Moncada释ernò Castello, Pietro

Thesis

Evolution of EU corporate R&D in the global economy : intensity gap, sectors' dynamics, specialisation and growth

Solvay Brussels School of Economics and Management

Université libre de Bruxelles (ULB)

Evolution of EU corporate R&D in the global economy: intensity gap, sectors' dynamics, specialisation and growth

Thesis presented in view of getting the degree of Doctor in "Sciences économiques et de Gestion" by

Pietro Moncada Paternò Castello

Under the direction of Professor

Michele Cincera

Jury composed by Professors

Bruno van Pottersberge de la Potterie (ULB)

Reinhilde Veugelers (Katholieke Universiteit Leuven)

Marco Vivarelli (Università Cattolica di Milano)

Nicolas van Zeebroeck (ULB)

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Evolution of EU corporate R&D in the global economy: Intensity gap, sectors' dynamics, specialisation and growth

Pietro Moncada-Paternò-Castello

Candidate to PhD in Economics and Management Sciences - at Solvay Brussels School of Economics and Management - Université Líbre de Bruxelles (ULB)

Abstract:

The Thesis is composed by three complementary research investigations on the economic and policy aspects of EU corporate R&D. Collectively, the work first reviews the theoretical and empirical literature of corporate R&D intensity decomposition; it then investigates the EU R&D intensity and its decomposition elements comparatively with most closed competitors and with emerging economies over the period 2005-2013. Finally, it inspects further some key aspects that can be associated to the EU R&D intensity gap: sectoral dynamics and the resulting sectoral and technological specialisations as well as the drivers for R&D investment growth across sectors and firms' age groups of top R&D investing firms over time. These studies also address the possible policy implications that derive from their outcomes.

The investigations rely on literature as well as on company data, mainly from nine editions (2006-2014) of the EU Industrial R&D Investment Scoreboard. For analytical purposes they use literature review, meta-analysis, descriptive statistics, R&D intensity decomposition computational approach, Manhattan distance and Technological Revealed Comparative Advantage metrics, and a multinominal logit regression model.

The results of these three research works are novel in several aspects. They indicate that literature results on R&D intensity decomposition differ because of data and methodological heterogeneities, and that the structural cause is the main determinant of EU R&D intensity gap if sector compositions of the countries are considered. It inspects how the use of different data sources and analytical methods impact differently on R&D intensity decomposition results, and what the analytical and policy implications are.

The empirical research results of this Thesis confirm the structural nature of the EU R&D intensity gap. In the last decade the gap between the EU and the USA has widened, whereas the EU gap with Japan has remained relatively stable. In contrast, the emerging countries' R&D intensity gap compared to the EU has remained relatively stable, while companies from emerging economies are considerably reducing such gap. Besides, as novel contribution to the state of the art of the literature, this Thesis uncovers the differences between EU and US by inspecting which sectors, countries and firms are more accountable for the aggregate R&D intensity performance of these two economies, and it finds a high heterogeneity of firms' R&D intensity within sectors. Furthermore, it shows that there is a bigger population of both larger and smaller US top R&D firms which invest more strongly in R&D than competitors, and that the global R&D investment is concentrated in a few firms, countries and industries.

Finally, the research founds a slightly higher EU R&D shift over sectors compared to the US, but not strongly enough towards high-tech sectors. Also, the EU has an even broader technological specialisation than its already broad industrial R&D sector specialisation, while the USA leads by number of technological fields mostly belonging to the industrial R&D sectors of its specialisation. Furthermore, the EU has been better able than the USA and Japan to maintain its world share of R&D investment even during the years of economic and financial crisis. Lastly, the study also indicates that firms make a complementary use of capital expenditures and R&D intensity for their R&D investment growth strategies and it reveals that there are differences in their use between firms' age classes across sectors.

Overall, the main results of the Thesis suggest that to reach a more positive R&D dynamics and boost its competitiveness, the EU should adapt its industrial structure and increase the weight of high R&D intensive sectors. A focus on creating the conditions for firm creation and growth in new-emerging innovative sectors is advised together with favouring the exploitation of the full capacity of EU leading - but mature - sectors to also absorb high-technology from other sectors.

JEL classification: O30; O32, O38; O57; F23; R39

Keywords: EU corporate R&D intensity gap, world top R&D investors, corporate R&D distribution, sectors' dynamics, sector specialisation, technological specialisation, R&D investment growth, EU industry, EU R&D policy, literature survey, empirical analysis.

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Introduction

1. Background: the economic and policy context

Corporate R&D activity has a twofold relevance for its economic and social returns, therefore of private and policy interests. Since Schumpeter (1949) the evolutionary economic theory points to knowledge development, capital outlay and technical change (Solow, 1957; Romer, 1990; Dosi & Nelson, 2010) as the major sources of productivity and job creation which lead to the economic growth and competitiveness of a given economy (Kruger, 2008; Coccia, 2008; Bogliacino *et al*., 2012). As a matter of fact, most of the arguments that provide justification for policies targeted at raising the level and efficiency of R&D rely on the assumption of close links between R&D spending and micro- and macro-economic performance (Mitchell, 1999; Kafouros, 2008; Guellec and van Pottelsberghe de la Potterie, 2001; Bilbao-Osorio and Rodríguez-Pose, 2004; Griffith, Redding and Van Reenen, 2004).

Europe is challenged at the same time to overcome the economic crisis, to become more competitive and to create more and better job in a sustainable way. One of the most pivotal roles in such sought development is expected to be played by innovation. This conviction has originated one of the main objectives of the new European Union's research and innovation policy agenda: namely the Lisbon strategy of 2000 and the related Barcelona target, set in 2003, which states that the EU should spend 3 %[1] of GDP on R&D, two-thirds of which should come from the private sector. The strategy was reiterated and reinforced in the more recent Europe 2020 strategy as in the related European Union Flagship initiative (European Commission, 2010). This initiative emphasises the need to support increased private research and innovation investment and to generate positive demographics (creation and growth) of companies operating in new or knowledge-intensive industries. 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 economic growth, coupled with more and better jobs (Sheehan and Wyckoff, 2003). Key research achievements in this framework relate to a better understanding of corporate R&D and innovation, its contribution to business performance and employment creation as well as the factors determining firms' growth and their R&D/innovation activities in the global economy.

2. Motivations and problems addressed

The importance of the EU corporate R&D intensity gap for the future of the economy and society has stimulated the study by researchers of this very topic. One of the approaches that has been developed and used by scholars and policy analysts to investigate the EU R&D intensity gap, and to determine the extent to which it is attributable to differences in R&D investment between countries, sectors, or even firms, has been the ‘decomposition’ of the R&D intensity gap into its major economic determinants. Actually, the decomposition

[1] This target was set taking into consideration the fact that, at that time, the EU was investing only 1.9 % of its GDP in R&D, whereas Japan was investing 2.7 % of GDP and the USA 2.98 % (European Commission, 2003).

methodology for the R&D intensity gap was originally conceived with the aim of evaluating the extent to which changes in aggregate R&D intensity can be explained by changes in industrial structure (van Reenen, 1997) or by the aggregate efforts of single companies in R&D investment related to their sales or value added.

Despite the significance of the analytical purpose, the theoretical framework and the methodology needed to decompose countries' R&D intensity have been elaborated only recently, and are still not extensively used in literature. According to Becker and Hall (2013), the literature on the determinants of R&D investment in industry sub-groups, as well as on sectoral decomposition of such determinants, is rather limited. Yet the results of the decomposition studies of corporate R&D intensity are often contradictory (Moncada-Paternò-Castello *et al.*, 2010).

The micro–macro statistical issue is a major topic for economic policy research. In fact, the analysis of micro-level statistics allows the evaluation of the characteristics of an economic system at the most accurate (unitary) scale. Aggregate micro-level statistics can, in turn, be particularly useful for understanding industry and macro-level dynamics, and thus are extremely valuable for policy design, monitoring and evaluation. Despite this, large-scale application of aggregate micro-level statistics is still limited, especially in the field of the knowledge economy, for different reasons but mostly because the available information is limited and inhomogeneous owing to measurement problems and some conceptual and methodological differences (De Panizza and De Prato, 2009; Bjørnskov and Foss, 2016) ([2]).

The examination of firms' R&D intensity in industries and at different layers of aggregation leads to results that are mixed and not completely understood. For policy purposes, it is particularly important to determine whether the differences between countries/regions are intrinsic, for example due to firms' underinvestment in R&D (something that can be expected to be relatively easily changed), or structural, for example attributable to the sector composition of an economy (change in which is likely to require more effort and time).

The literature that deals with the EU's overall company R&D intensity compared with that of competing economies and the various factors that could explain this gap is quite extensive (e.g. Dosi, 1997; Pianta, 2005; Erken and van Es, 2007; Moncada-Paternò-Castello *et al.*, 2010; Cincera and Veugelers, 2013).[3] 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[4] – and reaches differing conclusions (Moncada-Paternò-Castello, 2010, 2017b). In contrast, only a limited number of studies have investigated the intensity of corporate R&D by combining several parameters (Ciupagea and Moncada-Paternò-Castello, 2006; Moncada-Paternò-Castello *et al*., 2010; Reinstaller and Unterlass, 2012). In addition, the comparative evolution of the R&D intensity

[2] According to Bjørnskov and Foss (2016), other micro–macro problems are common to many economic studies. These include the use of detailed micro-level data beyond case studies towards meso- and macro-statistical interests, the interaction between macro-level institutions and policies and firm-level responses and, in particular, the potentially complex interactions between different institutions and policies.

[3] The first literature survey on this subject has been recently elaborated by Moncada-Paternò-Castello (2017a).

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

performance of EU companies compared to other economies since the introduction to the mentioned "Barcelona target" has not been extensively investigated.

