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**A Schumpeterian view of the
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concentration in the EU defence
industry**

May 1, 2023

Abstract

The relationship between industry structure, aggregate R&D activity and the pace and quality of the resulting innovation process is currently the subject of a lively debate across NATO in general and even more so among its European members. This paper tackles this issue from a standpoint belonging to the tradition of industrial economics, adapting it to the specific context of the defence sector. This is done with a view to stressing the need of increasing the degree of concentration in order to increase standardization and interoperability of defence systems and facilitate the exploitation of scale economies. In the traditional jargon of industrial organization theory, this amounts to vindicating the Schumpeterian view according to which increasing concentration (eventually all the way up to pure monopoly) monotonically fosters innovation incentives, while mitigating effort duplications affecting large and long-lasting R&D projects. One additional implication, equally relevant, is that the concentration process can indeed be facilitated, in the short to medium term, by systematically resorting to the creation of research joint ventures and/or R&D cartels so as to boost spillover effects and reduce excess investments.

Keywords: innovation; concentration; technological spillovers; industrial policy

1 Introduction

The ongoing debate concerning the possibility of restructuring the defence sector so as to favour both standardization and integration of the European defence forces at all levels and in all directions poses very appealing and also familiar questions to researchers belonging to industrial economics, although this discipline has very seldom shown any interest in these matters, probably because the defence market looks very different from standard markets for consumption goods, starting with the fact that the price mechanism mainly relies on negotiations which cannot be likened to the endogenous determination of equilibrium prices demand functions dictated by the preferences of a large population of atomistic consumers. This notwithstanding, my objective is to show that one can borrow from the tradition of industrial economics many prescriptions which may indeed (i) foster our understanding of the implications of fragmentation/concentration in a strategic sector, and (ii) offer stylised policy recommendation to improve the efficiency and effectiveness of investments.

A quick look at well known agglomeration episodes and processes may be a useful avenue to isolate some key issues. As a departure point, we may take the progressive increase in the degree of concentration that has characterised the aerospace sector in the US over the last three quarters of a century, leading to the arising of two large entities like BMD and Lockheed Martin, through several waves of mergers and acquisitions. In Western Eu-

rope, with the notable exceptions of the creation of Airbus Group (formerly EADS) and the similar merger process which lead to Leonardo, the aerospace industry has resorted, more often than not, to individual or joint ventures for specific items, as, e.g. the MRCA Tornado or the Eurofighter Typhoon, and the same is happening now with two consortia, respectively proposing the Tempest (involving UK, Italy and Sweden) and FCAS (Future Air Combat System, involving France, Germany and Spain). Should both reach the operational stage, the European air defence would once again deal with a manifold problem of lack of standardization, with a less-than-full interoperability, an involved workshare decision to disentangle within each project, and, with a high degree of likelihood, a collectively inefficient duplication of investments. From this standpoint, the A400M was initially conceived as a prototypical joint initiative for modelling cooperative procurement accounting for commercial and defence aspects, and it quickly gained a symbolical value on political grounds, but did not permanently steer the EU defence sector in that direction (Mawdsley, 2013; Calcara, 2018). All in all, arms procurement in the European Union, both before and after Brexit, is characterised by a permanent tension between collective and individual interests, and it is appropriate to stress that the same holds along several other dimensions concerning macroeconomic, industrial and environmental policies, for the same reasons.

This remains true even in presence of the action of EDA (European De-

fence Agency)¹ with the design of EDTIB (European Defence Technology Industrial Base) and EDRT the (European Defence Research and Technology) strategies and the role played by EDF (European Defence Fund) and PeSCo (Permanent Structured Cooperation). While the creation of such offices and related strategies reveals a revived interest in promoting political coordination and industrial cooperation, it also proves that defence procurement is not working efficiently at a collective level as every project is hampered by the fact that, more often than not, individual States try to achieve the desired combinations of national security, domestic firms' competitiveness on international markets, industrial and foreign policy objectives, in addition to equipping their armed forces as effectively and efficiently as possible (Mawdsley, 2018; Calcara, 2020). The recent discussion on these aspects has focussed on the role of relative gains (Calcara, 2018) and market size (Calcara and Simón, 2021), including also critical view about the use of offsets (Fevolden and Tvetbråten, 2016) often appearing in the parallel theoretical and empirical analysis of the same issues in industrial organization (Martin, 1996).

Overall, one can trace back the problems affecting the Western European defence procurement to the anarchic nature of international relations (Waltz, 1979), but this does not explain the coexistence of competition and cooperation, this hybrid scenario being possibly the consequence of diverging indi-

¹On the making of EDA and the shaping of its objectives, see Oikonomou (2015).

vidual interests interacting with sound incentives to cooperate, engendered by the arising of unipolarism after the end of the cold war (Simón, 2017). The recent formulation of the liberal view on these matters holds that economic integration and the resulting will end up preventing any single State to autonomously project, develop and deliver weapon systems with the desired features, and this will necessarily promote cooperation (Brooks, 2005; Britz, 2010; Castellacci and Fevolden, 2015).

A thorough assessment of the idea whereby cooperation is a sound and fruitful way to organise the European defence sector involves a comparative evaluation of the alternative organization designs that could shape such a cooperation. In this respect, the first fact to be stressed is that merging is not equivalent to collaborating through explicit R&D cartels or building up consortia or research joint ventures (RJVs) *ad hoc*, i.e., for specific (and possibly very expensive and far reaching) projects. All of these architectural structures have in common the intention to reduce wasteful effort duplications in terms of investments related to R&D and productive capacity which might become irredeemable sunk costs, as compared to a fully fragmented scenario in which every single firm in the sector goes for a project of its own. Yet, merging and cooperating in some form imply completely different long-run consequences on a sector's ability to maximise the effectiveness of aggregate R&D efforts, as a long-lasting literature in the theory of industrial organization has demonstrated.

