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Entry Deterrence Through Cooperative R&D Over-Investment

Clémence Christin*

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Abstract

In this paper, we highlight new conditions under which R&D agreements may have anti-competitive effects. We focus on cases where two firms compete with each other and with a competitive fringe. R&D activities need a specific input available to all firms on a common market, the price of which increases with demand for the input. In such a context, if a firm increases its R&D expenses, it increases the cost of R&D for its rivals. This induces exit from the fringe and may increase the final price. Therefore, by contrast to the case where the cost of R&D for one firm is independent of its rivals' R&D decisions, cooperation between strategic firms on the upstream market may induce more R&D by strategic firms, in order to exclude firms from the fringe and increase the final price.

JEL Classifications: L13, L24, L41.

Key words: Competition policy, Research and Development Agreements, Collusion, Entry deterrence.

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1 Introduction

Horizontal agreements in general are forbidden by Article 101 of the Treaty on the Functioning of the European Union because of their anti-competitive effects. Research and development (R&D) agreements however are considered to create efficiency gains that are likely to offset their potential anti-competitive effects, and consequently benefit from a "block exemption" as long as the market share of participants is lower than 25%. Even R&D agreements involving firms with a total market share higher than 25% may be allowed.[1]

The anti-competitive concerns of the EU Competition Commission as well as US antitrust authorities regarding R&D agreements are essentially of three types:[2] First, firms may want to engage in R&D agreements in order to slow down R&D efforts and reduce variety on the final market. Second, R&D cooperation may be transferred to other markets and lead to increased final prices. Finally, R&D agreements may lead to market foreclosure. The main concern of competition authorities is thus the direct restriction of competition on the final market that may result from an R&D agreement. Less attention however is given to the indirect effect of R&D agreements on competition through the market for inputs necessary for R&D.

In this paper, we highlight one specific means through which an R&D agreement may indirectly deter entry on the final market through entry deterrence on the market for R&D inputs. We also show that R&D agreements may be anti-competitive even when members of the R&D agreement increase their R&D efforts. Indeed, when firms must compete to purchase some inputs necessary for R&D, members of the agreement may increase their R&D efforts only to increase the cost of R&D for their rivals, hence reducing competition on the final market. Although increasing R&D also increases the efficiency of the members of the agreement, this second effect may be offset by the former.

Besides often competing on the same final market, firms engaging in (similar) R&D activities need inputs for which they also have to compete, the main example of which is skilled workers. According to a survey by the US National Science Founda-

[1] See the *Guidelines on the applicability of Article 101 of the EC Treaty on the Functioning of the European Union to horizontal cooperation agreements*, Official Journal of the European Union, 2011.

[2] See again the European *Guidelines* (2011) and the *Antitrust Guidelines for Collaborations Among Competitors* issued by the Federal Trade Commission and the US Department of Justice (April 2000).

tion, wages and related labor costs accounted for more than 40% of the US industrial R&D costs in the 1990s, and for 46.6% in 2006. Although this hides a relative variety among industries, labor-related costs are a particularly large part of R&D costs in large R&D consuming industries such as pharmaceuticals and medicine (where labor costs represent 28.8% of all R&D costs), computer and electronic products (51.9%), computer systems designing (55.3%) and information (62%).[3] Parallel to this, concerns are often raised both by firms in innovative markets and by governments as to the need for more research personnel.[4] High skilled labor, especially labor in the science and technology fields typically needed for R&D activities is usually characterized by significantly lower unemployment rates than other types of labor, and some countries such as Germany have suffered from skills shortage in the past years.[5]

Given the more or less stringent capacity constraint on skilled labor, one can then argue that R&D costs of firms engaging in similar R&D activities are not as independent from one another as is usually assumed.[6] Then, there exists a risk that firms with enough market power on the market for R&D inputs manage to prevent the entry of firms with less market power on this market. This is a particularly legitimate concern in R&D intensive industries, as they are often characterized by large size asymmetries between the firms. Focusing for example on the biotechnology industry, one can find at different levels of the innovation and production process large pharmaceutical companies competing with medium sized to very small biotechnology companies. The IT services industry is characterized by the same type of market structure: in 2001, while only 0.2% of the IT service companies in

[3] National Science Foundation, National Center for Science and Engineering Statistics. 2011. *Research and Development in Industry: 2006-07.* Detailed Statistical Tables NSF 11-301. Arlington, VA. Available at http://www.nsf.gov/statistics/nsf11301/. These four industries account for almost 60% of all industrial R&D costs in the US for the years 2006-2007.

[4] See for example *A more research-intensive and integrated European Research Area, Science, Technology and Competitiveness key figures report 2008/2009*, European Commission, 2008.

[5] See Eurostat, *Science, technology and innovation in Europe*, 2011 Edition, may 2011, and European Commission, “eSkills Demand Developments and Challenges”, Sectoral e-Business Watch Study Report No. 05/2009.

[6] Focusing not on competition between firms but on competition between countries, Nuttal (2005) describes this concern for skilled workers in the nuclear industry: “A particular example might be that a firm US resolve to embark on a nuclear renaissance might lead the US to recruit nuclear engineers from other countries, such as the UK. [...] this might jeopardize UK capacity to meet its existing nuclear skills needs [...] and thereby prevent any UK nuclear renaissance.” This reasoning could extend to competition between private firms in related sectors.

the European Union had more than 250 employees and on the contrary 93% were micro-enterprises of less than 10 employees, the large companies accounted for 30% of employment in this sector.[7] Besides, it is very likely that large firms will have more resources than small firms to hire high skilled workers.

The existing literature does not analyze the indirect effect of R&D agreements through the market for R&D inputs but focuses on comparing the efficiency effects of R&D agreements (D'Aspremont and Jacquemin, 1988; Kamien, Muller and Zang, 1992) to their direct anti-competitive effects on the final market, so as to give insights as to when to allow them. When firms are identical and all take part in the R&D agreement, cooperation tends to reduce R&D unless spillovers are high enough. Nevertheless, Simpson and Vonortas (1994) show that even when R&D cooperation leads to "underinvestment", i.e. to lower investment than would be optimal, it may still be socially better than noncooperative R&D. Grossman and Shapiro (1986) argue that one must evaluate the barriers to entry and the market shares of the members of the R&D agreement both on the downstream market and on the "upstream research market". In the presence of large barriers to entry in the downstream market or when members of the R&D agreement have large market shares, it is argued that R&D agreements may facilitate collusion on the downstream market.[8] Such anticompetitive effects of R&D agreements may occur in an industry where all the firms take part in the R&D agreement.

The risk of entry deterrence when the R&D agreement does not include all the firms in the market has also been analyzed to some extent. Yi (1998) focuses on a framework where firms only increase their productive efficiency by entering a research joint-venture, and not by individually investing more in R&D. Assuming that a research joint-venture can only arise if all members agree to it, he then shows

[7]See European Commission, "ICT and Electronic Business in the IT Services Industry, Key issues and case studies", Sector Report No. 10-I (July 2005). A more recent study of the French National Institute of Statistics and Economic Studies (INSEE) of May 2009 confirms these findings and argues that since 2000, the IT service sector has been more and more concentrated and employment increases only in very large firms (more than 2000 employees) and very small ones (less than 10 employees). See INSEE Premiere nr 1233, B. Mordier, (Mai 2009), "Les sociétés de services d'ingénierie informatique".

[8]Focusing not on research joint-ventures but on an input joint-ventures, i.e. agreements between several firms to commonly produce an input necessary to the production process of their final output, Chen and Ross (2003) show that entering a joint-venture may enable firms to compete less on the final market. Noticing that members of input joint-ventures may be in contact in markets that are not even related to their joint activity, Cooper and Ross (2009) show that joint-ventures may have anti-competitive effects on such other markets too.

that although the industry-wide joint-venture is the social optimum, the equilibrium structure may be such that not all firms are part of the joint-venture. In this framework, members of the joint-venture use the membership rule to enjoy a cost advantage relative to outsiders. Carlton and Salop (1996) highlight that similar exclusionary practices may arise in the case of input joint-ventures, where the joint-venture may prevent some (possibly more efficient) firms from entering the joint-venture or by reducing rival input producers' incentives to enter the input market.

