Market Shares, R&D Agreements, and EU Competition Policy*

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December 23, 2010

Regulation (EC) No 1217/2010 on the application of Article 101(3) of the Treaty on the Functioning of the European Union to categories of R&D agreements exempts horizontal R&D agreements from antitrust concerns when the combined market shares of participants are low enough. We show that existing theory does not support limiting the exemption to low market shares. Building on standard models and assuming that a subset of firms invests in R&D whereas others imitate, we assess the link between the combined market share of innovating firms and the product market benefits of R&D cooperation. With R&D output choices, the market share criterion, while helping to rule out the most socially harmful R&D cooperation agreements, also hinders the most beneficial ones. With R&D input choices, R&D cooperation is more likely to harm consumers at lower combined market share. In so-called "RJV cartels", consumers always benefit from R&D cooperation and relative consumer surplus increases monotonically with the number of innovating firms and decreases with industry size when imitation is sufficiently strong.

JEL Classification: K210, L410, O380
Keywords: R&D, Cooperation, Competition, Regulation

*The authors are grateful to Philippe De Donder, Raymond De Bondt, and seminar participants at GATE and the 2009 EARIE annual conference in Ljubljana for extremely useful comments on a previous version of this paper.

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"In order to make Europe more competitive what we need to do is to promote Europe's capacity for research and development, for innovation and for entrepreneurship."[1] – Joaquín Almunia

1 Introduction

Horizontal research and development (R&D) agreements, whereby firms in the same industry coordinate their R&D operations and jointly exploit the results, restrict *de facto* inter-firm competition in the discovery of new products or processes. However, horizontal R&D agreements can lead to economic benefits, as they permit participating firms to avoid the duplication of budgets, to combine complementary resources, and to internalize knowledge spillovers, possibly toward more innovative goods and lower production costs.

The European Commission recognizes that R&D cooperation can result in net economic benefits. In December 2010, it adopted Regulation (EC) No 1217/2010 on the application of Article 101(3) of the Treaty on the Functioning of the European Union (henceforth the Treaty) to certain categories of R&D agreements, together with corresponding guidelines on the assessment of horizontal cooperation agreements under the European Union competition rules (henceforth, the Guidelines). The new legislation updates and replaces Regulation No 2659/2000 and the precedent version of the Guidelines. They had been adopted a decade earlier in order to introduce a more economic approach in the assessment of the anti- and pro-competitive effects of inter-firm R&D agreements than the previous formalistic procedures.

Although it introduces several amendments, the new regulation maintains the use of a market share criterion to discriminate firms that will be exempted or not from the burden of assessing the compatibility of their contractual relationships with the competition law.[2] If the firms engaged in R&D cooperation have limited market power, in that their combined ex-ante market share does not exceed 25%, their agreement is presumed to have no or negligible harmful anti-competitive effects. The Guidelines clearly assert that, in that case, the parties are more likely to transmit efficiency gains to consumers in that case. However, above the 25% threshold the firms

[1] Address at Confindustria Conference, 9 April 2010.

[2] In a discussion of the draft Regulation and Guidelines, published by the European Commission in May 2010, Gutermuth (2010) estimates that "[t]he proposed amendments aim to improve the existing framework of assessment rather than to radically change it" (p. 2). The main changes are: (i) the distinction between R&D activities carried out jointly and the so-called "paid-for research and development" agreements, where a firm finances the R&D operations carried out externally by another independent firm; (ii) the specification that all parties must have full access to the final outcomes of the R&D activities, including intellectual property rights and the know-how, as a condition for exemption from the general prohibition of all concerted practices which restrict competition (under Article 101(1) of the Treaty); (iii) the extension of the list of hardcore restrictions (conditions under which the exemption does not apply) to the case of active sales limitations of the products/technologies resulting from the cooperative R&D; (iv) the clarification of the distinction between an "actual" and a "potential" competitor.

are excluded from the exemption. The Guidelines indicate that the parties to the agreement are then less likely to pass on efficiency gains to consumers. The firms must then proceed to the self-assessment of their agreement, as they bear the burden of proving that the restriction in competition implied by the agreement is outweighed by the R&D results and the related benefits to consumers. They also risk the annulment of the agreement together with financial penalties.

The use of a market share criterion by the European Commission is compatible with the general view that innovation increases with product market competition. However, both the theoretical and empirical literature has established that the exact connection between the intensity of market competition and R&D investments is not necessarily monotone (see Gilbert (2006), Vives (2008), and Schmutzler (2009) for recent authoritative surveys). In particular, in two-stage oligopoly models where a subset of firms cooperate in R&D, before competing in the market with outsiders, equilibrium R&D levels and consumer surplus can be inverted U related with the number of cooperating parties (De Bondt and Vandekerckhove (2010)).

The main issue of this paper is whether the market share criterion, as used in the current European legislation, is an economically grounded screening mechanism. We use the most standard industrial organization approach of R&D cooperation to ask whether this criterion does in fact facilitate, or penalize, the formation of R&D agreements which are most beneficial to consumers.

We construct a model that draws from well-established contributions to the theoretical literature (d'Aspremont and Jacquemin (1988), Kamien, Muller, and Zang (1992), Amir, Evstigneev, and Wooders (2003), among others).[3] Ex-ante symmetric firms, in a Cournot oligopoly, compete on a market for substitutable products. A subset of these firms may engage in R&D activity to enhance the quality of their products or reduce the marginal costs of production (satisfying the condition of "economic progress"). These firms may choose R&D decisions either non-cooperatively to maximize their individual profit, or cooperatively to maximize joint profits, before competing in the market. The other firms are imitators, in that they benefit at no cost from some fraction of the innovators' R&D.

Our finding is that existing theory does not support limiting the exemption to low market shares. We derive a necessary and sufficient condition for cooperation to result in more R&D than competition, consequently in more consumer surplus, and apply it to several specifications of the R&D stage of the model. In the simplest setup that theory provides, where firms' decisions are R&D results (or "outputs"), we obtain that the regulation actually hinders the best agreements, where R&D cooperation is most beneficial to consumers, by only exempting from regulatory control those collaborations whose impact on consumer surplus is relatively negligible. Then, turning to cases where firms choose the level of R&D expenditure (or "inputs"), we see that the relationship between market share and the relative benefit of R&D cooperation can

[3] Thus, we model firms that do not collude tacitly. For an analysis of the connection between R&D cooperation and collusion, see Martin (1995, 1997), and Cabral (2000).

in fact be the opposite of what Regulation 1217/2010 seems to assume. R&D cooperation can actually penalize consumers when the market share of the cooperating firms is lower than the regulatory threshold. Beyond the threshold, the higher the ex-ante market share of the cooperating firms, the greater the benefit of the agreement for consumers. Finally, in the important case of research joint venture cartels where spillovers are very high, R&D cooperations are found to be always beneficial, and these benefits increase with market share. In that case the regulation penalizes cooperation precisely when economic analysis indicates such agreements would benefit consumers.

The remainder of the paper is as follows. Section 2 briefly presents the regulation, the underlying motivation of the market share criterion, and its implications for firms which have a large market share and contemplate participation in an R&D agreement. Section 3 presents the model and offers the necessary and sufficient condition for consumer surplus to be higher under R&D cooperation than competition. We apply the condition to two standard specifications to reveal non-univocal connections between consumer surplus and innovating firms' ex-ante market share. Section 4 concludes. All the proofs are relegated to the appendix.

2 Market Share Threshold and R&D Block Exemption

Regulation (EC) No 1217/2010 covers all agreements, between two or more firms, that relate to the conditions under which those parties pursue joint research and development of products or technologies, with or without joint exploitation of the results.[4] In the prolegomena, enhanced consumer satisfaction is presented as the motivation for encouraging the agreements that result in more R&D. It is clearly asserted that "[*c*]*onsumers* can generally be expected to benefit from the increased volume and effectiveness of research and development", through "the introduction of new or improved products or services" or "the reduction of prices brought about by new or improved technologies or processes" (paragraph 10, added emphasis). In order to let consumers benefit from the positive outcomes of horizontal R&D cooperation, the regulation sets limits to the application of Article 101(1) of the Treaty on the Functioning of the European Union that prohibits in principle all agreements "which have as their object or effect the prevention, restriction or distortion of competition within the common market." This is done by introducing a block exemption regulation for R&D agreements.