One of the important factors undermining European competitiveness is the modest capacity 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 to major competing economies (Hölzl et al., 2011; Jorgenson and Timmer, 2011; Pianta, 2014). Other authors have investigated the use of firms' financial resources for their R&D activities (Hall and Lerner, 2010; Wang *et al.,* 2016), also under their financial constraints (Czarnitzki and Hottenrott, 2011; Cincera *et al*., 2012 and 2016; Hall *et al*., 2016).

However, despite the importance in the policy agenda some aspects of the relationship between firms' R&D investment dynamics and the resulting technological and industrial (sectoral) specialisations as well as between firms' R&D and capital intensity and their profitability with R&D investment growth, have been not yet fully analysed.

Alongside with the investigation of whether (or not) the different structure of the economy or firms' engagement in R&D determine the EU R&D investment gap, many contributions considered firms' demography and dynamic (with the capacity of rapid growth) as key factors influencing this gap (e.g. Bartelsman *et al*., 2005; O' Sullivan, 2006). The theoretical framework for this is settled by the evolutionary economists on their arguments on technical change and industrial dynamics for competitiveness and growth (e.g., Kruger, 2008; Perez, 2009; Dosi and Nelson, 2010), and on the role of the innovative firms in such dynamic process (e.g., *Schumpeter Mark I model*, according to Malerba and Orsenigo, 1997).

However, despite its relevance, and although some contributions on 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 R&D investment changes across sectors and to the evolution of the related countries' sectoral and technological specialisation, as well as to the internal financial factors which affect firms' R&D growth performance *across sectors* and the possible differences *across firm age* characteristics.

3. Aim, objectives and research questions

The main aim of the overall investigation is to contribute to the economics of innovation literature by focusing on the evolution of EU corporate R&D in the global economy.

The research has a three-folds interlinked objective and related research questions.

The first objective has the ambition to offer an original critical review of scientific studies on the decomposition of corporate R&D intensity. The first question of this research is whether the differences in corporate R&D intensity arising from decomposition studies at country/world region level are sector specific, firm- or data/methodological- specific. The second question is why some of the of empirical corporate R&D decomposition studies deliver different results. The third question is how the use of different data sources and analytical methods impact differently on R&D intensity decomposition results, and what the analytical and policy implications are.

The second objective of the research is to identify the structural characteristics that explain the differences in aggregate R&D intensity observed between two groups of companies: those located in the EU and those located elsewhere. It pursues this objective by answering the following questions: (i) To what extent does sector composition (the 'structural' effect) affect the aggregate EU R&D intensity gap not only in relation to the USA and Japan, but also in comparison with other competing (and emerging) economies? (ii) Has the R&D intensity gap changed over time (2005-2013) and, if it has, how has the impact of the main factors affecting that gap changed during the time period under consideration? And which sectors, countries and firms are the most responsible for the gap? (iii) How has the distribution of R&D investment among top R&D-investing firms and groups of sectors changed in different world regions/countries over time? This evidence allows appreciating the causes, trends and achievement of EU corporate R&D intensity (Barcelona) target.
The third objective of the investigation is to disentangle further the reasons and characteristics of the disparity of EU private sector's R&D investment performance compared to competing and emerging economies by analysing the R&D sectoral dynamics and the resulting sectorial and technological specialisation during the last decade through and the financial drivers for firm's R&D investment growth across sectors. The related study addresses the following questions: (1) What are the country/world regions specificities in the change of R&D investment across sectors and their resulting industrial R&D sector and the technological specialisation? (2) What happened to the R&D investment and its trend of countries/world regions with different sectoral (R&D) specialisations? Which of those shows more stable R&D investment patterns during the economic crisis? (3) What financial and economic factors affect firms' R&D growth performance across sectors? Are these factors different across firm age?
These objectives and questions are addressed by the Thesis's research which is constituted by three complementary papers with the following titles: #1. Survey of *corporate R&D intensity decomposition: Theoretical and empirical issues*; #2 *EU corporate R&D intensity gap: What has changed over the last decade?*; #3 *Sector dynamics, specialisation and R&D growth of top innovators in the global economy*.

4. Referred literature and the PhD Thesis's contribution

The three complementary papers of the Thesis address relevant literature of the economics of innovation and their contribution to it is rich.

The **first paper** addresses the literature of corporate R&D intensity (gap). The theoretical models - as by Pakes and Schankerman (1984) - indicate three factors for the structural effects of Corporate R&D intensity: expected market size and growth in demand, appropriability differences, and technological opportunities. Theoretical frameworks for the intrinsic effect - as by Aghion and Howitt, 2006; Baker and Hall, 2013 - indicate that depends on availability of internal resources, access to external sources and in high levels of product market competition on innovation. The empirical evidence of the decomposition of EU R&D intensity gap provides controversial results; for example, Guellec and Sachwald (2008) Mathieu and van Pottelsberghe (2010) indicate that the gap is mainly due to the differences in sectoral composition; while Intrinsic effects are mayor responsible for the gap according to, e.g. Pianta (2005), Erken and van Es (2007), Foster-McGregor et al., (2013).

Furthermore, other authors (Duchêne et. al. 2010; Lindmark et al., 2010; Reinstaller and Unterlass, 2012; Stancik and Biagi, 2015) prove that there is a simultaneous (mixed) effect of both determinants on the gap.

The first paper systematically surveys and analyses data and methods used in the literature to decompose private R&D intensity; it also offers a new consistent theoretical framework of corporate R&D intensity decomposition' determinants. It represents the first study in the literature which (i) provides a comprehensive identification of the main reasons why different studies come up with different results, although most studies rely on very similar data and similar methodological approaches; (ii) it goes over details of the different impacts on R&D intensity decomposition results that are originated by the use of different data sources, and their limitations; (iii) it suggests which data and methods should be better approached depending on the analytical aim, data availability and how much reliable the results are, providing some hints for their analytical interpretation, including in term of policy implications.

The **second paper** on the empirical evolution of the EU corporate R&D intensity gap mainly addresses the literature of the *determinants* of corporate R&D intensity differences of countries mentioned above, with a particular focus of the EU vs US differences, as well as the one that which support the widening corporate EU R&D intensity gap and the *concentration* of innovative activities.

The theoretical foundation of the *determinants* of corporate EU R&D intensity gap indicates the combination of the productivity deceleration (e.g., Baumol, 1986; Guellec and Sachwald, 2008), the slow structural industrial dynamics (e.g., Perez, 2009; Dosi and Nelson, 2010) and rapid rise of new competitors (Chen, 2015). It would be also simply due to the divergences in the growth paths of one or both elements of the R&D intensity ratio (e.g. GDP or firm' sales) in each of the benchmarked country (Moncada-Paternò-Castello and Smith, 2009; Moncada-Paternò-Castello, 2017a).

The theoretical basis for the *concentration* of innovative activities is given by Schumpeter Mark II model (concentration occur when economies operate with larger companies in more traditional sectors, with high appropriability and high cumulativeness (at the firm level), and/or operating in economies with limited capacity of creating firms which enter and rapidly grow in new high-tech sectors (Schumpeter, 1942; Malerba, 2005).

The empirical evidence that the EU R&D intensity gap has widened during the years observed is, e.g., provided by Duchêne et al., (2011), Veugelers (2013) and Chung (2015). Evidence of the global concentration of corporate R&D by firms, sectors and countries is supplied by Stam & Wennberg (2009), Coad & Rao (2010), Reinstaller and Unterlass (2012).

The novelty of the second paper regards several aspects: (a) It compares micro-data from different editions of the EU Industrial R&D Investment Scoreboard to analyse how the R&D intensity gap decomposition has changed over a long time period (2005-2013) that includes the year(s) of economic and financial downturn[5]; (b) it contrasts data from firms in the EU with data from firms not only in the USA and Japan, but also in some emerging economies

[5] Novel compared to all other studies is the decomposition exercise provided by this study where it is of the EU vs US R&D intensity gap for the year 2009 by using value added (VA) as denominator, as well as BERD/VA intensity and confronted these results with results obtained by decomposing the R&D investment / net sales.

such as the Asian Tiger countries (Hong Kong, Singapore, South Korea and Taiwan), and the BRIC countries (Brazil, Russia, India and China); (c) It investigates which sectors, countries and firms within the EU are accountable for most of the aggregate EU R&D intensity performance compared to its main competing economy, the USA; (d) It addresses the concentration of corporate R&D with respect to several parameters (sector, countries, number of firms) and their evolution over time. To our knowledge, there are no studies published in peer-reviewed scientific journals that have considered these characteristics in combination in a comparative analysis.

The **third paper** on sector dynamics and sectoral and technological specialisation as well as on the financial factors driving firms' R&D growth - and if these factors are different across firm age - of top R&D investing firms addresses three main streams of the literature of technical change & industrial dynamics for competitiveness, where a) evolutionary economists have demonstrated that technological development and innovation capability are important drivers of the evolution of the industrial structure (Krüger, 2008; Dosi and Nelson, 2010). b) The industrial sectors' composition and its dynamics affects R&D investment and (Baker & Hall, 2013; Matthieu & Van Pottelsberghe, 2010). c) There could be a high heterogeneity of firm's R&D intensity and investment across and within sectors (Mairesse and Mohnen, 2005; Coad, 2017; Moncada-Paternò-Castello, 2017b). The expectation of a higher demand/sales (Grabowski, 1968), returns (Pollack and Adler, 2014) are only some examples of economic and financial factors that influence the firm's R&D growth. Kumbhakar *et al.* (2012) show that R&D activities affect firms' productivity by shifting the production frontier and increasing efficiency in high-tech sectors. On the other hand, physical capital stock results in higher productivity especially in low-tech and service sectors. Part of this literature indicates that R&D investment growth is associated to smaller newer companies (Matsumura and Matsushima, 2010; Schneider and Veugelers, 2010), and that young leading innovators in the USA are more R&D intensive than in the EU as they are more likely to be active in (younger) R&D-intensive sectors (Cincera and Veugelers, 2011; 2013).

