiv \frac{36(1+\lambda)}{(\alpha - c)^2} I$.

δ is present in the expression of x. So it is not possible to find analytically the expression of δ_{FD}^T. We have to proceed numerically.

Firm 2 does not either have incentive to produce more than its quota. In order to check this condition,

[12] Our sharing rule tries to minimize the difference between $\Pi_1^T(F, D)$ and $\Pi_2^T(F, D)$.

we need to calculate its deviation profit. If firm 2 cheats, we have:

$$q_2^{dB} = \frac{1}{2}\left(1-x+\frac{\lambda}{2}\right)\left(\frac{\alpha-c}{1+\lambda}\right) \quad , \quad p^{dB} = c+\frac{1}{2}\left(1-x+\frac{\lambda}{2}\right)\left(\frac{\alpha-c}{1+\lambda}\right)$$
$$\text{and} \quad \pi_2^d = \frac{1}{4}\left(1-x+\frac{\lambda}{2}\right)^2\left(\frac{\alpha-c}{1+\lambda}\right)^2$$

Firm 2 does not chisel in the production phase if:

$$\delta(1-\rho) \geq \frac{\pi_2^d-\pi_2^c}{\pi_2^d-\pi_2^{nc}} \Leftrightarrow \delta(1-\rho) \geq \frac{9\left(x+\frac{\lambda}{2}\right)^2+36\rho\frac{(1+\lambda)^2 f}{(\alpha-c)^2}}{5+9x(x-2-\lambda)+\lambda-\frac{7}{4}\lambda^2}$$

δ is present in the expression of x. So we cannot solve this inequality analytically. But, we can evaluate the solution numerically.

5 Technological choices

In this section, we study the impact of collusive agreements' breadth on the equilibrium technological configuration. So we assume that this breadth is exogenous (we endogenize it in the next section). In addition, we assume that there is no AA, which formally means $\rho^T = 0$. Finally, we focus on the cases in which the monopoly price is sustainable in all technological configurations, so we assume $\delta \geq 9/17$.

5.1 Technological choices without collusion

The firms' technological best reply functions are:

$$\Pi_1^{NC}(F,F) \geq \Pi_1^{NC}(D,F) \Leftrightarrow \frac{\delta}{1-\delta}\frac{1-\lambda}{9(1+\lambda)} \geq \frac{I}{(\alpha-c)^2}$$
$$\Pi_1^{NC}(F,D) \geq \Pi_1^{NC}(D,D) \Leftrightarrow \frac{\delta}{1-\delta}\frac{(1-\lambda)\left(16+12\lambda+5\lambda^2\right)}{36(1+\lambda)(2+\lambda)^2} \geq \frac{I}{(\alpha-c)^2}$$

Both firms choose flexible technologies if $\Pi_1^{NC}(F,F) \geq \Pi_1^{NC}(D,F)$ and $\Pi_1^{NC}(F,D) \geq \Pi_1^{NC}(D,D)$. Both firms choose dedicated technologies if $\Pi_1^{NC}(F,F) \leq \Pi_1^{NC}(D,F)$ and $\Pi_1^{NC}(F,D) \leq \Pi_1^{NC}(D,D)$. In the area where $\Pi_1^{NC}(F,F) \geq \Pi_1^{NC}(D,F)$ and $\Pi_1^{NC}(F,D) \leq \Pi_1^{NC}(D,D)$, two pure strategies Nash equilibria coexist. Either both firms choose flexible technologies or both choose dedicated technologies. Firms earn more profits in the equilibrium with dedicated technologies. There is no equilibrium in pure strategies where firms choose different technologies.[13]

[13] See Röller and Tombak (1990) and Kim, Röller and Tombak (1992) for more details on the case without collusion. The two firms can choose different technologies at the equilibrium if some assumptions are changed. Bárcena-Ruiz and Olaizola (2008) assume that production choices are delegated to managers. The firms choose to ask at these managers to maximize functions that are different from the profit of the firms. He, Ding and Hua (2012) assume that the fixed costs of the flexible technology are not the same for the two firms.

5.2 Technological choices with semi-collusion

In the semi-collusion case, the two technological best reply functions are equivalent:

$$\Pi_1^S(F,F) \geq \Pi_1^S(D,F) \Leftrightarrow \Pi_1^S(F,D) \geq \Pi_1^S(D,D) \Leftrightarrow \frac{\delta}{1-\delta}\frac{1-\lambda}{8(1+\lambda)} \geq \frac{I}{(\alpha-c)^2}$$

The reason is rather intuitive. Technological configuration does not impact joint profits (apart from fixed costs) but only their sharing. If it is profitable for a firm to pay the additional fixed cost I to switch from (D,D) to (F,D) and obtain a bigger profits share, then it is also profitable for the other firm to pay I to revert to the initial sharing.