In this paper, contrary to the previous literature, we assume that R&D requires an input available to all firms on the same market, and that the price of the R&D input increases quickly with demand for the input. In order to take into account some distinctive features of R&D intensive industries, we consider a market where all firms have to engage in R&D to be able to produce output, and where two strategic firms compete with one another and with a competitive fringe. While strategic firms have market power both on the final market and on the market for the R&D input, fringe firms are price-takers on the two markets. Then, strategic firms anticipate that purchasing more R&D inputs will enhance their own efficiency on the one hand and increase the cost of fringe firms on the other hand. This induces part of the fringe to leave the market and softens competition on the final market. To this extent, this article is related to the literature on "raising rivals' costs" strategies, first studied by Salop and Scheffman (1983, 1987), in a framework with one dominant firm and a competitive fringe. More generally, Riordan (1998) studies potential exclusionary practices in a framework with a dominant firm and a competitive fringe.

Focusing on R&D cooperation between strategic firms, we then show that R&D agreements may have anti-competitive effects even though the R&D agreement increases the members' R&D investments, as it reduces the access of rivals of the R&D agreement members to the R&D input. R&D cooperation between large firms tends to increase the level of their R&D investment when large firms are efficient enough relative to fringe firms, when demand is not too elastic or finally when production costs are convex enough. Besides, when such an increase of R&D investment occurs following cooperation, this always increases the final price, and hence harms consumers. Moreover, the R&D agreement tends to harm total welfare too when large firms have a high enough cost advantage over small firms. As a consequence, R&D agreements that result in more R&D input purchase than would have occurred without the agreement harm consumer surplus and potentially social welfare, and can thus be considered as "overbuying strategies".

We compare our main framework to two benchmarks. First, we assume that there is no competitive fringe. In that case, as in D'Aspremont and Jacquemin (1988), strategic firms invest less in R&D when they are cooperating than when they are competing, because they use cooperation to reduce competition among them rather than between them and the competitive fringe, and can only do so by not reducing their marginal cost too much. We then compare our main framework to the standard case where costs of R&D are independent of rivals' R&D decisions. In that case, if a strategic firm increases its R&D expenses, it is still true that less firms enter the fringe, as they face a more efficient rival. However, the raising-rivals'-cost effect no longer exists. Therefore, collusive strategic buying only occurs if firms all purchase the R&D input on the same market and is a means to deter entry.

Note that as in Yi (1998), since we want to focus on the exclusionary effect of R&D agreements, we do not consider collusion on the final market. Nevertheless, we show in an extension that such downstream collusion may not be profitable for members of the R&D agreements. Indeed, downstream collusion relies on output reduction, which does not necessarily lead to a final price increase here, since fringe firms increase their output as a response to strategic firms' decisions.

The structure of the paper is as follows. In Section 2, we present the general model. In Section 3 we determine the R&D input purchase decisions of strategic firms in the presence of a competitive fringe. In Section 4, we compare our results to two benchmarks: when the size of the competitive fringe is exogenous and when R&D costs are independent from one firm to another. In Section 5, we derive a welfare analysis. In Section 6, we offer some extensions to test the robustness of some of our assumptions. Section 7 concludes.

2 Model

Consider a market where two strategic firms denoted by 1 and 2 compete in quantity with each other and with a competitive fringe to sell a homogeneous good. We denote by $p(Q)$ the inverse demand function, where Q is the total quantity sold on the final market. The inverse demand function p is twice differentiable and such that $p' < 0$ and $p''Q + p' < 0$. Fringe firms are price-takers on the final market.

As we focus on R&D intensive industry such as biotechnology or software designing, we assume that R&D investment is a *sine qua non* condition for entering the market. Therefore, a firm enters the market by buying at least one unit of R&D input. Besides, buying more than one unit of R&D input increases the firm's productive efficiency. We denote by $k_i \in [1, +\infty)$ the amount of R&D input purchased by strategic firm i, and we assume that a fringe firm can only buy 1 or 0 unit of R&D input. Then, the cost of producing the cost of a fringe firm producing q_f is $C(q_f)$, whereas q_i for strategic firm i is given by $\gamma k_i C(q_i/k_i)$. The parameter $\gamma \in [0, 1]$ thus represents the efficiency advantage of strategic firms over fringe firms: the lower γ, the higher this efficiency advantage. The function C is assumed twice differentiable, increasing and convex. Using similar cost functions for the fringe and the strategic firms allows us to reduce the difference between the two types of firms to one parameter and simplifies the analysis. Besides, as far as the fringe is concerned, it is reasonable to assume convex costs as it represents the capacity constraint of these firms. In that sense, the parameter γ is a measure of the difference between the capacity constraint of the fringe firms and the strategic firms. Indeed, the lower γ, the flatter the cost function of the strategic firms relative to the fringe firms.

All firms buy the R&D input on a common market represented by the supply function $R(K)$, where $K = k_1 + k_2$ is the demand for R&D input of strategic firms. In order to simplify computations, we assume that the R&D input purchase of fringe firms does not affect the price of R&D. We will however show in Section 4 that our results are qualitatively the same if we assume that fringe firms' R&D purchase similarly affects R (that is if we instead assume that $K = k_1 + k_2 + n$). R is assumed twice differentiable, increasing and convex, which reflects the existence of a capacity constraint on the input. We assume that fringe firms are price-takers on the R&D input market. As a fringe firm either buys one unit of R&D input and enters the market or buys no R&D input and stays out, $R(K)$ can be interpreted as the entry cost of fringe firms. Finally, the size of the fringe n is thus equal to the total amount of R&D input bought by fringe firms, and is assumed continuous.

Strategic firms can then compete both on the input and output markets, or cooperate on the input market. Such a cooperation can be interpreted as a research joint venture and is thus legal. For simplicity, we assume that there are no synergies due to research cooperation. However, we will show later that our results hold even if such synergies exist. Assuming that cooperation on the input market is legal allows us to consider only the static game, as firms can design a contract that defines the terms of cooperation and of the punishment in case of a deviation, and can be enforced by law. Fringe firms are price-takers on the input market.

The timing of the game is as follows. The outcome of each stage is subsequently observed.

1. Strategic firms simultaneously invest in R&D. Firm i's R&D input demand is denoted by k_i ($i = 1, 2$). If they are competing in R&D, then i sets k_i to maximize its own profit. If however they are cooperating in R&D, then i sets k_i to maximize the joint profit of the two strategic firms.

2. Fringe firms decide whether or not to enter the market by each purchasing one unit of R&D input. Entry is free and n denotes the size of the fringe at the end of this stage.

3. Strategic firms simultaneously set their output on the final market. Firm i's output is denoted by q_i.

4. Fringe firms simultaneously set their output on the final market.

The game is solved by backward induction.

Note that we do not endogenize the decision of strategic firms to cooperated or not, but merely compare their purchasing behaviour when they are competing and cooperating on the upstream market. However, considering the numerical example of Section 5, cooperation is always profitable for the strategic firms. Therefore, were the choice of cooperation endogenous in that case, firms would always choose cooperation. We thus assume that this is also the case in the more general model presented here.

3 R&D Decisions

In this section, we determine conditions under which final price is increasing in the R&D input purchase of strategic firms, and conditions under which strategic firms buy more R&D input when they form a R&D joint venture than when they compete on the R&D market.

3.1 Quantity setting

We show here that for a given size of the fringe, the total efficiency of the market increases when strategic firm i increases its R&D expenses k_i.

The fringe firms are price takers on the final market and therefore all set their output so that the final price is equal to their marginal cost. We define $Q_s \equiv q_1 + q_2$ and we denote by $q_f(Q_s, n)$ the resulting output of one fringe firm. In stage 4, by symmetry, we thus have:[9]

$$p(Q_s + nq_f) = C'(q_f), \tag{1}$$

It is immediate that q_f is decreasing in Q_s: as the output of strategic firms increases, the price decreases and each fringe firm must thus set a lower output to reduce its marginal cost. However, an increase of the strategic firms' output still always leads to an increase of total output (and hence a decrease of the final price). Indeed, deriving equation (1) with respect to Q_s yields:

$$\left(1 + n\frac{\partial q_f}{\partial Q_s}\right) p' = C''(q_f)\frac{\partial q_f}{\partial Q_s} \quad \Rightarrow \quad 1 + n\frac{\partial q_f}{\partial Q_s} > 0. \tag{2}$$

In the third stage of the game, strategic firms then set their output anticipating the fringe firms' decision. Firm i's programme is then:

$$\max_{q_i} \pi_i = p(q_1 + q_2 + nq_f(q_1, q_2, n))q_i - \gamma k_i C\left(\frac{q_i}{k_i}\right).$$

and the corresponding first order condition is:

$$\frac{\partial \pi_i}{\partial q_i} = p + \left(1 + n\frac{\partial q_f}{\partial q_i}\right) p' q_i - \gamma C'\left(\frac{q_i}{k_i}\right) = 0 \tag{3}$$

In the following, we define the equilibrium outcome of the quantity-setting subgame by the use of an asterisk (for instance the equilibrium price is p^*). A comparative statics analysis of these values with respect to R&D input purchase allows us to highlight the effect of R&D when the size of the fringe is given. We also determine the effect of n on prices and outputs.

