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Sector dynamics and demographics of top R&D firms in the global economy

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Pietro Moncada-Paternò-Castello

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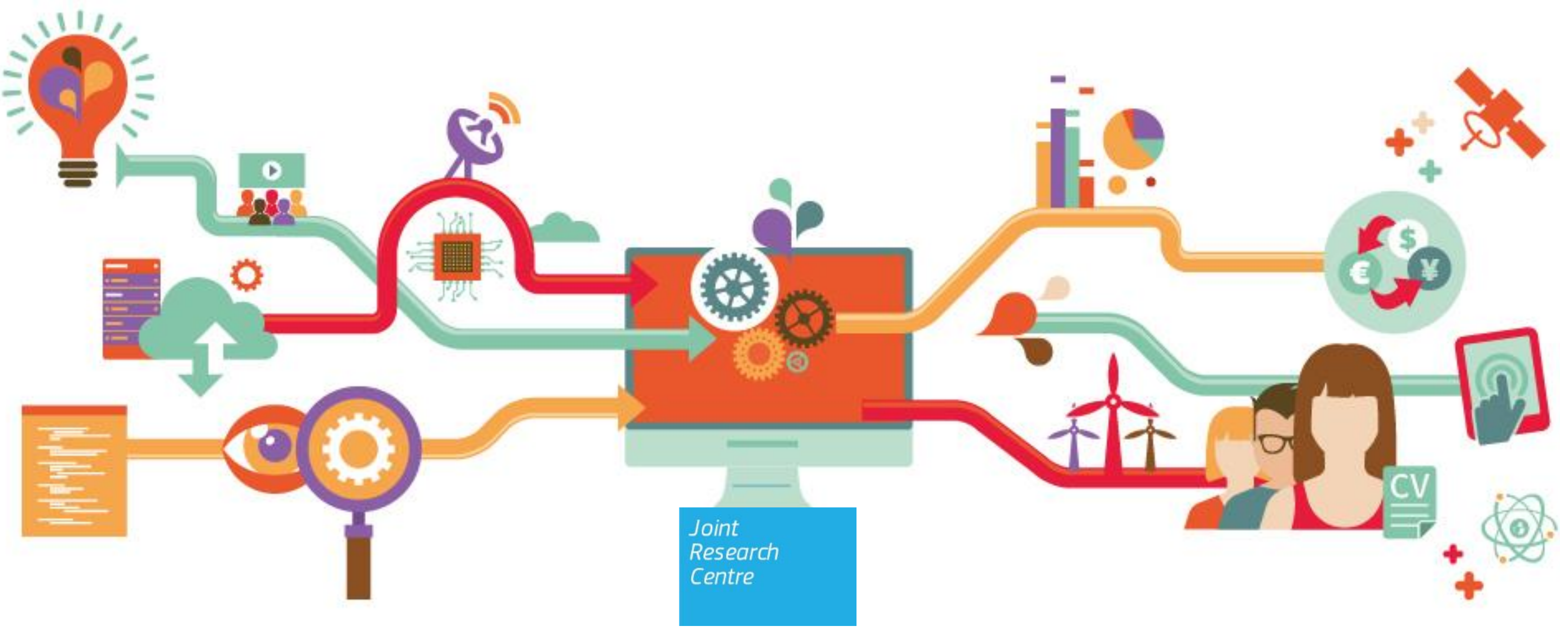

Contact information
Fernando Hervás Soriano
Address: Edificio Expo. c/ Inca Garcilaso, 3. E-41092 Seville (Spain)
E-mail: jrc-ipts-kfg-secretariat@ec.europa.eu
Tel.: +34 954488463
Fax: +34 954488316

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Sector dynamics and demographics of top R&D firms in the global economy

Pietro Moncada-释ernò-Castello [1]

European Commission, Joint Research Centre, Seville, Spain

Abstract

This paper investigates the sectoral dynamics of the major economies during the last decade through the lens of the top 1000 R&D investors worldwide and looks at how firms' demographics are related to sector distribution. In doing so, it contributes to the literature on the EU corporate R&D intensity gap as well as on that on industrial dynamics. Contrary to the common understanding, the results show that in the EU the distribution of R&D among sectors has changed more than in the USA, which has experienced a shift mainly towards ICT-related sectors. In both the EU and the USA the pace of R&D change is slower than in the emerging economies. Furthermore, the EU has been better able than the USA and Japan to maintain its world share of R&D investment. Even more interestingly, the results show that age is strongly related to the sector (and dominant technology) in which firms operate. This suggests that focusing on sector (technological) dynamics could be even more relevant from a policy perspective than focusing only on young leading innovators. In fact, EU firms are less able to create or enter new high-tech sectors in a timely way and fully exploit the growth opportunities offered by first mover advantages.

Keywords: Corporate R&D, sector dynamics, firms' age, EU R&D intensity deficit

JEL Classification: O30; O32; O38; O57

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1. Introduction

One of the important factors undermining European competitiveness is the modest capacity of EU firms to profit from the opportunities offered by the technological change and exploit them by creating (or rapidly entering) new sectors and markets. This weakness of the EU economic system has resulted in a rather static industry sector dynamics in the last decades compared with major competing economies (Hölzl *et al*., 2011; Jorgenson and Timmer, 2011; Pianta, 2014). However, despite the importance in the policy agenda[2], some aspects of the relationship between innovative firms' demographics, technological development and industrial dynamics have been not yet fully analysed.

Alongside the investigation of whether (or not) differences in the structure of the economy or in firms' engagement in R&D determine the EU R&D investment gap, many contributions have considered firms' demography, size and dynamic (capacity for rapid growth) as key factors influencing this deficit (e.g. Bartelsman *et al*., 2005; O'Sullivan, 2006). However, despite its relevance, and although some contributions discuss the growth of R&D-intensive firms and their demographic profiles (García-Manjón and Romero-Merino, 2012; Cincera and Veugelers, 2013; Ciriaci *et al*., 2014), little attention has been given to the relationship between *sector specificities* and firms' age and how these specificities could influence our understanding of the R&D intensity gap.

In this paper we analyse the R&D sectoral dynamics in the major world economies and the relationship between sectoral distribution and the age of firms.

For the empirical application, we use nine editions of the EU Industrial R&D Investment Scoreboard (covering the 2005-2013 period) considering the top 1000 R&D investing companies worldwide (accounting for more than 80% of global private R&D expenditure)[3]. Starting from this micro-level dataset, we aggregate data to investigate the evolution of R&D investment in a given country and compare it with the overall world trend. We also analyse how change in R&D investment across sectors differs in different countries, as well as their relative sectoral composition (i.e. their sectors' R&D specialisation).

Furthermore, we examine how (if) sector (and country) characteristics favour the presence of different age classes of R&D-intensive firms.

We do so by first investigating the change in R&D investment distribution across sectors, identifying the sectors that account for the greatest changes in R&D investment in the economies considered, as well as the comparative evolution of corporate R&D specialisation. We then scrutinise the sector characteristics and the age of firms, with the aim of identifying if the age (calculated from the year of their establishment) of top R&D firms varies according to the industrial sector in which they operate.

Our contribution complements the literature in three main aspects. First, we discuss country specificities in the change of R&D investment across sectors and the resulting R&D sector specialisation. By doing so, we disentangle the technological transformation paths (if

[2] The Europe 2020 strategy and follow-up initiatives such as the 'Innovation Union' and the 'Industrial policy for a globalisation era' are flagship initiatives. Many of these initiatives are based on Article 173 of the Lisbon Treaty, which states that 'The Union and the Member States shall ensure that the conditions necessary for the competitiveness of the Union's industry exist.'

[3] Based on European Commission (2014), p. 15, footnote 3.

any) of major knowledge-intensive economies, uncovering their strengths and specificities (e.g. Gambardella *et al.*, 2007; European Commission, 2010; Foray and Lhuillery, 2010). The findings of this study indicate that distribution of R&D among sectors has changed more in the EU than in the USA, which has specialised even more in ICT sectors.

Second, new to the literature, our results show that the EU's share of private R&D investment by the top R&D firms worldwide has been stable over the last decade, even during the financial crisis, and that the EU experienced appreciable sectoral R&D dynamism compared with the USA. However, the pace of change in the Triad economies (the EU, Japan and the USA) has been slower than in the emerging economies.

Third, we investigate whether there is a substantial difference in the demographics of innovative companies among world regions/countries. This is linked to the question whether firm demographics matters in determining the sector R&D intensity gap (e.g. between the EU and the USA, as in Cincera and Veugelers, 2013). The extent to which *sector specificities* have a role in determining firms' demographics may help us to understand the importance of targeting new/emerging knowledge-intensive sectors whose growth potential is not fully exhausted. Our findings reveal that the structural (sectoral) R&D composition affects firms' age, and complement the recent literature on R&D intensity and firms' demographics by providing a novel perspective. The weakness of the EU private R&D system seems to be mostly related to its relative inability to enter (or create) new industries in the first development phase. This may be unsustainable in the long run because of its adverse consequences on EU knowledge capacity and economic competitiveness.

The remainder of the paper is structured as follows. Section 2 introduces the literature on innovative sector dynamics and the role of R&D-intensive firms' demographics in the EU R&D intensity gap dynamics. Section 3 describes the dataset and variables used. Section 4 provides the analytical results, and section 5 concludes.