Hence, before delving into the issues related to the defence industry, I would like to briefly expose a few relevant elements of the connection between innovation and concentration, belonging to the backbone of industrial economics. The debate about the bearings of industry structure (or, equivalently, concentration) and the size and pace of technological innovation has been for decades - and still is - a *leitmotiv* of the theory of industrial organization, having been triggered by the asynchronous discussion between Schumpeter (1942, chapter VIII) and Arrow (1962). The Schumpeterian vision is illustrated in the following quotation:

"As soon as we go into details and inquire into the individual items in which progress was most conspicuous, the trail leads not to the doors of those firms that work under conditions of comparatively free competition but precisely to the doors of the large concerns - which, as in the case of agricultural machinery, also account for much of the progress in the competitive sector - and a shocking suspicion dawns upon us that big business may have had more to do with creating that standard of life than with keeping it down."
(Schumpeter, 1942, p. 82)

The essence of the matter is whether market power or the lack thereof is the most efficient booster of innovation. The position of Schumpeter, which has become traditionally known as the Schumpeterian hypothesis (although it should rather be considered as a thesis), is that aggregate innovation in-

centives (that is, total R&D at the industry level) is maximised under a monopolistic regime, because a monopolist is in a position to extract the highest profits from the market and may systematically outperform any other market regime from a duopoly to perfect competition. This reasoning relies on the so called *strategic effect*. The objection raised by Arrow twenty years later - without mentioning Schumpeter (1942) - relies instead on the *replacement effect*, pointing out that an innovative monopolist can't do more than replace itself in a better form, while any atomistic firm operating under perfect competition knows that acquiring a patent on virtually any innovation, no matter how small it can be, would turn it into a monopolist as all competitors would be driven out of the market once the patent has been issued to the innovator.² On the basis of these considerations, Arrow claims that the market form generating the highest aggregate incentive to invest is indeed perfect competition.

The resulting debate has shaped the backbone of the theory of industrial organization for decades, along three different avenues. The first, initiated by Scherer (1967), has reached its peak with Gilbert and Newbery (1982) and Reinganum (1983). These authors model the competition for innovation as an auction taking place under full certainty, in which firms bid for a patent con-

²The obvious, and perhaps most intuitive example is that in which the innovation at stake is a marginal cost reduction in a competitive sector supplying a homogeneous good. The firm attaining it may slightly undercut the price of all rivals and expand its market share to 100%.

cerning an innovation of a given size or nature. The second describes proper innovation races which include uncertainty by defining as a random variable the date at which the innovation is obtained. The related literature relies on two alternative assumptions, by which the R&D effort is either *contractual* and is chosen at the outset (Loury, 1979), or *non-contractual*, being chosen by firms at every instant until the winner patents the innovation (Lee and Wilde, 1980). The third approach, from Futia (1980) and Rogerson (1982) to Taylor (1995) and Baye and Hoppe (2003), illustrates tournament games featuring uncertainty as far as the innovator's identity is concerned, while the precise nature and size of the innovation is public domain. The departure point of this literature can be traced back to Futia (1980) and Rogerson (1982), stretching to Taylor (1995) and Baye and Hoppe (2003). This approach, which has also been empirically tested using data related to the aerospace sector (Rogerson, 1989), promotes the adoption of research tournaments as a solution to the problems connected to unobservable research efforts and outcomes, unverifiable in court. Concerning public procurement contracts, this is particularly true for the quality of the final product being supplied to the monopsonist sponsoring the tournament. What follows is indeed connected with this strand of literature, coupling it, at the same time, with the spirit of the recent debate about the possible arising of a non-monotone relationship between innovation incentives and industry concentration.

In a nutshell, the two polarised positions that gave rise to the aforemen-

tioned research streams point at the existence of opposite monotone patterns, whereby innovation incentives and the related aggregate R&D effort at the industry level should either decrease (according to Schumpeter) or increase (according to Arrow) in the intensity of competition or, equivalently, in the number of firms. The consequence has taken the shape of countless theoretical and empirical contributions pointing at validating either monotone pattern, alternatively (for exhaustive accounts of this literature, see Kamien and Schwartz, 1982; Tirole, 1988; Reinganum, 1989; Martin, 1993, 2001; and Scotchmer, 2004).

The turning point leading to reconsider the problem anew, as one possibly delivering a non-monotone behaviour, is the paper by Aghion *et al.* (2005), showing empirical data illustrating the emergence of a concave and single-peaked aggregate R&D curve, and complementing this evidence with a theoretical model producing the inverted-U shaped R&D curve observed in the data. This generated a renewed and very intense interest concerning the relationship between industry structure and innovation, vividly summarised in Gilbert (2006), Shapiro (2012) and Aghion *et al.* (2015, 2019).³

In what follows, I will illustrate a toy model capturing a few essential elements of the issue at stake, on the basis of which it is possible to outline

³The related stream of research has also found analogous cases delivering a peak of aggregate R&D in models belonging to the early literature, which neglected or explicitly assumed away concave outcomes precisely because the attention systematically focussed on the monotonicity property. On this, see Delbono and Lambertini (2022), *inter alia*.

the ranking of different organizational designs of R&D activities in terms of the overall R&D effort at the industry level and the resulting ranking of the quality of the final product delivered by each of these solutions. The flavour of the model, which is a deterministic version of a tournament game, in which the level of the innovation is endogenously determined, is typically Schumpeterian, and delivers a neat prescription in favour of industry-wide RJVs, as a milder possible alternative to merger waves leading all the way up to pure monopoly.