[9] Obviously, we must also ensure that fringe firms earn a positive total profit (taking into account the cost of purchasing R&D). As we will see later on however, firms only enter the fringe if they are sure to earn a positive profit, and the equilibrium size of the fringe is given by a 0 profit condition.

Comparative statics with respect to R&D input endowment. First, it is immediate that firm i's best reply output is increasing in its own R&D input endowment since $\frac{\partial^2 \pi_i}{\partial q_i \partial k_i} = \gamma / k_i^2 C''(q_i/k_i) > 0$. By contrast, the best reply output of i's rival is not affected by a change in i's R&D input endowment: $\frac{\partial^2 \pi_j}{\partial q_j \partial k_i} = 0$. Besides, we show in Appendix A.1 that the strategic firms' output decisions are strategic substitutes. As a consequence, assuming that there exists a unique equilibrium of the quantity-setting subgame, the equilibrium output choices are such that $\partial q_i^* / \partial k_i > 0$, $\partial q_j^* / \partial k_i < 0$ and $\partial q_i^* / \partial k_i + \partial q_j^* / \partial k_i > 0$. In other words, for a given size of the fringe, the output of a strategic firm increases with its R&D input endowment more than the parallel decrease of its strategic rival's output and of the fringe's output.

Consider now the effect of k_i on a fringe firm's output q_f^* and consequently on the final price p^*. Indeed, it should be noted that since $p^* = C'(q_f^*)$, it is immediate that p^* and q_f^* vary similarly with k_i (as well as with all other parameters). As $q_f^* = q_f(q_1^* + q_2^*, n)$, the output of each fringe firm decreases with the R&D input endowment of any strategic firm.

Therefore, for a given size of the competitive fringe, the final price decreases with k_i. This effect is straightforward and can be explained as follows: when the marginal cost of production of a firm is reduced, everything else being equal, the industry becomes globally more efficient and consequently, the final price decreases while the total output increases. We denote this effect *efficiency enhancing effect*.

Comparative statics with respect to the size of the fringe. Noticing that $q_f^*(n, k_1, k_2) = q_f(q_1^*(n, k_1, k_2) + q_2^*(n, k_1, k_2), n)$ and $p^* = p(q_1^* + q_2^* + nq_f^*)$, the effect of the number of fringe firms on the final price is given by the following equation:

$$\begin{aligned}
\frac{\partial p^*}{\partial n} &= \left(\frac{\partial q_1^*}{\partial n} + \frac{\partial q_2^*}{\partial n} + n \left(\frac{\partial q_f}{\partial Q_s} \left(\frac{\partial q_1^*}{\partial n} + \frac{\partial q_2^*}{\partial n} \right) + \frac{\partial q_f}{\partial n} \right) + q_f^* \right) p'(q_1^* + q_2^* + nq_f^*), \\
&= \left(\left(1 + n \frac{\partial q_f}{\partial Q_s} \right) \left(\frac{\partial q_1^*}{\partial n} + \frac{\partial q_2^*}{\partial n} \right) + \left(q_f^* + n \frac{\partial q_f}{\partial n} \right) \right) p'(q_1^* + q_2^* + nq_f^*),
\end{aligned}$$

Besides, deriving equation (1) with respect to n yields:

$$\left(q_f + n \frac{\partial q_f}{\partial n} \right) p' = \frac{\partial q_f}{\partial n} C''(q_f) \tag{4}$$

Finally, from (2) and (4), we deduce that $\partial q_f / \partial n = q_f \partial q_f / \partial Q_s$, which gives us a simpler expression of the variation of p^* with respect to n:

$$\frac{\partial p^*}{\partial n} = \left(1 + n\frac{\partial q_f}{\partial Q_s}\right)\left(\frac{\partial q_i^*}{\partial n} + \frac{\partial q_j^*}{\partial n} + q_f^*\right) p'$$

We then find as in Riordan (1998) that the final price p^* is decreasing in the size of the fringe n. Indeed we show in Appendix A.2 that the additional output produced by one more firm in the fringe is higher than the output loss of incumbent firms following this entry, and therefore total output $Q^* = q_1^* + q_2^* + nq_f^*$ increases when the size of the fringe increases. However, as shown in Appendix A.2, the output of a strategic firm always decreases with n: the direct effect of n on q_i^* is always stronger than its indirect effect through reducing the rest of the fringe's output.

3.2 Entry decision of the fringe firms

Consider now Stage 2 of the game. Competition on the upstream market determines the number of fringe firms that enter the market. Indeed, in order to enter the market, a fringe firm must buy one unit of R&D input at the market price R. Fringe firms enter as long as this entry cost is lower than their profits on the output market. As a consequence, for a given pair (k_1, k_2), the size of the fringe is determined by the following equation:

$$p^* q_f^* - C(q_f^*) = R(K) \tag{5}$$

where $K = k_1 + k_2$. We denote the equilibrium size of the fringe by $n^*(k_1, k_2)$.

Lemma 1. *The size of the fringe decreases with the R&D input endowment of any strategic firm.*

Proof. Equation (5) is satisfied for all values of k_i. Therefore, the derivative of expression (5) gives us the following equation:

$$\left(\frac{\partial p^*}{\partial k_i} + \frac{\partial p^*}{\partial n}\frac{\partial n^*}{\partial k_i}\right) q_f^* = R'. \tag{6}$$

which we can rewrite:

$$\frac{\partial n^*}{\partial k_i} = \frac{R' - p' q_f^*(n^*) \left(1 + n^* \frac{\partial q_f}{\partial Q_s}\right) \left(\frac{\partial q_i^*}{\partial k_i} + \frac{\partial q_j^*}{\partial k_i}\right)}{p' q_f^*(n^*) \left(1 + n^* \frac{\partial q_f}{\partial Q_s}\right) \left(\frac{\partial q_i^*}{\partial n} + \frac{\partial q_j^*}{\partial n} + q_f^*(n^*)\right)}. \tag{7}$$

Given that $R' > 0$, $p' < 0$, $1 + n\partial q_f/\partial Q_s > 0$, $\partial q_i^*/\partial k_i + \partial q_j^*/\partial k_i > 0$ and $\partial q_i^*/\partial n + \partial q_j^*/\partial n + q_f^*(n^*) > 0$, it is immediate that $\partial n^*/\partial k_i < 0$. □

An increase in firm i's R&D input purchase has two parallel effects on fringe firms. First, for a given size of the fringe, the final price and the output of each fringe firm decrease: the industry becomes globally more efficient, but only firm i benefits from it as all its rivals become less efficient relative to i. As a consequence, the "short-term" profit of a fringe firm, *i.e.* its profit on the final market, decreases. Parallel to this, as the total demand for R&D input increases, the market price of the R&D input, hence the cost of entry on the market $R(K)$, increases.

The consequence of these two effects is that less firms enter the fringe when strategic firms purchase more R&D input. Therefore, the purchase of R&D input by a strategic firm has a second effect parallel to the efficiency enhancing effect highlighted previously: it increases market concentration. Finally, as the final price increases when the size of the fringe shrinks, the efficiency enhancing and market concentration effects are contradictory. We thus have to determine the conditions that ensure that the final price raises following an increase of R&D input purchase. From here on, we use a double asterisk for outcomes of the equilibrium of the subgame including Stages 2 to 4 (for instance, the equilibrium price is p^{**}).

Comparative statics with respect to R&D input endowment. Equation (6) gives us a simple expression of the price variation following R&D input purchase: $\partial p^{**}/\partial k_i = R'/q_f^{**}$, from which we immediately deduce the following proposition. This proposition is an extension of Riordan (1998) to a framework with two strategic firms.