2. Theoretical background

The literature addressing innovative firms' behaviour and structural economic characteristics, and the role of these factors in R&D investment (especially the distribution of private R&D investment across sectors), is quite extensive, and attempts to explain the reasons for the corporate R&D intensity gap between the EU and the USA and Japan. Until now most of the attention has been focused on the fact that European firms specialise in high-tech sectors to a relatively low extent, compared with the USA in particular, and the role played by the specific characteristics of firms, such as size and age.

This paper contributes to the literature by addressing the issue from a slightly different perspective. First of all, we explicitly examine the industrial dynamics (changes in sector composition), technical changes and competitiveness of the main world knowledge-based economies (and emerging ones) through the lens of the top corporate R&D investors worldwide. Second, we assess to what extent industrial change and the resulting sector composition contribute in explaining firms' demography (age). In doing so, we show that the recent emphasis on the role of the age of innovative companies can be restated from a technological (sector) perspective. The existing literature related to these research themes is introduced in the following three subsections.

2.1 Technical change, industrial dynamics and specialisation for competitiveness and growth

Starting from the Schumpeterian theory that entrepreneurship and technical change are at the core of the economic growth process, more recently evolutionary economists (Krüger, 2008; Dosi and Nelson, 2010) have demonstrated that technological development and innovation capability are important drivers of the evolution of the industrial structure. According to these economists, knowledge accumulation and diffusion (the introduction and use of new technologies and products) represent the main elements determining the development of abilities across firms and the evolution of industrial structures as a whole. This evolutionary process implies a continuous shift of resources from older industries to the new emerging ones (Dosi and Nelson, 2010), the rate and the direction of technological change being determined by the specific characteristics of the industrial and economic structure of the system at each point in time and by their changes (Antonelli, 2014). However, the idea that changes in dominant technological systems influence the behaviour of the entire economy has already been discussed by Perez (1985, 2002, 2009). Perez coined the term 'techno-economic paradigms' to describe such changes, which are connected with the Schumpeterian idea of creative destruction.

Today, in the new technological landscape, the sources of invention (discovery of new potential output) and innovation (production and commercialisation of new products and services) are not necessarily located in the same country, new technologies (e.g. in ICTs) find applications in multiple sectors, and no single country or company can dominate the full value chain. In this new 'multipolar paradigm', demand is expanding in large emerging economies, which provide the locations for production, innovation, branding and other activities (Abdulsomad, 2014; Hirst *et al.*, 2015). In this context, countries and firms can choose to deploy different R&D and innovation strategies to enhance their economic performance; these strategies range *from radical to incremental innovation* depending on the distance from the technological frontier and the maturity of the industries (Lundvall, 2010; Acemoglu *et al.*, 2012; Hölzl and Janger, 2014). The relevance of R&D and innovation output coming from all industries, including low-tech ones, has also been emphasised by Peneder (2003) and Andries *et al.* (2015). The latter authors put particular importance on *structural upgrading*, an improvement in firms' innovation/economic performance that does not necessarily require a change in the overall composition of its economic activities[4]. In this framework, what really matters for growth and competitiveness is not increasing specialisation itself, but the ability to exploit areas of technological opportunity.

2.2 Sectoral changes, sector specialisation and differences in corporate R&D investment

Pakes and Shankerman (1984), Erken and van Es (2007) and Baker and Hall (2013), among others, having studied the relationship between the composition and dynamics of industrial sectors and their aggregate corporate R&D intensity, have theorised that this relationship is determined by the market size and demand, the R&D/innovation appropriability and the technological opportunities. The existence of these effects has been empirically proven by

[4] *Technology absorptive capacity* is a key element affecting how incumbent firms in established sectors perform in the face of the emergence of (new) radical innovations. A strong capacity can generate the technological transformation of firms and favour the positive evolution process of an entire industry (Begg *et al.*, 1999; Zahra and George, 2002; Hill and Rothaermel, 2003; Chang *et al.*, 2012).

several scholars, such as Sachwald (2008), Matthieu and Van Pottelsberghe (2010) and Moncada-Paternò-Castello (2016a), who found that the R&D intensity gap between the EU and the USA, Japan and other countries can be attributed to more modest specialisation of European firms in high-R&D-intensity sectors.

The different pace of *industrial structural change* in Europe compared with the USA during the 1980s and 1990s has been documented, for example by Gambardella *et al.* (2007) and Moncada-Paternò-Castello (2010). However, in the last two decades the greatest structural changes in industrial R&D in the USA have occurred towards a particular set of new industries and services (European Commission, 2010; Timmer *et al.*, 2011). In 2009, Mowery showed that the structure of USA industrial R&D has considerably changed over a period of 30 years. This finding has been confirmed by other authors; for instance, Foray and Lhuillery (2010) found that corporate R&D underwent a considerable change in structure between 1985 and 2005 in the USA, but to a much lesser extent in Europe.

Hypothesis H1: R&D investment in the EU does not show appreciable dynamism compared with the other Triad economies and emerging countries, especially in R&D-intensive sectors.

Empirically, many studies support the idea that robust sectoral dynamics and different patterns of *specialisation*, generally coupled with high product quality and/or high R&D intensity, are prerequisites for the growth of firms and the increased competitiveness of economies (Peneder, 2003; Janger *et al.*, 2011; Krafft *et al*., 2014). Gambardella *et al*. (2007), Mowery (2009) and Agrawal *et al.* (2015) point out that the markets for (new) technologies are generally less efficient and more difficult (in terms of economic and financial performance, survival) than more established markets, and this is a matter of concern, especially when considering new high-tech sectors. A main shared conclusion of these literature sources is that economies that are able to move towards more high-tech sectors may perform better in terms of corporate R&D intensity than those that do not.

2.3 Firms' demographics, sector composition and corporate R&D performance

A stream of the economic literature investigates the demographics (size and age) of innovative firms in relation to their growth behaviour, while a smaller number of studies focus on the association between sector characteristics and the age of innovative firms.

The theoretical ground was originally set by Gibrat's 'law of proportionate growth' (Gibrat, 1931), which hypothesises that a firm's growth is independent of its size and driven only by idiosyncratic events (Bottazzi *et al.*, 2011). However, according to Schumpeter's Mark I theory (Schumpeter, 1934), the positive influence of *new* firms on economic growth can be described as 'creative destruction' —, new firms introduce innovations into the market in order to put pressure on, and displace, the incumbents. Schumpeter's Mark II theory (Schumpeter, 1942), in contrast, defines a system of 'creative accumulation'[5], in which incumbents have a greater tendency to introduce innovation in the market. Arrow (1962) and Jovanovic (1982) further extend this theoretical setting by arguing that a firm's growth

[5] In this system, *economies of scale* apply: large firms are the most effective at exploiting and internalising the tacit and cumulative features of technological knowledge (Cohen and Klepper, 1996; Love *et al*., 1996).

depends on its age, and this relationship very much depends on entrepreneurs' ability to learn over time[6].

Hence, the factors theoretically responsible for firms' growth are controversial and subject to debate, because multiple models exist and, depending on the barriers to entry and the market (sector) structure in a particular industry, one model can be more prominent than others (Audretsch *et al*., 2014). A survey by Santarelli *et al.* (2006) confirms this view. The authors conclude that studies that focus not only on size but also on firms' age as a determinant of growth cannot either validate or reject Gibrat's law as the results strongly depend on the *industrial sector* analysed.

Furthermore, the effects of age on firms' growth behaviour have in other studies been found to depend on the baseline level of growth and on the *business cycle*: less concentrated industries, industries with fewer sunk costs and industries in the early stages of the life cycle favour the appearance of new (young) small innovative firms (Utterback, 1996; Malerba, 2004; Fort *et al.*, 2013; Audretsch *et al*., 2014). That the age of firms plays a key role in growth rates and the emergence of new firms has been indicated by Haltiwanger *et al*. (2013), who emphasised that is important that theoretical models and empirical analyses focus on the start-up process — both the entry process itself and the subsequent post-entry dynamics.

Within this stream of the literature, a few studies have investigated the extent to which differences in the age distribution of firms and differences in sectoral composition account for aggregate differences in corporate R&D intensity between economies. Only recently, Cincera and Veugelers (2011, 2013) incorporated the age distribution of top R&D-investing companies into the EU–US R&D intensity gap framework, and found that the gap is largely driven by differences in firms' age and in sectoral composition. In particular, they show that young leading innovators in the USA are more R&D intensive as they are more likely to be active in (young) R&D-intensive sectors, such as biotechnology and the internet. The reason for the low dynamism in knowledge-intensive sectors in the EU appears in part to be the limited capacity of European countries to create *new* enterprises in promising sectors and to support high start-up rates and growth phenomena in R&D-intensive sectors, thus exploiting in full the *first mover advantage* (Stam and Wennberg, 2009; Coad and Rao, 2010). Similarly, Bartelsman *et al.* (2005) conducted an analysis of firm dynamics at country level and found that *post-entry performance* differs markedly between Europe and the USA; US firms tend to perform better than their European counterparts, which may be indicative of barriers to firm growth as opposed to barriers to entry. O'Sullivan (2007) pointed to the lack of growth of new technology-based firms in the EU as one of the causes of the EU R&D intensity deficit.

Hypothesis H2: Structural composition affects the age of top R&D firms in a given economy, i.e. a higher share of high-tech sectors is associated with the presence of younger, R&D-intensive, firms.