More precisely, Article 2(1) of the new regulation establishes that "Article 101(1) of the Treaty *shall not apply* to research and development agreements" (added emphasis). However, an important proviso of the regulation is that, when R&D activities are carried out jointly by several firms, the block exemption applies

[4] Several categories of R&D agreements are defined in Article 1(1). In addition to R&D activities carried out jointly by several firms, on which we focus in this paper, the new regulation covers paid-for R&D agreements, where a firm finances the R&D activities carried out by another party.

> *only if*, at the time the research and development agreement is entered into (...) the combined market share of the parties to a research and development agreement does not exceed 25 % on the relevant product and technology markets (article 4.2.(a), added emphasis).[5]

It follows that only firms with little market power, typically small and medium-sized businesses, benefit from a guarantee of legal validity. Larger companies must submit to self-assessment the R&D cooperation they envisage, in order to evaluate compliance with antitrust rules and decide to go ahead with the agreement. The combined market share is calculated on the basis of the existing product/technology market capable of being improved by the R&D results of the inter-firm cooperation.[6]

A horizontal R&D agreement, by definition, substitutes cooperation for competition in R&D. The new Guidelines emphasize that the efficiency gains attained by R&D cooperation should be passed on to consumers to an extent that outweighs the restriction of competition effects. A low combined market share is then seen as a sufficient condition for the transmission of benefits to consumers to occur with a high probability. This is first asserted in the section that describes the basic principles for the assessment of horizontal agreements of all kinds:

> If the parties have a low combined market share, the horizontal cooperation agreement is unlikely to give rise to restrictive effects on competition within the meaning of Article 101(1) (paragraph 44).

Specifically, in the section dedicated to R&D agreements, one reads that

> the higher the market power of the parties the less likely they are to pass on the efficiency gains to consumers to an extent that would outweigh the restrictive effects on competition (paragraph 143).[7]

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[5] Article 4.2.(a) applies to all R&D agreements in which the parties pursue joint R&D of contract products or contract technologies, and possibly joint exploitation of the results, as precisely defined in point (a) (i), (ii) or (iii) of Article 1(1).

[6] The Horizontal Guidelines indicate that, when the agreement aims at obtaining a completely new product/technology, the R&D block exemption regulation treats it as an agreement between non-competitors irrespective of market share (paragraph 120). In the formal analysis of the present paper, we focus on R&D efforts that aim at improving an existing product (toward more quality) or technology (for lower marginal costs).

[7] This echoes the Commission guidelines of the previous regulatory regime which expired on 31st December 2010: "Generally, the transmission of the benefits to the consumers will depend on the intensity of competition within the relevant market. Competitive pressures will normally ensure that cost-savings are passed on by way of lower prices or that companies have an incentive to bring new products to the market as quickly as possible. Therefore, if sufficient competition which effectively constrains the parties to the agreement is maintained on the market, the competitive process will normally ensure that the consumers receive a fair share of the economic benefits" (paragraph 34 of the guidelines on the applicability of Article 81 [now Article 101] of the EC Treaty to horizontal cooperation agreements, issued in 2001).

This describes a deep underlying motivation of the regulator for excluding large firms from the block exemption. The regulator's approach is that, when the parties to an agreement have limited market power, cooperative R&D is likely to result in more consumer surplus, and not only in higher firm profits. The combined market share of the parties is then used as a proxy for measuring their market power.

The obligation for large firms to conduct their own assessment of the legality of R&D cooperation agreements, in the light of the legislation in force, the Guidelines, and case-law, is a costly and uncertain process.[8] According to Article 2 of Regulation 1/2003, it is not possible to seek legal protection by notifying in advance the terms of the agreement to the competition authority. An agreement must be proved not to infringe Article 101(1) in order to be valid and enforceable. This occurs when the agreement can be shown to fulfill the conditions of Article 101(3). These conditions are that (i) it contributes to improving the production or distribution of products or to promoting technical or economic progress; (ii) it allows consumers a fair share of the resulting benefit; and (iii) it does not impose restrictions which are not indispensable to the attainment of the above listed objectives; (iv) nor does it afford the possibility of eliminating competition in respect of a substantial part of the products in question. The parties to the agreement, with a combined market share above the 25% threshold, bear the burden of proving that all four conditions are satisfied in order to claim the benefit of Article 101(3).[9]

The market share criterion affects the decision process of large firms that may either rely exclusively on their proprietary R&D assets or opt for cooperation. It is not easy for firms to show that they satisfy the conditions of Article 101(3), as some notable past cases illustrate. For example, in the late 1990s General Electric and Pratt & Whitney, which formed an alliance to develop an innovative aircraft engine, had to go through a number of important obligations to respond to the observations of the Commission, although the new product was designed to meet an uncertain demand on a market that did not exist yet.[10] The regulatory pressure can lead firms to give up initial plans. The perspective of going through the detailed assessment of a challenged project can convince the parties to its abandonment. In 2004, Microsoft and Time Warner stopped a project to jointly control ContentGuard, a US entity specializing in the development and licensing of intellectual property rights, after the Commission opened an in-depth investigation and expressed concerns about anti-competitive aspects of the operation.[11]

[8] For a detailed discussion on the legal uncertainty and the costs for the undertakings entailed by the current EC antitrust enforcement rules, see Di Federico and Manzini (2004).

[9] See Müller (2004) for a detailed analysis of the applicability of Article 81(3) [now Article 101(3)] and of the individual responsability of the parties to a horizontal agreement in assessing the compliance of their practices with competition law.

[10] Following a notification of the agreements to the Commission, the obligations imposed on the parties included a limitation of the design of the engine for only precisely identified aircrafts, the yearly submission of accounting and auditing records to the Commission, and other safeguards to prevent the exchange of competitively sensitive information among the parties. See the Official Journal, 2000 L58/16, and Van Bael & Bellis (2005) for comments.

[11] In that case the parties had notified the project under the Merger Regulation. See the initiation of proceedings,

Business lawyers draw lessons from past cases, and are aware of the risks involved by infringing the regulation. Recently, GlaxoSmithKline and Pfizer announced their agreement to create a new common entity that will focus on R&D and commercialisation of HIV medicines. The press release, and related newspaper articles, emphasize that the new joint venture will hold only a 19% share of a growing market.[12]

In addition to self-assessment costs, before engaging unrecoverable resources the firms excluded from the block exemption must weigh the risk of seeing the legality of an agreement challenged by a client or a non-participating competitor. Should an agreement be found to infringe Article 101(1), then Article 101(2) applies, implying the automatic annulment of the agreement.[13] The cost of ceasing functioning R&D operations before term can be extremely high and reduce expected profits. Moreover, the competition authorities of the Member States and the Commission may impose non-negligible fines or periodic penalty payments. The pecuniary sanctions can attain up to 10 per cent of a firm's total turnover in the preceding business year, and daily penalties up to 5 per cent of the average daily turnover to secure compliance with a cease-and-desist order.[14] This forms negative incentives to cooperate in R&D, as faced only by firms with high market shares.[15]

In order to facilitate the preparation of the new regulation, in late 2008 the Commission invited stakeholders to present their views on their experiences in applying the current rules.[16] Several respondents, including firms (e.g., Google), industry associations (e.g., the European Chemical Industry Council), or representatives of professions (e.g., the antitrust and international law sections of the American Bar Association), argued that the market share threshold of 25% is not adequate. They called for a higher cap, up to 35%, on the grounds that anti-competitive concerns are unlikely below this level. A more radical view was put forth by the Antitrust Committee of the International Bar Association, which saw "no reason why the possibility of obtaining market power in the downstream market should be used to prevent companies from developing new technologies in the upstream technological market."[17] This, arguably,

in Case COMP/M.3445 Microsoft/Time Warner/ContentGuard/JV, Official Journal, 2004 C245/5.