So technological equilibria confine to two zones. Both firms choose flexible technologies if and only if $\Pi_1^S(F,F) \geq \Pi_1^S(D,F)$. Both firms choose dedicated technologies if and only if $\Pi_1^S(F,F) \leq \Pi_1^S(D,F)$. (F,D) configuration is not an equilibrium, except possibly on the border between the two zones.

5.3 Technological choices with full collusion

Firms' joint profits are highest with (D,D) agreement. So firms choose this configuration if it is sustainable. Joint profits are higher with (F,D) agreement than with the (F,F) one, but the profits' sharing is unequal. If firms were risk-averse or averse to inequalities, they would prefer (F,F). But, firms are risk-neutral, so they prefer to choose (F,D) and randomize the distribution of roles. (F,D) configuration is chosen when it is implementable and (D,D) is not. When (D,D) and (F,D) cannot be supported, firms resign themselves to (F,F) agreement.

5.4 Technological equilibria comparison

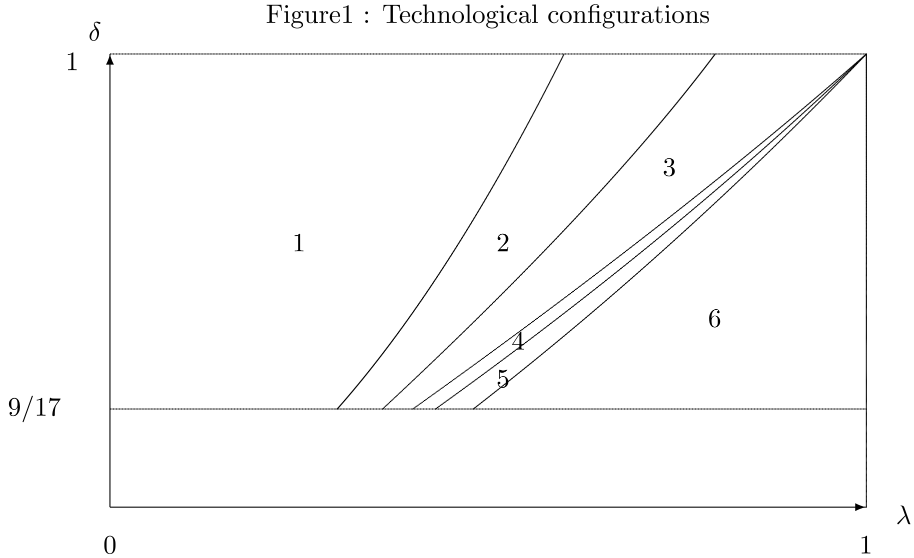
We draw all the previous conditions on the same figure to see the impact of collusive agreement breadth on the technological configuration (we put: $\frac{I}{(\alpha-c)^2} = 0.05$).[14]

There are six different zones. The table below sums up technological equilibria for each zone according to the agreement's breadth.

	No collusion	Semi-collusion	Full collusion
Zone 1	(F,F)	(F,F)	(F,F)
Zone 2	(F,F)	(F,F)	(F,D)
Zone 3	(F,F)	(F,F)	(D,D)
Zone 4	(F,F) or (D,D)	(F,F)	(D,D)
Zone 5	(D,D)	(F,F)	(D,D)
Zone 6	(D,D)	(D,D)	(D,D)

[14] From left to right, the first curve is the border of the zone where (F,D) is sustainable in full collusion, the second is the border of the zone (D,D) in full collusion, the third is the condition $\Pi_1^{NC}(F,D) \geq \Pi_1^{NC}(D,D)$, the fourth is the condition $\Pi_1^{NC}(F,F) \geq \Pi_1^{NC}(D,F)$ and the fifth is the condition $\Pi_1^S(F,F) \geq \Pi_1^S(D,F)$.

Figure1 : Technological configurations



By comparing technological equilibria, we see that:

Proposition 1 *Semi-collusion favors adoption of flexible technologies whereas full collusion decreases firms' investments in the flexible technology.*

Corollary 2 *Investments in the flexible technology are non monotonic in collusion breadth.*

In the semi-collusion game, firms adopt flexible technology in order to increase their bargaining power in the negotiation about the profits sharing. As collusion in the production phase increases profits, firms' incentives to invest in flexibility to increase their market shares are higher with semi-collusion than without collusion. So the zone where (F, F) is the equilibrium is larger with semi-collusion than without collusion.

The game without collusion has a prisoner's dilemma structure in zones 1, 2 and 3. Firms' profits are higher in (D, D) configuration than in (F, F) one, but the choice of the flexible technology is a dominant strategy. In the full collusion game, firms can extend the collusive agreement to technological choices. They can design a mechanism to influence their technological choices. The choice of a dedicated technology is rewarded by collusion on quantities and the choice of a flexible technology is punished by reversion to competition. This mechanism allows firms to escape the prisoner's dilemma structure in zone 3 and sustains (D, D) configuration. In area 2, firms can only partially get away from the dilemma by using this type of mechanism. Only one firm reduces its technological investment. In zone 1, the extension of the collusive agreement to technological choice does not modify the game structure. In this zone, retaliation possibilities of a dedicated firm are too weak to deter the other firm to adopt a flexible technology. So only (F, F) configuration is implementable. Full collusion, contrary to semi-collusion, widens the area in which (D, D) is an equilibrium.

