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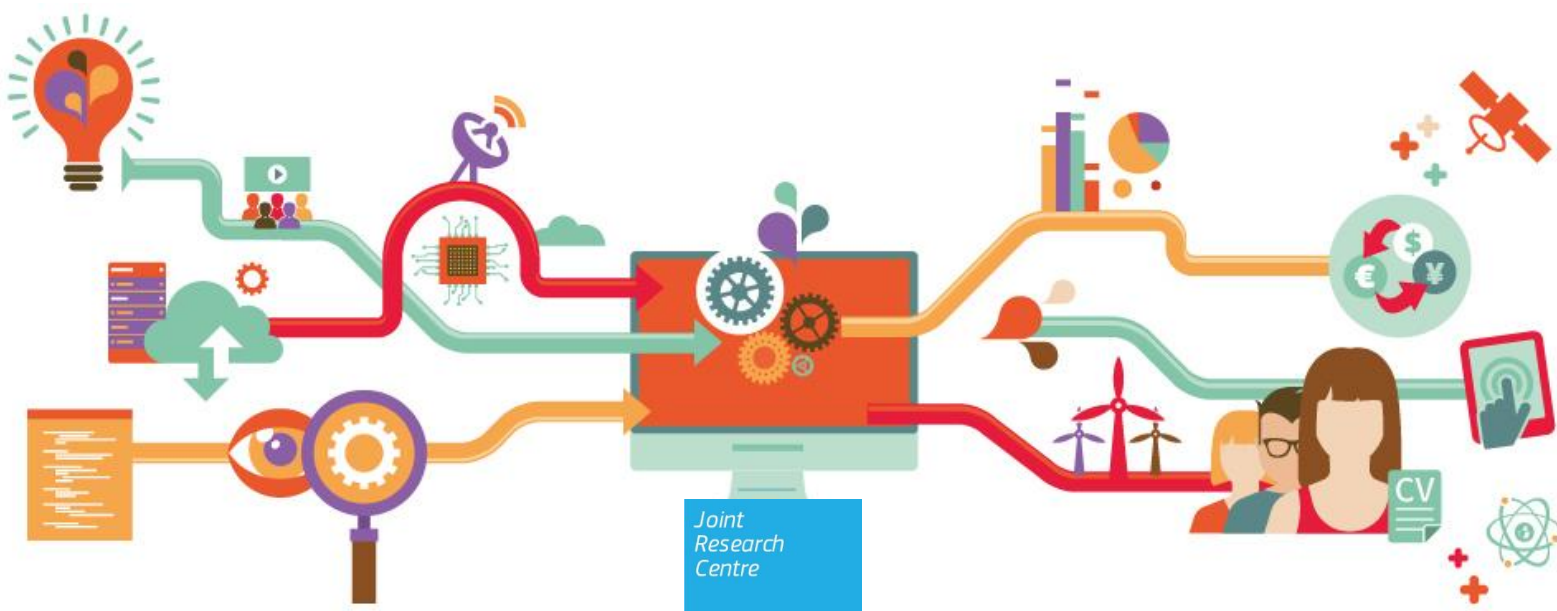How to cite this report : Moncada-Paternò-Castello, P. and Grassano, N., (2020). The EU vs US corporate R&D intensity gap: Investigating key sectors and firms, Working Papers on Corporate R&D and Innovation No 02/2020 - JRC120008, Joint Research Centre, Seville (Spain).

The EU vs US corporate R&D intensity gap: Investigating key sectors and firms

Pietro Moncada-Paternò-Castello(*) and Nicola Grassano

Abstract

This paper contributes to the literature on corporate research and development (R&D) intensity decomposition by examining the effects of several parameters on R&D intensity. It draws on a longitudinal company-level micro-dataset, built using four editions of the EU R&D Scoreboard, and confirms the structural nature of the EU R&D intensity gap with the US, which has widened in the last decade. As a novel contribution to the literature, this paper uncovers the differences between the EU and the US by inspecting which sectors and firms are more accountable for the aggregate R&D intensity performance of these two economies. Furthermore, the study shows that a large share of R&D investment by the EU sample is mostly conducted in sectors with medium or low R&D intensity, and that there is a high concentration of R&D in a few sectors and firms. Interestingly, the investigation finds a high heterogeneity in firms' R&D intensity within sectors, indicating the coexistence of firms with different R&D investment strategies and efficiencies. Finally, the study reveals that the EU holds a much lower number of both larger and smaller R&D investors than the USA, in the four high-tech sectors that are key to the aggregate EU R&D intensity gap vis-à-vis the USA.

JEL classification: O30; O32; O38; O57

Keywords: Corporate R&D, R&D intensity decomposition, EU vs US R&D intensity gap, R&D distribution; comparative performance; top world R&D firms.

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1. Introduction

Europe is currently facing multiple challenges simultaneously: to improve its economic stability, to become more competitive, and to create more and better jobs in a sustainable way (Dosi and Mohnen, 2019). The research and development (R&D) activities of companies in the private sector are expected to play a pivotal role in overcoming these challenges. In fact, R&D expenditure has long been of intense interest to innovation analysts, who have used it as a proxy for innovation inputs and view it as a determinant of growth, productivity and competitiveness. For this reason, R&D intensity targets are one of the main pillars of the European Union's research and innovation policy agenda, where most of the R&D effort comes from the private sector ([1]). The strategy was reiterated and reinforced in the Europe 2020 strategy, as in the related European Union Flagship initiative (2010), in the Renewed EU Industrial Policy Strategy to foster industrial competitiveness, innovation and technological leadership (2019) and in the new political orientation of European Commission's President von der Leyen (2019-2024). These policy initiatives emphasize the need to support increased private research and innovation investment, as such companies play an important role in shaping the dynamics of the economy's sectorial composition, favouring the transition towards a more knowledge-based economy and contributing to overall *sustainable* economic growth, (Sheehan and Wyckoff, 2003; Moncada-Paternò-Castello, 2010, European Commission, 2019).

There is extensive literature dealing with the deficit in the EU's overall company R&D intensity, compared with that of competing economies, and the various factors that could explain this gap (e.g. Dosi, 1997; Pianta, 2005; Erken and van Es, 2007; Moncada-Paternò-Castello et al., 2010; Cincera and Veugelers, 2013). However, much of the research into the main factors that determine corporate R&D intensity seems to address just one main issue – the relative importance of the 'intrinsic' compared with the 'structural' effect ([2]) – and reaches differing conclusions (Moncada-Paternò-Castello, 2010). In contrast, only a limited number of studies reported in the literature have investigated the intensity of corporate R&D (Ciupagea and Moncada-Paternò-Castello, 2006; Moncada-Paternò-Castello et al., 2010; Reinstaller and Unterlass, 2012). For example, Cincera and Veugelers (2013; 2014) found that 55 % of the EU gap is accounted for by greater R&D intensity in younger US firms, although there could be high variations in firms' R&D intensity within the same sectors (Coad, 2019), and this is almost entirely due to the different sectoral compositions of the two economies.

To our knowledge, however, there are no studies which decompose R&D intensity (in intrinsic and structural components) by single sectors, analysing their individual impact as well as the impact of key single firms in the overall EU corporate R&D intensity gap vis-à-vis the US.

This paper seeks to contribute to the literature by going deep into both the structural (i.e. sectoral) and intrinsic (i.e. firm level) components of the gap, addressing two main questions:

> (i) To what extent does sector composition affect the aggregate EU R&D intensity gap in relation to the US? And how has it changed over a decade (including pre-and post-crisis)?

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[1] Namely the Lisbon Strategy of 2000 and the related Barcelona target, set in 2002 (European Commission, 2003), which states that the EU should spend 3 % of GDP on R&D, two thirds of which should come from the private sector.

[2] 'Intrinsic' refers to firms' R&D intensity levels across a wide range of sectors; 'structural' refers to the sector composition of a given economy.

(ii) Which sectors and firms are key to the EU R&D intensity gap vis-à-vis the US?

This study relies on company data accessible from the EU Industrial R&D Investment Scoreboard (hereafter the EU R&D Scoreboard) ([3]). Based on the EU R&D Scoreboard, we compiled and conducted the analysis on a database of microdata from EU and non-EU firms, covering the years 2005-2017 ([4]).

2. Related literature

2.1 Structural versus intrinsic effects in R&D intensity

As regards the firm-level dimension, the theoretical framework of determinants of corporate R&D intensity is graphically summarised in Figure 1, which illustrates that the total corporate R&D intensity of a given economy (country) depends on both the *structural* composition effect and *intrinsic* effect (Pakes and Schankerman, 1984; Erken, 2008; Mathieu and van Pottelsberghe de la Potterie, 2010; Becker and Hall, 2013).

The *structural* factors affecting an economy can be exogenous or endogenous. Endogenous factors are characteristics typical of a given industry sector(s), while exogenous factors are usually external to the sector(s) and the country's macro-economic system. *Intrinsic* factors are those that determine the characteristics of the firm(s) and its behaviour, for example the firm's knowledge, financial capacity or strategy and its R&D investment.