Proposition 1. *In the subgame composed of Stages 2 to 4, the equilibrium final price p^{**} is increasing in k_i.*

In particular, if there is a capacity constraint on the amount of R&D input available, then assuming that the market is such that fringe firms buy all the remaining

R&D inputs after strategic firms' purchasing decision, then if firm i increases its R&D input purchase by one unit, it excludes one firm from the fringe, which results in a higher final price.

As a consequence, as long as R&D decisions of one firm on the market has an impact on its rivals' R&D decisions, the price increasing effect of R&D may arise. This may be the case when R&D needs specific inputs such as high skilled workers or a given amount of time slots to use a specific facility. Therefore, although an increase of R&D expenses following the creation of a R&D agreement is considered desirable, as it increases efficiency on the market, such an increase of expenses, shall it occur, may not have the expected competitive effects. In Section 4, we will analyze how assumptions on R&D purchase affect our results.

Focusing now on firms' output decisions, it is immediate that the output of strategic firm i increases with k_i. This results both from the efficiency enhancing and from the market concentration that follow an increase of i's R&D investment. Paradoxically, an increase of k_i may also increase the output of firm i's strategic rival: this happens when the market concentration effect offsets the efficiency enhancing effect, which happens under the conditions described in the following proposition.

Proposition 2. *If we assume that C is three times differentiable and $p''(C'')^2 - (p')^2C'''$ is not too negative, then the output of strategic firm j ($j \in \{1,2\}$) increases with k_i ($i \in \{1,2\}$, $i \neq j$).*

Proof. See Appendix A.3. □

Note that this condition only needs to be true in equilibrium. This is all the more likely to happen that the cost function of fringe firms is convex enough and the inverse demand function is convex. In that case, an increase of k_i tends to reduce fringe firms' revenue more, and therefore the number of fringe firms decreases faster with k_i than when the cost function is not too convex. In other words, the market concentration effect is all the stronger that the cost function C is more convex. It is also more likely that one strategic firm's output increases with its strategic rival's R&D endowment when the inverse demand function is not too steep. In that case, the reason is that the efficiency enhancing effect is less strong than with a steep inverse demand curve, which benefits i's strategic rival.

Finally, it should be noted that the latter condition is satisfied with rather standard demand and cost functions. For instance, it is satisfied when the cost function is quadratic and demand is linear or iso-elastic.

3.3 R&D decisions of strategic firms

We now determine conditions that ensure that strategic firms invest more in R&D when they cooperate than when they compete on the upstream market.

Anticipating decisions in the following stages of the game, strategic firms make their R&D input purchase decisions by each maximizing its individual profit in the competitive case, and maximizing the joint-profit of the two strategic firms in the cooperative case. Thus, firm i maximizes π_i in the competitive case and $\pi_i + \pi_j$ in the cooperative case, where profits of strategic firms are given by:

$$\pi_i = p(q_1^{**} + q_2^{**} + n^* q_f^{**})q_i^{**} - \gamma k_i C\left(\frac{q_i^{**}}{k_i}\right) - k_i R(k_i + k_j).$$

Then, it is worth noting that the only difference between competition and cooperation on the upstream market is that firm i takes into account the effect of its own investment on the profit of firm j in addition to its effect on its own profit. In particular, assuming that firm i's R&D investment is equal to its competitive best reply to k_j, which we denote $BR(k_j)$, then the additionnal effect that i must take into account is given by the following equation:

$$\frac{\partial \pi_j}{\partial k_i}(BR(k_j), k_j) = \underbrace{\frac{\partial p^{**}}{\partial k_i} q_j^{**}}_{I} + \underbrace{\left[p^{**} - \gamma C'\left(\frac{q_j^{**}}{k_j}\right)\right]\frac{\partial q_j^{**}}{\partial k_i}}_{II} \underbrace{-k_j R'}_{III}. \tag{8}$$

Then a firm will buy more R&D input in cooperation than in competition if and only if $\frac{\partial \pi_j}{\partial k_i}(BR(k_j), k_j) > 0$.

This effect can be decomposed into three parts that may be contradictory: the final price effect (I), the output effect (II) and the cost effect (III). The comparative statics of (I) and (II) with respect to k_i are described in the previous subsection: the final price increases with k_i and so does firm j's output under some conditions. By constrast, it is straightforward that the cost effect is negative: an increase of k_i increases the unit cost of R&D and thus j's cost of R&D (at k_j given). The following proposition gives some insights as to the effect of cooperation on strategic firms' R&D investments.

Proposition 3. *Strategic firms increase investment in R&D in cooperation relative to competition when:*

- *The demand for strategic firm i's good does not decrease to much with j's ($j \neq i$) R&D input purchase (i.e. $p''(C'')^2 - (p')^2 C'''$ is not too negative),*

- *The cost advantage of strategic firms is high enough (i.e. γ is low enough).*

Proof. The first condition is immediate and derives from Proposition 2: $\frac{\partial \pi_j}{\partial k_i}(BR(k_j), k_j)$ is more likely to be positive if an increase of k_i increases q_j, which happens under the first condition.

The second condition ensures that the price effect is high enough relative to the cost effect. Indeed, we know that $\partial p^{**}/\partial k_i = R'/q_f^{**}$. Therefore, the sum of these two effects is given by $\partial p^{**}/\partial k_i q_j^{**} - k_j R' = R'\left(q_j^{**}/q_f^{**} - k_j\right)$. This implies that the price effect offsets the cost effect if and only if $q_j^{**} > k_j q_f^{**}$, which is equivalent to $C'\left(q_j^{**}/k_j\right) > C'(q_f^{**})$. Besides, from equations (1) and (3), we find that $p^{**} = C'(q_f^{**}) > \gamma C'\left(q_j^{**}/k_i\right)$. Therefore, there exists $\gamma^* \in [0, 1)$ such that the price effect offsets the cost effect if $\gamma < \gamma^*$ and the opposite happens otherwise. □

Finally, when determining how much to invest in R&D in cooperation relative to the competitive level, a strategic firm must solve the trade-off between its effect on both the fringe firms and its strategic rival.

To this extent, increasing k_i allows strategic firm i to increase the competitive pressure faced by fringe firms, but at the same time increases competition between the two strategic firms. This trade-off is essentially described by (II), that is the output effect: On the one hand, for a given number of fringe firms, an increase of k_i reduces i's production cost and leads to a decrease of firm j's output. On the other hand, as k_i increases, the size of the fringe decreases, which is beneficial to firm j. Then, depending on which of these two effects prevails, the effect of k_i on output can be either positive or negative, as shown in the previous subsection. This effect corresponds to the first condition in Proposition 3.

Similarly, increasing k_i both increases fringe firms' entry costs and the rival strategic firm's R&D expenses. Again, depending on which of the two effects prevails, the effect of k_i on firm j's profit can be either positive or negative. This effect corresponds to the second condition in Proposition 3. Indeed, increasing fringe firms' entry costs results in less entry, which increases the final price. Then, the more R increases with k_i, the faster the final price increase following an increase of k_i. The effect on strategic firm j is however symmetrical: the higher R', the more j's R&D expenses increase with k_i. Finally, the latter effect offsets the former only when strategic firms are efficient enough relative to fringe firms, which implies that a strategic firm's output per unit of R&D is higher than a fringe firm's output (per unit of R&D).

Finally, it is important to note that in cases where strategic firms indeed buy more R&D input in cooperation than in competition, they do so in the sole purpose of excluding fringe firms and increasing final price. As a consequence, despite the efficiency gains resulting from more R&D, the effect of R&D cooperation on consumer surplus is negative when the condition given in Proposition 3 are satisfied. In that case, the strategy of strategic firms can be described as "over-buying" or strategic buying.

4 Benchmarks

In this section, we disentangle the different effects explaining our previous result by comparing our model to two benchmarks. In particular, we show that the collusive over-buying strategy neither occurs when the size of the fringe is fixed, nor when the cost of R&D for one firm only depends on its own R&D input purchase.

4.1 R&D input purchase when the size of the fringe is exogenous

We have shown that under free entry in the competitive fringe, the strategic firms may buy more R&D input in cooperation than in competition. By contrast, we show here that if the size of the fringe is fixed, then strategic firms never buy more R&D input in cooperation than in competition.