6 With time, young and inexperienced firms learn about their efficiency level with certainty, and this could reduce the variance in their growth rate (Navaretti *et al*., 2014).

In summary, despite its relevance, there is still a lack of empirical literature addressing the association between the characteristics (i.e. size and age) of top R&D investors and sector features and dynamics when analysing the evolution of the EU R&D intensity gap relative to the USA and other major world regions. This article aims to fill this gap by providing new evidence to feed the policy discussion on the need to support innovative firms and reduce the EU R&D intensity deficit in a context of technological change and industrial dynamics.

In particular, we first investigate country specificities in the change in R&D investment across sectors during the last decade. Specifically, we are interested in uncovering the R&D sector specialisation of countries and the extent to which sector dynamics and specialisation differ among main economies. Second, we examine how (if) sector characteristics favour the presence of old versus young R&D-intensive companies, and how EU firms' demographics compare with those of US firms in key technological sectors.

3. Data

The analysis utilised data from nine editions of the EU Industrial R&D Investment Scoreboard (2006-2014). However, the structure of the data sampled changed over this period. The 2006 edition included information on the top 1000 R&D investors in the EU and the top 1000 non-EU investors. The sample size gradually increased over time such that the 2014 edition included the top 2500 R&D investors worldwide. For this reason, our analysis is focused on the top 1000 R&D investors worldwide, as reported in each of the Scoreboard editions considered[7].

A possible limitation of the analysis is the fact that many R&D-investing companies in a given country do not reach the threshold of R&D investment to enter the top 1000 top ranking. However, these companies altogether represent a small fraction of R&D investment compared with the group of 1000 top R&D investors. Therefore, although the sample may be unrepresentative when considering relatively small countries, the aggregation used in the following analysis (as will be discussed later) rules out this type of problem.

For each firm included, the EU Industrial R&D Investment Scoreboard records the country where the headquarters is located (we refer to this when considering the location of companies), R&D investment, net sales, number of employees and industrial sector in which the company operates (following the Industrial Classification Benchmark (ICB)). The advantages and limitations of these data have been broadly discussed in the recent literature (Cincera and Veugelers, 2013; Moncada-Paternò-Castello, 2016b). We supplement the information in the EU R&D Scoreboard by age of companies (the year of foundation), which we obtained from different sources[8]. The main sources of this additional information are companies' annual reports and other publicly available official documents and the ORBIS database (Bureau Van Dijk).

[7] As mentioned in the introduction, and based on European Commission (2014), p. 15, footnote 3, these 1000 firms represent, on average, 81% of the global private R&D expenditure in R&D during the period considered.

[8] Age data were first collected for firms listed in the 2008 edition of the R&D Scoreboard and published in Cincera and Veugelers (2013). Subsequently these data were expanded and completed by the author.

The analysis focuses on the distribution of companies in terms of number, size, R&D investment and age, paying particular attention to a selected group of high-R&D-intensity sectors: 'Pharmaceuticals and biotechnology',' Software and Computer Services', 'Technology Hardware and Equipment, 'General Industrial', 'Automobiles and Parts', 'Chemicals' and 'Electronic and Electrical Equipment'. These sectors account for more than 75% of total R&D investment in each of the EU R&D Scoreboard editions.

Information on the sector grouping by sector average R&D intensity levels can be found in Box 1 of the Annex and descriptive statistics of the dataset for sectors (R&D investment and relative shares) and firms' demographics (age, number, R&D investment and size) are reported in Table A1. Table A1 also shows the representativeness of each country/region in terms of R&D with respect to the total R&D of the global 1000 top R&D investors[9].

The dataset used in this study (apart from section 4.4) comprises pooled data variables collected for several statistical units (i.e. firms) at different points in time (years) during the time frame 2006-2013. Such statistical units in fact are not always the same, as the composition of the 1000 top R&D-investing companies slightly differs from one EU R&D Scoreboard edition to another.

When using the EU R&D Scoreboard data, a number of factors should be taken into account in interpreting figures. In particular, information is nominal and expressed in euros using the exchange rate as of 31 December each year. However, as the purpose of this study is - to monitor the evolution of the R&D investment not in monetary terms, but in the change of R&D shares between sectors and countries, possible trends due to inflation are ruled out[10].

Furthermore, the growth in corporate R&D investment (and firm size) can be organic, due to acquisitions, or a combination of the two. Finally, the terms 'EU company', 'US company' or others are used throughout this paper to refer to the country (or region) where a firm's headquarters is located.

4. Empirical analysis

4.1 Sectoral R&D changes

When analysing the industrial dynamics of different economic areas it is important to consider how the distribution of R&D among sectors changes over time and the extent to which R&D investments are directed towards new, possibly more R&D-intensive, industrial sectors (or continue to be cumulatively concentrated in the same ones). We call this process of change in the R&D investment across sectors 'R&D shift'. In presence of a strong R&D shift, R&D investments (and related competencies) are moved from one set of industries to

9 The disaggregation of R&D investment by each country within EU sample in 2013 with respect to the total R&D investment of the top 1000 global R&D investors for the same year is as follows: 11.7% Germany, 5.5% France, 4.2% UK, 2.5% The Netherlands, 1.7% Sweden, 1.7% Italy, 0.9% Finland, 0.8% Spain, 0.7%.Ireland, 0.6% Denmark, and other EU countries 0.6%.

10 See, for example, García-Manjón and Romero-Merino (2012), Brossard *et al*. (2013) and Hernandez *et al*. (2013), all of whom use data from several EU R&D Scoreboard editions, or the approach used in Eurostat (2015).

another; in the presence of a low R&D shift, specialisation profiles tend to be stable over time, reflecting high levels of cumulativeness, but possibly a lower capacity to grasp (new) technological opportunities.

We therefore measure the extent to which the R&D profiles of the *i*th economic area change across time by computing the Manhattan distance[11] of the R&D investments (or number of companies) shift across industries over different years (R&D_shift$_{it}$).

There are three main metrics to calculate the distance between two points, which can be derived from the *Minkowski* distance, which calculates the absolute magnitude of the differences between coordinates of two objects/vectors and generalises the *Manhattan*, *Euclidean* and *Chebyshev* distances.

The Minkowski distance, $(\sum_{i=1}^{n} |x_i - y_i|^p)^{1/p}$, becomes the Euclidean distance for $p = 2$, the *Manhattan* distance for $p = 1$ and the *Chebyshev* distance for $p = \infty$ (Kaufman and Rousseeuw, 2009; Kouser and Sunita, 2013; Knippenberg, 2014). Therefore, the lower p, the less relevant is a large difference in a given dimension. The use of the Chebyshev distance is not advised when many dimensions need to be considered, because it ignores the different dimensionality, resulting in a distance based on a single attribute. The *Manhattan* and the *Euclidean* metrics are those commonly used in practice; however, for high-dimensional vectors the *Manhattan* distance is preferred[12]. According to Kaufman and Rousseeuw (2009), *Manhattan* and *Euclidean* metrics are most indicated when the distance reflects 'absolute magnitude' (for example, to identify stocks that have similar mean values). However, Jajuga (1987) and Lee *et al.* (2011) suggest that the usual *Euclidean* distance measure cannot be used to specify the distance between sequences because a sequence consists of ordinal values while the *Manhattan* distance metrics has been used by several authors in innovation studies, e.g. by Lee *et al.* (2011) Wang *et al.* (2013) and vom Stein *et al.*, (2015). In our framework, the *Manhattan* distance could be written as:

$$R\&D\_shift_{it} = \sum_j |s_{ij,t} - s_{ij,t-1}|$$

where $s_{j,t}$ is either the share of R&D expenditures or the share of number of top R&D companies from country/region *i* in sector *j* at time *t*, and $s_{j,t-1}$ is the same share one period earlier. The range of variation of the index is between 0 (no change in the R&D investment profile) and 2 (complete change in the R&D specialisation)[13]. In other words, this index provides the sum of the annual R&D differences between one year and the preceding year for the nine EU R&D Scoreboard editions.

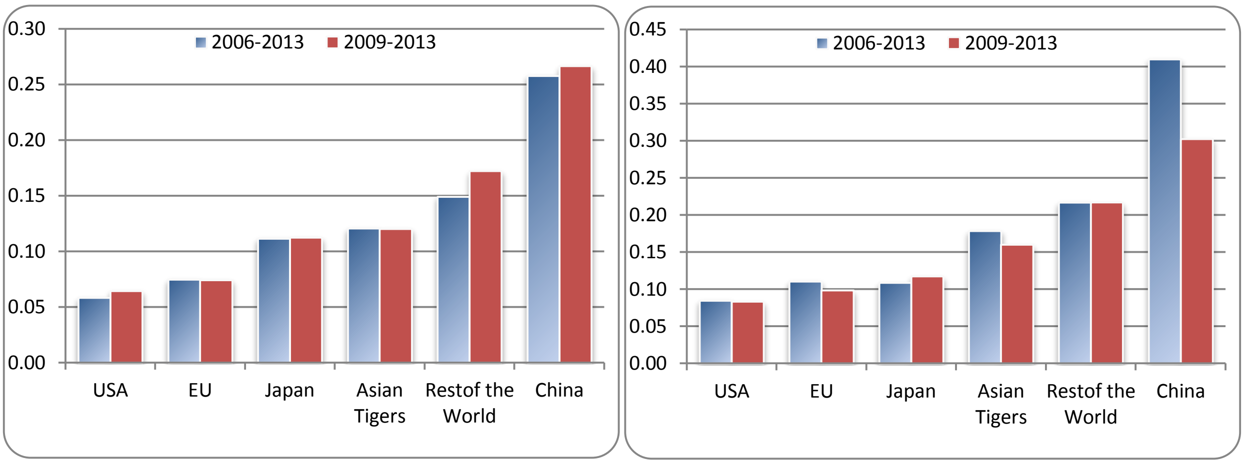
[11] The Manhattan distance between two items is the sum of the differences in their components (Black, 2006).