Finally, we can remark that full collusion is the only game where (F, D) configuration can be an equilibrium.[15]

[15] (F, D) can be an equilibrium in the semi-collusion game but only on the border between zones 5 and 6.

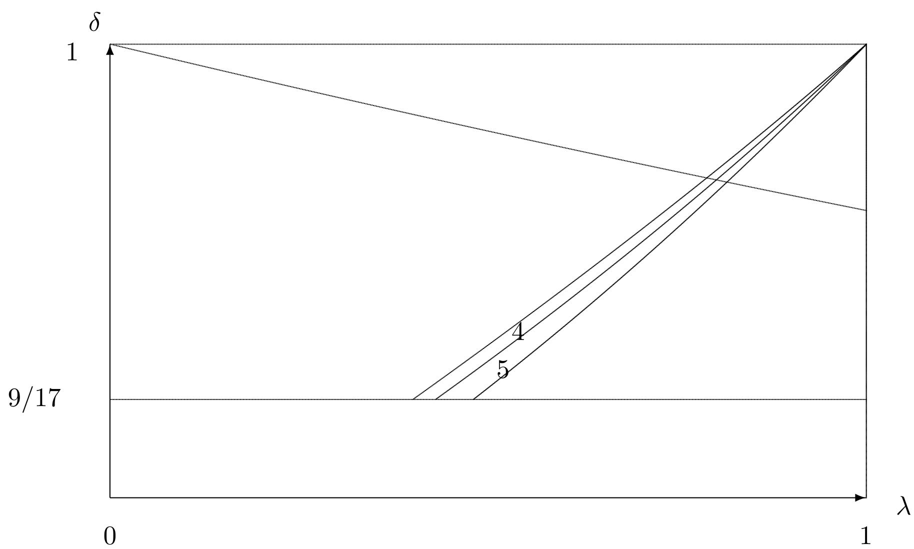
5.5 Profits comparison

We now compare profits earned by firms according to the breadth of collusive agreements. In areas 1 and 6, technological configurations are the same for the three scope of collusion. Profits in full collusion and semi-collusion are equals and higher than the profits with competition. In areas 2 and 3, full collusion has the advantage to decrease fixed cost. Joint profits are highest in full collusion and lowest in competition. In zones 4 and 5, technological equilibrium[16] is (D, D) in full collusion and competition case whereas it is (F, F) in semi-collusion. Profits are highest in the full collusion case. Profits comparison between semi-collusion and competition is ambiguous. Prices are higher in semi-collusion but fixed costs are also higher. Profits are weaker in semi-collusion than in competition if:

$$\Pi_1^{NC}(D, D) \geq \Pi_1^S(F, F) \Leftrightarrow \frac{I}{(\alpha - c)^2} \geq \frac{\delta}{1-\delta} \frac{\lambda^2}{4(1+\lambda)(2+\lambda)^2}$$

We plot this condition and borders of areas 4 and 5 on a figure to visualize the zone (below the new condition) in which profits are higher with competition than with semi-collusion.

Figure 2: Disadvantageous semi-collusion



The result that profits can be lower in semi-collusion than in competition is not a specific characteristic of this model. Similar results have been found by Fershtman and Gandal (1994) in a model in which firms choose production capacities or advertising expenditures non cooperatively before to collude on prices, by Brod and Shivakumar (1999) in a model in which firms choose R&D expenses before to collude on quantities, and by Jacques (2006) in a model analogous to the one studied in this paper but in which firms compete in prices.

[16] We assume that in the competition case firms succeed in coordinating themselves on the equilibrium (D, D) in area 4.

6 Breadth of collusive agreements

In this section, we endogenize the collusive agreements' breadth. We assume that firms have the possibility to meet before technological choices to negotiate a full collusive agreement. If they choose to not meet, they have a new possibility to arrange a meeting after technological choices to reach a semi-collusive agreement.

6.1 Breadth choice

In areas 1 and 6, technological choices are identical for the three collusive breadths. So investment levels do not depend on the agreement breadth. The breadth choice depends on level of prices and the detection probability. The assumption $\rho^S = 0$ implies that semi-collusion dominates competition. With semi-collusion, firms can increase prices without risking to be fined by AA. The assumption $\rho^T > 0$ implies that semi-collusion dominates full collusion. Because full collusion generates a positive probability to be detected and fined without creating any advantage. In these two areas, firms choose to negotiate a semi-collusive agreement.