Consider the following framework. We assume that there is no competitive fringe, and that the two strategic firms thus only compete against each other.[10] The game has only two stages: First, the two firms simultaneously invest in R&D, and firm i's R&D input demand is still denoted by k_i. Second, they simultaneously set their

[10]The results we obtain are robust to the presence of a competitive fringe with a fixed size.

quantities on the final market. We determine the competitive R&D investment k^* and the cooperative R&D investment k^c of each firm in the symmetric equilibrium.

Lemma 2. *In the absence of a competitive fringe, firms buy less R&D input in the cooperative equilibrium than in the competitive equilibrium:* $k^c < k^*$.

Proof. See A.4. □

The intuition for this result is as follows. In both cases (endogenous or exogenous competitive fringe), the purpose of cooperating strategic firms is the same: They seek to reduce competition on the final market in order to increase final prices. However, the means to reduce competition are different, depending on whether the size of the fringe is exogenous or endogenous. If it is exogenous, then strategic firms can only reduce competition among themselves. In order to do so, they buy less R&D input than in the competitive equilibrium, hence decreasing their production cost less and finally, softening competition on the final market as compared to the competitive case. By contrast, when the size of the fringe is endogenous, strategic firms have an incentive to reduce competition by increasing market concentration. They do so by increasing their R&D input purchase, hence driving firms out of the competitive fringe. If the effect of k_i on fringe firms is high enough relative to its effect on i's strategic rival, strategic firms buy more R&D input in cooperation than in competition. Obviously, this can never happen when buying more R&D input has no effect on the size of the fringe.

4.2 R&D choices with independent costs of R&D

In this subsection, we show that there is no collusive strategic buying of R&D input if a firm's R&D purchase does not affect its competitors' costs.

Assume that the cost of the R&D input for a firm is only a function of its own R&D input purchase, which we denote by $R(k)$, where k is the R&D input purchase by the concerned firm. As in the previous section, we first analyze the effect of k_i on the final price, and then compare the cooperative and competitive strategies of strategic firms.

Lemma 3. *When the R&D cost of a firm only depends on its own R&D investment and not on its rivals' investment, the final price* p^{**} *is constant with* k_i.

Proof. See Appendix A.5 □

When the fringe firms' cost of entry is not affected by other firms' purchases, the market concentration effect exactly offsets the efficiency enhancing effect, and the final price is not affected by strategic firms' R&D input purchase. Then, the following proposition is immediate.

Proposition 4. *When the R&D cost of a firm only depends on its own R&D investment and not on its rivals' investment, strategic firms always invest less in R&D in cooperation than in competition.*

Proof. Equation (8) becomes:

$$\frac{\partial \pi_j}{\partial k_i}(BR(k_j), k_j) = \left[p^{**} - \gamma C'\left(\frac{q_j^{**}}{k_j}\right)\right]\left(\frac{\partial q_j^*}{\partial k_i} + \frac{\partial q_j^*}{\partial n}\frac{\partial n^*}{\partial k_i}\right),$$

for the increased R&D input purchase of k_i has no effect on fringe firms' and j's cost of buying R&D input anymore, and the final price is unchanged following an increase of k_i. Then, using equation (17) and the inequality $-\partial q_j^*/\partial k_i < \partial q_i^*/\partial k_i$, we find that $\frac{\partial \pi_j}{\partial k_i}(BR(k_j), k_j) < 0$ for all values of k_j. □

It is a standard result that in the absence of spillovers, firms invest less in R&D when they cooperate than when they compete (see D'Aspremont and Jacquemin, 1988). We show here that another crucial assumption for this result to hold is that the cost of R&D of one firm is independent of other firms' R&D input purchase. Indeed, in that case firm j cannot benefit from an increase of k_i: If firm i buys more R&D input, final price remains unchanged but firm j's output decreases because of its relative loss of efficiency. Besides, the size of the fringe never shrinks so much that this offsets j's output loss.

As a consequence, by not taking into account that many inputs necessary for R&D processes are available in limited quantity and sold at a common price to all the firms in an industry, one will miss the potential price increasing effect of R&D input purchase. Nevertheless, if large firms have easier access to some necessary facilities than small firms, increasing R&D efforts may be perceived as an overbuying strategy by large firms, in an attempt to prevent or reduce the access of small rivals to the same facilities.

5 Welfare analysis

We now illustrate our result with a numerical example. We show that in our framework, R&D cooperation decreases consumer surplus as well as total welfare.

We assume in the following that the inverse demand function on the downstream market is $p(Q) = 1 - Q$ where $Q = q_1 + q_2 + nq_f$ is total output. The cost function of a fringe firm is quadratic and given by $C(q_f) = q_f^2/2$, and consequently, we have $k_i C(q_i/k_i) = q_i^2/(2k_i)$. Finally, we assume that the R&D input supply function is $R(K) = K^2/z$, where z is a positive parameter and $K = k_1 + k_2$ is the total purchase of R&D input. As previously, we compare R&D input purchase decisions when strategic firms are competing and cooperating on the market for R&D input.

Consider first the output decision of fringe firms. Each fringe firm sets q_f so that its marginal cost is equal to final price, which implies $q_f = p$. The resulting residual demand for strategic firms is then given by $RD(p) = 1 - p - nq_f$ and the associated inverse demand function is $\widetilde{p}(Q_s) = (1 - Q_s)/(n + 1)$. Firm i $(i = 1, 2)$ then sets output q_i to maximize its profit $\pi_i = \widetilde{p}(Q_s)q_i - \gamma k_i C(q_i/k_i) - k_i R(K)$. The equilibrium outputs and final price are thus given by:

$$
\begin{aligned}
q_i^* &= \frac{k_1(\gamma + k_2 + \gamma n)}{3k_1k_2 + 2\gamma(k_1 + k_2)(1 + n) + \gamma^2(1 + n)^2}, \\
p^* = q_f^* &= \frac{(\gamma + k_1 + \gamma n)(\gamma + k_2 + \gamma n)}{(1 + n)\left(3k_1k_2 + 2g(k_1 + k_2)(1 + n) + \gamma^2(1 + n)^2\right)}.
\end{aligned}
$$

The equilibrium size of the fringe firm is given by $p^2/2 = (k1 + k2)^2/z$. Because of computation issues, we only simulate the resulting R&D input purchases in the two relevant cases. We set $z = 2.10^5$ and determine the values of k^* and k^c for various values of $\gamma \in [0, 1]$. Figure 1 summarizes the effect of cooperation on R&D investment and final price.

We see on the left-hand side of Figure 1 that strategic firms always invest more in R&D in cooperation than in competition here and that the difference between k^c and k^* decreases with γ. When γ is low, the efficiency advantage of strategic firms over fringe firms is high, and therefore, a strategic firm benefits more from an increase of its R&D input endowment. The fringe thus suffers all the more from an increase of k_i that γ is higher. The over-buying strategy of cooperative strategic firms is thus stronger when they are very efficient relative to their smaller rivals. However, although one would then expect final price to decrease due to the

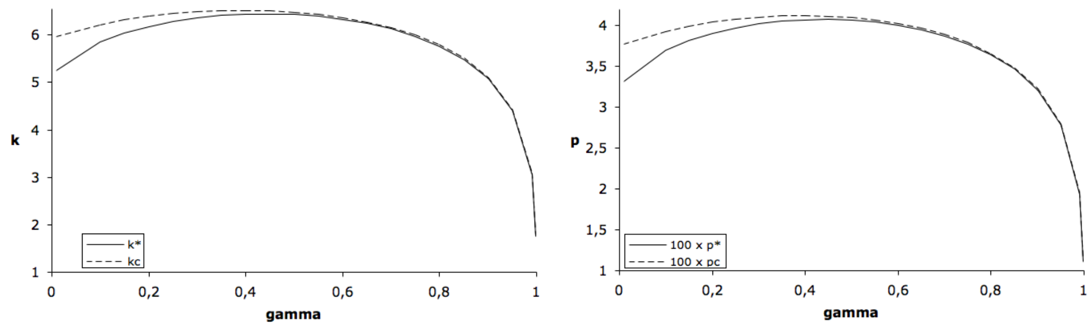

Figure 1: R&D investment (left-hand) and final price (right-hand) with respect to strategic firms cost advantage γ, with competition (full line) and cooperation (dotted line).

enhancing of global efficiency, this never happens, as is predicted by Proposition 1: the cooperative final price is also higher than the competitive final price for all $\gamma \in [0,1)$. Consumer surplus here is simply given by $SC = (1-p)^2/2$, from which we deduce that consumer surplus is always lower when strategic firms cooperate in R&D than when they compete in R&D. Total welfare is then given by $W = \pi_1^* + \pi_2^* + SC$. As Figure 2 shows, welfare is lower with R&D cooperation than competition for all values of γ.