The contribution of the third paper complements the literature on three main aspects.
First, it discusses country specificities in the change of R&D investment across sectors and the resulting R&D sector specialisation. By doing so, it disentangles the technological transformation paths of major knowledge-intensive economies, uncovering their strengths and specificities. Second, it inspects the differences in private R&D investment capacity of the EU compared to the US and Japan the USA and other regions in the world. Third, as the study finds a weak link between sectorial dynamics and aggregate R&D investment patterns, it also investigates the R&D investment growth and the firms' age at the micro-level, besides the traditional sectoral classifications. These aspects have little coverage in present literature.

5. Setting the Thesis vs other published papers authored by the PhD candidate

The three papers of the PhD thesis constitute a further contribution to literature in the economic and policy of corporate R&D and innovation authored by the PhD candidate. Since 2005 he has published on this very area of research, revealing a coherent continuity of the investigation in the subject. Table 1 reports a selection of papers (co-)authored by the PhD candidate issued in 2006-2017 and related to the subject of the PhD Thesis.

Table 1. A selection of scientific articles published in 2006 – 2017

Forthcoming
Dosso M., Martin, B. and Moncada-Paternò-Castello P. (2017) "Towards evidence-based industrial research and innovation policy"; an introductory article for a Special Issue in *Science and Public Policy* journal. Oxford university press (to be issued in autumn 2017).
Published
Amoroso S., Moncada-Paternò-Castello, and P., Vezzani, A. (2017) "R&D profitability: the role of risk and Knightian uncertainty " – *Small Business Economics,* Springer editor. February 2017, Volume 48, Issue 2, pp 331–343
Moncada-Paternò-Castello, P. and Grassano, N. (2016), "Innovation without corporate R&D? Analysis of the Italian case and implications for policy". Contribution to a book edited by Malgorzata Runiewicz-Wardyn (Kozminski University) published by Wydawnictwo Naukowe PWN SA - ISBN: 978-83-01-18526-8 Warsaw (Poland), August 2016.
Ciriaci, D., Moncada-Paternò-Castello, P., Voigt, P. (2016) "Innovation and job creation: a sustainable relation?". *Eurasian Business Review,* Springer editor, Vol. 6, No. 2, August 2016, pp. 189-213.
Hall, B.H., Moncada-Paternò-Castello, P., Montresor, S., and Vezzani, A., (2016) **"**Financing constraints, R&D investments and innovative performances: new empirical evidence at the firm level for Europe". *Economics of Innovation and New Technology*. Taylor & Francis editors. Vol. 25, Issue 3, pages 183-196, February 2016
Ciriaci, D., Moncada-Paternò-Castello, P., Voigt, P., (2014). "Does size of innovative firms affect their growth persistence?". *Brussels Economic Review,* Volume 57, Issue 3, p. 317-348. ULB-Dulbea editor. Brussels, autumn 2014.
Voigt, P. and Moncada-Paternò-Castello, P. (2012) "Can fast growing R&D-intensive SMEs affect the economic structure of the EU economy? - A projection to the year 2020 –". *Eurasian Business Review Journal* (EBRJ) - Vol. 2, No.2, pp 96-128, December 2012.
Moncada-Paternò-Castello, P. and Cincera, M. (2012) - "Enterprises' growth potential in the European Union: Implications for research and innovation policy"- The *IUP Journal of Entrepreneurship Development*, - Vol. IX, No. 4, pp 7-40, November 2012.
Moncada-Paternò-Castello, P., Vivarelli, M. and Voigt, P. (2011). "Drivers and impacts in the globalization of corporate R&D: an introduction based on the European experience". *Industrial and Corporate Change, 20(2), 585-604*. April 2011.
Moncada-Paternò-Castello, P. (2010). "Introduction to a special issue: New insights on EU–US comparison of corporate R&D". *Science and Public Policy*, 37(6), pages 391–400; July 2010
Moncada-Paternò-Castello, P., Ciupagea, C., Smith, K., Tübke, A., and Tubbs, M. (2010). "Does Europe perform too little corporate R&D? A comparison of EU and non-EU corporate R&D performance". *Research Policy*, 39(4), 523–536, April 2010.
Ciupagea C., and Moncada-Paternò-Castello P. (2006). Industrial R&D Investment: A comparative analysis of the top EU and non-EU companies Based on the EU 2004 R&D Scoreboard. *Revista de Economía Mundial*, *15*, 89–120.
Moncada-Paternò-Castello, P., Ciupagea, C., and Piccaluga, A. (2006) - "Industrial innovation in Italy: the persistence of a model 'without R&D'?" *Journal of Industrial Economics* – Vol. 03; pp 533-551, July/September 2006.

To illustrate the novelty of the PhD Thesis contribution vis-à-vis the published papers (co-) authored by the PhD candidate, some examples are provided below.

Paper #1 on the survey of the corporate R&D intensity decomposition. It represents a systematic and novel analytical work that go much deeper and more beyond for its methodological, empirical and theoretical research respect to the papers in Table 1, as for example compared to Ciupagea C., and Moncada-Paternò-Castello P. (2006) and Moncada-Paternò-Castello *et al.,* (2010):

Paper #2 on the evolution of EU R&D intensity gap. It encompasses many aspects which add upon the previous contribution to the literature of the PhD candidate. For example, the evolution of the R&D intensity gap and the distribution of R&D including of the emerging economies, the comparison of the R&D intensity decomposition results using different intensity definition, the further analysis of EU vs US intensity gap using new parameters and analytical methods are only few of the novel aspects of the Thesis's paper #1 compared to the articles by Moncada-Paternò-Castello (2010) and Moncada-Paternò-Castello *et al.,* (2010).

Paper #3 on sector dynamics, specialisation and R&D growth. This part of the PhD Thesis provides additional contributions by disentangling the R&D sectorial changes, by observing a much broader time span, by using different metrics to analyse it together with the derived R&D and technological specialisations when compared with the work by Moncada-Paternò-Castello (2010), Moncada-Paternò-Castello *et al.* (2010), Voigt and Moncada-Paternò-Castello (2012). This is also the case of this PhD thesis contribution when investigating on the effects of economic and financial drivers to R&D investment growth by firm age classes across sectors, which add and complement the published work referred to in the previous sentence as well as to that of Moncada-Paternò-Castello and Cincera (2012) and Ciriaci *et al.,* (2014).

Other published papers relate to the subject of corporate R&D and innovation and complement the three papers of this Thesis on aspects of corporate R&D investment that are investigated more in depth or are additional/complementary, such as the size of the firms (Voigt. and Moncada-Paternò-Castello, 2012; Ciriaci *et al*., 2014), job creation (Ciriaci *et al.,* 2016) the focus on one country (Moncada-Paternò-Castello *et al.,* 2006; Moncada-Paternò-Castello and Grassano, 2016), globalisation (Moncada-Paternò-Castello *et al*., 2011), R&D profitability (Amoroso *et al.,* 2016), financial constraints (Hall *et al*., 2016), or policy (Dosso *et al*., 2017).

6. Methodological approach

These studies rely on literature sources as well as on company data accessible from the EU Industrial R&D Investment Scoreboard (hereafter the EU R&D Scoreboard).[6] The EU R&D Scoreboard data are collected from publicly available audited annual reports and company accounts. 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 main sources of complementary information are companies' annual reports, ORBIS database (Bureau Van Dijk) and other publicly available official documents and databases as EU and World KLEMS, ANBERD (OECD), BERD (EC), COR&DIP (EC-JRC/OECD) databases.

[6] http://iri.jrc.ec.europa.eu/scoreboard.html

Based on the EU R&D Scoreboard, a database of micro-data was compiled from the EU and non-EU firms that invest the most on R&D and covering the years 2005-2013. The EU R&D Scoreboard covers about 90 % of global private R&D investment worldwide.[7]

For analytical purposes, these studies use literature review, meta-analysis, descriptive statistics, R&D intensity decomposition computations, Manhattan distance and Technological Revealed Comparative Advantage metrics, and a multinominal logit econometric model.

7. A snapshot of the anticipated results obtained

The results of the literature investigation of the corporate R&D intensity decomposition clearly indicates that the rather contradictory results encountered in the literature are due to some methodological problems which make it difficult to converge on generally accepted measures of structural and intrinsic effects. The meta-analysis implemented in this study shed the light on one particular aspect of the methodological approach which is key to explain the contrasting results of studies on business R&D intensity decomposition. Additionally, there is a relevant issue about the interpretation of corporate R&D intensity data and their availability and quality. The study indicates how the use of different data sources and analytical methods impact differently on R&D intensity decomposition results. Furthermore, the provision of a new consistent theoretical framework for corporate R&D intensity determinants represents an additional output of this study.

The results confirm the structural nature of the EU R&D intensity gap. In the last decade the gap between the EU and the USA has widened, whereas the EU gap with Japan has remained relatively stable. In contrast, the emerging countries' R&D intensity gap compared to the EU has remained relatively stable, while companies from emerging economies are considerably reducing such gap. Besides, as novel contribution to the state of the art of the literature, this paper uncovers the differences between EU and US by inspecting which sectors, countries and firms are more accountable for the aggregate R&D intensity performance of these two economies, and it finds a high heterogeneity of firms' R&D intensities within sectors. Moreover, the study shows a high concentration of R&D in a few countries, sectors and firms, and in the EU there are fewer smaller top R&D firms that invest more intensively in R&D than in the most closed competing countries.