[12] The press release it available at http://www.gsk.com/media/pressreleases/2009/2009_pressrelease_10041.htm. For an example of the many newspaper articles, where the combined market share of the two parties to the same R&D agreement is also mentioned, see: "GSK and Pfizer to merge HIV portfolios", *Financial Times*, April 16, 2009.

[13] Article 101(2) of the Treaty stipulates that "[a]ny agreements or decisions prohibited pursuant to this Article shall be automatically void."

[14] See articles 23 and 24 in the Council Regulation (EC) No 1/2003 of 16 December 2002 on the implementation of the rules on competition laid down in Articles 81 and 82 of the Treaty.

[15] Anderman (2002) observes that EC competition law "acts as a detailed regulator of R&D agreements with a aim of discouraging cooperation that is a tool to engage in disguised cartel or to foreclose markets but ending up possibly *discouraging investments in such joint ventures* that might have been encouraged by a more user-friendly legal framework" (p. 305, added emphasis).

[16] http://ec.europa.eu/competition/consultations/2009_horizontal_agreements/index.html.

[17] http://ec.europa.eu/competition/consultations/2009_horizontal_agreements/iba_en.pdf.

amounts to suggesting the withdrawal of the market share criterion.

The conclusion of the formal analysis that we develop in the next sections actually points to the same direction.

3 R&D, Combined Market Share, and Consumer Surplus

Consider an industry with n firms indexed on $N = \{1, \ldots, n\}$, $n \geq 2$, which are identical ex-ante. Each firm i faces an inverse demand $p_i = \alpha_i - Q$ where the parameter α_i measures the vertical quality of firm i's product and with $Q = \sum_N q_j$, and there is a constant marginal cost of production c_i.[18] The variable margin is thus $a_i - Q$, where $a_i \equiv \alpha_i - c_i$ may differ from firm to firm ex-post.

A subset $M = \{1, \ldots, m\}$ of firms engages in research and development, by each choosing a decision variable $z_j \geq 0$ at a cost $g(z_j)$, $j \in M$, whereas the remaining firms in $N \setminus M$ do not. The choices $\mathbf{z} = (z_1, \ldots, z_m)$ describe either R&D outputs or R&D inputs, and impact the a_i, hereafter $a_i(\mathbf{z}; \cdot)$, for all $i \in N$ (the exact specifications of the two cases are given below). This impact can be interpreted indifferently as a quality improvement (in the "product" case, α_i increases with z_j) or as a cost reduction (in the "technology" or "process" case, c_i decreases with z_j).[19]

Firms within each of the two subsets M and $N \setminus M$ have symmetric profit functions. The firms which invest in R&D benefit from positive spillovers, each of them receiving a fraction $\beta \in [0, 1]$ of the other innovators' quality improvement/cost reduction or R&D spending, with no monetary compensation. These spillovers are *reciprocal*, as they capture the technological information flows generated by any firm $j \in M$ toward all other firms in $M \backslash \{j\}$. The firms in $N \setminus M$ which do not invest in R&D still benefit from a lower fraction $\mu \in [0, \beta]$ of the R&D of innovating firms. In that case the information flow is *one-directional*. Therefore, we refer to it as imitation.[20]

[18] This inverse demand function can be derived as a limit case, as $\delta \to 1$, of a utility function described in Häckner (2000), that is: $U(q, I) = I + \sum_{i \in N} \alpha_i q_i - \frac{1}{2} \left(\sum_{i \in N} q_i^2 + 2\delta \sum_{i \neq j} q_i q_j \right)$, which is quadratic in the consumption of q-products and linear in the consumption of the composite I-good (i.e., the numeraire). The parameter $\delta \in (0, 1)$ is a horizontal differentiation parameter, while α_i is a measure of vertical differentiation, that is of product quality.

[19] The regulation refers to "contract products" and "contract technologies" or "processes" as the outcome of joint research and development activities.

[20] The distinction between reciprocal spillovers and one-directional imitation follows Zhou (2009). By formalizing imitation we capture the fact that a part of the technological information received by firms, including non-innovating entities, are involuntary leakages. In a seminal empirical paper, Mansfield (1985) has found that information concerning the detailed nature and operation of a new product or process generally leaks out to competitors within about a year. Moreover, the assumption that firms which invest in R&D benefit from a higher level of spillovers reflects the fact that they increase their absorptive capacity, as first evidenced by Cohen and Levinthal (1989). For empirical investigations of the connection between technological spillovers and R&D outcomes in the European Union context, see Cassiman and Veugelers (2002), Kaiser (2002), and Belderbos,

The net profit functions of innovating and imitating firms are thus:

$$\pi^j(\mathbf{q},\mathbf{z}) = [a_j(\mathbf{z};\beta) - Q]\, q_j - g(z_j) \text{ and } \pi^k(\mathbf{q},\mathbf{z}) = [a_k(\mathbf{z};\mu) - Q]\, q_k, \tag{1}$$

all $j \in M$ and $k \in N \setminus M$, with $\mathbf{q} = (q_1, \ldots, q_n)$.

As is standard in the literature, we consider two games:

R&D competition The firms play a two-stage non-cooperative game. In the first stage, the m innovating firms simultaneously decide their levels of z_i. In the second stage, given the variable profit intercepts $a_i(\mathbf{z};\cdot)$, all n firms engage in quantity competition. The equilibrium of the quantity competition stage is denoted by $\mathbf{q}^*(\mathbf{z})$, which is assumed to be differentiable in z_j. Assume that sufficient conditions in the style of Amir et al. (2003) hold, so that this first game has a unique symmetric equilibrium in R&D decisions denoted by $\mathbf{z}^{\mathrm{n}}$, where the superscript n refers to "non-cooperation".

R&D cooperation In the first stage, the m parties to the R&D agreement collectively choose $\mathbf{z}$ to maximize the sum of their profits. In the second stage, given the variable profit intercepts $a_i(\mathbf{z};\cdot)$, all n firms engage in quantity competition. This also results in an equilibrium vector $\mathbf{q}^*(\mathbf{z})$ that is differentiable in z_j. Assume that the joint profits $\Pi(\mathbf{z}) = \sum_{i \in M} \pi^i(\mathbf{q}^*(\mathbf{z}), \mathbf{z})$ are a twice differentiable, strictly quasiconcave function of $\mathbf{z}$, with a unique symmetric optimum $\mathbf{z}^{\mathrm{c}}$, where the superscript c refers to "cooperation".[21]

In each case, we proceed by backwards induction. The second stage is common to the two games. Given $\mathbf{z}$, individual profit maximization yields a set of n first-order conditions, which we use to solve for the Cournot-Nash equilibrium in the product market subgame:

$$q_j^*(\mathbf{z}) = a_j(\mathbf{z};\beta) - Q^*(\mathbf{z}) \text{ and } q_k^*(\mathbf{z}) = a_k(\mathbf{z};\mu) - Q^*(\mathbf{z}), \tag{2}$$

all $j \in M$ and $k \in N \setminus M$, where $Q^*(\mathbf{z}) = \frac{\sum_M a_j(\mathbf{z};\beta) + \sum_{N \setminus M} a_k(\mathbf{z};\mu)}{n+1}$. The resulting consumer surplus is

$$CS(\mathbf{z}) = \frac{1}{2}\left(\frac{\sum_M a_j(\mathbf{z};\beta) + \sum_{N \setminus M} a_k(\mathbf{z};\mu)}{n+1}\right)^2. \tag{3}$$

Recalling that $a_j(\mathbf{z};\beta)$ and $a_k(\mathbf{z};\mu)$ are non-decreasing in any dimension of $\mathbf{z}$ by assumption (either directly if z_j increases, or indirectly through spillovers or by imitation if z_k increases for $k \neq j$), it is clear from (3) that the consumer surplus is a monotone increasing function of R&D.[22]

Caree, Diederen, Lokshin, and Veugelers (2004).

[21] For sufficient conditions for a symmetric optimum in R&D decisions, see Leahy and Neary (2005).

[22] To paraphrase the European legislation, in this model R&D always contributes to "technical or economic progress", and firms pass on to consumers a "share of the resulting benefit". Moreover, as there is no collusion, and we focus on equilibria in which non-innovating firms participate by selling positive outputs, conditions (iii) and (iv) of Article 101(3) of the Treaty, as listed in the introduction, are satisfied.