Figure 1. *Theoretical framework of determinants of corporate R&D intensity*
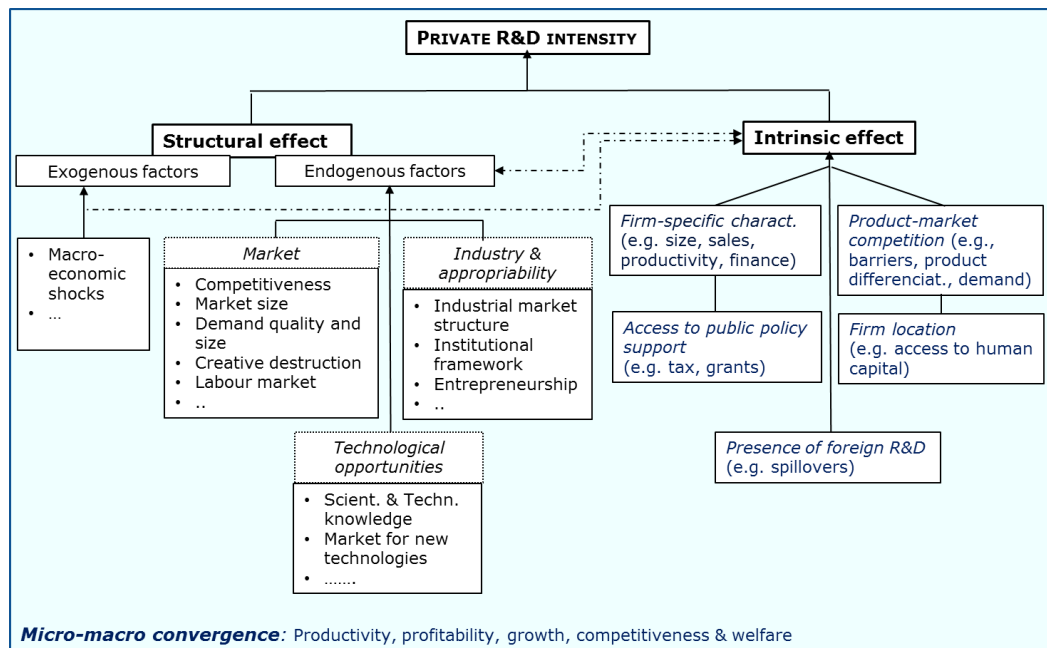
However, structural endogenous factors are also, at least to some extent, dependent on intrinsic factors (Erken and van Es, 2007) ([5]). In other words, the sectoral structure of a

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[3] https://iri.jrc.ec.europa.eu/scoreboard

[4] Data are from four editions of the EU R&D Scoreboard survey: those published in 2006, 2010, 2014 and 2018.

[5] For more information on this relationship, see Erken and Donselaar (2006).

country depends on not only, for example, historical industrial footprints, but also (especially) on the country's aggregate capacity to be successful in technological development or in competition for technology markets and on its collective capacity for R&D-led growth. We should add that structural factors can influence firm-intrinsic factors; for example, although firms' access to government funding for R&D depends on their strategy and their ability (intrinsic factors) to successfully obtain such funding, it is conditional on such public incentives being available in the first place (structural factor).

The literature attempting to determine reasons for differences in R&D investment and intensity between economies is extensive (e.g.: Bartelsman *et al.* 2019; Capone *et al.,* 2019; Ortega-Argilés *et al.*, 2015; Becker and Hall, 2013). To summarize, the main findings from this literature focus on three main arguments: (i) productivity ([6]) as one of key drivers that links structural and intrinsic factors, (ii) structural endogenous factors and (iii) the intrinsic factors determining corporate R&D intensity.

The theoretical foundation of corporate R&D intensity differences, which is determined by firms' own levels of R&D investment and sales (intrinsic effects), is anchored by Schumpeterian arguments that R&D expenditure very much depends on the availability of internal resources, on access to external sources, and on high levels of competition regarding innovation in the product market (Aghion and Howitt, 2006).

Empirically, however, we identified divergent findings in the literature concerning the decomposition of the corporate R&D intensity gap between countries, which suggests that caution should be exercised when drawing general conclusions based on individual studies (Moncada-Paternò-Castello, 2010). It is apparent that some studies support the idea that the R&D intensity gap in the EU is mainly due to sectoral composition or 'structural effects' (e.g. Guellec and Sachwald, 2008; Mathieu and van Pottelsberghe, 2010; Moncada-Paternò-Castello et al., 2010). Meanwhile, a number of other studies indicate that the EU R&D intensity gap is mainly due to intrinsic effects (Pianta, 2005; Erken and van Es, 2007; Foster-McGregor et al., 2013), whilst yet other researchers have found that the R&D gap is due to a mixture of both structural and intrinsic effects (Duchêne et al., 2011; Reinstaller and Unterlass, 2012; Chung, 2015). Duchêne *et al.* (2010), Lindmark *et al.* (2010) and Moncada-Paternò-Castello (2017) indicate that the contradictory results of the decomposition of R&D intensity are mainly due to differences in the nature of the data and their comparability, and discrepancies resulting from the use of different measurement instruments and indicators.

Another stream of the literature investigates the other factors that may have an impact on R&D intensity decomposition parameters. For example, some authors argue that differences in the age, size and dynamics of new, technology-based firms play a role in the overall R&D intensity in a particular country (O'Sullivan et al., 2007; Ortega-Argilés and Brandsma, 2010; Cincera and Veugelers, 2013). Others suggest that the underlying causes of differences in R&D intensity and its decomposition parameters reside in differences in framework conditions: entrepreneurship, intellectual property rights regimes, taxation, access to skills, social security regimes, access to labour and capital markets (Aghion, 2006; de Saint-Georges and van Pottelsberghe, 2013; Cincera and Veugelers, 2014; Veugelers, 2015).

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[6] Actually, there are different elasticities linking R&D and productivity in EU and US (significantly lower in the EU). This gap may be due to both strong institutional and technological path-dependency and to a lower level of connectivity in Europe (this latter aspect is also linked to the key industrial sectors which are the most determinant for the most the overall EU-US R&D intensity gap).

2.2 Direction and magnitude of the R&D intensity gap between countries

Productivity underperformance may reflect underperformance in the creation, diffusion and utilisation of new knowledge (Guellec and Sachwald, 2008). Growing productivity can in fact free resources that can be invested in new knowledge, creating a virtuous circle where knowledge/technology is the main determinant of further productivity improvements and a driver of economic growth (Schumpeter, 1934; Solow, 1957; Baumol, 1986; Dosi, 1988) ([7]). Therefore, differences in productivity levels, together with differences in the effectiveness of return on knowledge investment, may determine the differences in R&D intensities among countries. On the other hand, in the Schumpeter (1934) view of market power and innovation, competition appears to be rather detrimental to innovation and technological progress. These theoretical frameworks could explain the slower rate of productivity and innovation growth in the EU, e.g. in comparison with the US and the emerging economies which rely increasingly on technology, and human and financial capital, as a basis for competitiveness (Fagerberg et al., 1999; Rincon-Aznar et al., 2014). In addition, other studies suggest that being slow to implement structural industrial change towards highly technology-intensive sectors, and failure to fully exploit the opportunities offered by ICT openings, hamper productivity gains and have a detrimental effect on the R&D/innovation intensity performance of a given economy (van Ark et al., 2008; Cardona et al., 2013; Kumbhakar et al., 2012; Cette et al., 2015). Modern evolutionary economic theory, in fact, supports a framework of a continuous shift of resources from older to new, emerging, industries, enabled by knowledge accumulation and diffusion (resulting in new technologies, products and services), which positively influences the competitiveness of the entire economy (Krüger, 2008; Dosi and Nelson, 2010; Perez, 2010; Malerba and Pisano, 2019).

These theoretical frameworks would support the theory that the combination of productivity deceleration and slow structural industrial dynamics, together with the rapid rise of new competitors (Chen, 2015), would result in a widening of corporate R&D intensity gaps, as well as decreasing the technology export of a given economy in relation to its main direct and emerging competitors. This is, in fact, confirmed by a group of empirical studies on the subject (Duchêne et al., 2011; Veugelers, 2013; Chung, 2015).

2.3. Dispersion versus concentration in R&D investment among firms

According to Schumpeterian theory, innovative activities at sector level may be dispersed among a large number of firms that are characterised by 'creative destruction' (Schumpeter Mark I model: Malerba and Orsenigo, 1997). In this case, technological barriers to entry are low, and entrepreneurs and new firms play a major role. Alternatively, innovation may be concentrated in just a few innovators that are characterised by 'creative accumulation' (Schumpeter Mark II model: Breschi et al., 2000). In this case, sectors are dominated by large established firms, a stable core of innovators, and barriers to entry for new innovators are high. Malerba (2005) argues that a high number of technological opportunities, low appropriability, low cumulativeness (at the firm level), along with limited generic knowledge, lead to a Schumpeter Mark I pattern. In contrast, high appropriability and high cumulativeness (at the firm level), along with a generic knowledge base, lead to a

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[7] See Grossman and Helpman (1994) for a discussion on the role of endogenous innovation in the theory of growth.

Schumpeter Mark II pattern. Therefore, we submit that those economies that comprise mainly large and established companies in more traditional sectors, and/or those with limited capacity to create firms that can enter new high-tech sectors and grow rapidly, are operating within a Schumpeter Mark II model. This is the case in the EU, as empirically supported by several studies (e.g. Bartelsman et al., 2005; Stam and Wennberg, 2009; Coad and Rao, 2010) and complemented by other research showing that, globally, corporate R&D is concentrated in a small number of large companies and of high R&D intensity sectors (Reinstaller and Unterlass, 2012; Hirschey et al., 2012; Montresor and Vezzani, 2015).

3. Data and samples selected for the analysis

Our analysis is based on data drawn from the EU R&D Scoreboard, which have been gathered annually since 2004. The EU R&D Scoreboard data are taken from publicly available audited accounts of each company's consolidated operations worldwide. The database is compiled by pulling together four editions of the EU R&D Scoreboard: those published in 2006, 2010, 2014 and 2018. The main variables considered are firms' R&D investment, net sales and R&D intensity by country/region, industry (sector) and group of sectors.

The 2006 and 2010 editions list the top 1000 corporate R&D investors headquartered all over the EU, and the top 1000 R&D-investing companies headquartered outside the EU. The 2014 and 2018 editions list the top 2500 corporate R&D investors notwithstanding where they are headquartered. EU R&D Scoreboard covers about 90 % of global private R&D investment worldwide ([8]).

We pull together four editions of the EU R&D Scoreboard instead of using the longitudinal dataset of the same firms in the time span considered because in doing so we can appreciate the sector composition changes (due to firms' entry and exit dynamics), which is the main interest for this research. Nonetheless, we have also applied the decomposition of the longitudinal balanced dataset of years 2006-2018, which comprised data for enterprises worldwide taken from several editions of the EU R&D Scoreboard. In general, when comparing the data of the four different EU R&D Scoreboards with those of the balanced dataset, there is a similar general trend in the parameters analysed, but in most cases, parameters are lower for the companies in the longitudinal dataset than for those of the four different EU R&D Scoreboards. Overall, the results from the decomposition applied to the two datasets are very similar, especially comparing the results for the EU, the USA and Japan.