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. Also, the EU has an even broader technological specialisation than its already broad industrial R&D sector specialisation, while the USA leads by number of technological fields mostly belonging to the industrial R&D sectors of its specialisation. In both the EU and the USA the pace of R&D change is slower than in the emerging economies; while the EU has been better able than the USA and Japan to maintain its world share of R&D investment. Finally, this study indicates that firms make a complementary use of capital expenditures and R&D intensity for their R&D investment growth strategies and, new to the literature, it reveals that there are differences in their use between firms' age classes across sectors.

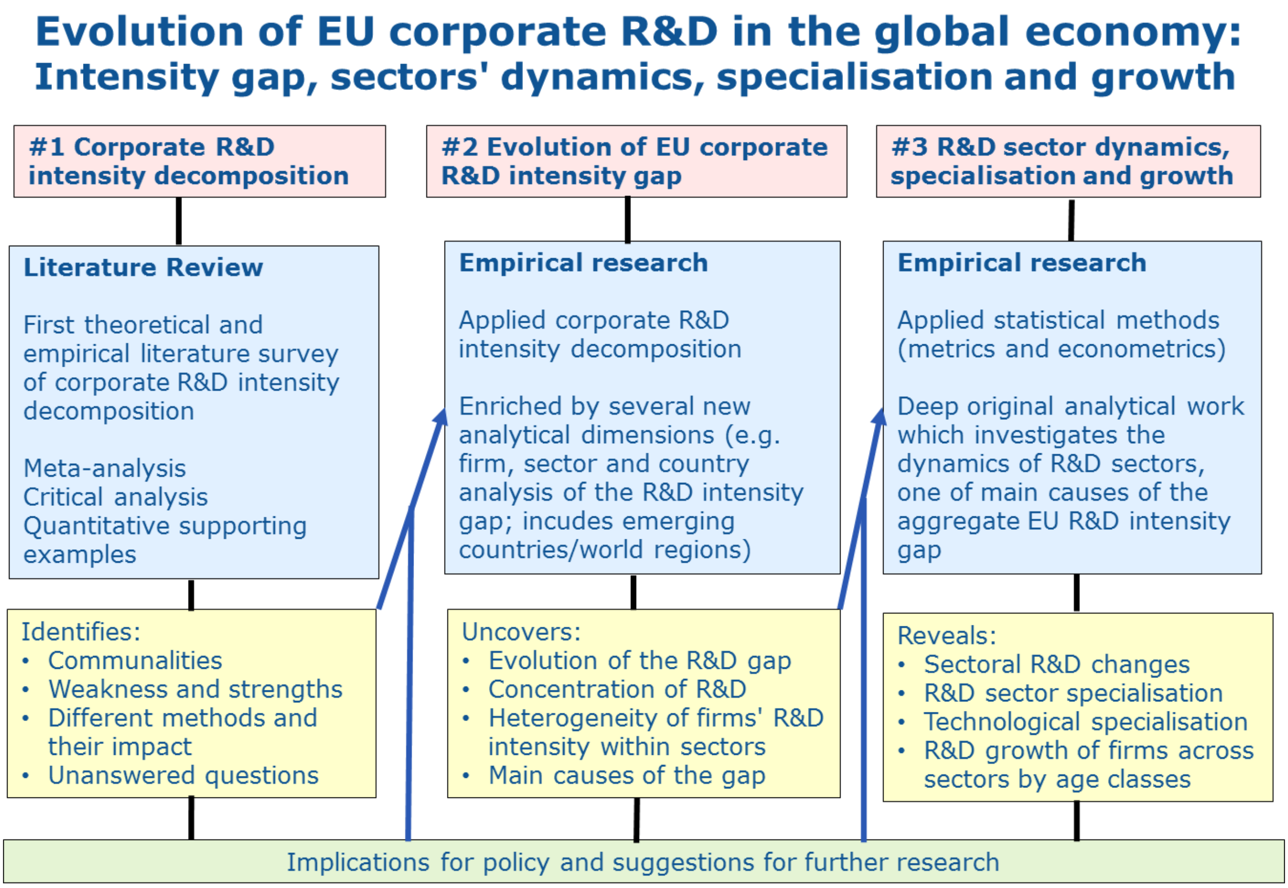
[7] Based on European Commission (2014, p. 15, footnote 3).

8. "Red-line" of the Thesis

As seen, the PhD Thesis's focuses on economic aspects of EU R&D intensity gap and aims at contributing to literature in this area. Its line of coherency, complementary and completeness (the so called "read line") bases first on exploring the theoretical, empirical ground; it then approaches the central matter by investigating empirically the EU R&D intensity and its decomposition comparatively with most closed competitors and with emerging economies. With the purpose of broadening the knowledge of this subject, it finally inspects further some key aspects associated to the R&D intensity performance of the selected countries or world regions by examining the effects of several parameters on two main causes of EU R&D intensity gap: the sectorial composition and its dynamics (and the resulting sectoral and technological specialisations), and the effect of the different use of financial resources to firm's R&D investment growth. On the overall, this research addresses the possible policy implications that derive from the outcomes of different theoretical and methodological undertakings of scholars in the present literature as well as from the original contribution of the PhD Thesis.

Figure 1 below shows schematically the coherency, complementary and completeness of three original papers which compose the PhD Thesis.

Figure 1 Diagram of the three original papers which compose the PhD Thesis



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Essay #1

Survey of corporate R&D intensity decomposition studies: theoretical and empirical issues

Pietro Moncada-Paternò-Castello(*****)

Abstract

Research and development (R&D) indicators are increasingly used not only to facilitate international comparisons, but also as targets for policies stimulating research. An example of such an indicator is R&D intensity. The decomposition of R&D intensity was conceived with the aim of evaluating aggregate R&D intensity and explaining the differences in R&D intensity between countries by determining whether they are *intrinsic* (e.g. due to firms' underinvestment in R&D) or *structural* (e.g. due to differences in the sectors that make up an economy). Despite its importance for analytical purposes, the theoretical and empirical literature of the decomposition of corporate R&D intensity has been developed only recently. This survey paper reviews for the first time the theoretical and methodological frameworks of corporate R&D intensity decomposition and how it is applied in the literature in order to determine why the empirical results seem to be contradictory. It inspects how the use of different data sources and analytical methods impact differently on R&D intensity decomposition results, and what the analytical and policy implications are.

JEL classification: O30; O32, O38; O57; F23; R39

Keywords: corporate R&D intensity gap; decomposition; literature survey; R&D policy

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(*) <u>Contact Information</u>: European Commission – Joint Research Centre (JRC), Growth and Innovation Directorate. Edf. Expo, Calle Inca Garcilaso No 3, 41092 Seville, Spain. Email: pietro.moncada-paterno-castello@ec.europa.eu

1. Introduction

Research and development (R&D) intensity indicators are increasingly used not only to facilitate international comparisons, but also as targets for policies stimulating research. The two goals are, of course, intimately linked; it makes little sense to set a quantitative policy target unless it is known whether it is high or low compared with economies at similar stages of development.

In fact, R&D expenditures have long been an important concern for innovation analysts, who have used them as proxies for innovation inputs and have considered them to be a determinant of growth, productivity and competitiveness. For this reason, R&D intensity targets are one of the main objectives of the European Union’s research and innovation policy agenda, namely the Lisbon Strategy, devised in 2000, and the related Barcelona Target, set in 2003 (which states that the EU should spend 3% of gross domestic product (GDP) on R&D, two-thirds of which should come from the private sector). A benchmarking exercise performed at the time revealed that the EU was not performing at the same level as its main competing economies, notably the USA and Japan. In the EU, only 1.9% of GDP was being invested in R&D, compared with 2.7% in Japan and 2.98% in the USA; in other words, there was an ‘R&D intensity gap’ (European Commission, 2003). As a result, a target for EU R&D intensity was set in an effort to close the gap (Sheehan and Wyckoff, 2003).

More recently, the importance of the Barcelona Target has been reiterated and reinforced in the Europe 2020 strategy, part of the EU flagship initiative (European Commission, 2010a), which supports an increase in private research and innovation investment and puts the emphasis on the importance of policies positively affecting the demographics (creation and growth) of companies operating in new/knowledge-intensive industries. One of the approaches that has been developed and used by scholars and policy analysts to investigate the EU R&D intensity gap, and to determine the extent to which it is attributable to differences in R&D investment between countries, sectors, or even firms, has been the ‘decomposition’ of the R&D intensity gap into its major economic determinants. Actually, the decomposition methodology for the R&D intensity gap was originally conceived with the aim of evaluating the extent to which changes in aggregate R&D intensity can be explained by changes in industrial structure (van Reenen, 1997).

Despite the significance of the analytical purpose, the theoretical framework and the methodology needed to decompose countries’ R&D intensity have been elaborated only recently, and are still not extensively used in literature. According to Becker and Hall (2013), the literature on the determinants of R&D investment in industry sub-groups, as well as on sectoral decomposition of such determinants, is rather limited. Yet the results of the decomposition studies of corporate R&D intensity are often contradictory (Moncada-Paternò-Castello *et al.*, 2010).

The micro–macro statistical issue is a major topic for economic policy research. In fact, the analysis of micro-level statistics allows the evaluation of the characteristics of an economic system at the most accurate (unitary) scale. Aggregate micro-level statistics can, in turn, be particularly useful for understanding industry and macro-level dynamics, and thus are extremely valuable for policy design, monitoring and evaluation. Despite this, large-scale application of aggregate micro-level statistics is still limited, especially in the field of the knowledge economy, for different reasons but mostly because the available information is limited and inhomogeneous owing to measurement problems and some conceptual and methodological differences (De Panizza and De Prato, 2009; Bjørnskov and Foss, 2016) ([8]).