[12] To better understand the differences between Manhattan and the Euclidean metrics, and their limitations, Knippenberg (2013) provides the following examples. When travelling by plane, the Euclidean straight-line distance (ignoring the earth's curvature) usually gives the best approximation of travelling time. When travelling by taxi in a city, it is necessary follow the streets, and in this case the Manhattan or 'city-block' distance metric is the best approximation of the time taken to travel from one point to another.

[13] For example, consider an economy with two sectors: A and B. If all the R&D (investment or number of companies) is concentrated in sector A in the first period (1.0) and in sector B in the second (0.1), the sum of the absolute differences would be exactly 2. Therefore, this index does not indicate a percentage change.

As companies in the emerging economies were poorly represented in the first editions of the R&D Scoreboards (see Table A1 in the Annex), the average R&D shift was calculated over both the period 2006-2013 and the period 2009-2013. Figure 1 reports the results.

Figure 1: Average annual changes of R&D across sectors (R&D_shift) by economic area: investments (left), number of companies (right), 2006-2013 and 2009-2013; y-axes: R&D_shift index; x-axes: countries



Source: own calculations.

Overall, the shift of the companies' distribution (Figure 1, right) has been higher than the relative change in R&D investment (Figure 1, left); Japan seems to be an exception. The very high shifts shown by China are at least in part determined by its increasing presence among the top R&D investors, and the very small number of companies included in the early years (which were concentrated in one sector). However, the Chinese economy has undergone a profound transformation in recent years. The number of companies in China has increased considerably, due to the privatisation or splitting of public enterprises in the early years of our observation. In addition, it has become more specialised in high-tech sectors; for example, China is now the world's leading producer of solar panels and printed circuit boards and has more semiconductor plants under construction than any other economy in the world (Atkinson and Ezell, 2012).

Top EU and US R&D investors are those presenting the lowest R&D shift values, with the former showing a slightly higher degree of shifting than the latter. The higher performance of the USA compared with the EU in changing its industrial R&D structure in the years mostly preceding 2000, as in the work of Mowery (2009), and even between 1985 and 2005 (Foray and Lhuillery, 2010), does not hold in our sample for the 2005-2013 period. This is probably due to two factors. The biggest structural changes in the USA took place before the millennium as US firms were responsible of the insurgence of the ICT era, with EU companies following (but a slower pace) soon after. Another possible explanation is the use of different methodological approaches by Mowery (2009) and by Foray and Lhuillery (2010)[14]. Finally, especially considering the shift in company distribution, emerging economies show a higher capacity to change their R&D profile.

[14] In particular, the data used in the studies of Mowery (2009) or Foray and Lhuillery (2010), i.e. territorial focused Business Enterprise Expenditure on R&D (BERD) from national statistical offices, could give different analytical results from studies that use data on firms' R&D investment from the EU R&D

R&D shifting *per se* does not tell us anything about the direction of change in the sectoral dynamics that occurred in the economies considered. Therefore, in Table 1 we report, for each economic region, the sectors that experienced the largest changes (positive and negative) in R&D shares with respect to overall R&D investments.

The changes in the distribution of R&D are calculated by comparing the sectoral R&D shares for 2013 with those for 2005; the resulting differences are called 'R&D delta'. Table 1 shows, for each economy, the five sectors that experienced the largest and smallest change in R&D (positive and negative R&D delta respectively), the technological group to which they belong (they are classified according to the average global R&D intensity of the sector; see Box 1 in the Annex for specifications and references) and the average R&D intensity of the sector in the given economy.

'Industrial Engineering', 'Automobiles and Parts' and 'Software and Computer Services' are the sectors that are most represented in the sectors displaying the greatest increases in R&D shares, being in the top five growing sectors in four out of the six economies considered, followed closely by the 'General Industrial' sector (in the top five growing sectors in three out of six economies). This gives us a hint as to which sectors attract most R&D investment in particular countries'. In contrast, 'Electronic', 'Technology and Hardware' and 'Leisure Goods' are among the top five sectors experiencing the greatest decline in R&D share in three out of the six economies considered.

In the EU there has been an increase in the relative share of R&D investment going to the banking sector, but the EU economy has also strengthened its specialisation in the 'Automobiles and Parts', 'General Industrial' and 'Industrial Engineering' sectors. The first two sectors, although classified as medium-high tech, show an average R&D intensity slightly higher than 5%, the threshold for classification as high-tech (the classification is based on global R&D intensity averages — see the definitions and sources in Box 1 in the Annex). On the other hand, the already low proportion of R&D investment attracted by the Technology and Hardware' sector in the EU declined further during the period considered.

Most of the R&D shifting in the US economy occurred in two sectors. The share of total R&D expenditure attributable to the 'Software and Computer Services' sector increased by 6.3 percentage points while, in contrast, the share accounted for by the 'Automobiles and Parts' sector fell by almost 5%. It is notable that the decrease (–2.2 percentage points) in the 'Pharmaceuticals and Biotechnology' sector was mainly driven by companies operating in the 'Pharmaceuticals' subsector.

The Asian countries exhibit considerable differences arise. In particular, the Asian Tigers considerably reduced their share in 'Automobiles and Parts' (–6.1 percentage points) whereas Japan (+2.3 percentage points) and China (+10.8 percentage points) strengthened their specialisation in this sector. A remarkable increase in the 'Construction and Materials' share (+21 percentage points) in China is coupled with an increase in 'Industrial Engineering' (+9.7 percentage points).

Scoreboard, as in the present study — see Moncada-Paternò-Castello (2016b) for more information on these methodological aspects.

Table 1: The five sectors experiencing the greatest changes in R&D shares in the economies considered: 2005-2013

The 5 sectors with the highest increases in R&D shares					The 5 sectors with the highest decreases in R&D shares			
Region	ICB Sector	Tech. Group	R&D Delta	R&D Int.	ICB Sector	Tech. Group	R&D Delta	R&D Int.
Asian Tigers	Leisure goods	High	8.6%	5.5%	Automobiles & parts	Medium/High	-6.1%	1.8%
	Technology & Hardware	High	2.8%	3.6%	Electronic	Medium/High	-4.9%	4.1%
	Industrial engineering	Medium/High	1.0%	0.5%	Mobile telecom	Low	-2.9%	1.6%
	Oil & gas producers	Low	0.9%	0.3%	Electricity	Low	-0.8%	0.9%
	Fixed line telecom	Medium/Low	0.8%	1.6%	Industrial Transport	Low	-0.7%	-
China	Construction & materials	Low	21.0%	1.2%	Oil & gas producers	Low	-55.5%	0.4%
	Automobiles & parts	Medium/High	10.8%	1.9%				
	Industrial engineering	Medium/High	9.7%	2.7%				
	General industrials	Medium/High	2.6%	1.5%				
	Banks	Low	2.3%	2.4%				
EU	Banks	Low	3.0%	2.1%	Chemicals	Medium/High	-2.8%	2.1%
	Automobiles & parts	Medium/High	1.8%	5.5%	Technology & Hardware	High	-2.7%	14.6%
	General industrials	Medium/High	1.6%	5.5%	Leisure goods	High	-2.3%	2.6%
	Industrial engineering	Medium/High	1.6%	4.3%	Electronic	Medium/High	-1.9%	5.0%
	Software & computer	High	1.0%	13.4%	Aerospace & defence	Medium/High	-1.6%	5.8%
Japan	Pharma & biotech	High	5.6%	20.4%	Technology & Hardware	High	-12.0%	5.3%
	General industrials	Medium/High	4.1%	3.7%	Leisure goods	High	-4.8%	8.8%
	Software & computer	High	2.5%	4.7%	Fixed line telecom	Medium/Low	-1.3%	2.3%
	Automobiles & parts	Medium/High	2.3%	4.2%	Electricity	Low	-0.9%	4.8%
	Electronic	Medium/High	1.7%	4.8%	Construction & materials	Low	-0.4%	1.6%
RoW	Software & computer	High	5.2%	10.2%	Pharma & biotech	High	-6.2%	14.8%
	Aerospace & defence	Medium/High	4.8%	8.1%	General industrials	Medium/High	-4.1%	1.7%
	Banks	Low	3.2%	3.0%	Electronic	Medium/High	-2.8%	4.5%
	Oil & gas producers	Low	2.9%	0.4%	Food producers	Medium/Low	-2.3%	1.8%
	Automobiles & parts	Medium/High	2.1%	3.3%	Technology & Hardware	High	-1.6%	10.4%
USA	Software & computer	High	6.3%	12.4%	Automobiles & parts	Medium/High	-4.9%	3.8%
	Industrial engineering	Medium/High	1.1%	3.2%	Pharma & biotech	High	-2.2%	15.8%
	General retailers	Medium/Low	0.7%	3.2%	Leisure goods	High	-1.2%	5.3%
	Electronic	Medium/High	0.6%	4.2%	General industrials	Medium/High	-0.6%	3.3%
	Fixed line telecom	Medium/Low	0.6%	1.2%	Aerospace & defence	Medium/High	-0.4%	3.4%

Source: Own calculation. Note: **Sectors** are classified at the three-digit level according to the International Classification Benchmarking (ICB). The **technology groups** (medium/high/low tech) are groups of industrial sectors classified according to their level of R&D intensity (see Box 1 in the Annex for more information). **R&D delta** values for a country are the result of the differences (percentage increase or decrease) in the sectoral R&D shares compared with the total in that country between 2005 and 2013. The **R&D intensity** values are referred to the year 2013.