Therefore, in order to construct comparable sub-samples of companies from each country/world region, we reduced the complete set of companies for each of the four EU R&D Scoreboard editions to 1 250 ([9]). In this way we could ensure that the four samples

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[8] Based on European Commission (2018, p. 17).

[9] All of the firms are among the top 1 250 R&D investors worldwide and all provided data for both R&D expenditure and net sales. This approach resulted in the following sub-samples: in 2005, 1 247 companies with a minimum total R&D investment of EUR 27.98 million; in 2009, 1 247 companies with a minimum total R&D investment of EUR 34.70 million; in 2013, 1 242 companies with a minimum total R&D investment of EUR 46.70 million; and in 2017, 1 240 companies with a minimum total R&D investment of EUR 67.6 million. These firms account for 98 %, 97 %, 94 % and 93 % of total R&D expenditure by the complete EU R&D Scoreboard sample in 2005, 2009, 2013 and 2017, respectively.

were comparable, including the top R&D investors for each year, notwithstanding their geographical location ([10]). These four editions do not contain exactly the same companies, due to company dynamics (entry and exit behaviour to and from the ranking of top private R&D investors, and mergers and acquisitions). About 620 firms – approximately 50 % – remain the same in all four years/samples.

The sectorial composition of the countries/regions analysed by sector groups is illustrated in Figures 2 and 3, in terms of R&D investment and net sales – the two elements that make up R&D intensity. The two figures show considerable differences in both R&D investment and net sales between sector groups and between countries/regions.

Figure 2. R&D investment in selected years by group of countries and R&D intensity sectors
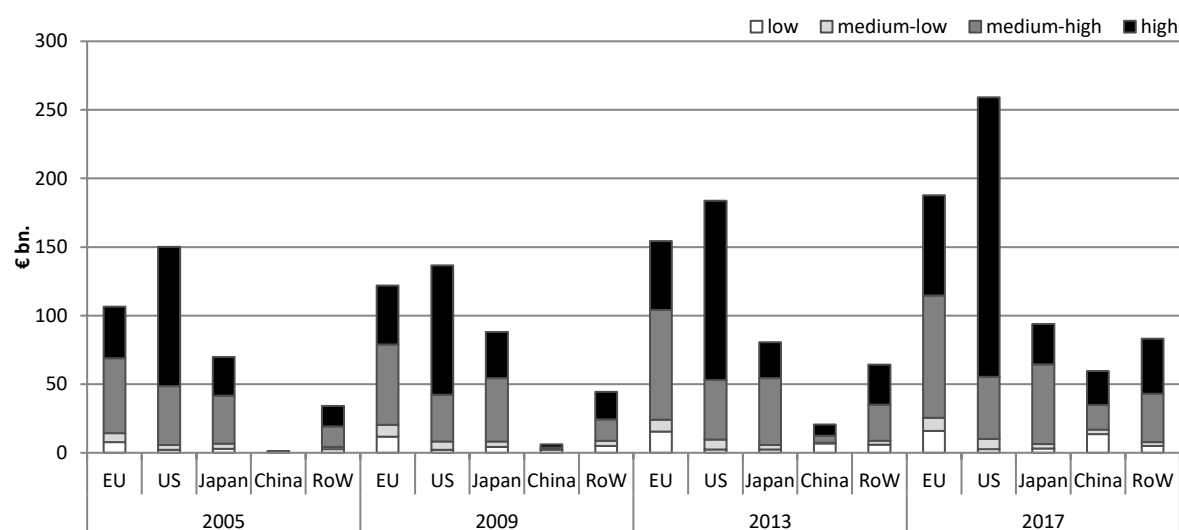
Source: Computed from EU Industrial R&D Investment Scoreboard (European Commission, 2006, 2010, 2014 and 2018).

Overall, the R&D investment of the firms in the sample represents on average 84% of the global BERD (Business R&D Expenditures in R&D), as accounted by the territorial statistics of Eurostat. Moreover, the global and European corporate R&D investment growth in the time span 2005-2017 are also comparable with that of BERD in the same period.

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[10] In the first two editions taken into account (2006 and 2010), the sample of 2 000 companies was compiled as the union of two samples: the top 1 000 EU and the top 1 000 non-EU R&D investors. In the other two editions included in the analysis (2014 and 2018), the list of the top 2 500 R&D investors has been compiled with no such geographical limitation. To make the four samples comparable, we had to restrict the number of companies in the analysis to 1 250.

Figure 3. Net Sales in selected years by group of countries and R&D intensity sectors
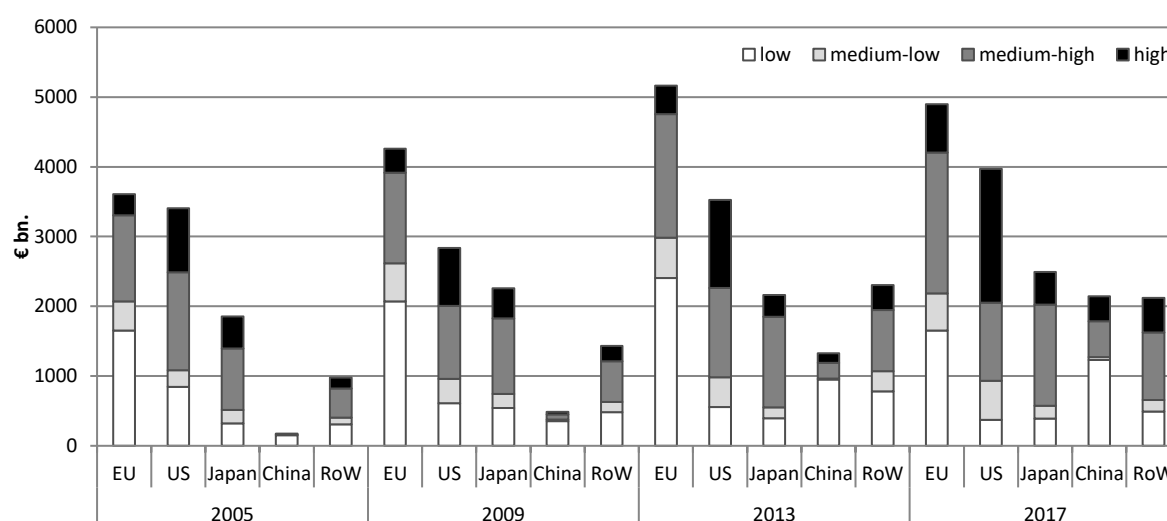
The majority of the largest EU companies, by net sales, in the EU R&D Scoreboard operate in lower-tech sector groups ([11]) (they represent 16.2 % of total EU companies and 33.8 % of total net sales of EU companies in 2017). This has consequences for total R&D intensity, which is as a result greatly influenced by the (lower) level of R&D intensity of the sectors to which these companies belong, and a higher net sales growth path. This means that the R&D intensity of US firms is generally higher than that of EU companies, as can be seen in Figure 4.

Figure 4. R&D intensity (R&D/net sales) in selected years, by group of countries
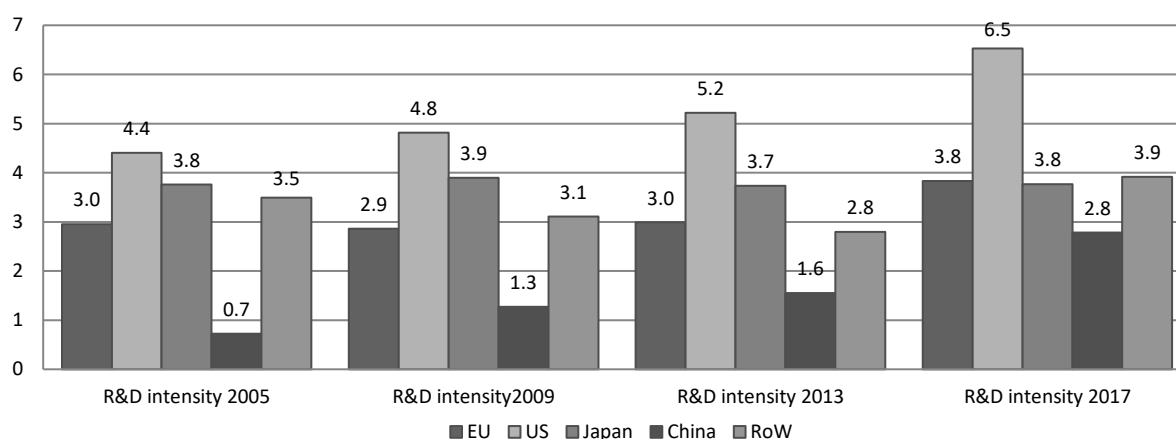
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[11] The industrial sectors are grouped according to their four R&D intensity levels – corresponding to ICB-3 classification. Namely,: **High** (> 5 %): Aerospace & Defence; Health Care Equipment & Services; Leisure Goods; Pharmaceuticals & Biotechnology; Software & Computer Services; Technology Hardware & Equipment. **Medium-high** (2-5 %)**:** Automobiles & Parts; Chemicals; Electronic & Electrical Equipment; Equity Investment Instruments; Financial Services; General Industrials; Household Goods & Home Construction; Industrial Engineering; Non-equity Investment Instruments; Personal Goods; Support Services; Travel & Leisure. **Medium-low** (1-2 %): Alternative Energy; Beverages; Fixed Line Telecommunications; Food Producers; General Retailers; Media; Oil Equipment, Services & Distribution; Tobacco). **Low** (< 1 %): Banks; Construction & Materials; Electricity; Food & Drug Retailers; Forestry & Paper; Gas, Water & Multiutilities; Industrial Metals & Mining; Industrial Transportation; Life Insurance; Mining; Mobile Telecommunications; Nonlife Insurance; Oil & Gas Producers; Real Estate Investment & Services.

Figure 4 also shows that EU and Japan R&D intensities stagnated, with a slight increase for the EU in the last year of observation. On the other hand, US and (especially) China R&D intensity increased appreciably in 2009 and 2013 and boomed in 2017, although to a much lesser degree for the USA.