The remainder of the paper defines the structure of the model (Section 2) and the analytical solution of each specific case (Section 3). The strategic implications engendered by the comparative assessment of these results, together with a few concluding remarks, are in Section 4.

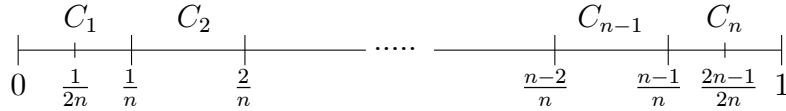
2 The model

Consider an area or a continent made up by a set of symmetric Countries $N = \{1, 2, 3, \dots, n-1, n\}$ aligned along a unit segment, as in Figure 1. The rest of the world, including potential hostile nations, implicitly exists outside the boundaries of the segment. The size of each Country C_i , $i = 1, 2, \dots, n$, is $1/n$, and it is measured in terms of its request of a certain weapon system, say, the quantity of sixth generation multirole fighters. The symmetry assumption about Countries' size is adopted to simplify calculations, and

could be dropped to reach qualitatively analogous conclusions in less friendly terms. Alternatively, one may think of the set as including Countries which are at least approximately comparable in terms of a mix of indicators such as the size of national orders, spending capability, technological knowledge, industrial infrastructure, etc.: say, Germany, France, UK, Italy and Sweden. Additionally, although mentioning this possibility below, I'm not explicitly taking into consideration product variety, for the following reason. The model discussed in the remainder can be replicated assuming explicitly, say, that what these Countries want is a multirole combat aircraft like MRCA Tornado or a mission-specific one, conceived for instance for air superiority only (as it was initially the case for the F15, later largely transformed into a multirole fighter-bomber, by the way). This hinges upon the idea that the inefficient cost replication may systematically characterise a range of either fully equivalent projects for the same general purpose weapon system or differentiated projects for a range of more or less specialised weapons systems, within a single Country or across Countries.

Each Country hosts its own national firm operating in the defence industry, endowed with a sufficiently large productive capacity to supply at least a fraction $1/n$ of total demand, which amounts to one.

Figure 1: The linear continent with n firms and Countries



This is possibly the simplest geographical representation of the set of Countries involved, *à la* Hotelling (1929). This approach accomodates as well an interpretation of the segment as a measure of the overall horizontal differentiation across possible varieties, which is the standard interpretation of a model like this in the field of industrial organization. For the two Countries at the left and right borders, the figure also illustrates the respective products positions at the midpoints of the two Countries, in $1/(2n)$ and $(2n - 1)/(2n)$. Shrinking the spectrum of product designs is equivalent to increasing standardization and compatibility. This of course has an interplay with industry structure, which can be modified through mergers, and therefore also with the incentives to invest and the resulting product quality at equilibrium, which are the subjects of Sections 3 and 4.

A brief description of the stance of the generic Country's government is appropriate. It will suffice to suppose that the government of Country i is characterised by a utility function $u_i^g = s(q_i, x_i)$ where $s(\cdot)$ is the level

of safety associated with the quality (q_i) and quantity (x_i) of weapon systems, and it is increasing in both arguments, with $\partial s(\cdot)/\partial q_i, \partial s(\cdot)/\partial x_i > 0$, according to the non-satiation axiom inherited from neoclassical microeconomics.

The only obstacle to unlimited procurement consists in the finite budget B allocated to the acquisition of the weapon system, which must cover the expenditure, at least at the margin, i.e., $B \geq px_i$, where p is the unit price determined after a negotiation between governments and firms, which I will intentionally leave out of the picture for the sake of brevity. Yet, one may sensibly suppose that $p = \bar{p} + q_i$, which means that the agreement signed contains a clause to the effect that the baseline price $\bar{p} > 0$ is augmented by the quality level of the final product. This reflects the fact that, as stressed by Rogerson (1989, pp. 1285-86; and 1994, pp. 68-69), contracting officers may not - and, in general, will not - aim at the lowest possible price, as the price agreed upon in the final procurement contract must account for the estimated total average cost connected with development and production (in addition to those pertaining to the overall operational life of the weapon system, not appearing in this model) and, at the same time, it must allow for a reasonable profit margin, in accordance with the existing profit policy regulations. In this case, such a margin is enhanced by any increase in the quality level. Additionally, this makes revenues an endogenous function of product quality, which plays a role in shaping the results emerging from the

ensuing analysis.

As Countries are assumed to be symmetric, $x_i = 1/n$ for all i , and therefore $B \geq p/n$ and $u_i^g = s(q_i, 1/n)$, the safety level having become invariant in the number of fighters or tanks.

The quality of firm i 's weapon system is

$$q_i = q_0 + k_i \left(1 + \beta \sum_{j \neq i} k_j \right) \quad (1)$$

where q_0 measures the quality level associated with the last generation of weaponry developed before the start of the present project, and this level increases in k_i , the R&D effort of firm i , being amplified by a spillover incoming from the overall amount of R&D activities carried out by the other $n - 1$ firms, weighted by the spillover parameter $\beta \in [0, 1]$. The long-standing debate about the measurement of knowledge spillovers, at both intra- and infra-industry levels, reveals that the involuntary transmission of know-how does play a significant role, thereby making R&D partly a public good. See Jaffe (1986), Geroski (1995) and Griliches (1995), among many others. As envisaged in the remainder of the analysis, reshaping the organizational design of R&D in terms of a cartel or an RJV allows firms to internalise spillover (von Hippel, 1987, 1988).