Overall, although the USA and the Asian Tigers show the greatest increases in high-tech ICT-related sectors, the only country showing a clear shift towards more R&D-intensive sectors is Japan, where no medium- or low-tech sector experienced an increase in R&D shares. In fact, in Japan, the 'Technology and Hardware' sector (high-tech) experienced a sharp decline in R&D share at the same time as increases in some high/medium-high sectors ('Pharmaceuticals and Biotechnology', 'General Industrial' and 'Software and Computer Services').

Therefore, the modest pace of industrial R&D structural change in Europe vis-à-vis the USA documented in the literature up to the beginning of the millennium (e.g. Malerba, 2005; Gambardella *et al.*, 2007; Moncada-Paternò-Castello, 2010) apparently was not continued in the period considered (2005-2013). These results refute the first part of the research hypothesis H1 for the EU (i.e. 'R&D investment in the EU does not show appreciable sectoral dynamism compared with the other Triad economies and emerging countries …') and confirm the second part of the same research hypothesis (i.e. '… especially in R&D-intensive/high-tech sectors').

4.2 R&D sector specialisation of countries/world regions

The above analyses offer specific information on the changes in R&D distribution across sectors in different economies. To complete the picture, a further analysis was implemented to assess the extent to which these sectoral changes in the R&D distribution affected the relative R&D specialisation of different economies. To measure countries' R&D specialisation in different sectors, we use the Technological Revealed Comparative Advantage (TRCA), as in other studies (Patel and Pavitt, 1991; Mancusi, 2001; Colombelli *et al.*, 2014; Dernis *et al.*, 2015), and computed following Balassa's (1965) Revealed Comparative Advantage (RCA). We use the term R&D Revealed Comparative Advantage (R&D_RCA) index to describe the extent to which a country has a comparative advantage in a given industrial sector when its share of R&D investment in that sector is *higher* than the share of the global (all countries) R&D investment in the same sector.

$$R\&D\_RCA_{ijt} = \frac{P_{ijt} / \sum_i P_{ijt}}{\sum_i P_{ijt} / \sum_{i,j} P_{ijt}}$$

where *Pijt* is the R&D investment in country *i* in the sector *j* and time *t*. *t* refers to the year 2005 or to the year 2013.

Therefore, a value of R&D_RCA index above unity (1) indicates that country *i* is comparatively R&D specialised in sector *j* (ICB-3 digits).

Table 2 presents the results of the computation and allows R&D_RCA indexes of 2013 and 2005 to be compared for the Triad economies (the EU, the USA and Japan). The table does not report the index scores for 2005 for other selected countries/world regions (Asian Tigers, China, Rest of the World) because companies in these regions were poorly represented in the top R&D-investing firms in 2005.

Table 2: Share of R&D investment in a particular industrial sector relative to the share of the global R&D investment in all sectors in different countries/regions (R&D Revealed Comparative Advantage index)

	2005	2013	2005	2013	2005	2013	2013	2013	2013
	EU		USA		Japan		Asian Tigers	China	Rest of the World
Aerospace defence	1.9	1.7	1.0	1.0	0.0	0.0	0.0	0.0	1.6
Alt energy	0.0	2.6	0.0	0.5	0.0	0.0	0.0	0.0	0.0
Automobiles parts	1.4	1.6	0.6	0.4	1.5	1.8	0.5	0.6	0.2
Banks	3.2	2.6	0.0	0.0	0.0	0.0	0.0	1.4	1.9
Beverages	0.0	0.8	0.0	1.1	4.9	2.3	0.0	0.0	0.0
Chemicals	1.3	0.9	0.7	0.8	1.3	1.9	0.1	0.0	1.5
Construction materials	1.1	0.6	0.3	0.2	2.2	0.6	0.0	18.2	0.3
Electricity	1.5	2.2	0.0	0.0	1.9	0.6	3.8	0.0	0.0
Electronic	1.0	0.7	0.2	0.3	1.5	1.8	6.7	0.3	0.2
Finance insurance	2.4	1.7	0.7	0.6	0.0	0.7	0.0	0.0	2.0
Fixed line telecom	1.7	1.7	0.0	0.4	1.8	1.4	1.3	1.2	0.2
Food producers	1.4	1.3	0.2	0.5	0.6	0.6	0.2	0.0	3.6
Food retailers	1.7	3.2	1.2	0.0	0.0	0.0	0.0	0.0	0.0
Forestry paper	1.4	2.3	0.7	0.0	1.4	1.7	0.0	0.0	0.0
General industrials	0.3	0.8	1.6	1.1	0.9	2.0	0.1	0.9	0.3
General retailers	0.0	0.7	2.2	2.2	0.7	0.0	0.0	0.0	0.0
Health care eq	0.7	0.8	1.9	1.8	0.1	0.5	0.0	0.0	0.4
Household goods	0.7	1.2	1.7	1.7	0.4	0.1	0.0	0.0	0.0
Industrial engineer	1.5	1.4	0.7	0.7	0.8	0.7	0.2	2.5	1.3
Industrial metals	1.2	1.1	0.3	0.1	1.6	2.0	2.5	3.2	0.7
Industrial transport	1.7	2.3	0.0	0.0	1.2	0.0	0.0	8.6	0.0
Leisure goods	0.5	0.0	0.4	0.2	3.4	4.2	3.7	0.0	0.4
Media	2.2	2.3	0.3	0.3	0.9	1.1	0.0	0.0	0.0
Mining	0.0	1.0	0.0	0.0	0.0	0.0	0.0	0.0	8.7
Mobile telecom	1.2	1.9	0.0	0.6	0.0	0.0	0.0	0.0	2.3
Oil equipment	0.0	0.4	2.6	1.8	0.0	0.0	1.3	1.0	1.4
Oil gas producers	1.4	0.9	0.6	0.4	0.1	0.2	0.5	7.9	2.9
Personal goods	0.9	1.4	1.0	0.5	0.9	1.4	0.9	0.0	1.2
Pharma biotech	0.9	1.0	1.3	1.2	0.3	0.6	0.0	0.0	2.3
Software computer	0.4	0.4	2.2	2.1	0.1	0.3	0.0	0.0	0.7
Support services	0.5	1.2	1.6	1.1	0.3	0.4	0.0	0.0	2.2
Technology haware	0.6	0.6	1.3	1.6	1.0	0.4	1.4	1.9	0.6
Tobacco	0.2	1.0	1.7	1.0	1.3	2.1	0.0	0.0	0.0
Travel leisure	1.0	0.3	1.2	0.2	0.7	4.1	0.0	2.7	1.3
Utilities	1.7	2.7	0.2	0.2	1.0	0.6	0.0	0.0	0.0

Source: Own elaboration. Note: sectors are at ICB-3 level of specification.

The value of the R&D_RCA index for 2013 (Table 2) reveals that EU firms consolidated their comparative advantage in R&D investment, especially in medium-tech sectors, for example in 'Aerospace and Defence', 'Alternative Energy', 'Automobiles and Parts', 'Banks', 'Electricity', 'Food Retailers', 'Forestry and Paper', 'Media', 'Utilities' and 'Industrial Transport', although the trend with respect to 2005 is not always positive.

In the USA, R&D_RCA values greater than 1 are found in fewer industrial sectors than in the EU, with US companies showing relative specialisation in ICT-related sectors and in the 'General Retailers', 'Household Goods' and 'Oil Equipment' sectors, as well as in other high-tech sectors such as 'Pharmaceuticals and Biotechnology' and 'Healthcare Equipment'.

In 2013, the sector specialisation of top R&D companies in Japan is quite scattered compared with competitors in the Triad economies, being specialised in sectors belonging to different technological groups, such as in 'Leisure Goods', 'Travel Goods', 'Personal Goods', 'Tobacco' and 'Beverages'. On the other hand, the findings confirm that specialisation among the top R&D companies remains comparatively high in the traditional Japanese sectors such as 'Automobiles and Parts' and 'Chemicals'.

Overall, the changes in sector specialisation between 2005 and 2013 have been more positive for the EU than for the other two countries of the Triad economies, especially the USA: the EU has increased its R&D comparative advantage in 12 subsectors, compared with only two in the USA and 11 in Japan. However, between 2005 and 2013 the number of sector specialisations remained the same in the EU, fell in the USA (by two sectors) and increased (by one sector) in Japan. The results shown in this subsection confirm the second part of the first research hypothesis regarding the lack of EU dynamism towards specialising in R&D-intensive/high-tech sectors.

Asian Tigers' R&D specialisation appears to be comparatively strongest in the 'Electronics' (high-tech) and 'Electricity' (medium-high tech) sectors but is also high in other, lower-tech, sectors such as 'Industrial Metals' and 'Leisure Goods'.