In areas from 2 to 5, the scope of collusive agreement has an impact on the level of fixed costs. In zones 4 and 5, firms could prefer competition and (D, D) configuration to semi-collusion implying (F, F) configuration (as we have seen in 5.5 subsection). But we have assumed that firms cannot commit before technological choice to not meet after this choice to negotiate a semi-collusive agreement. This no commitment assumption, added to assumption $\rho^S = 0$, implies that competition is never an equilibrium. So, to determine the equilibrium breadth of the agreement, we just need to compare semi-collusive and full collusive profits. Full collusion reduces fixed costs but increases conviction risk by AA.

In 3, 4 and 5, full collusion is preferred to semi-collusion if:

$$\Pi_1^T(D, D) \geq \Pi_1^S(F, F)$$

$$\Leftrightarrow \delta^2 \left[(1-\rho) I + \rho f - \rho \frac{\lambda^2 (\alpha - c)^2}{4(1+\lambda)(2+\lambda)^2} \right] - \delta \left[(2-\rho) I + \rho f \right] + I \geq 0 \Leftrightarrow \delta \leq \delta_{345}^E$$

In zone 2, full collusion is preferred to semi-collusion if:

$$\frac{1}{2}\Pi_1^T(F, D) + \frac{1}{2}\Pi_1^T(D, F) \geq \Pi_1^S(F, F) \Leftrightarrow$$

$$\delta^2 \left[(1-\rho) I + 2\rho f - \rho \frac{(\alpha - c)^2}{36} \right] - \delta \left[(2-\rho) I + 2\rho f \right] + I \geq 0 \Leftrightarrow \delta \leq \delta_2^E$$

See appendix for the expressions of δ_{345}^E and δ_2^E.

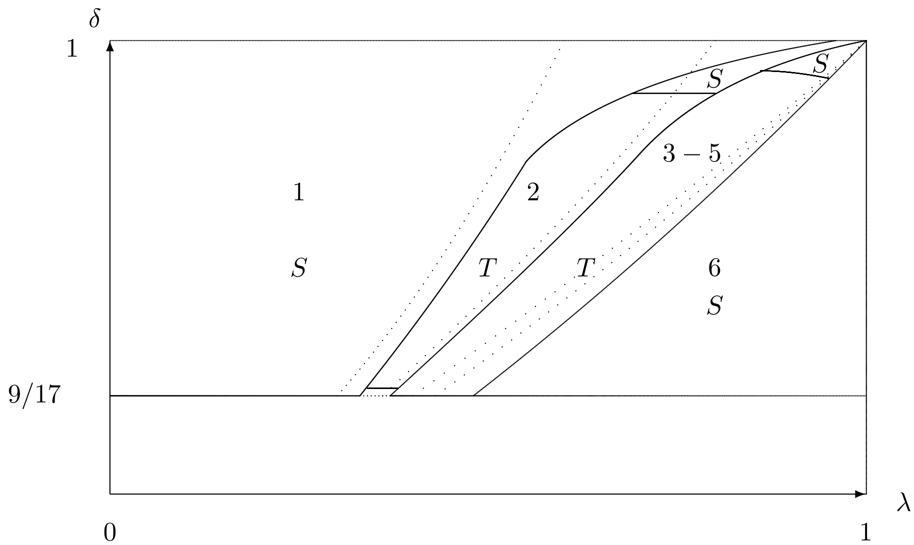
6.2 Impact of competition policy

We plot on a figure the borders of the previous areas and the curves of the two conditions above. We will try to distinguish the impacts of the detection probability and the effects of the fine by introducing these two elements successively. To make easier the comparison with the results found without antitrust policy, the figure 1's borders are drawn with dotted lines on the following figures.

Impact of the detection probability: We begin by illustrating the effects of the detection probability. We introduce a positive detection probability $\rho > 0$ but no fine $f = 0$. If a collusive agreement is detected, it is disbanded and firms cannot collude anymore.

Parameters values on the figure are equals to:[17] $I = 5$, $\alpha - c = 10$, $\rho = 0.01$,[18] $f = 0$.

Figure 3: Endogenous breadth - detection



Borders of the different technological equilibria in full collusion move to the right and curve to the bottom.

Proposition 3 *Antitrust authority increases the zone in which (F, F) is the equilibrium and decreases the zone in which (D, D) is the equilibrium in full collusion.*

When firms negotiate a full collusive agreement, they try to reduce their investment expenditures by stipulating, if it is enforceable, that they have to choose a dedicated technology. If firms respect this clause, they are rewarded by collusive profits in the following periods. If firms defect and choose the flexible technology, they are punished to the reversion to competition. If we introduce a probability that AA can detect and dissolve the collusion agreement, firms' incentives to respect the technological choices clause are weakened. If firms respect the clause, they earn collusive profits but only temporarily; because, after some periods,[19] the agreement is detected and disbanded. So if detection probability increases, it is more difficult to implement a reduction of investment expenditures. The borders of technological equilibria zones move to the right. They also curve to the bottom, because the dissolution of the agreement by the AA impacts future profits so its effect is higher if δ is higher.