The inverted U-shape of R&D purchase, and consequently of final prices, comes from two different effects. When γ is close to 1, the cost advantage of a strategic firm over the fringe is very low. Then, an increase of i's R&D purchase does not increase its cost advantage so much. This explains why as γ decreases, strategic firms increase their R&D purchases in competition as well as in cooperation. By contrast, when γ is close to 0, the cost advantage of a strategic firm is already so high that strategic firms sell most of the output. Then, an increase of i's R&D purchase, while highly increasing its cost advantage, cannot lead to a very high output increase and hence does not benefit the strategic firm. This explains why R&D input purchase decreases as γ tends to 0.

6 Extensions

In this section, using the framework specified in Section 5, we show that our result is robust to some extent to allowing the R&D cost to also depend on fringe firms'

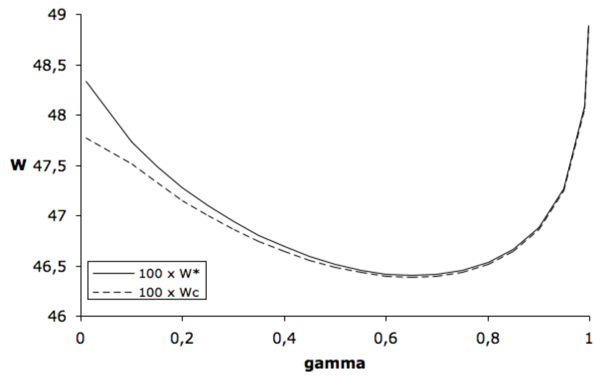

Figure 2: Welfare with respect to strategic firms cost advantage γ, in the competitive equilibrium (full line) and in cooperation (dotted line).

R&D input demand and to adding synergies resulting from cooperation. Finally, we assume that strategic firms collude on the final market in addition to cooperating on the upstream market and determine whether cooperative R&D facilitates cooperation on the downstream market.

6.1 R&D costs depending on total demand for R&D

We assume here that the cost of R&D investment does not only depend on strategic firms' demand for R&D but also on the fringe firms' demand. More precisely, we consider the following supply function: $R(k_1+k_2+n) = (k_1 + k_2 + n)^2/z$ with $z > 0$.

The equilibrium of the output-decision subgame is similar to that found in Section 5. What changes is the R&D investment stage. In Table 1, we give the results of the simulation. Then, with $z = 2.10^6$, we observe that k^c is higher than k^* as long as $\gamma < 0.2$, which is consistant with Proposition 3: cooperative over-buying is all the more likely to happen that strategic firms are more efficient relative to the fringe. From the table, we also observe that consumer surplus (through final price) as well as total welfare are lower in cooperation than in competition when $\gamma < 0.2$ and higher otherwise. Finally, even when we assume that R&D costs depend on the fringe's demand as well as on the demand from strategic firms, cooperative over-buying may still occur and is always harmful to consumers as well as to society.

Table 1: R&D input purchase, size of the fringe, final price and strategic firm's profit when strategic firms are competing ($*$) and cooperating (c) on the market for R&D input.

γ	k^*	n^*	$10^3 p^*$	$10^3 \pi_1$	$10^2 W^*$	k^c	n^c	$10^3 p^c$	$10^3 \pi_1$	$10^2 W^c$
0.01	3.52	14.75	21.79	6.17	49.08	5.30	13.23	23.83	6.27	48.90
0.02	4.26	14.29	22.81	6.07	48.95	5.56	13.18	24.30	6.13	48.82
0.05	5.39	13.77	24.55	5.73	48.72	6.10	13.14	25.34	5.75	48.65
0.10	6.34	13.53	26.21	5.18	48.45	6.66	13.23	26.54	5.19	48.42
0.20	7.26	13.64	28.16	4.21	48.06	7.26	13.64	28.16	4.21	48.06
0.50	7.74	15.42	30.90	1.95	47.35	7.51	15.72	30.73	1.96	47.37
0.90	4.8	21.99	31.61	0.17	46.92	4.66	22.23	31.55	0.17	46.93
0.99	1.75	27.71	31.21	57.1×10^{-4}	46.93	1.72	27.77	31.21	57.2×10^{-4}	46.93

6.2 Synergies from cooperation

We assume here that when strategic firms enter an R&D agreement, they enjoy full synergies from each other's R&D investment. The effect of an R&D agreement then is similar to the effect of a merger in Perry and Porter (1985). The production cost of firm i thus becomes $(k_1 + k_2)\gamma C\left(q_i/(k_1 + k_2)\right)$ when strategic firms cooperate in R&D. We consider again the example described in Section 5. Then, strategic firms still over-buy in cooperation with respect to competition for low enough values of γ. As before, only in cases where $k^c > k^*$ do we also have $p^c > p^*$, which implies that over-buying still harms consumer surplus even when cooperation induces full synergies. However, the effect of cooperation on total welfare then is positive because strategic firms benefit from cooperation in two ways: First, as in the absence of synergies, over-buying increases final price by reducing entry into the fringe. Second, in addition, R&D cooperation with synergies decreases strategic firms' production cost, which is not the case in the absence of synergies.

6.3 Downstream collusion

Note that in a framework with a competitive fringe, standard collusive strategies relying on output reduction are not profitable, for the fringe's reaction to an output reduction by strategic firms wipes out the subsequent price increase. We thus consider here the case where strategic firms collude both on the input and the output market, and show that in our framework, R&D cooperation is not a means to facilitate collusion on the final market.

For simplicity, consider again the specific framework described in the Section 5. Assume that strategic firms now maximize the joint profit of the strategic duopoly both on the R&D input market and on the final market, *i.e.* enforce collusion on the final market.

Output decisions of the fringe firms are again given by $p = q_f$ and the residual inverse demand function is still $\widetilde{p}(Q_s)$. Then, firm i sets output q_i to maximize profit $\pi_i + \pi_j = \widetilde{p}(Q_s)Q_s - \gamma(k_i C(\frac{q_i}{k_i}) + k_j C(\frac{q_j}{k_j})) - (k_i + k_j)R(K)$. The collusive outputs and final price are thus given by:

$$\begin{aligned} q_i^M &= \frac{k_i}{\gamma(n+1) + 2(k_1 + k_2)}, \\ p^M &= \frac{\gamma(n+1) + k_1 + k_2}{(n+1)(\gamma(n+1) + 2(k_1 + k_2)}. \end{aligned}$$

Unsurprisingly, for a given size of the fringe, the resulting final price (and hence the output of a fringe firm) is higher than in the competitive equilibrium. Besides, if strategic firms both buy the same amount of R&D input, firm i's output is reduced in collusion as compared to competition. The direct consequence however is that more firms enter the fringe than in the competitive case: $n^M(k,k) > n^*(k,k)$ for any $k > 1$, which reduces the final price as well as the output of strategic firms. Then, if the difference between n^M and n^* is high enough, the profit of strategic firm is higher in competition than in collusion for any value of k.

For $z = 2.10^6$, it is always the case that the profit of a strategic firm in competition is higher than its profit in collusion: $\pi_i^*(k,k) > \pi_i^M(k,k)$. In particular, since $\pi_i^*(k^c,k^c) > \pi_i^*(k,k)$ for all $k > 1$, we always have $\pi_i^*(k^c,k^c) > \pi_i^M(k,k)$. In other words, it is impossible for strategic firms to earn a higher profit when they enforce collusion successively on the market for R&D input and on the final market than when they only cooperate on the market for R&D input. Indeed, collusion on the final market increases the final price and therefore facilitates entry in the competitive fringe. Eventually, the increased competition on the final market more than offsets the initial price increase.

The usual concerns regarding the potential anti-competitive effects of R&D agreements are that cooperation at any stage of the production process (here, R&D) can facilitate cooperation in other stages, and in particular at the pricing stage. Interestingly enough, in our case, collusion on the final market would not be profitable for strategic firms. More importantly, the anti-competitive effect of R&D we observe thus does not result from softer competition between strategic firms on the final market: It results from softer competition between strategic firms and the competitive fringe, which has been analyzed in the previous Sections.