The R&D stage is game-specific, and cannot be solved analytically at this level of generality. However, an envelope theorem argument suffices to characterize the difference between and $\mathbf{z}^{\mathrm{c}}$ and $\mathbf{z}^{\mathrm{n}}$, and consequently between the equilibrium levels of consumer surplus across the two games.

Proposition 1. *Consumer surplus is higher under cooperation than under competition if and only if*

$$(n-m)\left(\frac{\partial a_i}{\partial z_j}(\mathbf{z}^{\mathrm{n}};\beta)-\frac{\partial a_k}{\partial z_j}(\mathbf{z}^{\mathrm{n}};\mu)\right)+\left(2\frac{\partial a_i}{\partial z_j}(\mathbf{z}^{\mathrm{n}};\beta)-\frac{\partial a_j}{\partial z_j}(\mathbf{z}^{\mathrm{n}};\beta)\right)>0, \tag{4}$$

with $i\neq j$, $i,j\in M$, and $k\in N\setminus M$.

Proof. See the appendix. ■

In the specifications of $a_j(\mathbf{z};\beta)$ and $a_k(\mathbf{z};\mu)$ that follow we shall see that $\mathbf{z}^{\mathrm{n}}$ in fact often drops out. The condition (4) in the proposition may be analyzed as follows. The difference $2\frac{\partial a_i}{\partial z_j}-\frac{\partial a_j}{\partial z_j}$ is a standard term, as most papers in the literature involve models that take $m=n$. This difference becomes less and less important as the total number of firms n rises. The first term is specific to our model and appears because $N\backslash M$ is non-empty. This term shows that the influence of firm numbers rests on the sign of the difference $\frac{\partial a_i}{\partial z_j}-\frac{\partial a_k}{\partial z_j}$ as n rises. One might think that R&D decisions have more impact on innovators in M than on other firms, so that the latter difference is positive. This is true when the impact of firms' decisions on product quality or the marginal cost is linear, but it is not always true, in particular in the case of R&D inputs that is examined below.

The logic of the proposition is fairly general. As detailed in the proof (see Appendix 5.1), the comparison of the symmetric R&D equilibrium levels z^{c} and z^{n} (therefore of the consumer surplus under cooperation and competition) depends on the sign of $\frac{\partial\pi^i}{\partial z_j}$, with $i\in M$ and $j\in M\backslash\{i\}$. This derivative can be broken down into a direct and an indirect effect, that is $\frac{\partial\pi^i}{\partial z_j}=\frac{\partial\pi^i}{\partial z_j}+\sum_{k\in N\backslash\{i\}}\frac{\partial\pi^i}{\partial q_k^*}\frac{\partial q_k^*}{\partial z_j}$. The sign of the first term is always positive with a product or process innovation, but the sign of the second term is indeterminate. Consider the simple example of a homogeneous good with cost-reducing R&D for an arbitrary inverse demand function $P(Q)$. In that case the second (indirect) effect simplifies to $q_i^*P'(Q^*)\frac{\partial\left(Q^*-q_i^*\right)}{\partial z_j}$. The sign of $\frac{\partial Q_{-i}^*}{\partial z_j}$ is unknown at this level of generality, and not clearly related to the market share of innovating firms m/n. More structure is needed on the exact effect of R&D, and on final market interactions, in order to determine whether the condition in (4) is satisfied or not. Moreover, a similar condition arises and the same argument can be made with price instead of quantity competition in the market stage.

Accordingly, in the remainder of section we concentrate on standard specifications for R&D choices which allow for tractable computations that reveal counter-intuitive connections between consumer surplus and innovating firms' ex-ante market share. Two specifications of the R&D process are considered successively. The first is output choice, in the style of d'Aspremont and Jacquemin (1988). The other one is input choice, as in Kamien et al. (1992), and Amir et al. (2003).

3.1 Cooperation in output choices

Following d'Aspremont and Jacquemin (1988), and many subsequent contributions to the economics literature on R&D cooperation, let the strategic variable x_j (we substitute here for z_j) denote firm j's R&D *output* decision.[23] The cost function is $g(x_j) = \frac{\gamma}{2}x_j^2$, although the nature of results (condition (6)) is unaffected if a more general cost function, as suggested in Amir et al. (2008), is adopted. The functions $a_j(\mathbf{x};\beta)$ and $a_k(\mathbf{x};\mu)$ are specified as

$$a_j(\mathbf{x};\beta) = a + x_j + \beta \sum_{i\in M\setminus\{j\}} x_i, \quad \text{and} \quad a_k(\mathbf{x};\mu) = a + \mu \sum x_j, \tag{5}$$

all $j \in M$, and $k \in N \setminus M$.[24] With this specification, a unique symmetric Nash equilibrium exists, and a unique cooperation outcome can be computed, for γ sufficiently high.[25] Then (4) leads to:

Corollary 1. *In the R&D output case, cooperation results in a greater R&D level and in greater consumer surplus than R&D competition if and only if*

$$\chi_{\mathrm{AJ}} \equiv (n-m)(\beta-\mu) + 2\beta - 1 > 0. \tag{6}$$

It is clear from the expression in (6) that, for a given number m of cooperating firms, as n increases, and consequently as the market share of innovating firms decreases, the necessary and sufficient condition in (6) is more likely to hold.[26] This provides *prima facie* support for Regulation 1217/2010, and the corresponding section of the Guidelines (which predict, as a justification for the use of a market share criterion, that "the higher the market power of the parties the less likely they will pass on the efficiency gains to consumers", in paragraph 143).

[23] Since $a_i = \alpha_i - c_i$, in order to ensure that the variable profit intercept is positive, assume here that R&D is of the product kind (i.e., it impacts α_i), or that γ is large.

[24] This specification of the effect of R&D on the marginal cost for two asymmetric subsets of firms follows De Bondt and Wu (1997), who perform numerical simulations, and Ceccagnoli (2005), though in the latter paper firms do not cooperate in R&D.

[25] For a simple example, taking $m = 2$ and $\mu = 0$, as in Figure 1 below, the symmetric equilibrium values are $x^{\mathrm{n}} = \frac{2(n-\beta)a}{\gamma(n+1)^2 - 2(n-\beta)(n-1)(\beta+1)}$ and $x^{\mathrm{c}} = \frac{2(n-1)(\beta+1)a}{\gamma(n+1)^2 - 2(n-1)^2(\beta+1)^2}$, in the non-cooperative and cooperative cases, respectively, with $n \geq 2$, $a > 0$, $\gamma > 2$, and $\beta \in [0,1]$.

[26] Suppose that $m = n = 2$, so that the model simplifies to a duopoly. Then the condition in (5) reduces to $\beta > \frac{1}{2}$. In that case, R&D cooperation always dominates R&D competition, as first established in d'Aspremont and Jacquemin (1988).

Figure 1 illustrates this first point. It plots the level curves of the relative consumer surplus with R&D cooperation for different levels of spillovers and market share (for $\mu = 0$, $m = 2$ and $\gamma = 10$). The dashed (dotted) curves in Figure 1 indicate values for which $\frac{CS^{\mathrm{c}}}{CS^{\mathrm{n}}} = 1 + 0.01k$ ($-0.01k$), with $k \in N$. The solid line represents values for which $\frac{CS^{\mathrm{c}}}{CS^{\mathrm{n}}} = 1$. Its slope is positive throughout, indicating that, for $\beta < \frac{1}{2}$, the higher the market share, the less likely it is that R&D cooperation is beneficial.