4. Decomposition of corporate R&D intensity

4.1 Methodological approach

The descriptive analysis in section 3 seems to suggest that the gap in R&D intensity between the EU and its main competitors, especially the USA, is mainly due to the sectorial composition of the economy (i.e. structural effect), rather than a lower level of firms' R&D intensity (i.e. intrinsic effects). This is also in line with the majority of the previous literature on the topic (i.e. Guellec and Sachwald, 2008; Mathieu and van Pottelsberghe, 2010; Moncada-Paternò-Castello *et al.*, 2010).

To calculate the relative contributions of each of the two effects to the total difference in R&D intensity between economies, we have followed the decomposition approach of Haveman and Donselaar (2008), Erken and van Es (2007), Lindmark et al. (2010) and Cincera and Veugelers (2013).

The approach is the same as that used by Moncada-Paternò-Castello *et al.* (2010) ([12]):

$$RDI_X - RDI_Z = \sum_i RDI_{Z,i}(S_{X,i} - S_{Z,i}) + \sum_i S_{X,i}(RDI_{X,i} - RDI_{Z,i}) \qquad \textbf{(1)}$$

where:

- *X* is the first sample (in our case the USA, Japan, China or Rest of World);

- *Z* is the second sample (in our case, the EU sample);

- *RDI* stands for R&D intensity (R&D/*Y*), where *Y* is the overall amount of net sales of companies from all sectors ($\sum y_i$) operating in a given economy; and

- *S* is the share of the sector *i* in terms of net sales within a given economy (y_i/Y).

Therefore, the aggregate difference in R&D intensity between two economies is equal to the sum of the differences in R&D intensity for all sectors over the period, weighted by their average share of net sales over the same period (intrinsic effect), plus the sum of the differences in output shares of net sales, weighted by their average R&D intensities (structural effect). Therefore, if the share of the R&D-intensive industries within the overall economy of country X is larger than in country Z, the sectorial composition effect is positive for country X and negative for country Z.

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[12] In the R&D intensity decomposition literature, most authors use similar formulas, while a few authors use different ones. For a review of these formulas, see Moncada-Paternò-Castello (2017) and Appendix A.1, which includes a table summarising a survey of R&D intensity decomposition formulas.

4.2 Applying the decomposition to data from four EU R&D Scoreboard editions

Before going into the in deep analysis of the sector composition to investigate which sectors and firms are key for the EU R&D intensity gap, we first evaluated to what extent the sector composition (*structural* effect) and the firm's own R&D intensity levels (*intrinsic* effect) affect the *aggregate* EU R&D intensity gap in relation to the US and how it has changed over a decade which includes the year of the global economic add financial downturn (2009).

To implement it, we applied the R&D intensity decomposition calculations to data from four EU R&D Scoreboard editions, collected in 2006, 2010, 2014 and 2018, all of them in the top 1 250 R&D investors worldwide and all providing both R&D and net sales data, as described earlier in section 3. The results of the decomposition, using the EU sample for comparison, are shown in Figure 5 below and can be summarised as follows.

Figure 5. Decomposition of R&D intensities in selected countries/regions, using the EU sample for comparison (2005, 2009, 2013 and 2017)
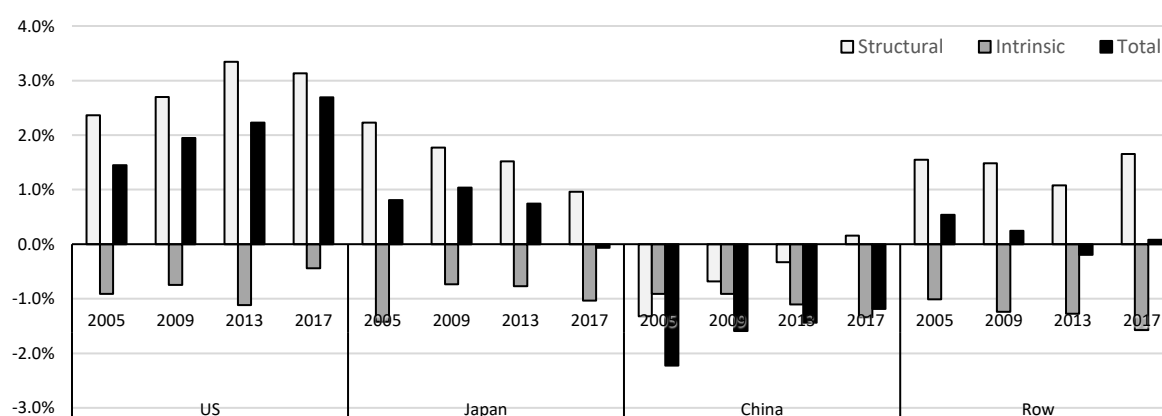
Note: number of EU companies 2005=321, 2009=351, 2013=355, and 2017=327. Number of US companies: 2005=541, 2009=448, 2013=412, and 2017=391. Number of Japanese companies 2005=227, 2009=238, 2013=205, and 2017=192. Number of Chinese companies 2005=10, 2009=30, 2013=85, and 2017=155. Number of Row companies 2005=148, 2009=180, 2013=185, and 2017=175.

Source: Computed from EU Industrial R&D Investment Scoreboard (European Commission, 2006, 2010, 2014 and 2018).

Firstly, in terms of R&D intensity, EU companies lag behind US and Japanese companies. What is more, the R&D investment gap between the EU and the US has widened over the period under study, whereas the gap between the EU and Japan has remained fairly stable and slightly improved in the last year of observation. In contrast, the R&D investment gap between the EU and China is positive, although it has reduced by half over the four years under examination.

Secondly, the decomposition figures confirm that the EU presents an unfavourable structural effect compared with the USA, Japan and firms from the rest of the world, except China in the first three years.

In particular, we observe that the structural gap of the EU in comparison with the USA is, in practice, entirely and largely due to the structural effect.

The third result of this decomposition computation is the finding that, in terms of intrinsic R&D investment, the EU consistently outperforms all of its competitor economies, and - new to the literature - that intrinsic R&D intensity in fact more often increases over the period, compared with firms from all competing countries. However, in the EU, the negative

structural effect counteracts the positive effect of corporate R&D investment efforts (intrinsic effect) largely than in any of the other regions/countries under examination.

The above analytical results are all in line with the extant literature.

Finally, analysis of the evolution of the EU R&D intensity gap indicates that it increased in 2009 (the year of the economic and financial crisis) compared with the USA and Japan, while it reduced compared with Japan after the year of the crisis. The different evolution of the components of R&D intensity is of interest in the R&D intensity path: as stated in the previous section, in the EU the growth in R&D investment has been stable but grew proportionally less than net sales in the EU sample. Both the R&D and net sales grew irregularly in the USA and in Japan, which have suffered the effects of the economic and financial crisis (the USA in 2009 and Japan after 2009). This result on the trend also adds to the extant literature on the topic.

To check the robustness of the results obtained by analysis of the four different editions of the EU R&D Scoreboard (2006, 2010, 2014 and 2018), an exercise new to the literature was also implemented. This decomposed the EU vs the USA R&D intensity gap for the year 2009 by using value added (VA) as denominator, as well as business expenditure of R&D (BERD)/VA intensity (as adopted by van Reenen, 1997a and Sandven and Smith, 1998), and confronted these results with results obtained in this section. The methodology used, the results obtained and discussion of them are offered in Appendix A.1.

5. A deeper analysis of the EU vs US R&D intensity gap

This section aims to analyse the gap between the EU and its major competing economy, the US. It inspects the features of sectors and firms within the EU and US that are 'key' to the aggregated EU R&D intensity performance and its gap compared to the USA. We also evaluate if and to what extent there is heterogeneity of EU and US firms' R&D intensity within sectors. In doing so, these novel analyses contribute to the state of the art in the literature.

5.1. Industrial <u>sectors</u> key to EU vs US aggregate structural R&D intensity difference

The four sectors which, in the years observed are key (i.e. are the sectors where the EU-US R&D intensity gap is larger) to the structural (and overall) EU gap in R&D intensity are all high-tech sectors: Technology Hardware & Equipment, Software & Computer Services, Pharmaceuticals & Biotechnology, and Health Care Equipment & Services. The first three of these have seen an increase in the structural EU R&D intensity gap between 2005 and 2017. In 2005, the General Industrials sector (medium-high) was the fourth sector, while this was Health Care Equipment & Services in 2009 and 2017. The negative structural effects of such sectors have been alleviated by EU firms' intrinsic effects in the same sectors, and much more importantly by the EU Automobile & Parts Sector (medium-high) in the years considered (see Figure 6). Figure 6 also suggests a positive trend in R&D intensity over the period 2005-2017 among EU firms in some sectors, especially Automobiles & Parts, and Banks (low).

Figure 6. EU vs US R&D intensity gap (decomposed) in selected sectors and years

2005

Legend:
- ☐ Structural
- ▨ Intrinsic
- ■ Total

Sectors (top to bottom): Technology Hardware & Equipment, Software & Computer Services, Pharmaceuticals & Biotechnology, General industrials, Aerospace & defence, Fixed line telecommunications, Electronic & Electrical Equipment, Automobiles & parts

Axis: -1.0, -0.5, 0.0, 0.5, 1.0, 1.5, 2.0, 2.5

2009

Legend:
- ☐ Structural
- ▨ Intrinsic
- ■ Total

Sectors (top to bottom): Technology hardware & equipment, Pharmaceuticals & biotechnology, Software & computer services, Health care equipment & services, Electronic & electrical equipment, Fixed line telecommunications, Banks, Automobiles & parts

Axis: -1.0, -0.5, 0.0, 0.5, 1.0, 1.5, 2.0, 2.5

2013

Legend:
- ☐ Structural
- ▨ Intrinsic
- ■ Total

Sectors (top to bottom): Technology Hardware & Equipment, Software & Computer Services, Pharmaceuticals & Biotechnology, Health Care Equipment & Services, Electronic & Electrical Equipment, Fixed Line Telecommunications, Banks, Automobiles & Parts

Axis: -1.0, -0.5, 0.0, 0.5, 1.0, 1.5, 2.0, 2.5

2017

Legend:
- ☐ Structural
- ▨ Intrinsic
- ■ Total

Sectors (top to bottom): Software & Computer Services, Technology Hardware & Equipment, Pharmaceuticals & Biotechnology, Health Care Equipment & Services, Electronic & Electrical Equipment, Fixed Line Telecommunications, Banks, Automobiles & Parts

Axis: -1.0, -0.5, 0.0, 0.5, 1.0, 1.5, 2.0, 2.5

Source: own calculations based on EU R&D Scoreboard 2006, 2010, 2014 and 2018 (ICB-3 sectors).