The R&D_RCA index for Chinese companies indicates, in particular, a specialisation in sectors related to infrastructure and energy such as 'Construction and Materials', 'Industrial Transport' and 'Oil and gas Producers', besides their specialisation in 'Industrial Metals' and 'Industrial Engineering' (all being low- or medium-tech sectors). The only high-tech sector where Chinese companies show a comparative advantage is the 'Technology Hardware' sector.

Finally, companies in the Rest of the World group show comparative R&D specialisation in the 'Food Producers', 'Mining', 'Mobile Telecom' and 'Pharmaceuticals and Biotechnology' sectors.

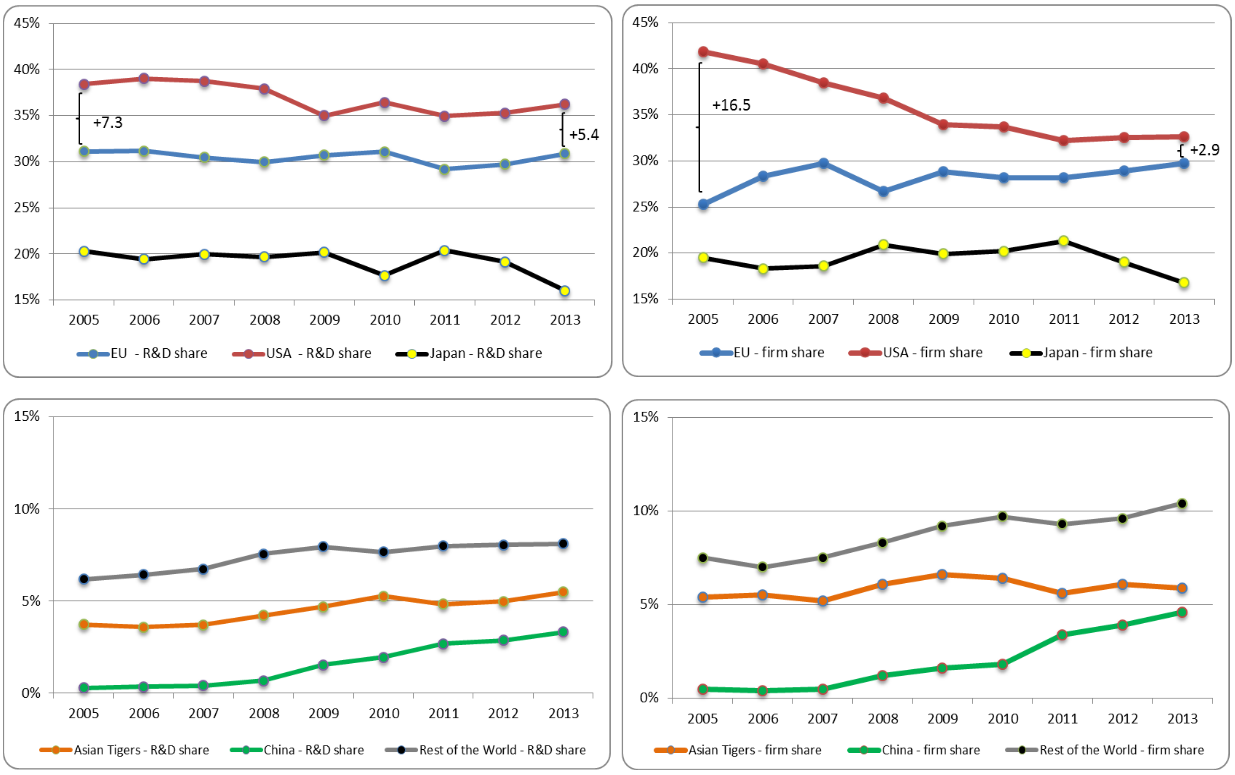
4.3 Country differences in private R&D investment capacity

Giving the sectoral pattern discussed above, the general argument that economies moving towards more R&D-intensive sectors are expected to also increase their overall R&D investment capacity does not seem to provide us with a clear expectation on the relative performances of the economies considered. The low capacity of the EU to move into (new) growing and highly R&D-intensive sectors (Malerba, 2005; Gambardella *et al.*, 2007; Timmer *et al.*, 2011) would suggest a negative trend in EU R&D investments with respect to its major competitors. Figure 2 investigates whether these general arguments apply to our sample of top R&D investors. The figure reports the shares of global R&D investment (left panels) and the shares of companies among the top 1000 R&D investors worldwide (right panels), across time and by economic area.

The different industrial dynamics in the EU and the USA have not resulted in marked differences in their overall R&D investment capacity. Moreover, the EU has slightly reduced the investment gap with respect to the USA, particularly in 2009. In fact, the global economic and financial crisis had a much greater negative impact on the R&D investment of firms in the USA and Japan (US in 2009, and Japan later) than on EU-based firms, which continued to show, overall, a rather steady profile of R&D investment, with only a slight decrease in 2011. This dissimilar R&D investment behaviour in the face of market turbulence may be explained by the different sector composition in the Triad economies. The EU is characterised by mature medium- and low-tech sectors (less R&D intensive) with a high proportion of larger firms, which are less sensitive to economic and financial downturns than new/developing high-tech (higher R&D intensive) sectors with a greater presence of smaller firms, as is the case in the USA (Cincera and Ravet, 2010; Brown *et al.*, 2012; Cincera *et al.*, 2012).

On the other hand, when considering the number of firms, the patterns followed by the two economic areas show important differences (Figure 2, right). In the USA, there was a considerable decrease in the number of top R&D investors over the period under study, whereas the EU slightly improved its global position. At same time, the relative importance of China and the Rest of the World (and, to a lesser extent, the Asian Tigers) increased steadily in terms of R&D investments, and to an even greater extent in terms of number of firms. Overall, this evidence suggests that the USA and Japan suffered more than Europe from the emergence of these new top global R&D players.

Figure 2: Shares by economic area: R&D investment (left) and number of firms (right), 2005-2013



Source: Own elaboration

The considerable decrease in the number of US companies among the top 1000 R&D investors, coupled with a much smaller decrease in their relative R&D investment, suggests that there has been an increase in the average size of US companies. This could be linked with the fact that some new, growing, high-tech sectors in which USA specialises, such as 'Software and Computer Services', came to maturity during this period. In these sectors, in which numerous medium-sized and small firms compete for the emerging market, the industrial dynamics show a turbulent picture, with merger, failures and successes much more marked than in other sectors, and leading to consolidation and the emergence of some big global players (e.g. Google was listed in 2004 and Facebook was launched in the same year).

At the same time, it should be noted that the private R&D investment path in the EU has remained rather stable, even during the years of the financial and economic crisis. This could be due to the EU's capacity to specialise (and become market leaders) in medium/high-tech industries (von Tunzelmann and Acha, 2005). In doing so, the EU has been able to maintain its relative share of R&D investment and to absorb technologies from other sectors. As pointed out by Andries *et al.* (2015), in determining a country's competitiveness, it is not only its structural composition, but also upgrading of innovation within industries (movement of companies and sectors towards higher innovation intensity production) that is important. A good example is the automotive sector: EU companies are market leaders and account for the largest share of R&D investment in this sector as well has having highest R&D intensity of the competing economies, fully exploiting the high technological opportunity from ICTs (Cardona *et al.*, 2013).

4.4 Association between sectors' composition and firms' age

According to the recent literature, young leading innovators ('yollies'), particularly in high-tech sectors, play a pivotal role in countries' R&D performance. Cincera and Veugelers (2013) showed that the lower aggregate R&D intensity of the EU compared with the USA is partly (one-third) because there are fewer young firms in the EU among its leading innovators and in largest part (55%) because R&D intensity of EU 'yollies' is lower than their US counterparts'. In our view, this implies that at least part of the focus put on young leading innovators should be transferred to innovative young emerging sectors ('YES'). In particular, whereas new sectors are almost completely composed of young firms (with the exception of a few established companies that re-orient their core business), the same does not hold for mature sectors. Therefore, a firm's age have to be considered together with the sector in which it operates, at least when considering top R&D-investing companies. If this is true, then age should not be considered the only key target of analysis (especially considering the difficulties in targeting specific young companies and guaranteeing their scale-up) and increasing the creation of new innovative sectors becomes even more relevant.

In the following our aim is to show the extent to which the age of companies is associated with sector and country specificities, rather than to try to analyse the evolution of age within different sectors. Firms' ages have mainly been sourced from their annual reports or websites[15]. The analysis is carried out on the top 1000 R&D investors as reported in the 2014 edition of the EU R&D Scoreboard[16]. We test the above-mentioned associations in a linear regression framework in which country group and sector dummies (at the ICB-4 digit level) are used as right-hand side variables. Table 3 reports the ordinary least squares (OLS) regression results and the analysis of the age variance (at the bottom).

[15] This information has been cross-checked with other databases (e.g. Bureau van Dijk/Amadeus). In particular, we use the very first year of the firms' creation (foundation), that is, *ex nihilo* creation. In the case of a merger or acquisition, the age of the entity acquirer is retained.

[16] We ran the same analysis on previous editions; the results are consistent across different EU R&D Scoreboard samples.

Table 3: Average company age conditional on sector and country (EU R&D Scoreboard 2014).

Relative importance of the two factors from ANOVA.