The magnitude $\beta k_i \sum_{j \neq i} k_j$ appearing in quality represents firm i 's absorptive capacity, which drops to nil if this firm doesn't invest at all (Kamien and Zang, 2000). This positive technological externality may exist irrespective of the nature of firms' attitude, which may either noncooperative or

cooperative. The emergence of cooperation may go along with an increase of the spillover level, and we shall examine this aspect of the matter in section 2.2. The R&D effort k_i operates at decreasing returns to scale as the effort k_i increases, whereby the cost function associated to R&D activity is $\Gamma_i = k_i(c + k_i)$, in which parameter $c \geq 0$ scales the linear component of R&D costs. To simplify notation, I stipulate that the baseline price \bar{p} already accounts for both the unit production cost of the weapon system and an adequate margin covering also the average cost of R&D, even in absence of the quality premium included in p . No additional cost components are included, notably not those associated with the ensuing operational life of the weapon system. This is due to the absence of time, as this implies that the overall operational costs would be condensed into an exogenous fixed cost which would not affect the optimality conditions of the R&D phase, in any of its specification.

On the basis of the above elements, the individual firm's objective function is identified by the following profits:

$$\pi_i = px_i - \Gamma_i = \frac{\bar{p} + q_0 + k_i \left(1 + \beta \sum_{j \neq i} k_j\right)}{n} - k_i(c + k_i) \quad (2)$$

and indeed the condition ensuring the individual firm's viability is $p \geq \Gamma_i/x_i$. In view of the problematic nature of offsets, I haven't included this feature into the model. If the game is fully noncooperative, firm i must choose k_i to maximise (2) to produce a simultaneous Nash equilibrium. Information is complete and symmetric across firms (as all of them know the structure of the

game, its solution concept, and basically possess exactly the same amount of information), but imperfect, because they play simultaneously and therefore none of them may observe any rivals' moves before choosing its own.

3 Equilibrium analysis

This Section contains the analytical exposition of the fully noncooperative game in which the n firms invest independently, and the alternative scenarios where, respectively, they either cooperate to maximise joint profits (which, literally, means that they form a cartel, or they merge to monopoly) or form an RJV.

3.1 The noncooperative game

We are looking for the Nash equilibrium delivered by n individual strategies, each one being non cooperatively chosen by firm $i = 1, 2, \dots, n$. This means that the strategy vector candidate to identify the Nash equilibrium must satisfy the following condition (Nash, 1950):

$$\pi_i(k_i^N, K_{-i}^N) \geq \pi_i(k_i, K_{-i}^N) \text{ for all } k_i \neq k_i^N \text{ and all } i = 1, 2, \dots, n \quad (3)$$

where $K_{-i}^N \equiv \sum_{j \neq i} k_j^N$. Here, the Nash equilibrium is engendered by the solution of the following profit maximization problem by each individual firm:

$$\max_{k_i} \pi_i = \frac{\bar{p} + q_0 + k_i \left(1 + \beta \sum_{j \neq i} k_j\right)}{n} - k_i (c + k_i) \quad (4)$$

for all $i = 1, 2, \dots, n$. That is, each firm must solve (4) taking as given the $n - 1$ rival's efforts k_j , $j \neq i$, and play its best reply against all of them.⁴ The set of necessary conditions for the Nash equilibrium corresponds to the following system of n first order conditions (FOCs):⁵

$$\frac{\partial \pi_i}{\partial k_i} = \frac{1 + \beta \sum_{j \neq i} k_j}{n} - c - 2k_i = 0, \quad i = 1, 2, \dots, n \quad (5)$$

Solving (5), one obtains the individual best reply function

$$k_i^* = \frac{1 + \beta \sum_{j \neq i} k_j - cn}{2n} \quad (6)$$

Imposing symmetry across effort levels, whereby $k_i = k_j = k$ for all i, j , (5) becomes

$$\frac{\partial \pi_i}{\partial k_i} = \frac{1 + \beta(n-1)k - (c+2k)n}{n} = 0 \quad (7)$$

whose solution - at the intersection of best replies (6) - delivers the expression of the optimal individual effort at the Nash equilibrium with n firms and R&D projects, $k^N(n) = (1 - cn) / [2n - \beta(n - 1)]$, which reveals that $\partial k^N(n) / \partial \beta > 0$. That is, individual efforts are monotonically increasing in the intensity of the knowledge spillover across the sector. This of course also holds for the aggregate effort at the industry level, $K^N(n) = nk^N(n)$. Since $2n - \beta(n - 1) > 0$ for all $\beta \in [0, 1]$, we have that $K^N(n), k^N(n) > 0$

⁴As convincingly stated by van Damme (1991, p. 24), a strategy combination is a Nash equilibrium if it is a best reply against itself, across the entire population of players. See also Lambertini (2011, pp. 24-26).

⁵The concavity condition $\partial^2 \pi_i / \partial k_i^2 = -2$ is satisfied by construction.

for all $c < 1/n$, which immediately implies that, taking c as given, increasing fragmentation may jeopardise innovation incentives. In the remainder of the paper, I will indeed assume $c \in (0, 1/n)$. The common quality level associated to the vector of Nash equilibrium efforts is $q^N(n) = q_0 + k^N(n) [1 + \beta(n-1)k^N(n)]$.

The impact of industry structure on aggregate R&D can be grasped by looking at the following derivatives:

$$\frac{\partial K^N(n)}{\partial n} = \frac{\beta - cn [n(2 - \beta) - 2\beta]}{[2n - \beta(n-1)]^2} \quad (8)$$

$$\frac{\partial^2 K^N(n)}{\partial n^2} = -\frac{2\beta [2 - \beta(1 - c)]}{[2n - \beta(n-1)]^3} \quad (9)$$

Consider first (8). This is surely negative (respectively, positive) if $\beta = 0$ (respectively, $\beta = 1$). This can be easily proven by using the extreme values of the spillover level and the assumption $c \in (0, 1/n)$. Hence, it can be claimed the following

Remark 1 *The absence of any technological spillovers suffices to deliver a Schumpeterian outcome where monopoly outperforms any fragmented oligopoly. Conversely, the presence of full spillovers is a sufficient condition for an Arrowian outcome to arise, where fragmentation monotonically increases the aggregate R&D effort.*

Note, in particular, that (i) the absence of spillovers makes monopoly (with full product standardization, by the way) preferable to any other mar-

ket form because the presence of a single firm automatically rules out information leakage,⁶ while (ii) full spillovers boost information leakage the most, enabling every single firm to benefit from the aforementioned property whereby $\partial k^N(n)/\partial\beta > 0$.