Proposition 2. *In an industry in which a subset of innovative firms cooperate in R&D outputs, with the cost specification of d'Aspremont Jacquemin (1988), an R&D cooperation agreement is more likely to be beneficial with a smaller number of cooperating firms (for a given market size) or a larger industry size (for a given number of cooperating firms). That is, on the frontier* $\chi_{\mathrm{AJ}} = 0$,

$$\left.\frac{\partial m}{\partial \beta}\right|_{\chi_{\mathrm{AJ}}=0} \geq 0, \quad \left.\frac{\partial n}{\partial \beta}\right|_{\chi_{\mathrm{AJ}}=0} \leq 0.$$

This result characterizes the dichotomous condition for the consumer surplus to be higher under cooperation, and shows that the shape of the frontier in Figure 1 is representative. However, the theoretical support to the 25% threshold (6) offers is only partial, as it does not inform regarding the magnitude of the benefits to consumers. In fact, the characterization of the consumer surplus as a function of the combined market share is less favorable to the regulation. Whenever condition (6) is satisfied, the relative consumer surplus $\frac{CS^{\mathrm{c}}}{CS^{\mathrm{n}}}$ is not monotone decreasing in market share, and the level of consumer benefits is likely to be lower when the ex-ante combined market share of the cooperating firms is below the 25% threshold.

Further examination of the figure leads us to three remarks that cast doubt on the relevance of the market share criterion in Regulation 1217/2010. Consider first the case of large spillovers, when β approaches 1. Then an increase in market share results in relative gains to cooperation for consumers. Next, consider the spillover rate β in the neighborhood of $\frac{1}{2}$. Then the relationship between market share and the relative consumer surplus is non monotonic. Finally, consider the vertical line at the market share threshold of 25%, which represents the threshold beyond which innovating firms do not benefit from the block exemption. Clearly the most desirable level curves, in the North-East of the figure, are ruled out. In this case, in order to avoid the worst outcomes the regulation disincentivises the formation of R&D agreements that are most beneficial to consumers. It actually sacrifices the best, only exempting from regulatory control those whose impact on consumer welfare is negligible.

3.2 Cooperation in input choices

Consider next R&D competition in *input* choice (that is, where R&D expenditure is the strategic variable), in the style of Kamien et al. (1992). Input and output choices are compared in Amir

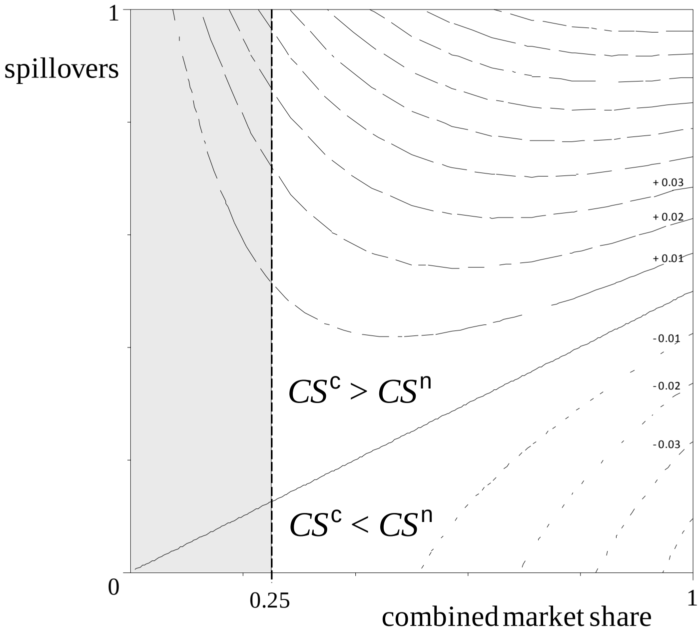

Figure 1: Level curves of relative consumer surplus $\frac{CS^c}{CS^n}$ at 1% intervals (with $\mu = 0$, $m = 2$, and $\gamma = 10$). Cooperation in R&D outputs is more likely to be beneficial to consumers at lower combined market share, for a given number of innovating firms. However, (i) for $\beta = 1$, an increase in market share results in relative gains to cooperation for consumers; (ii) for β in the neiborhood of $1/2$, the relationship between market share and the relative consumer surplus is non monotonic; (iii) if innovating firms may not collaborate for a combined market share greater than 0.25, the most desirable level curves are ruled out.

(2000) and Amir et al. (2008), the former being found to satisfy a general criterion regarding R&D technology and the spillover process. Let y_i denote firm i's R&D input decision. The R&D cost function is then simply $g(y_j) = y_i$. Here the functions $a_j(\mathbf{y}; \beta)$ and $a_k(\mathbf{y}; \mu)$ are specified as

$$a_j(\mathbf{y}; \beta) = f\left(y_j + \beta \sum_{i \in M \setminus \{j\}} y_i\right), \quad \text{and} \quad a_k(\mathbf{y}; \mu) = f\left(\mu \sum_{j \in M} y_j\right), \tag{7}$$

all $j \in M$, and $k \in N \setminus M$, where $\beta \in [0, 1]$ is now the rate at which R&D spending (in currency units) spills over between innovating firms, and $\mu \leq \beta$ is the corresponding imitation parameter. The R&D production function $f(.)$ is generally assumed to satisfy a number of Inada-like conditions (Amir et al. (2003), Kamien et al. (1992)). In particular, it is assumed to be twice differentiable, increasing, concave, and bounded. With this specification, from (4) we obtain:

Corollary 2. *In the R&D input case, cooperation results in a greater R&D level and in greater consumer surplus than R&D competition if and only if*

$$\chi_{\mathrm{KMZ}} \equiv (n-m)\left(\beta - \mu \frac{f'\left(\mu m y^{\mathrm{n}}\right)}{f'\left(\left(1+\beta\left(m-1\right)\right) y^{\mathrm{n}}\right)}\right) + 2\beta - 1 > 0. \tag{8}$$

This condition is more elaborate than its analog (6) above, and reveals a key difference between the two frameworks. Recall that, when strategic R&D variable is an output, an increase in market share m/n had an unambiguous effect on the left-hand term of the inequality (6). In the case of R&D input choice as generally modelled, this is no longer true. Higher industry size (or lower market share for the innovating firms) can lead to reversal of this qualitative relationship, whereby cooperation is desirable at high combined market share but harmful when it is low.

This goes squarely against the apparent rationale of using a market share criterion, as in Regulation 1217/2010. The effect is related to the nature of competition in R&D, via the term $\beta - \mu \frac{f'(\mu m y^{\mathrm{n}})}{f'((1+\beta(m-1))y^{\mathrm{n}})}$. Because of differing technological spillovers the actual R&D effect is lower for non-innovating firms ($\mu m y^{\mathrm{n}} < \left(1+\beta\left(m-1\right)\right) y^{\mathrm{n}}$), and since R&D production is a concave function, the marginal productivity of R&D spending at y^{n} can be higher for non-innovating firms. This can result in a negative coefficient for $n-m$, hence in a reversed sensitivity of (4) to market share.

Proposition 3. *In the R&D input case, cooperation in R&D is more likely to be beneficial to consumers at higher combined market share, for a given number of innovating firms. That is, there exists* $\mu_0 \in [0, \beta]$ *such that:*

$$\mu \geq \mu_0 \Rightarrow \frac{\partial \chi_{\mathrm{KMZ}}}{\partial n} \leq 0. \tag{9}$$

In other words, an increase in market share, for a given number of parties to an R&D agreement, can make R&D cooperation become less desirable for consumers than competition. Note that, without introducing more specification, in principle this effect can arise for μ arbitrarily small, so long as it is non zero.

More can be said by introducing further specification for the R&D production process, as in Amir (2000), where (7) is rewritten as

$$a_j\left(\mathbf{y};\beta\right) = a + \sqrt{\frac{2}{\gamma}\left(y_j + \beta \sum_{i \in M \setminus \{j\}} y_i\right)}, \quad \text{and} \quad a_k\left(\mathbf{y};\mu\right) = a + \sqrt{\frac{2}{\gamma}\mu \sum_{j \in M} y_j}, \tag{10}$$

all $j \in M$, and $k \in N \setminus M$. The expressions in (10) fit the spirit of the assumptions of Kamien et al. (1992), although the shift of the variable profit intercept is not a bounded function of $\mathbf{y}$.