The examination of firms' R&D intensity in industries and at different layers of aggregation leads to results that are mixed and not completely understood. For policy purposes, it is particularly important to determine whether the differences between countries/regions are intrinsic, for example due to firms' underinvestment in R&D (something that can be expected to be relatively easily changed), or structural, for example attributable to the sector composition of an economy (change in which is likely to require more effort and time).

This paper *aims* to contribute to the literature by offering the **first survey** of scientific studies on corporate R&D intensity decomposition.

The **main questions** that this paper aims to answer are the following:

- What is the most comprehensive theoretical framework of determinants of corporate R&D intensity, as well as what are the empirical studies of corporate R&D intensity decomposition in the literature and their results?
- Why these empirical studies deliver different results?
- What are the different impacts on R&D intensity decomposition result by using different data sources and methodological approaches, and their limitations?

The **original contribution** of this paper compared to the state of the present literature is multiple:

Firstly, as new to the literature, this paper provides a comprehensive identification of the main reasons why different studies come up with different results, although most studies rely on very similar data and similar methodological approaches. In fact, for the first time data and methods used in the literature are systematically analyses (also by way of a meta-study) and discussed.

Secondly, it also goes over details of the different impacts on R&D intensity decomposition results that are originated by the use of different data sources, and their limitations.

Third, it suggests which data and methods should be better approached depending on the analytical aim, and how much reliable the results are, also providing some hints for their analytical interpretation, also in term of policy implications.

Finally, this first literature survey offers a new consistent theoretical framework of corporate R&D intensity determinants, besides an updated scrutiny of empirical studies on the subject.

This paper is structured as follows. Section 2 surveys the literature on the main determinants of corporate R&D intensity and the methodologies used to decompose corporate R&D intensity and their main empirical results; section 3 discusses the main findings, including the reasons for the contrasting results and illustrates the implications (impact) for the quality of the comparisons derived; section 4 proposes some concluding remarks relevant to analysts and policy-makers, and suggests potential avenues for future research in this area.

([8]) According to Bjørnskov and Foss (2016), other micro–macro problems are common to many economic studies. These include the use of detailed micro-level data beyond case studies towards meso- and macro-statistical interests, the interaction between macro-level institutions and policies and firm-level responses and, in particular, the potentially complex interactions between different institutions and policies.

2. Literature review: theoretical and methodological frameworks — empirical results

In this section, the theoretical and empirical literature on the main determinants of corporate R&D is introduced. The central objective of investigation of this paper is then tackled by elaborating on the concept and purpose of decomposing corporate R&D intensity, and presenting the empirical decomposition results from the surveyed literature on the subject.

2.1. Theoretical framework of the determinants of corporate R&D intensity

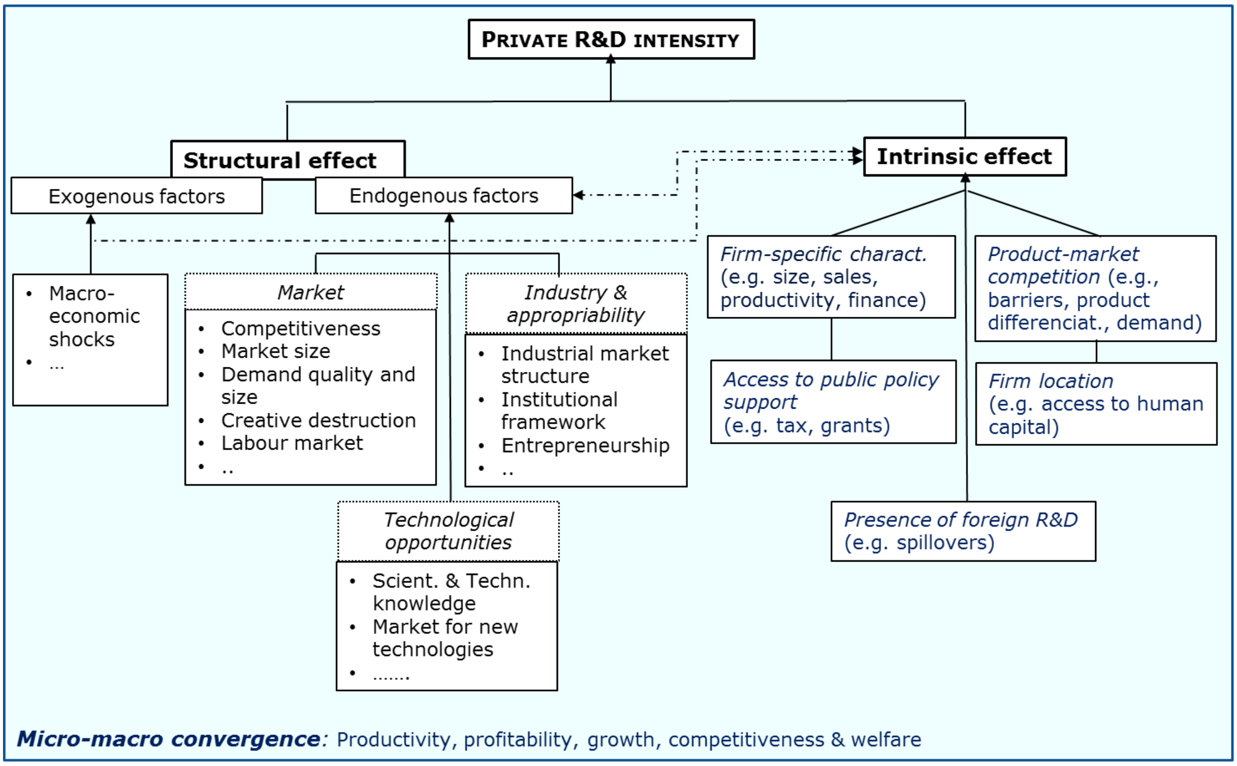
Before presenting the literature of the main determinants of corporate R&D intensity, a general theoretical framework of reference is provided. Economic theory indicates that knowledge development (Schumpeter, 1949) and technical change (Solow, 1957) are the major sources of productivity growth in the long term. R&D is a major source of technical change (Romer, 1990; Guellec and van Pottelsberghe de la Potterie, 2001), and this is recognised as a key element for increasing the knowledge base and, with it, the growth, productivity and competitiveness of an economy (Mowery and Rosenberg, 1989; Coccia, 2008). In fact, most of the arguments in favour of policies targeted at raising the level and efficiency of R&D rely on the assumption that there are close links between R&D investment and micro- and macro-economic performance (Mitchell, 1999; Bilbao-Osorio and Rodríguez-Pose, 2004; Griffith *et al*., 2004; Kafouros, 2008). The effects of 'micro–macro convergence' of private and public (social) drivers in the implementation and promotion of corporate R&D activities are visible the potential returns not only in productivity, but also in profitability, sales, market capitalisation, employment growth, competitiveness and socio-economic welfare (see, for example, Morbey and Reithner, 1990; Griliches, 1979, 1994; Cincera *et al.*, 2009a; Hall *et al.*, 2010).

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* (sector) composition effect and *intrinsic* effect (Pakes and Schankerman, 1984; Erken, 2008; Mathieu and van Pottelsberghe de la Potterie, 2010; Becker and Hall, 2013).

We consider that 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



Source: Author's elaboration from Pakes & Schankerman (1984), Gorg & Greenaway (2003), Erken & van Es (2007), Mathieu & van Pottelsberghe de la Potterie (2010), Vivarelli (2013) and Becker & Hall (2013).

However, structural endogenous factors are also, at least to some extent, dependent on intrinsic factors (Erken and van Es, 2007) ([9]). In other words, the sectoral structure of a 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. In the following sub-sections, we report the main findings from this literature, focusing on only three main arguments: (i) productivity 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.

i) Productivity as one of the main micro–macro drivers for corporate R&D activity

The literature suggests that a virtuous circle exists, whereby competitiveness promotes R&D and technological development, leading to productivity gains, which in turn increases profitability, which then releases resources that can be used to invest in (more) R&D.

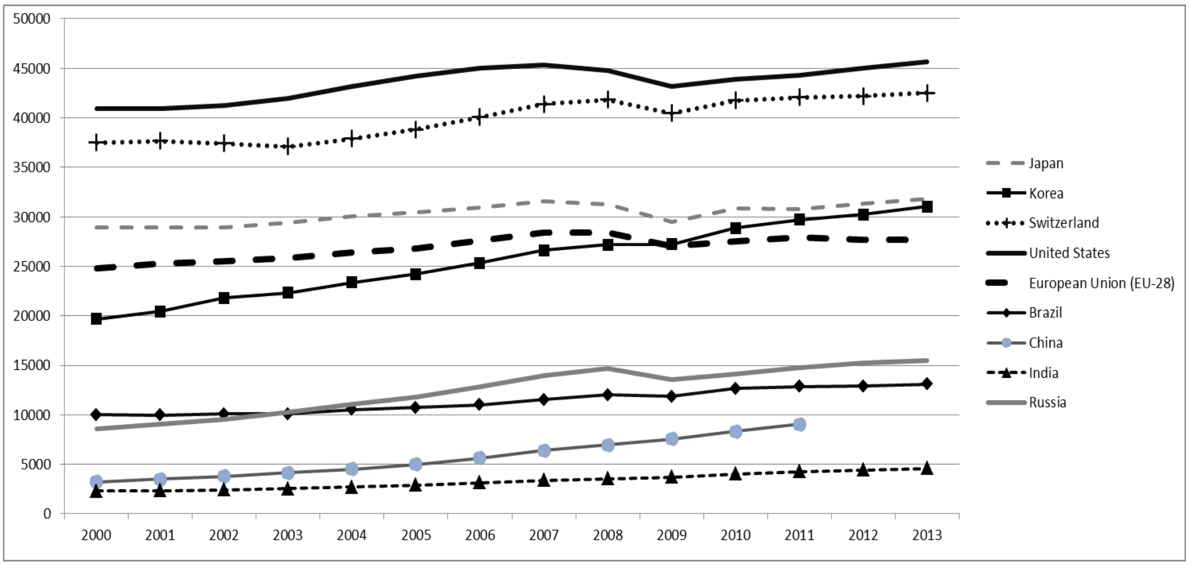
([9]) For more information on this relationship, see Erken and Donselaar (2006).