If instead one solves $\partial K^N(n)/\partial n = 0$ for a generic β , the following critical level of fragmentation

$$n_K^N = \frac{-c\beta + \sqrt{c\beta[2 - \beta(1 - c)]}}{c(2 - \beta)} \in \mathbb{R}^+ \forall c \in (0, 1/n) \text{ and } \beta \in (0, 1), \quad (10)$$

with $\partial^2 K^N(n)/\partial n^2 < 0$ in the same parameter range. This means that, provided $n_K^N \geq 2$, we observe a single peak of the collective R&D effort at the industry level in correspondence of an oligopolistic industry structure. The emergence of an admissible peak at least in $n_K^N \geq 2$ requires $c \leq \beta/8$. Moreover, $\partial n_K^N/\partial c < 0$ everywhere. These findings can be summarised in

Proposition 2 *Under independent ventures, with $c \in (0, 1/n)$ and $\beta \in (0, 1)$, there exists an infinitely dense subset of the admissible parameter space (c, β) in which the presence of partial spillovers yields an inverted-U shaped aggregate R&D investment. The industry structure delivering such peak becomes more fragmented as c decreases towards zero.*

How about product quality? Its partial derivative w.r.t. n is a cubic expression which can be solved but the resulting root is not easily tractable.

⁶In other words, since the spillover acts as a multiplier, if the technological externality is absent then a monopolist may always *at least replicate* the behaviour of an oligopolistic sector.

However, it is relatively easy to verify that, if evaluated in correspondence of the peak of industry-wide R&D, i.e., $\partial q^N(n)/\partial n|_{n=n_K^N} < 0$. Moreover, if $n = 0$ (and then, necessarily, $\beta = 0$), we have again $\partial q^N(n)/\partial n|_{n=1, \beta=0} < 0$.⁷ The different impact of industry structure on aggregate R&D effort and quality can be traced back to absorptive capacity: while $K^N(n) = nk^N(n)$, $q^N(n) = q_0 + k^N(n) [1 + (n-1)k^N(n)]$, with the nonlinear component $(n-1)(k^N(n))^2$ clears out the peak appearing in $K^N(n)$. Defining as $n_q^N \equiv \arg \max_n q^N(n)$, we may formulate

Proposition 3 *The industry structure maximising product quality is pure monopoly irrespective of the size of parameters and n^N .*

The special case of $n_K^N = 2$ is illustrated in Figure 2, where $c = 6/100$, $\beta = 48/100$, $q_0 = 1/5$ and $K^N(n) = 1/2$.⁸ Using any other set of admissible numerical values for the key parameters, the qualitative properties of the resulting graph would remain unchanged.

⁷Additionally, it can be verified through numerical methods that this derivative is negative for all $n \in (1, n^N)$.

⁸These numerical values have been chosen purposely to deliver an integer. Of course, any peak in correspondence of any \tilde{n} between two integers would imply that the maximum of $K^N(n)$ is reached for the highest integer lower than \tilde{n} .

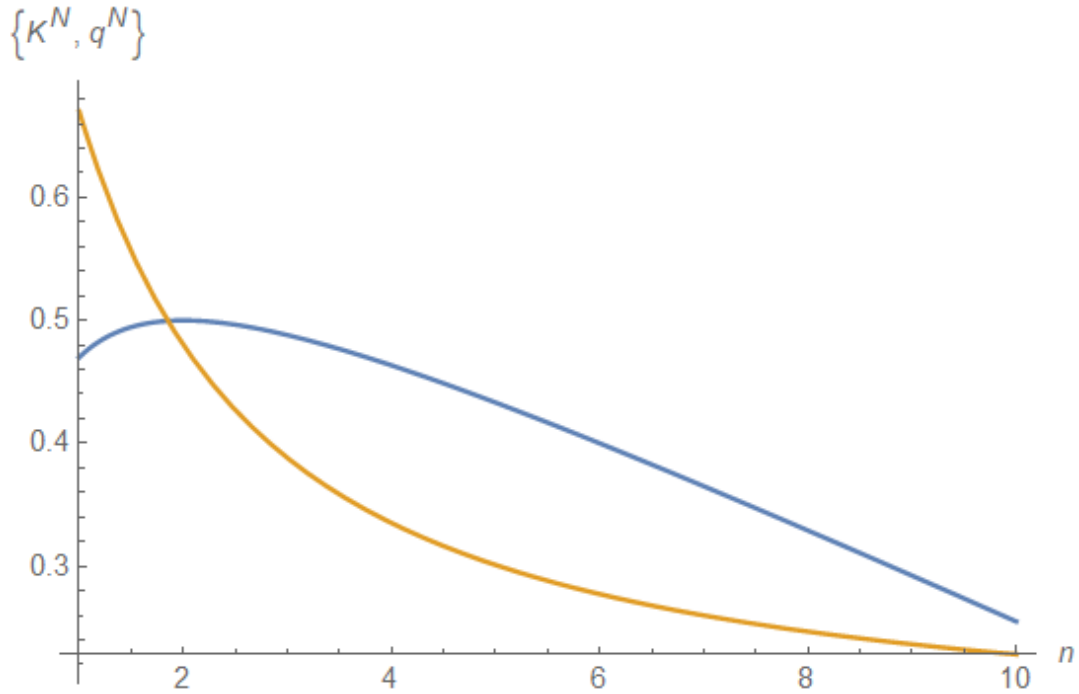


Figure 2 Aggregate R&D effort and quality with independent ventures.