There is a unique symmetric Nash equilibrium, and a unique cooperative outcome, for μ and β sufficiently close to 1.[27] Here, condition (8) reduces to

$$\chi_{\mathrm{A}} \equiv (n-m)\left(\beta - \sqrt{\frac{(1+(m-1)\beta)\mu}{m}}\right) + 2\beta - 1 > 0. \tag{11}$$

Clearly the coefficient of $(n-m)$ in (11) can be negative, so that reversal arises. This occurs if $\mu \in \left(\frac{m\beta^2}{1+(m-1)\beta}, \beta\right]$, with $\beta < 1$.

In Figure 2 we plot the level curves of the relative consumer surplus with cooperation in R&D inputs (for $\mu = \beta$, $m = 2$ and $\gamma = 4$). As in the R&D output case, we see in Figure 2 that, when β is sufficiently high, the level of consumer surplus with R&D cooperation increases with the combined market share of the participating firms. When β is in the neighborhood of $\frac{1}{2}$ or lower, the connection between the relative consumer surplus and the combined market share is non monotonic. When the market share m/n is less than the 25% threshold, the most desirable level curves are not accessible. Moreover, in contrast with the R&D output case, the slope of the solid line, which represents values for which $\frac{CS^{\mathrm{c}}}{CS^{\mathrm{n}}} = 1$, is here negative throughout. This indicates that, whenever (m,n) is such that consumers are indifferent between R&D cooperation and competition, an increase in m or a decrease in n, which raises the combined market share, induces $\frac{CS^{\mathrm{c}}}{CS^{\mathrm{n}}} > 1$.

The latter observation can be generalized to the following characterization of the frontier $\chi_{\mathrm{A}} = 0$ in (m,n,β)-space.

Proposition 4. *In an industry in which a subset of innovative firms cooperate in R&D inputs, with the cost specification of Amir (2000), the agreement is more likely to be beneficial with a larger number of cooperating firms (for a given industry size) or a smaller industry size (for a given number of cooperating firms). That is, on the frontier* $\chi_{\mathrm{A}} = 0$,

$$\left.\frac{\partial m}{\partial \beta}\right|_{\chi_{\mathrm{A}}=0} \leq 0, \; \left.\frac{\partial n}{\partial \beta}\right|_{\chi_{\mathrm{A}}=0} \geq 0.$$

As a consequence of the latter proposition, when firms cooperate in R&D inputs, the policy recommendation is to facilitate the formation of agreements with a large combined market share.

[27] Note that innovating firms' profit is a piecewise-defined function. Because of the asymmetry between innovating and non-innovating firms, the profit functions of the former may be non-differentiable when the non-negativity constraint binds the latter in the quantity stage. Taking $m = 2$ and $\mu = \beta$, as in Figure 2, the symmetric equilibrium values are $y^{\mathrm{n}} = \left(\frac{a\Gamma_1}{1-\Gamma_1\Gamma_2}\right)^2$ and $y^{\mathrm{c}} = \left(\frac{a\Gamma_3}{1-\Gamma_2\Gamma_3}\right)^2$ in the non-cooperative and cooperative cases, respectively, with the algebraic expressions $\Gamma_1 = (n+1)^{-2}\left(\frac{n-\beta}{\sqrt{1+\beta}} - (n-2)\sqrt{\frac{\beta}{2}}\right)\sqrt{\frac{2}{\gamma}}$, $\Gamma_2 = (n-1)\sqrt{\frac{2}{\gamma}(1+\beta)} - 2(n-2)\sqrt{\frac{\beta}{\gamma}}$, and $\Gamma_3 = (n+1)^{-2}\left((n-1)\sqrt{\beta+1} - (n-2)\sqrt{\beta}\sqrt{2}\right)\sqrt{\frac{2}{\gamma}}$. For y^{n} and y^{c} to be well defined, it must be the case that $\Gamma_1\Gamma_2 < 1$ and $\Gamma_2\Gamma_3 < 1$, respectively.

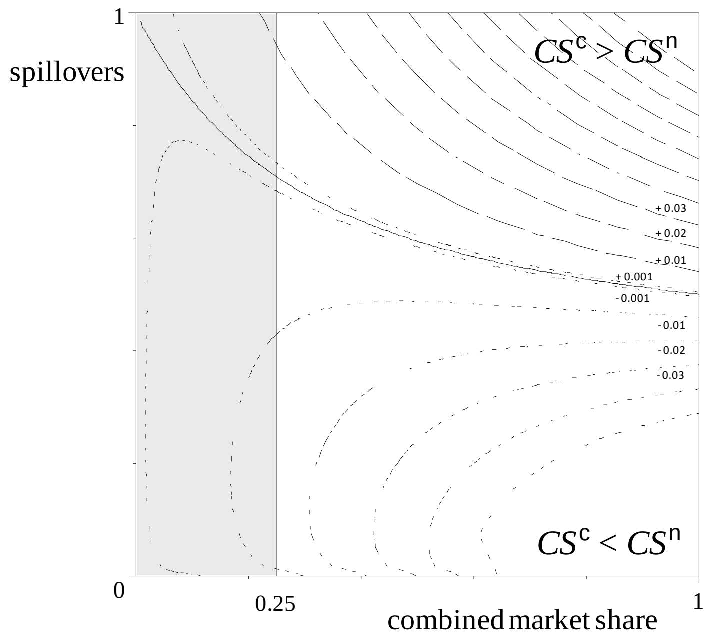

Figure 2: Level curves of relative consumer surplus $\frac{CS^c}{CS^n}$ at 1% intervals (with $\mu = \beta$, $m = 2$, and $\gamma = 4$). Cooperation in R&D inputs is more likely to be beneficial to consumers at *higher* combined market share, for a given number of innovating firms. Moreover, (i) for $\beta = 1$, an increase in market share results in relative gains to cooperation for consumers; (ii) for β in the neiborhood of $1/2$, the relationship between market share and the relative consumer surplus is non monotonic; (iii) if innovating firms may not collaborate for a combined market share greater than 0.25, the most desirable level curves are ruled out.

3.3 The Case of RJV cartels

In this section we focus on so-called "RJV cartels", in which the participating firms not only coordinate their R&D efforts to maximize joint profits, but also choose to fully share the R&D results. In our model, this is done by setting $\beta = 1$.[28] This is a natural specification for the economic assessment of the new regulation, which makes explicit that "[t]he joint exploitation of the results can be considered as the natural consequence of joint research and development" (paragraph 9). As a condition for exemption, Article 3(2) indicates that R&D agreements

[28] This follows the terminology in Kamien, Muller, and Zhang (1992). To compare, in a "R&D cartel", the firms coordinate the choices of R&D levels, without adjusting the given level of spillovers, as in the previous section of this paper. In a "R&D joint venture", the firms share their R&D results by setting the spillover parameter equal to its maximum level, without coordinating their R&D strategies.

“must stipulate that all the parties have full access to the final results of the joint research and development”. Moreover, where the agreement provides only for joint R&D, and not for the joint exploitation of the results, Article 3(3) indicates that “each party must be granted access to any pre-existing know-how of the other parties, if this know-how is indispensable for the purposes of its exploitation of the results.” The new legislation thus encourages the most cooperative type of R&D agreements.

Our final result holds for any number of cooperating firms, any industry size, and in both the R&D output and the R&D input cases.

Proposition 5. *With complete spillovers for innovating firms, R&D cooperation is beneficial for consumers in both the R&D output and the R&D input cases, regardless of market shares. For large enough spillovers to imitating firms, the relative benefit of R&D cooperation increases monotonically with the number of innovating firms (for a given industry size) and decreases with industry size (for a given number of innovating firms). That is,*

$$\beta = 1 \Rightarrow \chi_{\mathrm{AJ}}, \chi_{\mathrm{KMZ}}, \chi_{\mathrm{A}} \geq 0, \tag{12}$$

and there exists $\mu_0 \in [0, \beta]$ such that

$$\mu \geq \mu_0 \Rightarrow \left.\frac{\partial \frac{CS^{\mathrm{c}}}{CS^{\mathrm{n}}}}{\partial m}\right|_{\beta=1} \geq 0,\ \left.\frac{\partial \frac{CS^{\mathrm{c}}}{CS^{\mathrm{n}}}}{\partial n}\right|_{\beta=1} \leq 0. \tag{13}$$

It follows that, when a subset of firms agree to fully share the results of their R&D efforts, and other firms in the industry benefit from non negligible spillovers through imitation, the policy recommendation is to facilitate the formation of RJV cartels, independently of the combined market shares of the parties. Moreover, the larger this market share, the more consumers benefit from R&D cooperation.