Essentially, in accordance with endogenous Schumpeterian growth theory, productivity growth is positively influenced by R&D expenditure (Schumpeter, 1949; Griliches, 1979, 1994; Zachariadis, 2003; Guellec and Sachwald, 2008). Crepon *et al.* (1988) found a positive impact of innovation sales share on firms' productivity, while Mathieu and van Pottelsberghe de la Potterie (2010) suggested that that firms' return on R&D investment can be achieved through a higher level of productivity as a result of an accelerated rate of technological change. The increased effectiveness (due to higher productivity) of R&D investment (or 'effective' rate of return to R&D), together with a higher propensity to invest in R&D, allows for greater competitiveness of firms and of the economy as a whole. Therefore, heterogeneity of both sectors and firms should be taken into account as this explains the substantial differences in the rate of productivity return to R&D investment (Cincera *et al.*, 2009b, Ortega-Argilés *et al.*, 2010; Montresor and Vezzani, 2015).

In practice, micro- and macro-productivity returns to R&D (like the other drivers mentioned previously, such as profitability, growth, etc.) enable the possible convergence of objectives of the intrinsic and structural factors.

Unfortunately, the EU faces a productivity gap compared with its main competitors, and this has widened since the financial economic crisis that started in 2007, as can be seen in Figure 2, which shows productivity over the period 2000–2013 measured as GDP per capita. Figure 2 shows average productivity among the EU-28 countries, and thus does not disguises dissimilarities in the degree of development of different EU countries. This dissimilarity can be seen in Figure 3, which reports productivity (as GDP per capita) and R&D efforts/intensities (R&D expenditure as a percentage of GDP) in the different EU-28 countries in 2013.

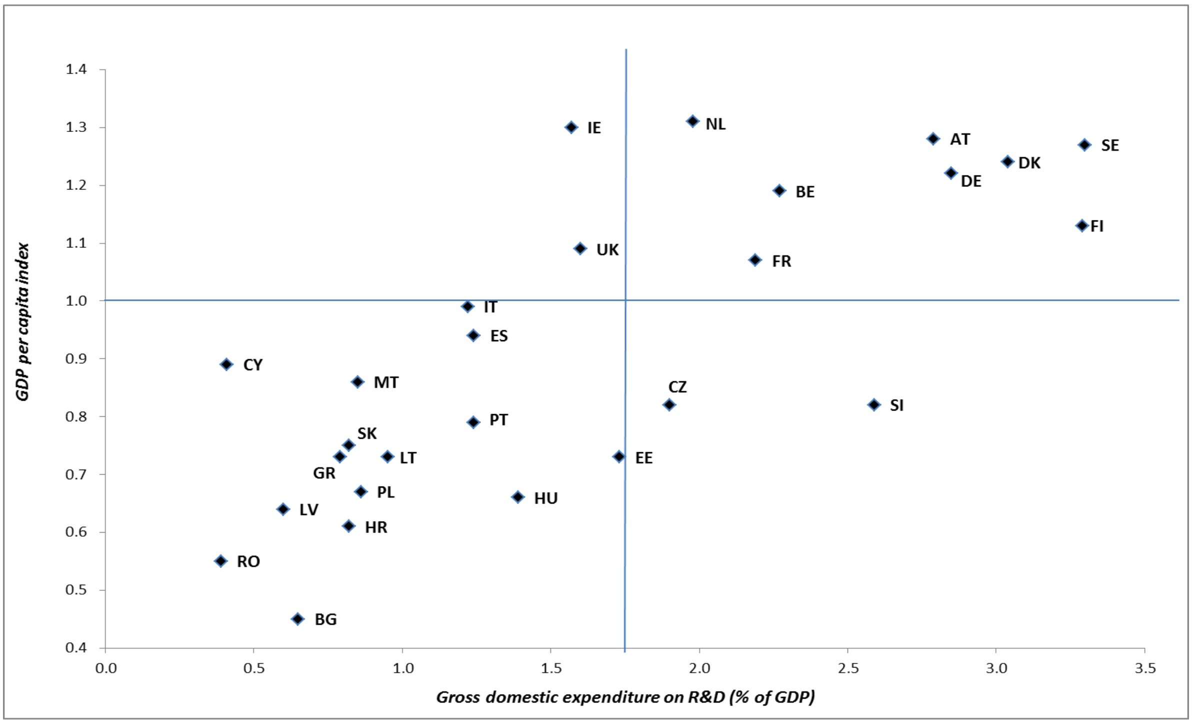
Figure 2. GDP per capita in the EU-28 and selected countries in 2000–2013



Source: author's own elaboration of data from OECD (2015) ([10]).
Note: data on the y-axis are in US dollars, constant prices, 2005 purchasing power parities.

(10) Data extracted on 6 March 2015 from http://stats.oecd.org/

Figure 3. GDP per capita and R&D intensity in EU-28 countries in 2013



Source: author's own elaboration of data from European Commission (Eurostat) (2015) ([11]).

Notes: EU-28 average productivity = 1 (index of reference); based on purchasing power standards per capita. The EU-28 GDP per capita in 2013 at current prices was EUR 26,600. The EU-28 R&D intensity (gross domestic expenditure on R&D as a proportion of GDP) was 1.98%. For a better graphical representation, data for Luxembourg (GDP per capita index = 2.57; R&D intensity = 1.16%) are not plotted in the figure.

It should be remembered that a firm's R&D investment can be either pro-cyclical or counter-cyclical and that R&D investment also depends on a firm's business cycle and their business characteristics (Voigt and Moncada-Paternò-Castello, 2009; Arvanitis and Woerter, 2014). Stephan (2004) stressed that the high-tech firms usually adjust their R&D expenditures less to the business cycle in contrast to low- and medium—tech ones. These are micro-level factors that, when analysed at the aggregate (macro-) level, could make between-country comparisons more difficult.

ii) <u>Sector composition (or structural) factors</u>

Industries are characterised by, among other things, very different levels of R&D investment relative to their output, and it should be noted that, in the absence of country-specific differences, differences in aggregate R&D intensities between countries reflect the mix of industries in particular countries (Moncada-Paternò-Castello and Smith, 2009).

The advanced economies of the world may be similar in terms of basic economic indicators (e.g. income levels), but they differ significantly in terms of their technological specialisations and hence industrial structures. These industrial structures, which influence aggregate corporate R&D intensity, can be affected by exogenous factors, such as the economic and financial shocks caused by global events, for example a financial downturn, a global oil crisis or a war.

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(11) Data extracted on 8 March 2016 from http://ec.europa.eu/eurostat/statistics-explained/index.php/R_%26_D_expenditure and http://ec.europa.eu/eurostat/statistics-explained/index.php/National_accounts_and_GDP

The theoretical basis for the effects of industry composition and sector characteristics (i.e. the endogenous structural effects) on the aggregate corporate R&D intensity of a given economy gives a clue as to why these inter-industry differences occur. Pakes and Schankerman (1984), based on the theoretical work of other authors (e.g. Schumpeter, 1950; Griliches and Schmookler, 1963; Scherer, 1982), while arguing that the output of research activities (industrial knowledge) exhibits unique economic characteristics, developed a theoretical model indicating that R&D intensity depends on the combination of three factors: expected market size and growth in demand, appropriability differences and technological opportunities.

Taking stock of this theoretical literature and complementing it with other studies (namely Erken and van Es, 2007; Mathieu and van Pottelsberghe de la Potterie, 2010; Becker and Hall, 2013), we classify the endogenous structural factors as market factors, technological opportunities factors and industry and appropriability factors. These factors are interlinked.

a) Market factors refer, in particular, to the competitiveness level, the expected size of the market and/or the demand inducement, the level of higher education and the degree of labour market mobility (Pakes and Schankerman, 1984; Saxenian, 1996; Lundvall and Borras, 2005; van Pottelsberghe, 2008; Mathieu and van Pottelsberghe, 2010; Becker, 2013. Aghion *et al.*, 2014). Furthermore as new technologies have success only if fit specific factors and market conditions, the identification of the determinants for the adoption/non-adoption is relevant (Stoneman, 1995).

b) Technological opportunities are based the availability and the cost (efficiency) of producing scientific and technical knowledge in different areas or industrial sectors. These factors also include the size and the homogeneity of the market for new technologies, for example the patent system (Foray and Lhuillery, 2010; de Saint-Georges and van Pottelsberghe de la Potterie, 2013). These authors argue that the key function of knowledge dissemination/adoption is to enable firms to rely on efficient R&D and innovation economic systems.

c) Industrial and appropriability factors include historical track record, sector capital specificity, industrial market structure, the level of industry–university collaboration, ‘creative destruction’ and entrepreneurial ability (success) and the general institutional framework (e.g. industrial policy, public R&D expenditures and infrastructures) in which firms operate. Abundant empirical studies (Cohen and Lorenzi, 2000; Aghion, 2006; van Pottelsberghe, 2008; Veugelers, 2015) have identified various other structural factors that contribute to countries’ R&D levels.

iii) Intrinsic factors

The theoretical foundation of corporate R&D intensity differences, which is determined by a firm’s own levels of R&D investment and sales (intrinsic effects), finds a solid anchorage in the Schumpeterian arguments that R&D intensity differences very much depend on the availability of internal resources, access to external sources and high levels of product market competition on innovation (Aghion and Howitt, 2006; Becker, 2013). Becker and Hall (2013) suggest five types of key intrinsic determinants of private-sector R&D expenditures: firm-/industry-specific economic and financial factors, product market competition, public policies, location and endowment, and the presence of foreign R&D.