Colour codes: blue = $K^N(n)$, yellow = $q^N(n)$.

In a nutshell, the flavour of the noncooperative game is fully Schumpeterian in terms of the resulting quality level at equilibrium, whereby any additional degree of concentration (through mergers) would be desirable from this point of view. Yet, the joint assessment of Propositions 2-3 delivers a picture telling that at the peak of the aggregate R&D effort quality is systematically decreasing in the number of firms. This has two relevant implications. The first is that a portion of total R&D investments is, bluntly speaking, wasted, precisely because it is carried out in excess of the maximum quality level. The second concerns the related fact that this excess investment is the

outcome of the spillover mechanism boosting all firms' efforts alike. On the one hand, we know that the mitigation of this effect may rely on the adoption of a different framework in terms of the organization of R&D activities, resorting to mergers, cartels and RJVs. On the other, any horizontal merger is bound to reduce wasteful duplications and increase the resulting quality, up to the transformation of the sector into a pure monopoly, a solution which may encounter non negligible obstacles, in view of the fact that the same firms may operate also in markets for consumption goods and services of different kinds, as for instance civil air transport. More explicitly, mergers among two or more corporations which have diversified their production across several sectors, including the defence industry and some civil sectors of comparable relevance, will necessarily attract the attention of antitrust authorities - most likely, in view of the size of the involved cash flow, DGIV and the Merger Task Force in Brussels. Or, it may be blocked by a unilateral decision, as Germany did with the merger proposal advanced in 2012 by BAE Systems and EADS (later Airbus Group). All in all, this appears to be a relevant additional element adding to the tension between competition and cooperation summarised in the Introduction, which calls for systematic communication and collaboration between competition authorities and the Governments involved in the procurement programme.

3.2 Cartel and RJVs

From the above discussion, we know that a horizontal merger to monopoly would deliver the highest quality level saving upon total R&D efforts and the related overall costs born by firms, the latter fact being particularly relevant in view of the quadratic component which ensures concavity and the existence of equilibrium. Yet, an industry-wide cartel or RJV might replicate the strategy and performance of a pure monopolist under certain conditions.

To ascertain the latter, one may proceed as follows.⁹ Consider the cartel involving all firms, each with its R&D division. If firms cooperate, they may also share all the relevant information concerning the respective technological achievements. This amounts to setting $\beta = 1$, in such a way that the objective function of the cartel is $\Pi^C = \sum_{i=1}^n \pi_i$, where π_i is defined as in (2) except that firms operate with full spillovers and cooperatively choose every k_i to maximise Π^C . This procedure delivers

$$K^C(n) = \frac{n(1 - cn)}{2[n(1 - \beta) + \beta]} \quad (11)$$

so that the associated quality level is $q^C(n) = q_0 + K^C(n)$.

The RJV may take two quite different shapes. The first consists in full information sharing with $\beta = 1$, with each firm retaining its own lab and

⁹In this Section, I adapt to the present setup a few typical representations of cooperative or quasi-cooperative R&D arrangements commonly used in the related literature in industrial organization. For an exhaustive overview, see Amir (2000).

selecting k_i to maximise its individual profit function π_i . The performance of this type of RJV can be quickly deduced by setting $\beta = 1$ in the expressions of $K^C(n)$ and $q^C(n)$, whereby one may define as

$$K^{RJV}(n) = K^C(n)|_{\beta=1}; q^{RJV}(n) = q^C(n)|_{\beta=1} \quad (12)$$

the levels of the two variables of interest when there exist n lab sharing 100% of any technical progress across themselves.

The second approach to the RJV consists in assuming that the structure emerging from the agreement among the n firms concentrates joint efforts into a single lab, in which all researchers obviously share their knowledge. This entails that each of the n members of the RJV bears a symmetric fraction of the costs associated to the single R&D unit, amounting to $\Gamma/n = k(c+k)/n$, and product quality is $q = q_0 + k$. The resulting equilibrium magnitudes are

$$K^{RJV}(1) = \frac{1-c}{2}; q^{RJV}(1) = q_0 + \frac{1-c}{2} \quad (13)$$

Without delving into the details of the related calculations, it is possible to appreciate the general flavour of the comparison of these different organizational designs of R&D activity and the fully noncooperative one with independent ventures and generic spillover levels, as portrayed in Figures 3, 4 and 5.

Figure 3 features the alternative equilibrium levels of industry-wide R&D efforts, with $c = 5/100$ and $\beta = 2/5$. The resulting graph has the same qualitative properties for any c sufficiently high (but still admissible, i.e.,

strictly lower than one). This graph tells that if the number of firms is relatively low, then the RJV using a single lab saves efforts and money as compared to any other arrangement of R&D activity.