4 Conclusion

Regulation (EC) No 1217/2010, and the Guidelines, reflect the laudable objective to make consumers benefit from the virtues of R&D cooperation, while filtering out arrangements that may not pass on benefits to consumers.

By introducing a market share criterion, so that only firms with limited sales may collaborate in R&D within “safe harbours”, the regulation penalizes the technological collaboration of larger suppliers. When firms have a high combined market share, horizontal R&D agreements take place in a more uncertain legal environment. The parties bear the burden of self-assessing the compatibility of their contractual relationships vis-à-vis the legislation. They face the risk of incurring pecuniary sanctions, in addition to unrecoverable costs in case of infringement and subsequent automatic annulment of the agreement.

Our message is that, by focusing too closely on the competition dimension via market shares, the regulation loses sight of the raison d'être of the R&D block exemption. In order to test the regulation from a theoretical economic viewpoint, we have established by means of a standard model, and for several specifications of the impact of R&D on existing products and/or processes, that the connection between the combined market shares of cooperating firms and the benefit of R&D to consumers, is not univocal. It can actually be the opposite of what the regulation seems to assume. A low combined market share, for the cooperating firms, is no guarantee of better products or lower costs, hence of more consumer surplus. In some cases, which are not *a priori* particularly improbable, R&D cooperation can penalize consumers, in comparison to R&D competition, when the market share of the cooperating firms is lower than the regulatory threshold. More competition in an industry can even lead to lower benefits of R&D cooperation to consumers. When it discourages the formation of the most efficient agreements, the regulation actually institutionalizes an adverse selection mechanism.

Another possible motivation for the use of a market share criterion, that we have not studied in this paper, relates to the restriction of competition on the final market (and not only in R&D efforts), as made easier by R&D cooperation. Martin (1995, 1997) and Cabral (2000) demonstrate that R&D joint ventures can facilitate collusion in the marketing of goods in the formal context of two-firm models. With more than two firms, if the impact on the economy is more negative when the colluding parties have high market power ex-ante, then the 25% threshold could be rationalized as a precautionary mechanism that systematically puts the most harmful potential colluders under scrutiny. However, the exact connection between the ex-ante combined market share of firms engaged in R&D cooperation and the likelihood that they participate simultaneously in a price fixing or quantity reducing agreement remains to be investigated. A recent empirical study by Goeree and Helland (2008) in the US environment has found that a shift in antitrust policy (the revision of the leniency program by the Department of Justice in 1993), which specifically aimed at deterring final market collusion, reduced significantly the probability that a firm joins a R&D joint venture in the telecommunications industry. This result suggests that some past R&D agreements were indeed motivated by non technological considerations. It also indicates that collusive behavior can be dealt with successfully with dedicated instruments.

In terms of policy implications, our analysis thus calls for both simplification and specialization. The simplification of the R&D block exemption by withdrawing the market share criterion would eliminate the disincentives to R&D cooperation faced by large firms. In that case the regulation would be specialized,[29] with the objective of making consumers benefit from R&D cooperation, leaving aside the detection and prosecution of welfare-reducing behavior to other specialized competition rules.

[29] On a similar note, cooperation agreements covering both joint R&D and joint exploitation may be construed as coming directly under merger rules (as in the case of the General Electric and Pratt & Whitney alliance cited above), although even in this case the market share threshold is relaxed in the case of new products.

5 Appendix

Because of space limitation, the standard computation of the equilibrium R&D strategies x^{n} and x^{c}, that we use in the proofs of Proposition 4 and 5 below, are not developed in this appendix. They are available from the authors on request.

5.1 Proof of Proposition 1

The consumer surplus, as in (14), is an increasing function of z_i, all $i \in M$. For a comparison of the consumer surplus in equilibrium across the R&D competition and cooperation games, compute the total derivative of $\Pi : R_+^m \to R$, that is

$$\mathrm{d}\Pi\left(\mathbf{z}\right) = \sum_{i \in M} \left[\frac{\partial \pi^i}{\partial z_i} \mathrm{d}z_i + \sum_{j \in M \backslash \{i\}} \frac{\partial \pi^i}{\partial z_j} \mathrm{d}z_j \right]. \tag{14}$$

Next, evaluate at $\mathbf{z} = \mathbf{z}^{\mathrm{n}}$ the two partial derivatives that appear in the expression above, for $\pi^i = \pi^i\left(\mathbf{q}^*\left(\mathbf{z}\right), \mathbf{z}\right)$, to get

$$\left.\frac{\partial \pi^i}{\partial z_i}\right|_{\mathbf{z}=\mathbf{z}^{\mathrm{n}}} = 0 \text{ and } \left.\frac{\partial \pi^i}{\partial z_j}\right|_{\mathbf{z}=\mathbf{z}^{\mathrm{n}}} = q_i^* \left(\frac{\partial a_i}{\partial z_j} - \sum_{k \in N \backslash \{i\}} \frac{\partial q_k^*}{\partial z_j} \right), \tag{15}$$

all $i, j \in M$, $i \neq j$. The zero value of $\frac{\partial \pi^i}{\partial z_i}$ results directly from the first-order condition for a NE in R&D decisions. The value of $\frac{\partial \pi^i}{\partial z_j}$ is obtained by recalling that $\frac{\partial \pi^i}{\partial q_i^*} \frac{\partial q_i^*}{\partial z_j} = 0$ from the first-order condition for a NE in quantities, and also by observing that $\frac{\partial \pi^i}{\partial a_i} \frac{\partial a_i}{\partial z_j} = q_i^* \frac{\partial a_i}{\partial z_j}$ and $\frac{\partial \pi^i}{\partial q_j^*} \frac{\partial q_i^*}{\partial z_j} = -q_i^* \frac{\partial q_i^*}{\partial z_j}$ from the specification of demand functions. Next, recall that firms are ex-ante symmetric to focus on the R&D vectors $\mathbf{z}$ verifying $z_1 = \ldots = z_m = z$, so that joint profits on M can be expressed as a strictly quasi-concave function of a single argument z. Then, the maximizer z^{c} is strictly greater than z^{n} if and only if $\left.\frac{\mathrm{d}\Pi(z)}{\mathrm{d}z}\right|_{z=z^{\mathrm{n}}} > 0$. From (14) and (15) the latter condition can now be rewritten as

$$\left.\frac{\partial a_i}{\partial z_j} - \sum_{k \in N \backslash \{i\}} \frac{\partial q_k^*}{\partial z_j}\right|_{z_j = z^{\mathrm{n}}} > 0, \tag{16}$$

all $i, j \in M$, $i \neq j$, and all $q_i^* > 0$. Concentrate on the second term in (16). We have $\sum_{k \in N \backslash \{i\}} \frac{\partial q_k^*}{\partial z_j} = \frac{\partial Q^*}{\partial z_j} - \frac{\partial q_i^*}{\partial z_j}$, with $\frac{\partial q_i^*}{\partial z_j} = \frac{\partial a_i}{\partial z_j} - \frac{\partial Q^*}{\partial z_j}$ from (2). Then observe from the expression of $Q^*\left(\mathbf{z}\right)$ in (2), that $\frac{\partial Q^*}{\partial z_j} = \frac{1}{n+1} \sum_{k \in N} \frac{\partial a_k}{\partial z_j}$, and that $\frac{\partial a_k(\mathbf{z})}{\partial z_j} = \frac{\partial a_i(\mathbf{z})}{\partial z_j}$ for all $k \in M \backslash \{j\}$ by symmetry. It follows that the condition in (16) simplifies to

$$\frac{\partial a_i}{\partial z_j} - \frac{2}{n+1} \left.\left[\left((m-1) - \frac{1}{2}(n+1) \right) \frac{\partial a_i}{\partial z_j} + \frac{\partial a_j}{\partial z_j} + (n-m) \frac{\partial a_k}{\partial z_j} \right]\right|_{z_j = z^{\mathrm{n}}} > 0,$$

all $i, j \in M$, $i \neq j$, and $k \in N \setminus M$. Then rearranging terms and multiplying through by $n+1$ leads to the desired result. ■