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To look even more closely at this phenomenon, Table 1 shows the ICB-4 subsectors within the four ICB-3 sectors identified that contribute most to the R&D intensity gap of the EU relative to the closest competing economy, the USA.

In particular, this table reports the differences in R&D intensity performance between the EU and the USA as ratios: values higher than 1 mean that R&D intensity is higher in the EU than in the US; a value of 2 means that R&D intensity in the EU is twice that in the US, while a value of 0.5 means the opposite, i.e. R&D intensity in the US is twice that in the EU.

Although overall R&D intensity is greater in the EU than in the USA in most of the sectors represented in Table 1, the last row shows that the overall balance is in favour of the USA. This is mostly because there are fewer larger companies operating in the key sectors in the EU than in the US.

Some important information in Table 1 is the difference in the number of firms in each sector between the two economies. This explains to a large extent the origin of the structural component of the EU R&D intensity gap: fewer EU firms very much implies smaller overall R&D investment and size (net sales) for the EU.

Table 1. EU to US ratio of average R&D intensity and number of firms by subsectors (ICB-4) within the four key sectors (ICB-3) in 2005, 2009, 2013 and 2017

Sectors (ICB-4) / years	R&D intensity				R&D investment				Size (net sales)				Number of firms			
	05	09	13	17	05	09	13	17	05	09	13	17	05	09	13	17
Pharmaceuticals	1.04	1.00	0.96	0.80	0.81	0.73	0.72	0.46	0.78	0.74	0.75	0.57	0.79	1.07	1.29	2.00
Software	0.85	0.98	1.05	0.98	0.91	0.68	0.74	0.81	1.06	0.69	0.70	0.83	0.18	0.35	0.27	0.22
Health care equipment & services	0.61	0.61	1.18	1.57	0.68	0.82	0.71	0.87	1.12	1.34	0.60	0.56	0.34	0.43	0.52	0.45
Biotechnology	0.63	0.74	0.57	0.90	0.37	0.43	0.27	0.35	0.58	0.59	0.48	0.39	0.26	0.24	0.35	0.27
Telecommunications equipment	1.09	0.88	1.02	1.11	2.83	3.38	2.03	1.89	2.60	3.85	1.99	1.71	0.29	0.30	0.38	0.32
Semiconductors	1.12	1.12	0.95	0.92	1.57	1.88	0.91	0.83	1.41	1.68	0.96	0.90	0.12	0.11	0.18	0.21
Al other sectors	0.90	0.82	0.75	0.72	1.10	1.11	1.03	0.87	1.22	1.36	1.37	1.20	0.98	1.26	1.27	1.26
Total	0.67	0.59	0.57	0.59	1.20	1.14	0.97	0.87	1.78	1.92	1.70	1.47	0.59	0.78	0.86	0.84

Note: Only sectors containing at least five firms, and accounting for at least 10 % of overall R&D expenditure in the EU and the US over the three years, are included in the calculation.

Source: own calculations based on EU R&D Scoreboard 2006, 2010, 2014 and 2018 (ICB-4 sectors).

5.2. EU and US <u>firms</u> key to intrinsic R&D effects on aggregated R&D intensity

Turning our attention to EU companies which operate within the four groups of sectors key to the EU R&D intensity gap, we examine their performance to disentangle which firms are key to the overall intrinsic effects within each sector and economy.

For the sample in the EU R&D Scoreboard, the answer to the question on the level of R&D intensity a firm holds, and the effect it has on the aggregated results for a given sector, depends not only on its level of R&D investment (it is a top R&D investor worldwide in the sector, by sample selection), but very much on its *size* by net sales.

Nonetheless, the relevance of the impact of a single firm is relative, as it very much depends on the number of firms present in a given sector, and their aggregate size by R&D and by net sales. In fact, the presence in a few high R&D intensity sectors of a much higher number of

firms in the US sample compared to the EU one explains in large part the structural cause of the EU R&D intensity gap: fewer EU firms in high R&D intensity sectors (and a simultaneous higher presence in lower R&D intensity sectors) very much implies smaller overall aggregate R&D investment and size (net sales) for the EU, compared to the US (see table 2).

To disentangle the contribution of different types of firms to the aggregate sector R&D intensity, we construct an index which captures the differences in R&D intensity and in the share of net sales.

For similar levels of R&D intensity, there may be two groups of firms that have a different contribution to final aggregate sectoral R&D intensity. Indeed, as net sales are the denominator for R&D intensity, the more R&D-intensive firms with larger shares of net sales are therefore responsible for a larger positive impact on aggregate sectoral R&D intensity. Another group, the firms with lower R&D intensities and larger shares of net sales, are responsible for a larger negative impact on aggregate sectoral R&D intensity.

More formally, an index of the *relative effect of R&D intensity and share of net sales performance of a firm i on the aggregate R&D intensity of sector j*, defined as a firm's *Impact Index* = Θ_{ij} RDI$_{ij}$, can be written as:

$$Impact\ INDEX = \ \theta_{ij} * (\text{RDI}_{ij} - \text{RDI}_{j}) \qquad\qquad \textbf{(3)}$$

where $\text{RDI}_j = \sum_{i \in j} \frac{\text{RD}_i}{\text{NS}_i}$ is the aggregate sectoral R&D intensity; θ_i is the measure of the firm's relative size, in terms of its net sales as a share of total sector net sales.

The index can be negative or positive, indicating respectively a negative or a positive effect of R&D intensity and share of net sales performance of a firm on the aggregate R&D intensity of the sector. The sum of the *Impact Index* values of the firms in a sector is equal to zero ([13]).

Table 2 (2a for the year 2005; 2b for the year 2017) shows the firms in the four sectors mentioned, both for the EU and USA, which hold the highest and the lowest levels of R&D intensity compared to the average in the EU or USA, together with their highest R&D investment shares and shares of net sales within each of the sectors considered. It includes the values of the Impact Index as defined earlier. Furthermore, we assess such firms for their behaviour in the period 2005-2017 for the main variable examined – primarily for their changes in R&D intensity – and then also in variables resulting in firms with a positive or negative behaviour ([14]). A possible drawback to take into consideration is the effect of mergers and acquisitions on firms' trends, or country/region performance that could have a considerable impact, as in the case of Medtronic, a firm formerly from the US but based in the EU (Ireland) since 2016.

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[13] $\sum_i \theta * (RD_i - RD_j) = \sum_i \left(\frac{RD_{ij}}{Y_{ij}} - \frac{\sum_i RD_{ij}}{\sum_i Y_{ij}}\right) * \frac{Y_{ij}}{\sum_i Y_{ij}}$ the right side of the equation can be written as $\sum_i \left(\frac{RD_{ij}*Y_{ij}}{Y_{ij}*\sum_i Y_{ij}} - \frac{\sum_i RD_{ij}}{\sum_i Y_{ij}}\right)$ and this as $\sum_i \left(\frac{RD_{ij} - \sum_i RD_{ij}}{\sum_i Y_{ij}}\right)$ which is also equal to $\sum_i \left(\frac{RD_{ij} - RD_j}{Y_j}\right)$ or $\frac{RD_j - RD_j}{Y_j} = \emptyset$

[14] We refrain from referring to these firms as 'lagging' or 'leading' because, as already said, they are top R&D investors in their respective sector, by the sample construction.

Table 2a. Key EU and US firms for intrinsic R&D effects on aggregated R&D intensity results in selected sectors (at ICB-3 level of classification), in 2005

	YEAR 2005	R&D intensity	% R&D	% Net Sales	Impact Index	# firms
Health Care Equip. & Services	**EU**	**4.5**	**1.1**	**0.7**		**12**
	Carl Zeiss	10.4	19.5	8.4	49.5	
	BioMerieux	13.1	11.1	3.8	32.7	
	Dragerwerk	6.6	9.2	6.2	13.5	
	B Braun Melsungen	3.2	8.3	11.4	-14.2	
	Gambro	2.9	6.7	10.2	-15.7	
	Fresenius	1.9	12.6	29.8	-76.5	
	US	**7.3**	**3.4**	**2.0**		**35**
	Guidant	16.8	10.1	4.4	41.6	
	Medtronic	9.9	18.7	13.9	35.5	
	Boston Scientific	10.8	11.4	7.7	27.2	
	Becton Dickinson	5.0	4.6	6.6	-15.1	
	Baxter International	5.4	9.0	12.1	-22.8	
	Fisher Scientific International	0.8	0.7	6.9	-44.6	
Pharmaceuticals & Biotechnology	**EU**	**14.8**	**17.5**	**3.5**		**38**
	Schering	18.6	5.3	4.2	16.2	
	Elan	54.8	1.1	0.3	11.5	
	UCB	20.2	2.7	2.0	10.8	
	Merial	7.7	0.7	1.3	-9.4	
	AstraZeneca	14.1	15.4	16.1	-10.6	
	Merck DE	12.1	3.8	4.6	-12.2	
	US	**15.7**	**23.3**	**6.5**		**77**
	Eli Lilly	20.7	7.3	5.6	27.8	
	Merck US	17.5	9.3	8.4	15.2	
	Schering-Plough	19.6	4.5	3.6	14.3	
	Pfizer	14.5	18.0	19.5	-22.9	
	Johnson & Johnson	12.5	15.3	19.2	-60.9	
	Abbott Laboratories	8.2	4.4	8.5	-63.8	
Software & Computer Services	**EU**	**10.5**	**2.4**	**0.7**		**18**
	SAP	12.8	42.3	34.7	80.0	
	Dassault Systemes	27.7	10.1	3.8	65.6	
	Symbian	47.5	3.1	0.7	25.2	
	Wincor Nixdorf	4.5	3.0	7.1	-42.7	
	TietoEnator	3.5	2.3	6.9	-48.1	
	LogicaCMG	1.4	1.4	10.9	-99.0	
	US	**10.8**	**13.5**	**5.5**		**80**
	Microsoft	14.9	27.5	20.1	80.7	
	CA	20.5	3.3	1.7	16.7	
	Oracle	13.0	7.8	6.5	14.1	
	SunGard Data Systems	6.3	1.0	1.8	-8.1	
	Unisys	6.8	1.6	2.6	-10.7	
	IBM	5.9	22.5	41.3	-204.2	
Technology Hardware & Equipments	**EU**	**13.7**	**11.8**	**2.5**		**22**
	Ericsson	16.9	21.6	17.6	55.5	
	Infineon Technologies	18.4	9.8	7.4	34.3	
	STMicroelectronics	17.5	10.4	8.2	30.9	
	Bull	4.3	0.4	1.3	-12.0	
	Oce	7.2	1.5	2.9	-19.0	
	Nokia	11.6	31.5	37.2	-77.8	
	US	**9.5**	**25.7**	**11.9**		**146**
	Intel	13.3	11.3	8.1	30.6	
	Cisco Systems	13.4	7.3	5.2	20.3	
	Texas Instruments	15.0	4.4	2.8	15.6	
	Apple	3.8	1.2	2.9	-16.3	
	HP	4.0	7.7	18.1	-98.3	
	Dell Technologies	0.8	1.0	11.6	-100.6	