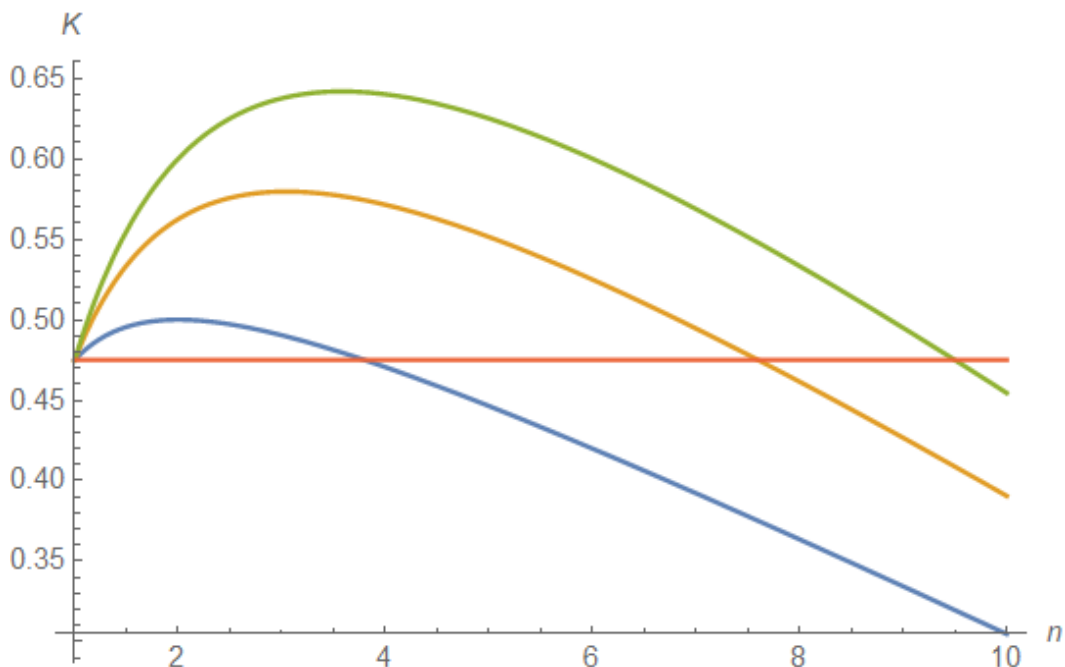


Figure 3 Aggregate R&D effort across regimes, with $c \gg 0$. Colour codes: blue = $K^N(n)$; yellow = $K^C(n)$; green = $K^{RJV}(n)$; red = $K^{RJV}(1)$.

Figure 4 portrays the case in which c is positive but extremely close to zero, and $\beta \in (0, 1)$. If so, the second type of RJV is strictly less expensive than any other alternative organization of R&D activities.

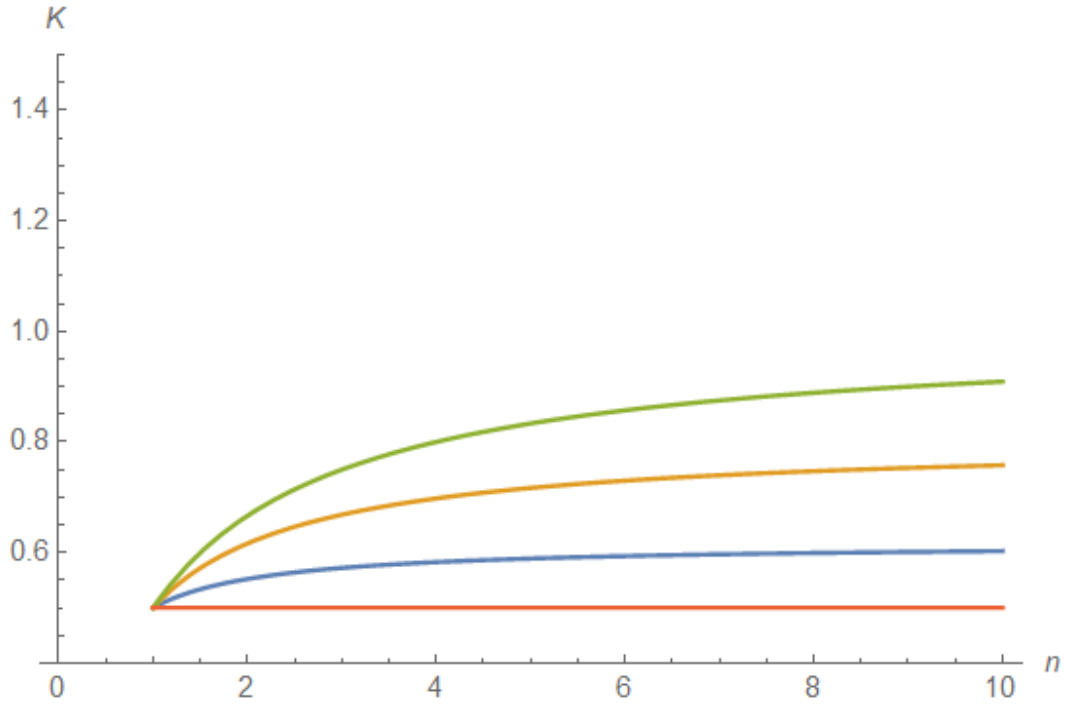


Figure 4 Aggregate R&D effort across regimes, with $c \simeq 0$. Colour codes: blue = $K^N(n)$; yellow = $K^C(n)$; green = $K^{RJV}(n)$; red = $K^{RJV}(1)$.

Finally, Figure 5 illustrate the quality levels engendered by each architectural design of R&D, showing that the cost-saving nature of the RJV based upon a single lab brings about a strictly higher quality level for all $n \geq 2$. Obviously, the four quality levels coincide in presence of a single firm, but this is a truism. Numerical simulations show that these properties hold in general, for all admissible values of c and β .