	Age	
China	-34.46***	
	(8.61)	
EU	25.23***	
	(6.17)	
Japan	31.09***	
	(6.51)	
Rest of the World	11.15	
	(6.97)	
USA	4.58	
	(6.06)	
Sector fixed effects	*Included*	
Constant	40.58***	
	(10.49)	
Observations	1,000	
R-squared	0.291	
F-test	5.139	
RMSE	39.59	
	Part. SS/Tot. SS	*Prob>F*
Country/Region	*9.5%*	*0.000****
Sector	*13.0%*	*0.000****

Standard errors in parentheses. ***p<0.01, **p<0.05. Reported is the p-value of an F-test of joint significance for the sector fixed effects (ICB-4 digit). Country and sector effects are highly significant.

Overall, the value of R-squared value is quite high considering that we use only two sets of binary variables. In particular, we are able to model about one-third of the total age variance in the sample. The result shows substantial differences in the average age of firms across sector and institutional (i.e. country' framework conditions) dimensions. Moreover, sector specificities have a higher explanatory power than country specificities with respect to the average age of firms (the partial sector sum of squares, *SS* in its abbreviation in the Table 3, is about 35% higher than the country one).

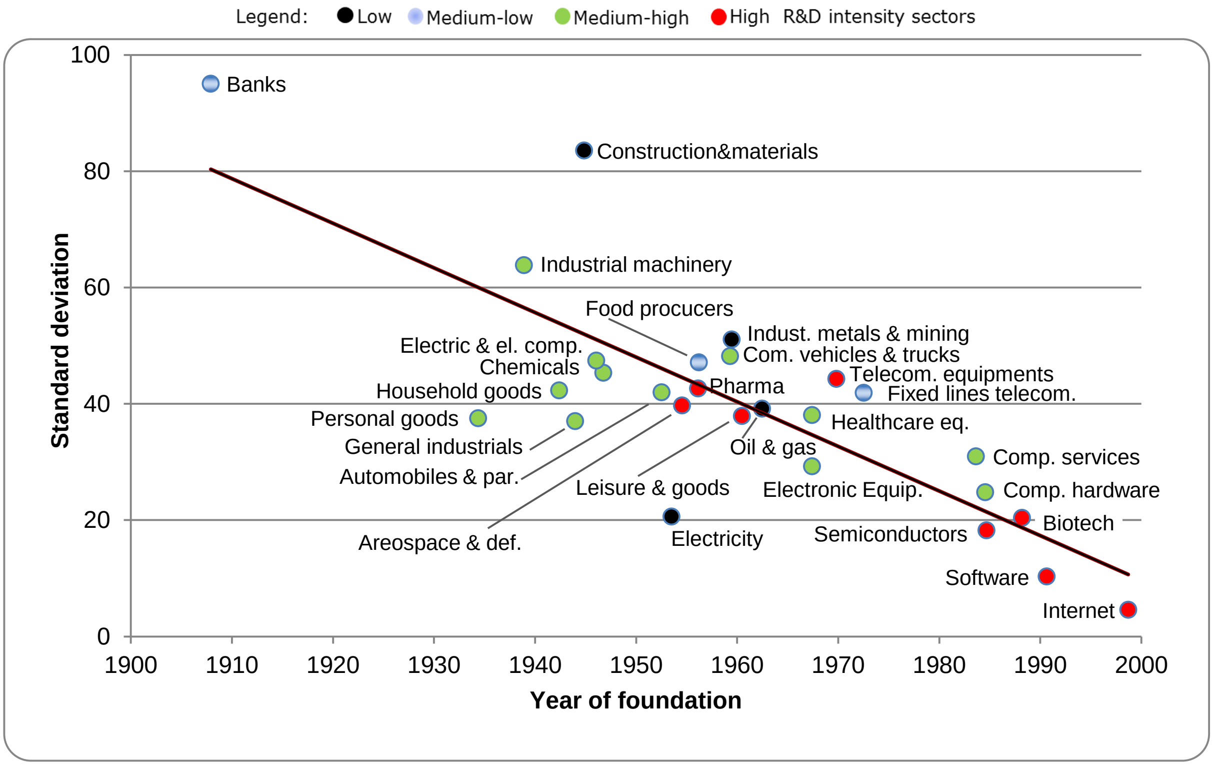
When considering regional/country age differences, Japanese and European companies are 'older' (and not different from each other) than other companies in the sample. The mean age of EU companies, after controlling for sector specificities, is 66.6 years (40.58 + 25.23 years). At the other end of the spectrum are the Chinese companies, which are, by far, the youngest of the sample. This is mainly due to privatisations in the late 1990s and early 2000s, when public companies were reborn as a result of privatisation. US companies and those in other world regions do not seem statistically older than Asian Tiger companies (the baseline; see the constant for the average age)[17]. When comparing companies from different economies, it should be remembered that companies can change their name, become listed

[17] In 2013, the average age of the entire sample of 1000 firms was 51.5 years.

on the stock market or split and merge in different ways. Indeed, US companies are more dynamic than those in other regions in restructuring and changing their business focus[18], especially during times of market turbulence and the appearance of new (more profitable) sectors;[19], Japanese companies, in contrast, tend to be more stable (the terms *zaibatsu* and *keiretsu* are used to describe an inability to evolve because of the huge size of industrial structures in Japan).

The differences found across industrial sectors are exemplified in Figure 3, which helps reveal the importance of sector (technology) for the age of the top R&D investors. The figure reports the sectoral average year of foundation of top R&D investors further disaggregated at ICB-4 digit level for some sectors (horizontal axis) versus its standard deviation.

Figure 3, Average year of foundation of top R&D firms and their variation by sector



Note: only sectors with > 10 firms have been included. EU R&D Scoreboard (2014). ICB sectors in the figure are at 3- or 4-digit levels; details of their ICB sector classifications are shown in Table A2 (Annex).

The figure reveals a high degree of heterogeneity of firms' age across sectors. Moreover, the standard deviation decreases when considering 'younger' sectors.

The 'Internet', 'Software' and 'Biotechnology' sectors are based on relatively recent technologies. In these sectors the average year of top R&D investors is the lowest of the

18 For example, one of the reasons could be, according to Bartram *et al.* (2012), because US stocks are more volatile than stocks of similar foreign firms. Specifically, stock volatility is higher in the USA because it increases with investor protection, stock market development, new patents and firm-level investment in R&D. Each of these factors is related to better growth opportunities for firms and better ability to take advantage of these opportunities.

19 See also Audretsch and Welfens (2013).

sample considered; the same holds true for the standard deviation of firm age. On the other hand, the 'Banks' and 'Industrial Machinery' sectors combine high values of average firm age with high within-sector heterogeneity (more details can be found in Table A2 in the Annex). Observing the sectors with the younger average years of foundation in Figure 3, three considerations stand out: (i) in all of these sectors R&D intensity is 4% or above; (ii) all of the sectors are ICT related (including a large part of the Healthcare Equipment' sector), except 'Biotechnology'; and (iii) the four youngest sectors are all highly R&D intensive, which may suggest that the knowledge and technology frontier of competing firms has moved forwards and, therefore, they need to invest more intensively in R&D.

This result confirms and further specifies the second research hypothesis (H2: Structural R&D composition affects the age of top R&D firms in a given economy). In other words, the results suggest that the EU R&D gap is not because there are fewer young firms in the ICT sectors in the EU, but because the younger R&D-intensive sectors (ICT-, and especially internet-, related and Biotechnology) are smaller in the EU, being dominated by the early-entrant and subsequently growing US companies.

These research findings are in line with the theory of the evolutionary industrial dynamics, which asserts that there is a continuous shift of resources from older industries to new, emerging ones (Kruger, 2008; Perez, 2009; Dosi and Nelson, 2010). In particular, only a small number of firms are able to successfully pass through the maturity phase of the sector, when profitability increasingly depends on improvement in productivity, thus leading to an increase in sectoral concentration. Most top R&D investors are already present in a sector when the underlying technologies are in the initial development stage. These dynamics show patterns similar to those contemplated by the theoretical and empirical foundations of entrepreneurship, new firms dynamics and economic competitiveness (Symeonidis, 1996; Bosma and Levie, 2010; Teruel and de Wit, 2011), which indicate the key role of entrepreneurship, creativity and the flexibility of new/young firms to create/early enter, compete and grow in new knowledge-intensive sectors.

5. Conclusions

This paper provides a fresh analysis of the sectoral dynamics of the major economies over the last decade through the lens of the top 1000 R&D investors worldwide. Moreover, it also looks at how firms' demographics are related to sector distribution. In doing so, we indirectly complement the literature on the EU corporate R&D intensity gap. In particular, our results show that the age distribution of firms is strongly related to the structural composition of the economy in which they operate.

We acknowledge that the analysis could have some limitations, especially when considering top R&D companies from the Asian Tigers and China, because these regions are less represented in the earliest editions of the EU R&D Scoreboards. Nonetheless, the study has provided novel and solid evidence related to firms of the Triad economies and, in particular, has shown that from 2005 to 2013 the shift of R&D firms' distribution across sectors was greater than the relative change in their R&D investment.

In contrast to previous studies focusing on the 1980s and 1990s, we find that R&D shift between sectors was slightly higher in the EU than in the USA during the study period 2005-2013. This is even more pronounced when considering the number of firms active in different sectors. However, in both economies the pace of change was slower than in the emerging economies. Furthermore, this study shows that in the EU R&D specialisation covers a wide range of sectors, a trend that continued in the last decade; the picture is different in the USA, where specialisation focuses on ICT-related sectors.