<u>Notes</u>: Data in regular font refer to the given firm in relation to the sector in which it operates. Data in bold refer to the sector mentioned in relation to the full sample (all sectors) for the EU or the US.

Source: own calculations based on EU R&D Scoreboard 2006

Table 2b. Key EU and US firms for intrinsic R&D effects on aggregated R&D intensity results in selected sectors (at ICB-3 level of classification), in 2017

|	YEAR 2017	R&D intensity	% R&D	% Net Sales	Impact Index	# firms
Health Care Equip. & Services	**EU**	**3.9**	**1.4**	**1.4**		**11**
	Carl Zeiss	10.7	21.4	7.9	53.3	
	Dragerwerk	8.9	8.6	3.8	19.0	
	Elekta	11.9	5.1	1.7	13.5	
	Coloplast	3.5	2.7	3.1	-1.5	
	Essilor International	2.9	8.1	11.1	-11.6	
	Fresenius	1.8	23.0	50.1	-106.8	▼
	US	**2.9**	**3.3**	**7.3**		**25**
	Medtronic*	7.5	22.1	8.6	39.5	▼
	Boston Scientific	11.0	9.8	2.6	21.0	
	Edwards Lifesciences	16.1	5.4	1.0	13.0	
	Dentsply Sirona	3.8	1.5	1.1	1.0	
	Teleflex	3.9	0.8	0.6	0.6	
	Mckesson	0.1	1.2	59.8	-171.8	
Pharmaceuticals & Biotechnology	**EU**	**14.0**	**19.9**	**5.5**		**46**
	Astrazeneca	24.1	11.9	6.9	70.0	
	Boehringer	17.0	8.1	6.7	20.5	
	Sanofi	15.5	14.4	12.9	20.4	
	Perrigo	3.4	0.4	1.5	-16.1	
	Mylan**	6.5	1.7	3.7	-27.4	
	Bayer	11.2	13.6	17.0	-47.1	
	US	**18.9**	**22.8**	**7.9**		**61**
	Merck US	25.3	14.5	10.8	69.4	▲
	Bristol-Myers Squibb	28.7	8.5	5.6	54.5	
	Celgene	30.5	5.6	3.5	40.7	
	Pfizer	14.1	10.5	14.1	-67.9	▼
	Abbott Laboratories	7.9	3.1	7.4	-81.0	
	Johnson & Johnson	13.8	15.0	20.5	-104.3	
Software & Computer Services	**EU**	**11.6**	**4.5**	**1.5**		**22**
	SAP	14.2	39.7	32.6	83.4	
	Ubisoft Entertainment	45.2	9.3	2.4	80.6	
	Dassault Systemes	17.9	6.9	4.5	27.9	
	Amdocs	6.7	2.6	4.5	-22.1	
	Sopra Steria	2.7	1.2	5.3	-48.0	
	Atos	1.0	1.4	17.6	-188.4	
	US	**14.2**	**25.5**	**11.7**		**90**
	Facebook	19.1	9.9	7.3	35.6	
	Workday	42.5	1.2	0.4	10.9	
	Electronic Arts	25.6	1.7	0.9	10.6	
	Microsoft	13.3	18.7	19.9	-17.6	▼
	Hewlett Packard Enterprise	5.1	1.9	5.2	-47.4	
	IBM	6.5	6.5	14.3	-111.1	
Technology Hardware & Equipments	**EU**	**15.9**	**8.0**	**2.0**		**17**
	Nokia	21.2	32.2	24.1	129.3	▲
	NXP Semiconductors	16.8	8.5	8.0	7.4	
	Dialog Semiconductor	21.6	1.6	1.2	6.7	
	ASML holding	12.8	7.6	9.4	-29.2	
	Seagate Technology	11.4	6.7	9.3	-41.4	
	Arris	8.2	2.9	5.7	-44.3	
	US	**10.2**	**24.6**	**15.7**		**72**
	Intel	20.9	17.3	8.4	90.1	▲
	Qualcomm	24.5	7.2	3.0	42.9	
	Broadcom	18.7	4.3	2.4	20.1	
	Dell Technologies	6.0	6.3	10.6	-43.5	
	HP	2.3	1.6	7.0	-55.0	▼
	Apple	5.1	15.3	30.8	-157.3	

Notes: Data in regular font refer to the given firm in relation to the sector in which it operates. Data in bold refer to the sector mentioned in relation to the full sample (all sectors) for the EU or the US. (*) is an Irish firm since 2016. (**) is Dutch since 2015.
Legend: The sign ▼ refers to firms present in the two years (2005 and 2017) that have had a negative trend, primarily in R&D intensity and then also in the other two variables, whereas ▲ refers to firms with positive trend.
Source: own calculations based on EU R&D Scoreboard 2018.

Table 2 brings an important value added to the analysis of the EU-US R&D intensity gap. It identifies which firms are responsible for the intrinsic effects (levels R&D intensity of the firms) and for the trends therein comparing the first and the last year of observation. In doing so it can be analysed the possible dynamics of firms within the same sectors over a decade.

Moreover, although a high heterogeneity has found in R&D intensity values within the same sectors, when aggregate at sector level EU firms perform at least as better as (and often much better than) the USA in terms of R&D intensity (intrinsic). In fact, as indicated before, the impact of a firm is relative as it also depends on the number of firms present in a given sector and their aggregate size by R&D and net sales.

The R&D investment by EU and US firms, and their distribution by R&D intensity and net sales, in the four sectors key to the overall EU R&D intensity gap are reported in Figure 7.

Figure 7. R&D investment by EU and US firms, and their distribution by R&D intensity and net sales, in the four sectors key to the overall EU R&D intensity gap in 2017
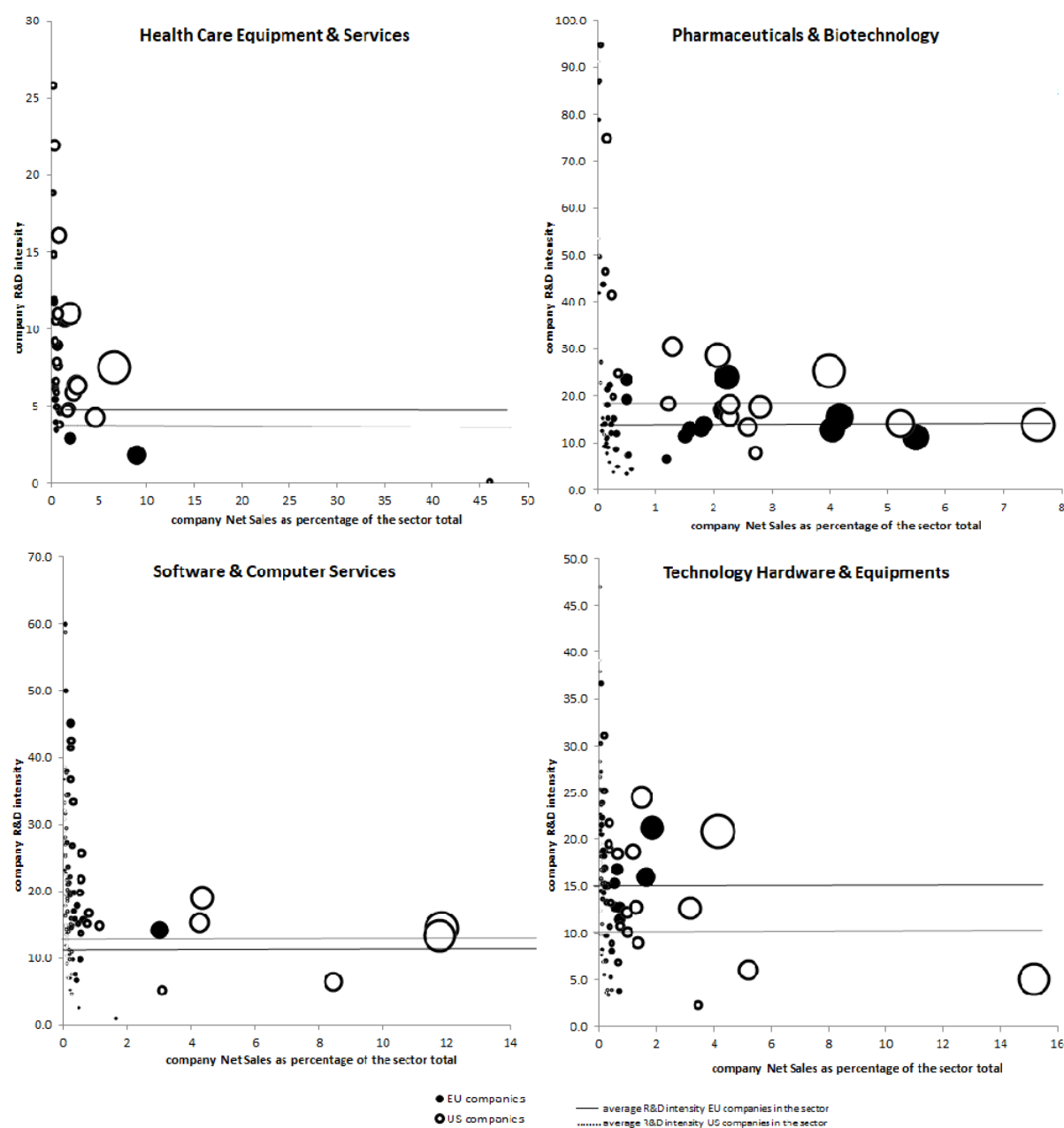

Note: The size of the bubbles is proportional to the share of EU or US firms' R&D investment in the sector (full sample).
Source: own calculations based on EU R&D Scoreboard 2018.