[17] Dotted lines are the borders of figure 1. Full lines are, from left to right, the borders of zones (F, D) and (D, D) in full collusion and the border of zone (D, D) in semi-collusion. Full lines near horizontal are, in the top of zones 2 and 3, borders between full collusion and semi-collusion, and, in the bottom of zone 2, the minimal value of δ necessary to sustain monopoly prices with a full collusive agreement.

[18] If we assume that one game period corresponds to a month, a detection probability equals to 1% is near the estimation of Bryant and Eckard (1991).

[19] The expected life duration of the agreement is equal to $1/\rho$.

In areas 2, 3, 4 and 5, firms choose a full collusive agreement when δ is low, but high enough to sustain monopoly prices (zones marked by T) and a semi-collusive agreement when δ is high (zones labeled by S).

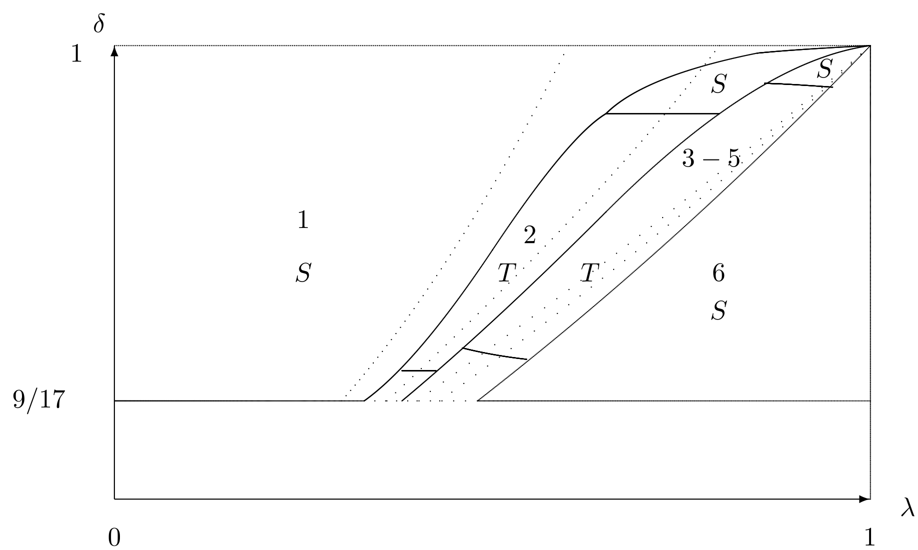
Proposition 4 *When technological choices depend on collusion breadth, firms choose a semi-collusive agreement when they are very patient (δ near 1) and a full collusive agreement when they are less patient.*

A semi-collusive agreement leads to higher fixed costs but it ensures that the collusive agreement will never be detected and can stand forever. To confine the collusive agreement to quantities has the same effect than to invest in an avoidance technology allowing to escape from the AA's scrutiny. The investment cost is paid in the first period whereas the benefits arise in expectations only after a lot of periods, when collusion carries on whereas it would probably be detected and dissolved with a full collusive agreement. So it seems intuitive that semi-collusive agreements are chosen for high δ but not for lower δ.

The last effect of a positive detection probability is to make full collusive agreements more difficult to sustain during the production phase. Firms respect the agreement for fear of reverting to competition. But if AA can detect and dissolve collusion, the return to competition will arise sooner or later. So AA decreases the difference between the expected profits firms earn when they respect the agreement and the punishment profits. So the possibilities to implement a full collusive agreement are weakened when ρ increases. On the figure, δ must be strictly higher than 9/17 to sustain full collusion in zone 2. In areas 3, 4 and 5, the minimal discount factor to support monopoly prices with full collusion increases but remains lower than 9/17.

Impact of fines: We now study the effects of fine. We keep ρ constant and assume $f > 0$. The parameters values chosen to draw the figure are: $I = 5$, $\alpha - c = 10$, $\rho = 0.01$, $f = 10$.

Figure 4: Endogenous breadth - fine



Fine accentuates the effects of the detection probability. The borders demarcating the different technological equilibria in full collusion move more to the right. The borders delimiting areas in which firms prefer semi-collusion to full collusion move toward the bottom in zones from 2 to 5. Minimal discount factors necessary to sustain monopoly prices in full collusive agreements increase.