7 Conclusion

In this paper, we highlight an anti-competitive effect of R&D agreements that has not been pointed out in the previous literature. In order to engage in R&D, firms must purchase specific inputs including high skilled workers or time slots for the use of a rare facility. Such inputs are necessary to all the firms engaging in the same type of research. Consequently, firms that compete to sell a final good are also likely to compete to purchase the inputs necessary to R&D.

We show that in such situations, if there are large size or cost asymmetries between firms on the market, as can be the case in industries such as software designing or pharmaceutical R&D, large firms with market power may engage in R&D cooperation for anti-competitive purposes. Cooperation may then induce them to overbuy the input, *i.e.* to buy more input than they would otherwise, so as to increase the input price or make it less available to small firms, and thus to exclude them from the final market. This strategy is all the more likely to occur that large firms are very efficient relative to their small rivals. In such a context, while one would expect final prices to decrease due to enhanced efficiency, the market concentration effect induces an increase in the final price. Such agreements thus harm consumer surplus.

A Appendix

A.1 Strategic substitutes

We show here that when the size of the fringe n is fixed, the output decisions of the strategic firms are strategic substitutes. Deriving equation (3) with respect to

q_j yields:

$$\frac{\partial q_i^{MR}}{\partial q_j} = -\frac{\left(p' + \left(1 + n\frac{\partial q_f}{\partial Q_s}\right) p'' q_i\right)\left(1 + n\frac{\partial q_f}{\partial q_i}\right)}{\left(2p' + \left(1 + n\frac{\partial q_f}{\partial Q_s}\right) p'' q_i\right)\left(1 + n\frac{\partial q_f}{\partial q_i}\right) - \frac{\gamma}{k_i} C''\left(\frac{q_i}{k_i}\right)}.$$

As $1 + n\frac{\partial q_f}{\partial Q_s} \in [0, 1]$, and since $p' + Qp'' < 0$, it is immediate that the numerator is negative. Besides, since $p' < 0$ and $C'' > 0$, the numerator is higher in absolute terms than the denominator. Therefore, we find classically that $\frac{\partial q_i^{MR}}{\partial q_j} \in [-1, 0]$, for any $i, j \in \{1, 2\}$ and $i \neq j$.

From this, we can deduce the variation of strategic firms' output with respect to k_i, noticing first that:

$$\frac{\partial q_j^*}{\partial k_i} = \frac{\partial q_j^{MR}}{\partial k_i} + \frac{\partial q_j^{MR}}{\partial q_i}\frac{\partial q_i^*}{\partial k_i} = \frac{\partial q_j^{MR}}{\partial q_i}\frac{\partial q_i^*}{\partial k_i}, \tag{9}$$

$$\begin{aligned} \frac{\partial q_i^*}{\partial k_i} &= \frac{\partial q_i^{MR}}{\partial k_i} + \frac{\partial q_j^{MR}}{\partial q_i}\frac{\partial q_j^*}{\partial k_i} = \frac{\partial q_i^{MR}}{\partial k_i} + \frac{\partial q_i^{MR}}{\partial q_j}\frac{\partial q_j^{MR}}{\partial q_i}\frac{\partial q_i^*}{\partial k_i}, \\ &= \frac{\frac{\partial q_i^{MR}}{\partial k_i}}{1 - \frac{\partial q_i^{MR}}{\partial q_j}\frac{\partial q_j^{MR}}{\partial q_i}} > 0, \end{aligned} \tag{10}$$

for $\frac{\partial q_i^{MR}}{\partial k_i} > 0$ and $\frac{\partial q_i^{MR}}{\partial q_j}\frac{\partial q_j^{MR}}{\partial q_i} \in [0, 1]$. From (9) and (10), it is immediate that $\frac{\partial q_j^*}{\partial k_i} < 0$. Finally, we have:

$$\frac{\partial q_i^*}{\partial k_i} + \frac{\partial q_j^*}{\partial k_i} = \frac{\partial q_i^*}{\partial k_i}\left(1 + \frac{\partial q_j^{MR}}{\partial q_i}\right) > 0.$$

A.2 Comparative statics over n

We prove here that $\frac{\partial q_i^*}{\partial n} < 0$ for any $i \in \{1, 2\}$, and:

$$\frac{\partial q_i^*}{\partial n} + \frac{\partial q_j^*}{\partial n} + q_f^* > 0, \tag{11}$$

which implies that when the size of the fringe increases, total output also increases, while the output of strategic firms decreases.

We first show tyhat total output increases with n. We consider two possible cases: either strategic firms' output increases or decreases with n.

Assume first that we have $\frac{\partial q_1^*}{\partial n} + \frac{\partial q_2^*}{\partial n} > 0$. Then it is immediate that (11) is satisfied. Assume now that on the contrary we have $\frac{\partial q_1^*}{\partial n} + \frac{\partial q_2^*}{\partial n} < 0$. Then there exists i such that $\frac{\partial q_i^*}{\partial n} < 0$. Consider the derivative of $\frac{\partial \pi_i}{\partial q_i}$ with respect to n and have the following equation:

$$\begin{aligned} \frac{\partial^2 \pi_i}{\partial q_i \partial n} &= \left(\frac{\partial q_i *}{\partial n} + \frac{\partial q_j^*}{\partial n} + q_f^*\right)\left[\left(1+n\frac{\partial q_f}{\partial q_i}\right)\left(p' + \left(1+n\frac{\partial q_f}{\partial q_i}\right)p'' q_i^*\right) + n q_i^* p' \frac{\partial^2 q_f}{\partial q_i^2}\right] \\ &+ \left(1+n\frac{\partial q_f}{\partial q_i}\right)\left(\frac{\partial q_f}{\partial q_i} q_i^* + \frac{\partial q_i^*}{\partial n}\right)p' - \frac{\gamma}{k_i}\frac{\partial q_i^*}{\partial n} C''\left(\frac{q_i^*}{k_i}\right) = 0, \end{aligned} \tag{12}$$

since for any value of n, we always have that $\frac{\partial \pi_i}{\partial q_i}(q_i^*, q_j^*, q_f^*) = 0$. Besides, we know that $C'' > 0$, $p' < 0$ and and $\frac{\partial q_f}{\partial q_i} < 0$. As we also have $\frac{\partial q_i^*}{\partial n} < 0$, we can write that $\left(1+n\frac{\partial q_f}{\partial q_i}\right)\left(\frac{\partial q_f}{\partial q_i} q_i^* + \frac{\partial q_i^*}{\partial n}\right)p' - \frac{\gamma}{k_i}\frac{\partial q_i^*}{\partial n} C''\left(\frac{q_i^*}{k_i}\right) > 0$, and consequently, we have the following inequality:

$$\left(\frac{\partial q_i^*}{\partial n} + \frac{\partial q_j^*}{\partial n} + q_f^*\right)\left[\left(1+n\frac{\partial q_f}{\partial q_i}\right)\left(p' + \left(1+n\frac{\partial q_f}{\partial q_i}\right)p'' q_i^*\right) + n q_i^* p' \frac{\partial^2 q_f}{\partial q_i^2}\right] < 0. \tag{13}$$

Therefore, if we find that the right term of this product is always negative, then it immediately follows that $\frac{\partial q_i^*}{\partial n} + \frac{\partial q_j^*}{\partial n} + q_f^* > 0$. In order to show that this is true, we now differentiate $\frac{\partial \pi_i}{\partial q_i}$ with respect to k_j. Using the same reasoning, we find:

$$\begin{aligned} \frac{\partial^2 \pi_i}{\partial q_i \partial k_j} &= \left(\frac{\partial q_i^*}{\partial k_j} + \frac{\partial q_j^*}{\partial k_j}\right)\left[\left(1+n\frac{\partial q_f}{\partial q_i}\right)\left(p' + \left(1+n\frac{\partial q_f}{\partial q_i}\right)p'' q_i^*\right) + n q_i^* p' \frac{\partial^2 q_f}{\partial q_i^2}\right] \\ &+ \left(1+n\frac{\partial q_f}{\partial q_i}\right)\frac{\partial q_i^*}{\partial k_j}p' - \frac{1}{k_i}\frac{\partial q_i^*}{\partial k_j} C''\left(\frac{q_i^*}{k_i}\right) = 0. \end{aligned} \tag{14}$$

Since $p' < 0$, $C'' > 0$ and $\frac{\partial q_i^*}{\partial k_j} < 0$, we have the following inequality:

$$\left(\frac{\partial q_i^*}{\partial k_j} + \frac{\partial q_j^*}{\partial k_j}\right)\left[\left(1+n\frac{\partial q_f}{\partial q_i}\right)\left(p' + \left(1+n\frac{\partial q_f}{\partial q_i}\right)p'' q_i^*\right) + n q_i^* p' \frac{\partial^2 q_f}{\partial q_i^2}\right] < 0.$$

Besides, we know that $\frac{\partial q_i^*}{\partial k_j} + \frac{\partial q_j^*}{\partial k_j} > 0$: the output of strategic firms increases when one of the strategic firm increases its R&D input purchase. It thus follows that:

$$\left(1+n\frac{\partial q_f}{\partial q_i}\right)\left(p' + \left(1+n\frac{\partial q_f}{\partial q_i}\right)p'' q_i^*\right) + n q_i^* p' \frac{\partial^2 q_f}{\partial q_i^2} < 0. \tag{15}$$

From this and (13), we deduce that (11) is satisfied.