This figure shows that there is a higher number of both larger and smaller R&D investors in the US samples than in the EU ones. Furthermore, to appreciate in detail the difference between the EU and the US, as well as the firms' heterogeneities in R&D intensity and net sales within the same sectors in both economies, we provide in Figure 8 an illustrative example for the Software & Computer Services sector in 2017. This has been done by computing a Kernel density distribution for the difference between the R&D intensity of the firm and average R&D intensity of the sector.

Figure 8. Triangular Kernel density distribution ([15]) for the difference between R&D intensity of the firms and average R&D intensity of the Software & Computer Services sector, EU and US (2017)
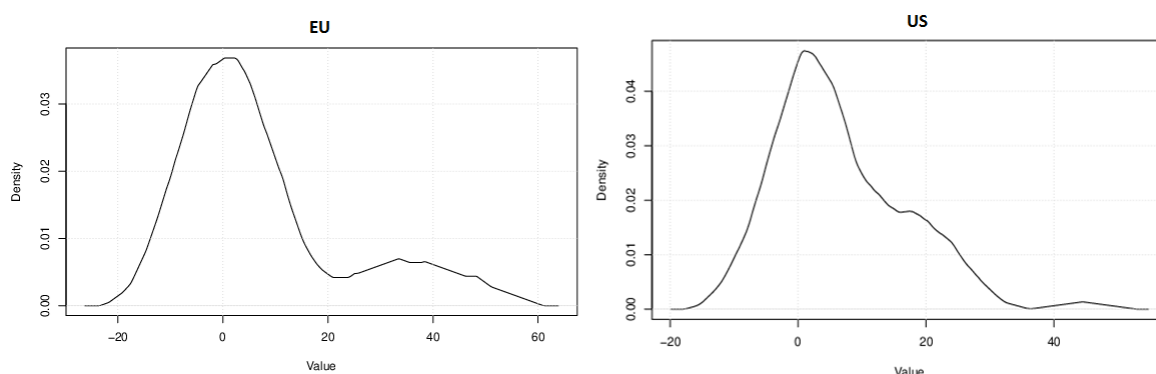
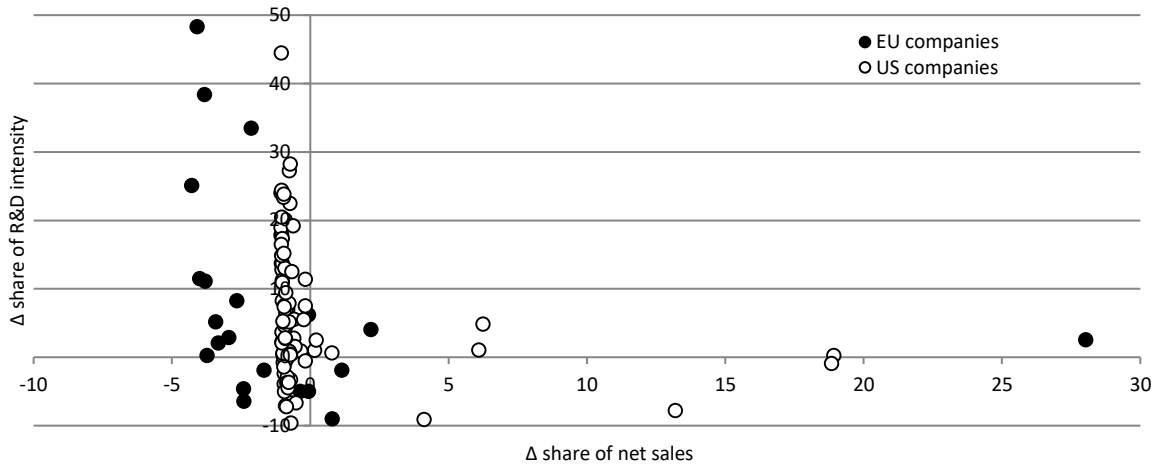Source: own calculations based on EU R&D Scoreboard 2018.

An interesting feature in Figure 8 is that the highest density of the shape of this distribution function f for the two samples is centred near to the zero x value, with a more uniform distribution in the EU shape between the -20 and +20 values compared with the US one. In fact, US firms' R&D intensity distribution is more concentrated from the zero to +30 x values, denoting a higher presence of high intensity R&D firms in the sample than in the EU one.

On the other hand, the quite high-density f values for both the EU and US denote high heterogeneities in firms' R&D intensity in both EU and US samples.

Figure 9 indicates that few large (by net sales) firms have much significance to differences in R&D intensities, in both the in EU and US samples, in the key R&D-intensive sector of Software & Computer Services.

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[15] Computed in Free Statistics Software (version 1.1.23-r7) from the Office for Research Development and Education; see Wessa (2015).

Figure 9. Differences (Δ^{16}) for firm's R&D intensity, and share of net sales, in relation to the respective average values for Software & Computer Services sector EU, US (2017)

Source: own calculations based on EU R&D Scoreboard 2018.

5.3 Discussion of results of firms' contribution to sectorial differences in R&D intensity gap

The main analytical results for the firms' contribution to the R&D intensity gap could be summarised as follows:

a) The firms' distribution in R&D intensity within the four key sectors reveals that, compared to the USA, in the EU sample: i) firms are less numerous; ii) there are less large firms (by R&D investment); iii) there are less small firms (by R&D investment); iv) there are less large R&D investors that hold a high share of net sales; and v) the sector's R&D intensity is superior, except in the Pharmaceuticals & Biotechnology sector.

b) As the EU holds a much lower number of companies than the USA, in the four key sectors for the aggregate R&D intensity gap, the EU holds a lower overall share of net sales and share of R&D investment compared with the full sample (all sectors), especially in Technology Hardware & Equipment and in Software & Computer Services.

c) There are few companies – in the four sectors and for the values examined - which determine the intrinsic R&D effects in the EU vs US R&D intensity gap. Few of them (37.5 %) are present in both years considered.

d) There is no clear path of a single firm or group of these top R&D firms, within the four sectors and in both economies examined, that dominates a common trend behaviour. Also, because of the nature of the sample (all are top R&D investors), we can't spot a clear problem of lower firm R&D intensity in these four sectors, nor that the firms with higher R&D intensity are underperforming in terms of sales (Andrews *et al*., 2015 found likewise for firms' productivity). The case of, for example, Fresenius in the Health Care Equipment & Services sector is revealing: the firm's R&D intensity is considerably below the EU average for the

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[16] $\Delta\ R\&D\ intensity = \mathrm{RDI}_i - \overline{\mathrm{RDI}}_j$; $\Delta\ share\ of\ Net\ Sales = \theta_i - \overline{\theta}_j$ – Note: the R&D intensity of the firm i belonging to a sector j $= RDI_{ij}$; the $\overline{\mathrm{RDI}}_j$j is the sector's R&D intensity mean; θi is a measure of the relative size of firm i as share of its net sales; $\overline{\theta}$j is the average share of the firms' net sales at the sector j level.

sector, with a negative trend for this value between 2005 and 2017. However, at the same time, the firm grew significantly in both shares of R&D investment and net sales in the sector.

e) The result of the previous point, together with the high heterogeneity in R&D intensity of firms within the same sector (confirming recent findings by Coad, 2019), shows that there is a coexistence of firms with different R&D investment strategies and efficiencies. That is, the firms with a large market share can enjoy their dominant position, with high R&D efficiency, because of high appropriability, high cumulativeness and high economy of scale in the exploitation of R&D results (Schumpeter, 1942; Baker and Hall, 2013). On the other hand, smaller (new) firms introduce innovations into the market in order to put pressure on, and displace, the incumbents, according to Schumpeter's Mark I theory (Schumpeter, 1934).

Finally, we should recall that the relative impact of top R&D investing firms on the overall EU R&D intensity gap depends heavily on their presence in the *high R&D intensity sectors* and their *size*. Of course, the larger the number of firms and their aggregate size in high R&D intensity sectors, the bigger their impact on the aggregate (all sectors) R&D intensity result.

In sum, the analytical outcomes of this section confirm the relative high sensitivity of sector performances to R&D intensities in a few EU and US firms. They reveal a general high heterogeneity of R&D intensity within the same sector in both regions, and also a significant dynamic of firms entering and exiting the group of six firms, three of them ranked for their most positive and other three for their negative impact on aggregate R&D intensity in the EU and in the USA.

7. Conclusions

This paper seeks to increase our understanding of how and why EU corporate R&D intensity differs from that of the USA by providing new findings.

In line with the literature, the analysis indicates that EU companies lag behind US and Japanese companies in terms of R&D intensity. The gap between the EU and the USA has widened over the period studied, while it has remained fairly stable between the EU and Japan. In contrast, the R&D investment gap between the EU and China is positive, although it has reduced by half over the four years under consideration.

As a novel contribution to the state of the art in the literature, this paper identifies the sectors and the firms that are 'key' to EU R&D intensity performances and to differences with the US group of firms. The decomposition of sectoral R&D intensity shows that Technology Hardware & Equipment, Software & Computer Services, Pharmaceuticals & Biotechnology, and Health Care Equipment & Services account for the bulk of the negative EU structural R&D intensity gap. On the other hand, the EU Automobile & Parts sector counterbalances the negative structural effects of such sectors. There is a concentration in a few EU and US companies of R&D intensity, R&D investment share and share of net sales in key sectors, which determines the aggregate R&D intensity gap between the EU and the US.