Proposition 5 *An increase of the fine reduces the breadth of collusive agreements and increases the firms' investments in flexible technologies.*

Impact of leniency programs: Leniency programs are an important tool to fight cartels in Europe and USA.[20] So it seems a priori interesting to study their impact on the choice between semi-collusion and collusion. But the model's assumptions are not well fit to study this question. Generally leniency programs grant amnesty to a firm which exposes a not detected cartel. In our model, this type of leniency program has no impact because we have assumed that the detection probability falls to zero if a firm deviates from the collusive agreement.[21] To defect from the agreement cancels the conviction probability and, in addition, allows the firm to earn deviation profits during one period. So deviation from the agreement strictly dominates application for leniency.[22] Leniency programs can also be used, when cartels have already been detected, to increase conviction probability or to decrease the duration and costs of investigations and trials (Motta and Polo, 2003). In our model, we have assume that the conviction probability is equal to one and we have not introduce judicial costs. So leniency programs can neither increase the probability of conviction nor save inquiries costs. The only potential impact could be to reduce fine. So the potential effects of leniency programs, with ours assumptions, are the same than with a cut in fine.

7 Conclusion

This paper contribution is twofold. First, we have studied the impact of (exogenous) collusive agreements breadth on firms' technological choices of flexibility. We have shown that semi-collusive arrangements incite firms to choose more flexible technologies in order to increase their bargaining power in negotiation on market shares allocation. On the other hand, full collusive agreements allow firms to cooperate in the technological choice stage and to choose less flexible technologies. Firms use the threat to revert to competition to implement the investments' reduction. We have assumed specific functions for firms' cost and demand to show these results, but intuition seems robust and we would find identical results with others cost or demand functions.

The second contribution of this paper is to present a way to endogenize the breadth of collusive agreements. The scope of collusive arrangements may depend on several factors: observability of other firms' actions, firms' commitment capacity and competition policy. In this paper, we focus on the third factor by assuming that the discovery's probability increases with the breadth of the collusive agreements. Firms face a trade-off between the possibility to decrease their fixed costs by reaching a full collusive agreement and the increased

[20] Spagnolo (2008) and Spagnolo and Marvão (2018) survey the literature on leniency programs. Brenner (2009) and Miller (2009) evaluate empirically their effects.

[21] In a previous version, I study an other model in which cheating does not cancel the risk to be sue by AA. In this model, leniency programs favors semi-collusive agreements because full collusive agreements are more difficult to sustain.

[22] If AA can reward informants with bounties (as in Aubert, Rey and Kovacic, 2006), we could find different results.

probability of being convicted. We find that firms choose full collusive arrangements when the differentiation between the two goods is intermediate and when the discount factor is not too high. An increase of the detection probability of full collusive agreement and a rise of the fine have the same qualitative effects. They reduce the area in which firms choose full collusive agreements and increase firms' incentives to invest in flexible technologies.

It seems premature to make accurate recommendations to improve antitrust policy from ours results. First, we have focused on only one determinant of the collusive arrangements breadth: the impact of this breadth on detection probability. It seems necessary to study in future research the impact of the commitment capacity of firms to not renegotiate and of firms' monitoring possibilities on the collusion breadth to have a good comprehension of this choice. Second, we have focused on the choice between full collusion and semi-collusion (mainly to shorten the text). It seems important to introduce the third choice - not collude - before to determine the optimal antitrust policy. Third, as we have underlined in subsection 2.2, the assumptions we made neutralize several potential effects of antitrust policy which must be taken into account in a real life application.

In spite of these reserves, it is possible to bring out some lessons. The main idea that can be extracted from this paper is that there are different degrees of collusion. The theoretical literature on optimal policy to fight cartels had focused on the impact of collusion on prices. In our model, collusion can be extended to other variables than prices. If collusion on prices generally decreases welfare, this is not necessary true for collusion on other variables. In our model, social welfare is higher with full collusive agreements than with semi-collusive agreements for two reasons. First, fixed costs are lower in full collusion and consumers have access to the same product range than in semi-collusion. Second the detection probability is higher with full collusive arrangements. This implies that the expected duration of full collusive agreements is lower than the one of semi-collusive arrangements (which to simplify the model last forever). In our model, collusion breadth may switch from full collusion to semi-collusion in some areas when competition policy is hardened. So in some cases, stricter competition policy can decrease social welfare by increasing firms costs[23] and by rising the length of cartels. Obviously, in other zones, a more stringent antitrust policy has positive effects. An increase of detection probability reduces the expected duration of cartels if it does not change their breadth. It may also incite firms to switch from collusion to competition for intermediate values of the discount factor (this effect appears in our model if we assume a positive detection probability of semi-collusive arrangements). To find the optimal trade-off between positive and negative effects, we have to understand deeply the potential impact of antitrust policy on collusive agreements breadth. This paper is just the first step toward this understanding.

[23] Sproul (1993) finds empirically that sometimes prices rise after a cartel is disbanded. He argues that the explanation of this counterintuitive effect is less efficient organization of product distribution when firms cannot exchange information.