We now show by contradiction that we always have $\frac{\partial q_i^*}{\partial n} \leq 0$: the output of strategic firm i decreases with n. Assume that there exists i such that $\frac{\partial q_i^*}{\partial n} > 0$. This implies that:

$$\left(1 + n\frac{\partial q_f}{\partial q_i}\right)\frac{\partial q_f}{\partial q_i} q_i^* + \frac{\partial q_i^*}{\partial n}\left(\left(1 + n\frac{\partial q_f}{\partial q_i}\right)p' - \frac{\gamma}{k_i}C''\left(\frac{q_i^*}{k_i}\right)\right) < 0.$$

Then it follows from (12) and (15) that $\frac{\partial q_i^*}{\partial n} + \frac{\partial q_j^*}{\partial n} + q_f^* < 0$, which as we have shown is not true. Finally, we always have $\frac{\partial q_i^*}{\partial n} \leq 0$, and therefore $\frac{\partial q_i^*}{\partial n} + \frac{\partial q_j^*}{\partial n} + q_f^* \in [0, q_f^*]$.

A.3 Proof of Proposition 2

We show here that the output of strategic firm j may increase with its strategic rival's R&D investment. The variation of q_j^{**} with respect to k_i is given by:

$$\frac{\partial q_j^{**}}{\partial k_i} = \frac{\partial q_j^*}{\partial k_i} + \frac{\partial q_j^*}{\partial n}\frac{\partial n^*}{\partial k_i}.$$

In order to simplify expressions, we use the following notations:

$$A = \frac{\partial q_i^*}{\partial n} + \frac{\partial q_j^*}{\partial n} + q_f^{**},\;\; B = \frac{\partial q_i^*}{\partial k_j} + \frac{\partial q_j^*}{\partial k_j},\;\; X = 1 + n\tfrac{\partial q_f}{\partial Q_s},\;\; T = X(p' + Xp'' q_i) + nq_i p'\frac{\partial^2 q_f}{\partial Q_s^2}.$$

Equations (7), (12) and (14) yield:

$$\begin{aligned}\frac{\partial q_j^{**}}{\partial k_i} &= -\frac{BT}{Xp' - \frac{\gamma}{k_j}C''\left(\frac{q_j^{**}}{k_j}\right)} - \frac{R' - BXq_f^{**}p'}{AXq_f^{**}p'}\frac{AT + X\frac{\partial q_f}{\partial Q_s}q_j^{**}}{Xp' - \frac{\gamma}{k_j}C''\left(\frac{q_j^{**}}{k_j}\right)},\\ &= -\frac{R'\left(AT + X\frac{\partial q_f}{\partial Q_s}q_i\right) - BX^2 q_f^{**}q_j^{**}p'\frac{\partial q_f}{\partial Q_s}}{AXq_f^{**}p'\left(Xp' - \frac{\gamma}{k_j}C''\left(\frac{q_j^{**}}{k_j}\right)\right)}\end{aligned}$$

Since $Xp' - \frac{\gamma}{k_j} C''\left(\frac{q_j^{**}}{k_j}\right) < 0$, $\frac{\partial q_j^{**}}{\partial k_i}$ is of the sign of $-R'\left(AT + X\frac{\partial q_f}{\partial Q_s} q_i\right) + BX^2 q_f q_i p' \frac{\partial q_f}{\partial Q_s}$, and is thus positive as long as:

$$\frac{\partial^2 q_f}{\partial Q_s^2} > \frac{1}{n q_j^{**} p'} \left(\frac{\partial q_f}{\partial Q_s} \frac{BX^2 q_f^{**} q_j^{**} p' - R' X q_j^{**}}{R' A} - X(p' + Xp'' q_j^{**}) \right).$$

Besides, from (2) we find that:

$$\frac{\partial^2 q_f}{\partial Q_s^2} = \left(\frac{\partial q_f}{\partial Q_s}\right)^2 \frac{p''(Q) C''(q_f)^2 - C'''(q_f) p'(Q)^2}{p'(Q)^2}.$$

Therefore, the condition for $\frac{\partial q_j^{**}}{\partial k_i}$ to be positive is:

$$p''(Q^{**}) C''(q_f^{**})^2 - C'''(q_f^{**}) p'(Q^{**})^2 > \frac{p'(Q^{**})}{n q_j^{**} \frac{\partial q_f}{\partial Q_s}} \left(\frac{BX^2 q_f^{**} q_j^{**} p' - R' X q_j^{**}}{R' A} - \frac{X(p'(Q^{**}) + Xp''(Q^{**}) q_j^{**})}{\frac{\partial q_f}{\partial Q_s}} \right).$$

The right-hand side of the latter inequality is negative. In particular, if $p''(Q)C''(q_f)^2 - C'''(q_f)p'(Q)^2 > 0$, then it is true $\frac{\partial q_j^{**}}{\partial k_i} > 0$.

A.4 Proof of Lemma 2

Consider first the second stage of the game, which corresponds to Stage 2 in the main framework. Each firm i $(i = 1, 2)$ sets its output q_i in order to maximize its individual profit, and thus solves the problem: $\max_{q_i} \pi_i = p(Q_s) q_i - k_i R(k_1 + k_2)$, and the first order conditions are thus given by:

$$p + q_i p' = \gamma C'\left(\frac{q_i}{k_i}\right). \tag{16}$$

Following the same reasoning as in the previous section, we find that $\partial q_i^* / \partial k_i > 0$, $\partial q_j^* / \partial k_i < 0$ and $\partial q_i^* / \partial k_i + \partial q_j^* / \partial k_i > 0$.

In the first stage of the game, the difference between cooperation and competition is given by:

$$\frac{\partial \pi_j}{\partial k_i}(q_1^*, q_2^*) = p' q_j^* \frac{\partial q_i^*}{\partial k_i} + \frac{\partial q_j^*}{\partial k_i}\left(p + p' q_j^* - \gamma C'\left(\frac{q_j^*}{k_j}\right)\right) - k_j R'.$$

We can simplify this expression using (16) and find that $\partial \pi_j / \partial k_i = p' q_j^* \partial q_i^* / \partial k_i -$

$k_j R'$. As $p' < 0$ and $R' > 0$, it is immediate that it is negative for all values of k_i and k_j, hence Lemma 2.

A.5 Proof of Lemma 3

When the cost of a firm only depends on its own R&D investment, equation (5) becomes simply $p^* q_f^* - C(q_f^*) = R$, and equation (6) becomes $(\partial p^*/\partial k_i + \partial p^*/\partial n \partial n^*/\partial k_i)\, q_f^* = 0$, as neither the increase of k_i nor the entry of a new fringe firm raises the price of the R&D input. Given that $q_f^* > 0$, the effect of an increase of R&D input purchase on the size of the fringe is simply:

$$\frac{\partial n^*}{\partial k_i} = -\frac{\frac{\partial p^*}{\partial k_i}}{\frac{\partial p^*}{\partial n}} = -\frac{\frac{\partial q_i^*}{\partial k_i} + \frac{\partial q_j^*}{\partial k_i}}{\frac{\partial q_i^*}{\partial n} + \frac{\partial q_j^*}{\partial n} + q_f^{**}}. \tag{17}$$

Obviously, it is still negative as the short-term profit of fringe firms is still reduced following an increase of k_i. However, since $q_f^{**} > 0$, it is straightforward that we now have $\partial p^{**}/\partial k_i = 0$.

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