(1) Firm-/industry-specific factors

The theoretical explanation underpinning firms' motivation to invest in R&D is centred on the expected (positive) return. Among the key investment sources and determining factors of such investment are cash flow and sales, especially when firms have difficulty relying on external funds; these arguments have a solid theoretical Schumpeterian foundation (Aghion and Howitt, 2006). We can therefore distinguish two main specific factors: the benefits from R&D and the costs of R&D. As regards the former, there is a rich literature indicating a positive correlation between R&D investment and a company's sale growth (Morbey and Reithner, 1990), while other studies have shown a strong link between R&D investment and productivity (see literature cited in 'Productivity as one of the main micro–macro drivers for corporate R&D activity'). More recent studies have found that the potential for increased profitability as a result of R&D investment is a key factor determining a firm's private R&D investment (Hall *et al*., 2010).

As far as the cost of R&D is concerned, and in particular the ability of firms to access sources of finance, demographics play a relevant role, since access to finance probably depends upon a firm's age and size. The empirical results of the effect of cash flow on R&D investment are mixed. Most studies report a significant positive effect (e.g. Hall *et al*., 1998; Cohen, 2010; Cincera and Ravet, 2010), especially in the case of more technology-intensive and/or smaller firms (Cincera *et al.*, 2015), but some authors report insignificant effects (e.g. Harhoff, 2000; Bond *et al.*, 2003). However, the effect of sales on R&D investment is likely to be positive (van Reenen, 2007; Borisova and Brown, 2013). Ortega-Argilés and Brandsma (2010), Cincera and Veugelers (2013) and Stancik and Biagi (2015) found that the size of R&D-intensive firms plays a role in explaining the overall R&D intensity gap between the EU and the USA. In both economies, R&D intensities tend to be higher in smaller firms, but the effect is more significant in the USA than in the EU. One reason for the high R&D intensity in the USA is the large number of small and medium-sized enterprises (SMEs) operating in strongly performing R&D sectors, notably those concerned with information and communications technology (ICT). These results are, in part, confirmed by a recent study by Moncada-Paternò-Castello (2017b) showing that the age distribution of top R&D investors is strongly related to the sector (and technology) in which these firms operate. In summary, age and size will affect the net private return to R&D but are not drivers of R&D *per se*.

Finally, there are important issues of corporate governance that could hamper the propensity of firms to invest in R&D activities - which respond to longer-term competitiveness objectives – to privilege favouring the short-term expectations of financial markets (Honoré, *et al.,* 2015).

(2) Product market competition

This has already been identified in Schumpeterian growth theory (Aghion and Howitt, 2006) as a factor having possible mixed effects on R&D investment. In fact, a high level of market competition may undermine incumbent firms' incentive to innovate because these firms are less efficient in exploiting innovation investment (Romer, 1994; Acs *et al.*, 2009). In contrast, other streams of empirical literature (Geroski, 1990; Damanpour, 2010; Ayyagari *et al.*, 2012) have found market competition to a positive effect have on innovation, because firms use R&D as a strategic investment to combat or prevent competition. In addition, Aghion and Howitt (1995) and Aghion *et al.* (2002) found that the relationship between product market competition and innovation forms an inverted U-shape: the escape competition effect dominates at low initial levels of competition, whereas the Schumpeterian effect dominates at higher levels of competition.

A possible explanation of these controversial results is provided by Wu (2012) and Kubick *et al.* (2014). They argue that a low level of competition, attributable to a small number of large incumbent firms and high barriers to access facing new entrants, provides little incentive to invest in R&D. The greater the access and the less differentiated the product, the greater is the incentive to achieve an advantage through R&D. On the other hand, in highly competitive markets, the time for innovation is short and the potential gains from R&D could be small and highly uncertain. The situation is different for every country and sector, and such structural differences need to be taken into account before asserting that any deficiencies in terms of R&D are intrinsic to the country.

(3) Access to public policy support

Tax credits and direct subsidies for R&D have positive effects on firms' R&D investment, but they also bring the threat of crowding-out/substitution effects (Bloom *et al.*, 2002; Guellec and van Pottelsberghe de la Potterie, and 2003 and 2005; Hall *et al.*, 2016).

to quantify the aggregate net effect of government funding on business R&D in 17 OECD Member countries over the past two decades. Grants, procurement, tax incentives and direct performance of research (in public laboratories or universities) are the major policy tools in the field. The major results of the study are the following: Direct government funding of R&D performed by firms has a positive effect on business financed R&D (except if the funding is targeted towards defence activities). Tax incentives have an immediate and positive effect on business-financed R&D; Direct funding as well as tax incentives are more effective when they are stable over time: firms do not invest in additional R&D if they are uncertain of the durability of the government support; Direct government funding and R&D tax incentives are substitutes: increased intensity of one reduces the effect of the other on business R&D

(4) Firm location

Firm location is an important factor as a firm's R&D investment increases with its proximity to universities and a skilled labour force (Vivarelli, 2013; Capello, 2014; Amoroso *et al.*, 2015). *A priori*, one would expect the economic structure of a particular country to be less important to investment in R&D than intrinsic qualities such as national incentives (e.g. taxes, grants). Yet the annual surveys of EU R&D Scoreboard companies, conducted since 2005, clearly indicate that, as reported in Moncada-Paternò-Castello *et al*. (2011) and Cincera *et al.* (2012), for these companies, the principal factors influencing R&D investment are, in order of importance, (a) access to specialised R&D knowledge, (b) the availability of researchers and (c) proximity to other company activities (e.g. production). In addition, the survey results show that top R&D investors' main reasons for locating R&D in China and India are market size and growth, together with the availability of R&D personnel (Tübke *et al*., 2015).

(5) Presence of foreign R&D

Studies of the role of foreign R&D as driver of domestic R&D investment show mixed results. For example, Gorg and Greenaway (2003), Moncada-Paternò-Castello *et al.* (2011) and D'Agostino and Santangelo (2012) have suggested that domestic R&D and innovative activity can be augmented by competition because this leads to knowledge spillovers from foreign firms, although Keller (2002) found that that technology is to a substantial degree local, not global, as the benefits from spillovers are declining with geographical distance. However, the same former authors argue that greater competition could reduce the propensity of domestic firms to invest in R&D investment because return on investment, in terms of profitability, is expected to be lower.

Therefore, both the *intrinsic* and *structural* components of corporate R&D intensity in a given economy are determined by a number of factors that could be macro or micro in nature or origin. In fact, it should not be forgotten that structural differences are the result of decisions by individual firms over a long period of time. Their performance and strategy may be influenced by government policy, but the focus on intrinsic factors may also remove the main impediments to corporate R&D.

2.2. Concept and purpose of decomposing corporate R&D intensity

The literature comparing private-sector R&D intensity in competing economies in different countries or regions of the world (e.g. EU vs. USA), and the various factors that influence it, is extensive. Much of the scientific effort devoted to studying this phenomenon seems to address one main issue: whether the R&D intensity differences between countries are the result of companies' different behaviour in R&D (*intrinsic effect*) or are mainly due to the structure of the economy (*structural effect*). In other words, the question is: are differences in overall R&D intensity due to differences in the investment behaviour of the companies within a particular country, compared with similarly positioned companies in other countries, or do they simply reflect differences in the structure of the economy that cannot be remedied in the short term?

Thus, the methodology for decomposing the R&D intensity gap has been conceived to evaluate the extent to which changes in aggregate R&D intensity can be explained by a change in industrial structure or by a change in R&D intensity of a given industry, and also for benchmarking purposes.

In one of the seminal works to analyse corporate R&D intensity, van Reenen (1997) defined decomposition as 'a straightforward accounting exercise'. Table A1 in the Annex reports the details of main methodological approach — including data sources used, the counties/regions compared, and the main results — of 16 recent studies on the decomposition of private R&D intensity. Almost all of these researchers use a basic equation when decomposing R&D intensity:

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

where RDI is R&D intensity, defined as R&D investments to net sales ratio (e.g. Moncada-Paternò-Castello *et al*., 2010; Stanick and Biagi, 2015) or by R&D expenditures to value-added ratio (e.g., Reinstaller Unterlass, 2012; Foster-Mc Gregor *et al*., 2013), R&D capital stock to gross value added (Gambau-Slbert and Maudos, 2013) or R&D expenditure to GDP (Lindmark *et al*., 2010). *S* is the share of the sales or value added, subscript *i* indicates the sector, X stands for the country/region X and Z represents the countries/regions with which country X is compared. Other researchers adapt this basic formula their research objectives. For example, Cincera and Veugelers (2013) use superscripts *y* and *o* to RDI and S, which denote respectively, "yollies" (young leading innovators) and "ollies" (old leading innovators); subscript i, S_i^y denotes the share of the sector accounted for by the total number of young firms and S_i^o denotes the share of the sector accounted for by total number of old firms.

2.3 Decomposition of corporate R&D intensity: empirical findings

The divergent findings in the literature concerning the causes of the R&D intensity gap between EU and US companies suggest that caution should be exercised when drawing general conclusions based on individual studies (Moncada-Paternò-Castello, 2010).