Furthermore, this study reveals that the EU corporate R&D investment effort remained stable over the last decade, even during the financial crisis: considering the total R&D investment by the top 1000 R&D firms worldwide, the EU R&D investment share gap relative to the USA has even been reduced.

The results of the investigation also suggest that it is mainly the typology of sectors (as well as country specificities) that determine the average age of firms and the sectoral dynamics. This result should be viewed alongside the findings of Cincera and Veugelers (2013) that most of the EU R&D investment gap with respect to the USA is due to differences in sectoral composition in the two regions and a shortage of young leading innovators in the EU. Our analysis suggests that the EU has exhibited follower behaviour in new high-intensive sectors, such as software and internet services, in contrast to the USA, which has led in these sectors since the beginning. In other words, we highlight the key role of young innovative firms when new markets emerge and how this impacts the dynamics of high-R&D-intensity sectors.

Although descriptive in their nature, some possible implications for research and innovation policy can be drawn from our results. First, policies should consider also identifying and targeting new promising R&D-intensive sectors (potentially more risky), favouring entrepreneurship in these sectors with the aim of increasing the number and size of new/young EU firms operating in these sectors. This would raise the probability that the "champions of tomorrow" will be European companies, ensuring in turn a better sector mix and dynamics. Therefore, part of the policy focus should be on creating the conditions needed for the emergence of "young innovative emerging sectors" ('YES') along with the traditional focus on young innovative firms independently from the sector in which they operate.

In other words, the economic and policy focus should be not only on creating a sufficient number of knowledge-intensive firms, but also an environment that favours the birth and success of firms in new strategic high-tech sectors. Finally, policy strategies can also consider the comparative R&D advantage of the EU companies in the medium-tech sectors as well as the role that these sectors play in the economy.

Overall, the structural shift towards high-R&D-intensity sectors should not be pushed with the sole goal of increasing R&D intensity at the aggregate level. In fact, what really matters is the competitiveness of firms and their capacity to turn innovation into value added. The open question is whether the present European industrial R&D and competitiveness model is sustainable in the long run.

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ANNEX

Box 1. Grouping of industrial sectors according to R&D intensity of the sector worldwide (ICB-3):

High R&D intensity *sectors (R&D intensity above 5%) include, for example, Pharmaceuticals and Biotechnology; Health Care Equipment and Services; Technology Hardware and Equipment; Software and Computer Services; Aerospace and Defence; Leisure Goods.*

Medium-high R&D intensity *sectors (between 2% and 5%) include, for example, Electronics and Electrical Equipment; Automobiles and Parts; Industrial Engineering; Chemicals; Personal Goods; Household Goods and Construction; General Industrials; Support Services.*

Medium-low R&D intensity *sectors (between 1% and 2%) include, for example, Food Producers; Beverages; Travel and Leisure; Media; Oil Equipment, Services & Distribution; Electricity; Fixed Line Telecommunications.*

Low R&D intensity *sectors (less than 1%) include, for example, Oil and gas Producers; Industrial Metals and Mining; Construction and Materials; Food and Drug Retailers; Industrial Transportation; Mining; Tobacco; Gas, Water and Multi-utilities; Banks.*

Source: European Commission (2014); OECD (1997) approach

Descriptive Statistics

Table A1. R&D investment, number of companies and their shares in the top 1000 R&D investors by regions/countries (2005-2013) - monetary values in € million

R&D investments of top 1000 companies									
region_analysis	2005	2006	2007	2008	2009	2010	2011	2012	2013
Asian Tigers	12118	12572	14155	17137	18442	21530	22952	24948	26944
China	984	1254	1563	2806	6031	7961	12727	14437	16262
EU	100981	108984	116324	121818	120667	127156	138392	148899	151525
Japan	65789	67959	76184	79924	79226	72184	96495	95808	78581
Rest of the World	20083	22517	25730	30753	31192	31298	37850	40326	39826
USA	124639	136428	147777	154159	137614	149018	165724	176778	177821
Total	**324594**	**349715**	**381733**	**406596**	**393172**	**409147**	**474142**	**501196**	**490958**
Share of R&D investments of top 1000 companies									
region_analysis	2005	2006	2007	2008	2009	2010	2011	2012	2013
Asian Tigers	4%	4%	4%	4%	5%	5%	5%	5%	5%
China	0.3%	0.4%	0.4%	0.7%	2%	2%	3%	3%	3%
EU	31%	31%	30%	30%	31%	31%	29%	30%	31%
Japan	20%	19%	20%	20%	20%	18%	20%	19%	16%
Rest of the World	6%	6%	7%	8%	8%	8%	8%	8%	8%
USA	38%	39%	39%	38%	35%	36%	35%	35%	36%
Total	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**
Companies in the Top 1000									
region_analysis	2005	2006	2007	2008	2009	2010	2011	2012	2013
Asian Tigers	54	55	52	61	66	64	56	61	59
China	5	4	5	12	16	18	34	39	46
EU	253	283	297	267	288	282	282	289	297
Japan	195	183	186	209	199	202	213	190	168
Rest of the World	75	70	75	83	92	97	93	96	104
USA	418	405	385	368	339	337	322	325	326
Total	**1,000**	**1,000**	**1,000**	**1,000**	**1,000**	**1,000**	**1,000**	**1,000**	**1,000**
Share of Companies in the Top 1000									
region_analysis	2005	2006	2007	2008	2009	2010	2011	2012	2013
Asian Tigers	5%	6%	5%	6%	7%	6%	6%	6%	6%
China	0.5%	0.4%	0.5%	1%	2%	2%	3%	4%	5%
EU	25%	28%	30%	27%	29%	28%	28%	29%	30%
Japan	20%	18%	19%	21%	20%	20%	21%	19%	17%
Rest of the World	8%	7%	8%	8%	9%	10%	9%	10%	10%
USA	42%	41%	39%	37%	34%	34%	32%	33%	33%
Total	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**

Note: R&D investment are reported in million euro.

Table A2. Year of foundation of Top R&D companies by subsector (4-digits, unless specified differently; year 2013)

Related ICB 3-digit sector	R&D intensity group	ICB 4-digit sector (unless otherwhise specified)	Year of foundation			No of firms	R&D intensity
			Average	SD	Median		
Pharmaceuticals and Biotechnology	H	**Biotechnology**	1988	20.4	1993	30	23%
Technology Hardware and Equipment	H	**Semiconductors**	1985	18.3	1989	72	17%
Software and Computer Services	H	**Software**	1991	10.3	1992	52	15%
Pharmaceuticals and Biotechnology	H	**Pharmaceuticals**	1956	42.7	1964	70	14%
Software and Computer Services	H	**Internet**	1999	4.6	1999	13	13%
Technology Hardware and Equipment	H	**Telecommunications Equipment**	1970	44.3	1991	39	11%
Leisure Goods	H	**Leisure Goods (ICB 3)**	1960	37.9	1968	19	8%
Software and Computer Services	H	**Computer Services**	1984	31	1997	21	6%
Aerospace and Defence	H	**Aerospace and Defence (ICB 3)**	1955	39.8	1960	33	5%
Electronics and Electrical Equipment	M-H	**Electronic Equipment**	1967	29.3	1974	53	5%
Health Care Equipment and Services	H	**Health Care Equipment and Services (ICB 3)**	1967	38.1	1977	43	4%
General Industrials	M-H	**General Industrials (ICB 3)**	1944	37.1	1939	29	4%
Automobiles and Parts	M-H	**Automobiles and Parts (ICB 3)**	1953	42	1948	75	4%
Industrial Engineering	M-H	**Commercial Vehicles and Trucks**	1959	48.2	1982	23	4%
Electronics and Electrical Equipment	M-H	**Electrical Components and Equipment**	1946	47.5	1950	23	4%
Technology Hardware and Equipment	H	**Computer Hardware**	1985	24.8	1988	32	3%
Industrial Engineering	M-H	**Industrial Machinery**	1939	63.9	1958	52	3%
Chemicals	M-H	**Chemicals (ICB 3)**	1947	45.4	1949	56	3%
Personal Goods	M-H	**Personal Goods (ICB 3)**	1934	37.5	1930	14	2%
Household Goods and Home Construction	M-H	**Household Goods and Home Construction (ICB 3)**	1942	42.3	1953	11	2%
Food Producers	M-L	**Food Producers (ICB 3)**	1956	47.2	1961	20	2%
Fixed Line Telecommunications	M-L	**Fixed Line Telecommunications**	1973	41.9	1994	15	2%
Banks	L	**Banks (ICB3)**	1908	95.1	1955	20	2%
Industrial Metals and Mining	L	**Industrial Metals and Mining (ICB 3)**	1959	51.1	1985	15	1%
Electricity	M-L	**Electricity (ICB 3)**	1954	20.7	1951	10	1%
Construction and Materials	L	**Construction and Materials (ICB 3)**	1945	83.6	1956	19	1%
Oil and gas Producers	L	**Oil and Gas Producers (ICB 3)**	1962	39.2	1972	19	0%

Note: only subsectors with > 10 firms have been included. H, M-H, M-L and L are abbreviations for High, Medium-High, Medium-Low, and Low respectively.

JRC Mission

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