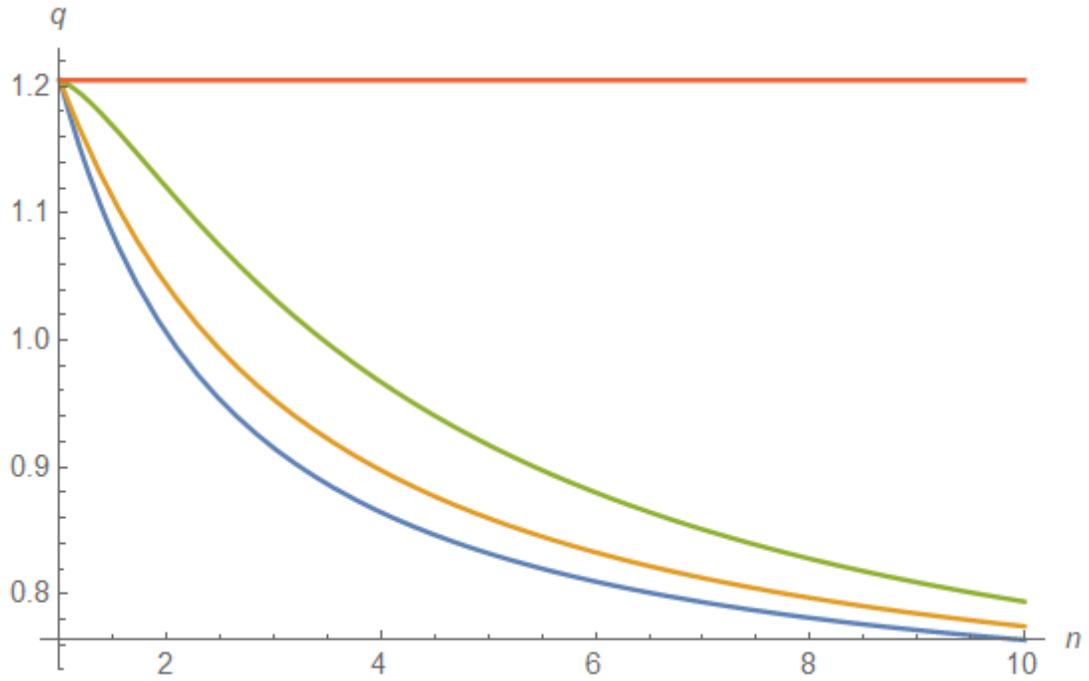


Figure 5 Equilibrium quality across regimes. Colour codes: blue = $q^N(n)$; yellow = $q^C(n)$; green = $q^{RJV}(n)$; red = $q^{RJV}(1)$.

The above discussion boils down to

Proposition 4 *An RJV pivoting around a single R&D unit with cost-sharing among members delivers a quality which is higher than those associated with any other R&D structure. However, cost-wise such R&D may not systematically dominate alternative arrangements.*

4 Implications and concluding remarks

The foregoing analysis produces at least three suggestions about policy prescriptions in terms of both firms' autonomous choices concerning the preferable organization of individual vs collective R&D projects and the stance that the EU and, in particular, EDA, could take to favour any endeavours aiming at reducing the total cost associated with the attainment of the highest feasible quality of a weapon system to be adopted by a cluster of States involved in some form of alliance.

The first one is a direct consequence of the comparative assessment appearing in the previous section, namely. that cooperation in R&D in itself may be formulated in several ways which are not equivalent, the most promising one - at least on the basis of the model illustrated in this paper - being the RJV relying upon a single research structure, in a large portion of the parameter space. When this is not the case, because the number of firms is large (as we know from Figure 3), one may envisage two remedies. The first materialises in subsidies to R&D (in particular, to reduce the relevance of the linear part of the R&D cost function) in order to deliver a picture like Figure 4. This may be a slippery slope though, as the long-lasting quarrel concerning this matter in the sector of civil air transport across the Atlantic Ocean has demonstrated. The second measure directly involves firms, as they might invest in process R&D to soften the impact of the linear component of R&D costs to pave the way to such an RJV.

The second policy implication, equally interesting, is connected with the outcome of the noncooperative game with n independent ventures. The presence of a peak in R&D which does not coincide with the attainment of the highest possible quality is in itself an issue, as the antitrust authority must take into account this elements when facing any merger proposal or, conversely, any parcelisation of an existing firm bound to increase segmentation (in particular if the firms involved in the merger proposal also operate outside the defence sector, possibly heavily so). In particular, the behaviour of the equilibrium along the dimension of quality has a fully Schumpeterian nature. Therefore, boosting segmentation amounts to decreasing quality, which brings us back to the desirability of an RJV outperforming any other organizational design along this dimension. The current layout of the projects aimed at delivering a sixth-generation fighter aircraft fits well: the two existing consortia resulting from an agglomeration of two groups of firms diminish but does not eliminate the problem of standardisation and compatibility, and almost certainly will not minimise the overall financial burden for any given quality associated with two comparable but not entirely identical fighters.

The third element emerging from the analysis of the model is that a cartel or a merger to monopoly taking as given the presence of n R&D divisions, in general, is not the most desirable solution. While it is true that it delivers a higher quality than the fully noncooperative scenario, it does so at a higher cost, the reason being that, by either cooperating or merging, firms fully

internalise the effects of spillovers but suffers from the booster associated to this mechanism. All of this ends up entailing excess investment as compared to the Nash equilibrium of the fragmented *status quo ante*. This is a familiar problem at least since d'Aspremont and Jacquemin (1988).

There remains to say that the model I have used in this paper for illustrative purposes does not exhaust all of the issues plausibly associated to the problem at hand. Indeed, it leaves aside several important aspects, as, e.g., (i) the bearings of the R&D architecture on the performance of the weapon system on the export market, whose assessment should also account for the corresponding decisions concerning the distribution of orders across firms once the final product has become marketable; and (ii) the very likely presence of industrial relations related to the choice of outsourcing the supply of critical components. The undesirable long-run consequences of outsourcing in the aircraft industry have been outlined and assessed at least since Pritchard and MacPherson (2007), and the downward distortion of quality levels due to the inefficiency of vertical relations as against in-house development has been analysed in detail in the theoretical literature (see, *inter alia*, Lambertini, 2018).

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