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.1 Appendix 1: Full collusion agreement with mixed technological configuration

If firms choose the asymmetric configuration (F, D), the sharing of the markets is such that the constraint of no incentive to cheat during the production stage is binding for the flexible firm (firm 1). So we must have:

$$\delta(1-\rho) = \frac{\pi_1^d - \pi_1^c}{\pi_1^d - \pi_1^{nc}} \Leftrightarrow \pi_1^c = [1 - \delta(1-\rho)]\,\pi_1^d + \delta(1-\rho)\,\pi_1^{nc}$$

We can write π_1^c and π_1^d as functions of the production quotas:

$$\pi_1^c = \frac{1}{4(1+\lambda)}(\alpha - c)^2 + \frac{1}{2}(\alpha - c)\,q_1^B - \rho f$$

The production quota allocated to firm 2 is equal to:

$$q_2^B = \frac{1}{2(1+\lambda)}(\alpha - c) - q_1^B$$

From which, we deduce the deviation profit of firm 1:

$$\pi_1^d = \frac{5+4\lambda}{16(1+\lambda)^2}(\alpha - c)^2 + \frac{1+2\lambda}{4(1+\lambda)}(\alpha - c)\,q_1^B + \frac{1}{4}\left(q_1^B\right)^2$$

We introduce these expressions in the first equation. We have:

$$\pi_1^c = [1 - \delta(1-\rho)]\,\pi_1^d + \delta(1-\rho)\,\pi_1^{nc}$$

$$\begin{aligned}\Leftrightarrow\quad & [1-\delta(1-\rho)]\frac{(1+\lambda)^2}{(\alpha-c)^2}\left(q_1^B\right)^2 - [1+\delta(1-\rho)(1+2\lambda)]\frac{1+\lambda}{\alpha-c}q_1^B \\ & + \frac{1}{4}\left[\delta(1-\rho)\frac{7-4\lambda-20\lambda^2}{9}+1\right] + 4\frac{(1+\lambda)^2}{(\alpha-c)^2}\rho f = 0\end{aligned}$$

We note: $x \equiv \frac{1+\lambda}{\alpha - c}q_1^B$. The previous equation becomes:

$$[1-\delta(1-\rho)]\,x^2 - [1+\delta(1-\rho)(1+2\lambda)]\,x + \frac{\frac{\delta(1-\rho)\left(7-4\lambda-20\lambda^2\right)}{9}+1}{4} + 4\frac{(1+\lambda)^2}{(\alpha-c)^2}\rho f = 0$$

This polynomial has two roots:

$$\begin{aligned} x_1 &= \frac{1+\delta(1-\rho)(1+2\lambda) - \sqrt{[1+\delta(1-\rho)(1+2\lambda)]^2 - X}}{2[1-\delta(1-\rho)]} \\ x_2 &= \frac{1+\delta(1-\rho)(1+2\lambda) + \sqrt{[1+\delta(1-\rho)(1+2\lambda)]^2 - X}}{2[1-\delta(1-\rho)]}\end{aligned}$$

where $X \equiv [1-\delta(1-\rho)]\left\{\frac{\delta(1-\rho)\left(7-4\lambda-20\lambda^2\right)+9}{9} + \frac{16(1+\lambda)^2\rho f}{(\alpha-c)^2}\right\}$

x must be between 0 and $\frac{1}{2}$. x_1 verifies this condition but x_2 does not.

So we have:

$$q_1^B = \frac{x_1}{1+\lambda}(\alpha - c)$$

Now we can compute the profits of both firms at each period in which the collusive agreement applies:

$$\begin{aligned}
\pi_1^c &= \frac{1}{4(1+\lambda)}(\alpha-c)^2 + \frac{1}{2}(\alpha-c)q_1^B - \rho f = \frac{1+2x_1}{4(1+\lambda)}(\alpha-c)^2 - \rho f \\
\pi_2^c &= \frac{1}{2}(\alpha-c)q_2^B - \rho f = \frac{1-2x_1}{4(1+\lambda)}(\alpha-c)^2 - \rho f
\end{aligned}$$

.2 Appendix 2: Expressions of the different thresholds of δ

.2.1 Sustainability constraints

Firms have no incentive to deviate from a full collusion agreement with (D, D) during the technological choice stage if:

$$\Pi_1^T(D,D) \geq \Pi_1^{NC}(F,D) \Leftrightarrow$$

$$I + \delta\left[Y(\alpha-c)^2 - (2-\rho)I - \rho f\right] - \delta^2\left[Z(\alpha-c)^2 - (1-\rho)I - \rho f\right] \geq 0 \Leftrightarrow \delta \leq \delta_{DD}^T$$

with $Y = \frac{\left(-16+4\lambda+16\lambda^2+5\lambda^3\right)}{36(1+\lambda)(2+\lambda)^2}$ and $Z = \frac{\left[9\lambda^2-(1-\rho)(1-\lambda)\left(16+12\lambda+5\lambda^2\right)\right]}{36(1+\lambda)(2+\lambda)^2}$.