5.2 Proof of Proposition 2

The frontier χ_{AJ} is defined by the condition:

$$\chi_{\mathrm{AJ}}(m, n, \beta, \mu) \equiv (n-m)(\beta-\mu) + 2\beta - 1 = 0.$$

It is direct to establish that $\frac{\partial n}{\partial \beta} = -\frac{\partial m}{\partial \beta} = -\frac{n-m+2}{\beta-\mu} \leq 0$, with strict inequality if $\mu < \beta$. ■

5.3 Proof of Proposition 3

Trivially, the proposition holds for $\mu = \beta$. Moreover, the concentrated profit function of a given innovating firm i in the R&D input game is:

$$\pi^i(\mathbf{y}) = \left(\frac{nf\left(y_i + \beta\sum_{M\setminus\{i\}} y_l\right) - (m-1)f\left(y_j + \beta\sum_{M\setminus\{j\}} y_l\right) - (n-m)f\left(\mu\sum_M y_l\right)}{n+1}\right)^2 - y_i.$$

In a symmetric interior equilibrium, the resulting first-order condition is:

$$\frac{2}{(n+1)^2}\left((n-\beta(m-1))f'(my^{\mathrm{n}}) - \mu(n-m)f'(\mu m y^{\mathrm{n}})\right)$$
$$\left((n-m+1)f(my^{\mathrm{n}}) - \mu(n-m)f(\mu m y^{\mathrm{n}})\right) - 1 = 0.$$

Therefore, $(n-\beta(m-1))f'(my^{\mathrm{n}}) - \mu(n-m)f'(\mu m y^{\mathrm{n}}) \geq 0$ in a symmetric equilibrium, from which it follows that:

$$\beta - \mu\frac{f'(\mu m y^{\mathrm{n}})}{f(my^{\mathrm{n}})} \geq -\frac{n(1-\beta)+\beta}{n-m},$$

i.e. the Nash equilibrium condition does not generally rule out other values of μ at which reversal may occur. Moreover, in the case of R&D input competition with Amir's specification, it is straightforward to verify that $\mu_0 = \beta^2$. ■

5.4 Proof of Proposition 4

The frontier χ_{A} is defined by the condition:

$$\chi_{\mathrm{A}}(m, n, \beta, \mu) \equiv (n-m)\left(\beta - \sqrt{\frac{((m-1)\beta+1)\mu}{m}}\right) + 2\beta - 1 = 0.$$

Suppose that $\beta \geq \frac{1}{2}$ and that $\mu \geq \frac{m\beta^2}{(m-1)\beta+1}$ (these constraints are consistent since $\frac{m\beta^2}{(m-1)\beta+1} \leq \beta$, with strict inequality if $\beta < 1$). Then, $\frac{\partial \chi_A}{\partial \beta} = (n-m)\left(1 - \frac{(m-1)}{2}\sqrt{\frac{\mu}{m((m-1)\beta+1)}}\right) + 2 \geq 0$, $\frac{\partial \chi_A}{\partial n} = \beta - \sqrt{\frac{((m-1)\beta+1)\mu}{m}} \leq 0$, and $\frac{\partial \chi_A}{\partial m} = -\left(\beta - \sqrt{\frac{((m-1)\beta+1)\mu}{m}}\right) + \frac{(n-m)(1-\beta)\mu}{2m^{\frac{3}{2}}\sqrt{((m-1)\beta+1)\mu}} \geq 0$, the latter two with strict inequality if $\beta < 1$. ■

5.5 Proof of Proposition 5

The first result in (12) is obtained directly by setting $\beta = 1$ in (6) and (8). Straight computation establishes that $\chi_{AJ}(m,n,1,\mu) > 0$. In the case of general R&D input choice, the required condition when $\beta = 1$ is

$$(n-m)\left(1 - \mu\frac{f'(\mu m y^{\mathrm{n}})}{f'(m y^{\mathrm{n}})}\right) + 1 > 0.$$

The concentrated profit function of a given innovating firm i in the R&D input game when $\beta = 1$ is

$$\pi^i(\mathbf{y}) = \left(\frac{(n-m+1)f\left(\sum_M y_l\right) - (n-m)f\left(\mu\sum_M y_l\right)}{n+1}\right)^2 - y_i.$$

In a symmetric interior equilibrium, the resulting first-order condition is

$$\frac{2}{(n+1)^2}\left((n-m+1)f'(my^{\mathrm{n}}) - \mu(n-m)f'(\mu m y^{\mathrm{n}})\right)$$
$$\left((n-m+1)f(my^{\mathrm{n}}) - \mu(n-m)f(\mu m y^{\mathrm{n}})\right) - 1 = 0.$$

When this holds, $(n-m+1)f'(my^{\mathrm{n}}) - \mu(n-m)f'(\mu m y^{\mathrm{n}}) > 0$ and therefore $\chi_{KMZ}(m,n,1,\mu) > 0$. We obtain $\chi_A(m,n,1,\mu) > 0$ in the same way by substituting (11) for (8).

Next, we must prove that $\mu \geq \mu_0 \Rightarrow \left.\frac{\partial \frac{CS^{\mathrm{c}}}{CS^{\mathrm{n}}}}{\partial n}\right|_{\beta=1} \leq 0$, $\left.\frac{\partial \frac{CS^{\mathrm{c}}}{CS^{\mathrm{n}}}}{\partial n}\right|_{\beta=1} \geq 0$, as claimed in (13). To do that, in the R&D output case we first compute[30]

$$\frac{CS^{\mathrm{c}}}{CS^{\mathrm{n}}} = \left(\frac{na + m(m+\mu(n-m))x^{\mathrm{c}}}{na + m(m+\mu(n-m))x^{\mathrm{n}}}\right)^2,$$

where

$$x^{\mathrm{n}} = \frac{2(1+(1-\mu)(n-m))a}{\gamma(n+1)^2 - 2m(1+(1-\mu)(n-m))^2},$$
$$x^{\mathrm{c}} = \frac{2m(1+(1-\mu)(n-m))a}{\gamma(n+1)^2 - 2m^2(1+(1-\mu)(n-m))^2}.$$

[30] We leave aside the proof in the R&D input case, which is very similar.

Since

$$\frac{x^{\mathrm{n}}}{x^{\mathrm{c}}} = \frac{\gamma\,(n+1)^2 - 2m^2\,(1+(1-\mu)\,(n-m))^2}{\gamma\,(n+1)^2 - 2m\,(1+(1-\mu)\,(n-m))^2}\frac{1}{m} < 1,$$

for all $\gamma > 0$, $m \geq 2$, $n \geq m$, and for $0 \leq \mu \leq 1$, it follows that $x^{\mathrm{n}} < x^{\mathrm{c}}$.

Next, suppose that $\mu = 1$, then $K \equiv \sqrt{\frac{CS^{\mathrm{c}}}{CS^{\mathrm{n}}}} = \frac{\gamma(n+1)^2-2m}{\gamma(n+1)^2-2m^2}$. Compute $\frac{\partial K}{\partial n} = -\frac{4\gamma m(m-1)n}{\left(\gamma(n+1)^2-2m^2\right)^2} < 0$ and $\frac{\partial K}{\partial m} = -2\frac{(2m-1)\gamma(n+1)^2+2m(m-2)}{\left(\gamma(n+1)^2-2m^2\right)^2} > 0$, for $m \geq 2$. Since $\frac{CS^{\mathrm{c}}}{CS^{\mathrm{n}}}$ is a C^1 function of its arguments, it follows that $\left.\frac{\partial \frac{CS^{\mathrm{c}}}{CS^{\mathrm{n}}}}{\partial n}\right|_{\beta=1} \leq 0$, $\left.\frac{\partial \frac{CS^{\mathrm{c}}}{CS^{\mathrm{n}}}}{\partial m}\right|_{\beta=1} \geq 0$ for μ sufficiently close to 1. ■

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