Only some 'key' firms – for their positive or negative impact on aggregate R&D intensity in both economies and the four sectors mentioned – are the same across the years considered and without showing appreciably different growth paths. On the other hand, within the group of such key firms, there is a much higher dynamic of entry and exit across the years within

the four sectors. This study also found a high heterogenic distribution of R&D intensity for firms *within* the same sector, indicating the coexistence of firms with different R&D investment strategies and efficiencies.

Moreover, one of the important differences found is in the number of top R&D investors present in such high R&D intensity sectors, with the USA having sometimes double or triple the number of EU companies.

A crucial analytical consideration is that the majority of R&D investment in the EU is mostly implemented in sectors with medium or low R&D intensity. Linked to this is the fact that the EU holds a much lower number of companies than the USA in the four sectors that are key to the EU structural R&D intensity gap. As a matter fact, it results considerably lower shares of net sales and R&D investment compared to the US, especially in Technology Hardware & Equipment, in Software & Computer Services, and in Health Care Equipment & Services.

This study provides new insights into the evolution of corporate R&D, by examining one of the factors on which the EU 3 % R&D investment policy target, introduced in 2002, was based.

It confirms that the reason for the EU R&D intensity gap, especially relative to the USA and Japan, is mainly structural, and that there have been no signs of the changes necessary to achieve the EU policy target in the near future (Pottelsberghe, 2008; Voigt and Moncada-Paternò-Castello, 2012).

Other sources of literature can help us to understand why this EU R&D intensity gap phenomenon occurs. Many authors suggest that dynamic changes in the structure of the economy, and associated company demographics, with socio-economic and policy framework conditions are the most important reasons (Mathieu and Pottelsberghe, 2010; Foray and Lhuillery, 2010; Moncada-Paternò-Castello, 2010, Demircioglu *et al.,* 2019).

The findings of this study clearly show that EU companies have only a weak presence, in terms of market (sales) and R&D investment shares, in the high-tech sectors compared with their most direct competitor; most of these sectors have been created in the last few decades (e.g. biotechnology, software, internet) by new, smaller R&D-intensive firms, as argued by Moncada-Paternò-Castello (2010) and Cincera and Veugelers (2013).

Therefore, when taking action to bridge the EU R&D intensity gap, policymakers should not consider only horizontal policy options across all sector and firm typologies. Tailored policies should also be considered that address technology development and diffusion, as well as barriers to entering R&D and innovation-intensive sectors, and that favour new/young R&D-intensive entrants.

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Appendix

A.1 – ROBUSTNESS CHECK: Decomposition of EU vs US R&D intensity gap using different definitions of R&D intensity

The EU R&D Scoreboard data used for decomposition of R&D intensity tends to indicate that the EU gap is mainly due to a structural effect. This result could be due to the sample composition: the decomposition is in fact based on the small number of EU and US leaders in R&D. Although representative of approximately 90 % of total private R&D in the full sample of 2 500 firms, these companies represent a small share of the total economy (where global denominator is GDP, or VA – contribution at sector level). Such bias could explain the difference in the decomposition result (i.e. intrinsic effect as main determinant) when using business expenditure on R&D (BERD) in the numerator, with GDP or VA as the denominator. Therefore, we tested the result of EU vs US decomposition in this paper (section 4.2) using R&D intensity as the share of EU Scoreboard R&D (SB_R&D) to firms' net sales (NS), and compared it with the decomposition results using other R&D intensity ratios, namely SB_R&D/VA and BERD/VA.

The R&D intensities of sector levels use ISIC Rev. 4 for the year 2009, relying on EU KLEMS (http://www.euklems.net/ - release 2012) as data source for EU VA, World KLEMS (http://www.worldklems.net/data.htm) for US VA, and OECD-ANBERD (https://stats.oecd.org/Index.aspx?DataSetCode=ANBERD_REV4#) for BERD values for both EU countries and the US.

The year 2009 was the most recent of the four years referred to in the R&D intensity decomposition in this paper (i.e. 2005, 2009, 2013 and 2019) for which it is possible to get VA data with the same classification (ISIC Rev. 4). The coverage of EU countries in EU KLEMS (for VA) and OECD-ANBERD ([17]) (for BERD) for 2009 is limited to the following: Belgium, Sweden, Finland, Netherlands, Germany, Italy, Spain, France, United Kingdom and Austria. Nonetheless, these countries are responsible for a large share of R&D in the EU: in 2009, they represented together about 97 % of the R&D investment of the entire EU sample.

The EU and US R&D intensity values for R&D and net sales, at ICB-3 as well as ICB-4 level classification on the EU R&D Scoreboard, were converted into ISIC Rev. 4 sector classification for comparability reasons. Also, all monetary values were converted into EUR million, using the exchange rate at 31 December 2009, following the EU R&D Scoreboard methodology.

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[17] Actually, there were also other EU countries in the OECD database, but these were not present in the KLEMS database; therefore, those mentioned are the only 10 EU countries that are available in both databases.

The overall result is shown in Table A-1:

Table A-1. Decomposition of different R&D intensity ratios in EU and US, using the EU sample for comparison (2009)

2009	**overall**	structural	intrinsic
SB_R&D/NS (ICB-3)	**1.944 %**	2.74 %	-0.80 %
SB_R&D/NS (ICB-4)	**1.944 %**	2.67 %	-0.72 %
BERD/VA (ISIC.4)	**0.515 %**	-0.11 %	0.62 %
SB_R&D/VA (ISIC.4)	**0.057 %**	-0.15 %	0.21 %

As expected, the R&D intensity decomposition results, using VA instead of net sales as the value of the fraction, differ substantially in overall R&D intensity gap, as we compared data that were very heterogeneous in many aspects.

Differences in decomposition results between SB_R&D/NS and SB_R&D/VA

- VA represents the output of overall economy (all companies) on a *territorial* (country) basis, as compared with net sales output that is one part of the *global* VA of a limited number of EU Scoreboard companies. For instance, territorial-based VA for the EU countries and for the US includes the portion of VA coming from multinationals (non-EU foreign affiliates operating in EU countries), while the NS of EU R&D Scoreboard companies arise from both national and international markets.

- The mismatch between the two R&D intensity decompositions, as well as the causes (intrinsic vs structural) of the EU vs US gap, are very likely to be due to where the R&D and where the production, VA or net sales of a company are located. For example, the US firms operating in many ICT sectors (all with high R&D intensity) implemented almost their entire R&D activities within the US, while the bulk of their production and VA is performed abroad (Lindmark et al., 2010; Hernandez et al., 2013). This significantly lowers the denominator for the US firms in these sectors, with a clear consequence of significantly increasing the R&D intensity of the US firms in the share *SB_R&D/VA.*

- The higher sectoral aggregation, at ISIC Rev. 4, of the R&D intensity values of firms is very likely to be one of the main reasons for the discrepancy in results: it does not enable significant increase/reduction in differences between subsectors as it did in the decomposition of *SB_R&D/NS* intensity using the lowest possible aggregation (as discussed in Lindmark et al., 2010) that data availability allows.

Differences in decomposition results between SB_R&D/NS and BERD/VA

- The problem of outward VA performance introduced above is also relevant in this case. In addition, the R&D share of BERD by foreign affiliates in 2013 is higher than 50 % in some EU countries, such as Hungary, Ireland, Belgium, Czechia, United Kingdom and Austria. On the other hand, Japan and the US, which have a low share (< 20 %) of R&D by foreign affiliates, show higher BERD intensity.

- Furthermore, although very highly representative for EU and US R&D investment, 1 247 firms represent 83 % of global BERD. If this is then divided by the VA of the full economy, this will substantially alter the final results and make them even less comparable with BERD/VA or R&D/NS for the EU R&D Scoreboard companies. In

practice, the value of the numerator will be decreased by about 17 % with respect to BERD, and the denominator increased exponentially with respect to net sales of Scoreboard companies.

These differences in R&D intensity decomposition results are very much in line with the result of a report authored by ETEPS (European Commission, 2008) ([18]) which concludes:

'On the whole, these differences are linked to the particular nature of the Scoreboard data, including the definition and location of the R&D activities and the process of data collecting, widely affected by different kinds of sample selection (see section 1.3). On the other hand – as with any other official data – OECD-ANBERD figures are not immune to severe drawbacks (see section 1.4.5). In other words, the heterogeneities between the two databases are so many and so remarkable that the resulting discrepancies listed above are only partially surprising.'

Differences in decomposition results between SB_R&D/NS (ICB-3) and SB_R&D/NS (ICB-4)
- Explanations for such (small) differences are basically due to the different level of sectoral aggregation (ICB-3 vs ICB-4), where the firms from a major aggregation drop in a sub-aggregation (in line with Jaumotte and Pain, 2005; Erken and van Es, 2007; Lindmark et al., 2010).

Overall, the results of the R&D intensity gap decomposition, using R&D investment and sector composition (structure) represented by the companies on the EU R&D Scoreboard in the sample, are reliable. This paper does not in fact assume that the mix of R&D sectors reflects the complete structure and size of the given economies. The result of the analyses that use EU R&D Scoreboard data, and the ratio of R&D intensity to net sales, provides complementary information and this is not comparable to the *SB_R&D/VA* or to *BERD/GDP* or *BERD/VA* ratios. Nor there is a rationale in mixing data of such different natures for the R&D intensity ratio, which obviously gives contradictory decomposition results; that is, it is meaningless to arbitrarily mix company and territorial data (e.g. the ratio SB_R&D/territorial VA).

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[18] European Commission (2008). *Impact of industrial R&D on business performance: evidence from quantitative analyses based on company data and official statistics*. ETEPS Contract 150083-2005-02-BE for the European Commission, JRC-IPTS, Seville (Spain). ETEPS Report authored by Nick von Tunzelmann, Simona Iammarino, Pari Patel (all from SPRU UK), Mariacristina Piva (Catholic University of Milan, Italy) and Constantin Ciupagea (Romanian Centre for Economic Studies, Romania). Final Report, Brussels (Belgium), 10 March 2008 (unpublished; available on request).