The two roots of this polynomial are:

$$\begin{aligned}
\delta_1 &= \frac{-\left[Y(\alpha-c)^2 - (2-\rho)I - \rho f\right] - \sqrt{\Delta}}{-2\left[Z(\alpha-c)^2 - (1-\rho)I - \rho f\right]} \equiv \delta_{DD}^T \\
\delta_2 &= \frac{-\left[Y(\alpha-c)^2 - (2-\rho)I - \rho f\right] + \sqrt{\Delta}}{-2\left[Z(\alpha-c)^2 - (1-\rho)I - \rho f\right]} > 1
\end{aligned}$$

with $\Delta \equiv \left[Y(\alpha-c)^2 - (2-\rho)I - \rho f\right]^2 + 4\left[Z(\alpha-c)^2 - (1-\rho)I - \rho f\right]I$.

δ_2 is always higher than 1. The relevant threshold is the other root: $\delta_{DD}^T \equiv \delta_1$.

Sustainability of the technological configuration (F, F) with a full collusion agreement:

$$\Pi_1^T(F,F) \geq \Pi_1^{NC}(D,F)$$

$$\begin{aligned}
&\Leftrightarrow \quad \frac{\delta}{1-\delta(1-\rho)}\left[\frac{(\alpha-c)^2}{36(1+\lambda)} - \rho f\right] + \frac{\delta}{1-\delta}\frac{2(\alpha-c)^2}{9(1+\lambda)} - I_F \geq \frac{\delta}{1-\delta}\frac{1}{9}(\alpha-c)^2 - I_D \\
&\Leftrightarrow \quad \frac{I}{(\alpha-c)^2} - B\delta + A\delta^2 \leq 0
\end{aligned}$$

with $B \equiv \frac{5-4\lambda}{36(1+\lambda)} - \frac{\rho f}{(\alpha-c)^2} + \frac{(2-\rho)I}{(\alpha-c)^2}$ and $A \equiv \frac{5-4\lambda-4\rho(1-\lambda)}{36(1+\lambda)} - \frac{\rho f}{(\alpha-c)^2} + (1-\rho)\frac{I}{(\alpha-c)^2}$.

The two roots of this polynomial are:

$$\delta_1 = \frac{B - \sqrt{B^2 - 4A\frac{I}{(\alpha-c)^2}}}{2A} \equiv \delta_{FF}^T \qquad \text{and} \qquad \delta_2 = \frac{B + \sqrt{B^2 - 4A\frac{I}{(\alpha-c)^2}}}{2A} > 1$$

.2.2 Borders between full collusion and semi-collusion

In areas 3, 4 and 5, full collusion is preferred to semi-collusion if and only if:

$$\Pi_1^T(D,D) \geq \Pi_1^S(F,F)$$

$$\Leftrightarrow \delta^2\left[(1-\rho)\,I+\rho f-\rho G\right]-\delta\left[(2-\rho)\,I+\rho f\right]+I\geq 0$$

with $G \equiv \frac{\lambda^2(\alpha-c)^2}{4(1+\lambda)(2+\lambda)^2}$.

The two roots of this polynomial are:

$$\delta_1 = \frac{(2-\rho)\,I+\rho f-\sqrt{\left[(2-\rho)\,I+\rho f\right]^2-4\left[(1-\rho)\,I+\rho f-\rho G\right]I}}{2\left[(1-\rho)\,I+\rho f-\rho G\right]} \equiv \delta_{345}^E$$

$$\delta_2 = \frac{(2-\rho)\,I+\rho f-\sqrt{\left[(2-\rho)\,I+\rho f\right]^2-4\left[(1-\rho)\,I+\rho f-\rho G\right]I}}{2\left[(1-\rho)\,I+\rho f-\rho G\right]} \geq 1$$

In area 2, full collusion is preferred to semi-collusion if and only if:

$$\frac{1}{2}\Pi_1^T(F,D)+\frac{1}{2}\Pi_1^T(D,F) \geq \Pi_1^S(F,F)$$

$$\Leftrightarrow \delta^2\left[(1-\rho)\,I+2\rho f-\rho\frac{(\alpha-c)^2}{36}\right]-\delta\left[(2-\rho)\,I+2\rho f\right]+I\geq 0$$

The two roots of this polynomial are:

$$\delta_1 = \frac{(2-\rho)\,I+2\rho f-\sqrt{\left[(2-\rho)\,I+2\rho f\right]^2-4\left[(1-\rho)\,I+2\rho f-\rho\frac{(\alpha-c)^2}{36}\right]I}}{2\left[(1-\rho)\,I+2\rho f-\rho\frac{(\alpha-c)^2}{36}\right]} \equiv \delta_2^E$$

$$\delta_2 = \frac{(2-\rho)\,I+2\rho f+\sqrt{\left[(2-\rho)\,I+2\rho f\right]^2-4\left[(1-\rho)\,I+2\rho f-\rho\frac{(\alpha-c)^2}{36}\right]I}}{2\left[(1-\rho)\,I+2\rho f-\rho\frac{(\alpha-c)^2}{36}\right]} > 1$$

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