Intrinsic effects

There is one group of researchers (e.g. Dosi, 1997; Pianta, 2005) who are more inclined to consider that the EU R&D deficit is generally the result of companies' underinvestment in R&D (*intrinsic effect*). Erken and van Es (2007) examined the differences in business R&D between 14 EU countries and the USA in 36 sectors over a 17-year period using OECD-STAN ([12]) and ANBERD ([13]) data. They concluded that the contribution of sector composition to the R&D funding gap between the EU and the USA was very low, whereas the intrinsic effect was undoubtedly responsible for the private R&D gap. They also argued that, if only manufacturing sectors are taken into account, corporate R&D intensity does not differ much between the USA and the EU. They suggest that the R&D gap is due mainly to institutional differences, including, for example, a lower level of government support for research activities in the EU.

Structural effects

In contrast, other researchers have concluded that the gap is mainly due to the structure of the economy (i.e. sectorial composition or *structural effect*). This is true for one of the first empirical studies (Scherer, 1967), which demonstrated that most R&D intensity can be explained by industry fixed effects. Later work by Cohen *et al*. (1987) showed that the sector in which firms operate accounts for half of the R&D intensity differences across firms. More recently, Ab Iorwerth (2005) undertook a detailed decomposition ([14]) of differences between Canadian and US R&D intensities across industries. He used the OECD-STAN database for industrial analysis and the OECD Research and Development Expenditure in Industry database and found that Canada's low aggregate R&D performance hides high research intensities in some research-intensive industries. Nonetheless, the results also indicated that the smaller relative size of these industries — together with the low R&D intensities in motor vehicle and service industries — accounted for the weak aggregate performance in Canada compared with the USA. Likewise, for the EU versus US comparison, Ciupagea and Moncada-Paternò-Castello (2006), O'Sullivan (2007) and Guellec and Sachwald (2008) suggest that the European private R&D investment deficit is mainly due to a sectoral composition effect. These authors found that the R&D intensity difference could be attributed to the fact that the ICT sector is smaller in the EU than in the USA. In fact, in the EU the ICT sector accounts for a relatively much smaller proportion of overall business expenditure on R&D than it does in the USA.

([12]) OECD stands for Organisation for Economic Co-operation and Development; STAN stands for 'STructural ANalysis Database'.

([13]) ANBERD stands for Analytical Business Enterprise Research and Development database.

([14]) He used the *Bennet decomposition* following Diewert (2005).

This conclusion confirms the findings of GFII (2007), of the European Commission (2007, 2008), and of Moncada-Paternò-Castello *et al.* (2010) and Cincera and Veugelers (2013), who based their analyses on samples from the EU R&D Scoreboard data. Moncada-Paternò-Castello *et al.* (2010) found that the structural effect accounted for 85% of the gap between the EU and the USA, with only 15% being attributable to the intrinsic effect ([15]).

Moncada-Paternò-Castello *et al.* (2010) also analysed the distribution of R&D among the top R&D-intensive firms and found that in the EU R&D investment is concentrated in a relatively smaller number of firms operating in sectors that are generally of lower R&D intensity than the USA. Cincera and Veugelers (2013) investigated the role of the older and younger firms in the corporate R&D intensity gap between the EU and the USA and found that 55% of the EU gap is accounted for by greater R&D intensity in younger US firms, and this is almost entirely due to the different sectoral composition in the two economies.

Furthermore, Stančik and Biagi (2015), who used EU R&D Scoreboard data (2002–2010) to decompose the R&D intensity gap, found that R&D intensity is lower in the EU than in the USA, Japan or the Asian Tiger countries, but higher than in the BRIC countries (Brazil, Russia, India, China). The authors concluded that the former finding can be attributed to structural effects, whereas the latter is the consequence of both higher R&D intensity within sectors and sectoral composition. Focusing on the R&D intensity gap between the EU and the USA and using firm-level data. These authors also found that there is strong between-sector variation and some evidence of within-sector variation, although not always in favour of the USA.

Several studies carried out in the last decades indicate that economic and technological specialisation is one of the main factors underpinning the EU R&D investment gap. For example, some have investigated the reasons for the commonly observed pattern that R&D investments in Europe as a whole are generally lower than in the USA. Although Pavitt and Soete (1982) found that one of the main factors underpinning this phenomenon was the high degree of international specialisation in individual EU Member States, a more recent study found that technological capabilities in the EU showed a tendency towards convergence between 1998 and 2008 compared with the USA (Fagerberg *et al*., 2014). These results indicate that social capabilities, such as a well-developed public knowledge infrastructure, condition the growth of technological capabilities. Moncada-Paternò-Castello (2017b) complemented these finding by suggesting that the EU firms are less able than USA companies to create high-tech sectors or join them quickly, and, therefore, to fully exploit the growth opportunities offered by first mover advantages.

Van Ark *et al*. (2003) observed that, in the USA, expenditure on R&D outside the manufacturing sector has been increasing since the mid-1990s and now accounts for about one-third of total R&D expenditure, up from less than one-fifth in 1995. So, although the manufacturing sector still accounts for the majority of R&D expenditure, its share is declining. These authors also note that growth in services R&D has been slower in Europe than in the USA, and has still not reached 20% of total R&D. At least part of this gap is probably explicable by the fact that ICT diffusion has been slower in Europe than the USA.

([15]) A complete discussion of these aspects is offered by Moncada-Paternò-Castello (2017a).

Mathieu and Van Pottelsberghe de la Potterie (2010) limit their analysis of R&D intensity to 20 manufacturing sectors, concluding that BERD ([16]) intensity is mainly driven by the degree of specialisation in R&D-intensive industries. This finding supports the argument that a sectoral composition effect is the cause of the low EU R&D intensity. This study focused on 10 European Member States and considered a range of data that covered the period from 1991 to 2002. The findings suggest that specialisation in sectors of high R&D intensity is the reason why R&D intensity is higher in some of the EU Member States than in others.

More recently, Reinstaller and Unterlass (2012), using BERD panel data, analysed the development of R&D intensity in the EU-27 countries and some other relevant non-EU countries over the period 2004–2007. They found that changes in aggregate BERD figures were driven by structural changes and by changes within same sector with rather different speed of changes depending on countries and sectors.

Gumbau-Albert and Maudos (2013) used the EU-KLEMS[17] database to calculate R&D capital stock (rather than R&D expenditures) with the aim of investigating differences in the technological capital intensity of various industries in the EU-11 countries and the USA. They found a technological gap in favour of the USA until the mid-1990s because of the greater accumulation of technological capital in most of the productive sectors considered. However, from 1995 onwards a change in productive specialisation occurred: a significant drop in the relative importance of lower technology-intensive industries in the EU-11 economy was accompanied by a significant drop in the relative importance of some medium technology-intensive industries in the USA, leading to a reduction in the technological gap between the EU and the USA. Gumbau-Albert and Maudos (2013) also found that differences in the productive structure of European countries explain most of the differences in technological capital intensity. Another recent decomposition analysis (Foster-McGregor *et al*., 2013) found that differences in the R&D intensity (defined as the expenditure of manufacturing firms on R&D relative to manufacturing value added) of manufacturing firms in seven EU Member States and the USA and Japan are mainly driven by the intensity effect. Industry structure (composition effect) plays a role in some EU Member States but is never the primary factor. However, the authors suggest that the relative importance of the composition effect and the intensity effect in a decomposition exercise depends on the level of aggregation of the industries, and they recognise that a more detailed industry breakdown would assign greater importance to the composition effect, assuming that companies in the same sub-sector are closer in terms of R&D intensity.

Mixed - intrinsic and structural - effects

Other studies find some clear path of mixed (intrinsic *together* with structural) effects. A recent study by Belitz *et al.* (2015) based on OECD data at two-digit level analysed the difference between private-sector R&D intensity in Germany and a selection of OECD countries. These authors found that the structural effect and the behavioural (intrinsic) effect play more or less equally important roles in explaining the differences between Germany and other OECD countries with regard to private-sector R&D intensity. Furthermore, they found that, although Germany often suffers from the behavioural effect, at the same time it usually benefits from the

([16]) BERD stands for Business Enterprise Expenditure on R&D.

([17]) EU KLEMS stands for EU level analysis of capital (K), labour (L), energy (E), materials (M) and service (S) inputs structural effect; both effects are strongly driven by a few particularly research-intensive industries. Another interesting paper comes from Lindmark *et al.* (2010), who compared two data sets — EU R&D Scoreboard micro-data and BERD statistics — to decompose EU and US R&D intensities. They concluded that about half of the overall R&D gap between the EU and the USA lies in the ICT sector. In turn, this ICT R&D gap has two facets. BERD data suggest that the gap is largely intrinsic: R&D intensity is lower in the EU than in the USA in several sub-sectors, even though ICT sector size and composition are quite similar. In contrast, company data from the EU R&D Scoreboard suggest that the gap is instead structural: the sector size and composition of sub-sectors differ greatly, whereas R&D intensity is similar ([18]).

In this context, it should be emphasised that the high-tech sectors are important not only because companies in them invest at a higher R&D intensity but also because, in such sectors, the link between R&D and productivity is greater and more significant (Ortega-Argilés and Brandsma, 2010). Nonetheless, Janger *et al.* (2011) decomposing R&D intensity at EU country level, found that some countries specialise in knowledge-intensive structures, but some other countries, despite focusing on less knowledge-intensive structures, present high R&D intensities.

([18]) Another reason could be that the top R&D investors are just more similar, even if they are in different sub-sector classifications.

3. Discussion

The literature survey reported above describes clearly contradictory results. In this discussion section, we will address the following main research questions:

- Why are the analyses of the EU R&D intensity gap reported in the literature controversial?
- What are the different impacts on R&D intensity decomposition result when using different data sources and methodological approaches, and their limitations?

To answer these questions in the following sub-sections, we strongly relayed on the hints offered by the literature as well as we implemented our own meta-analysis of the sixteen corporate R&D intensity decomposition studies that we primarily investigated in this survey. The last sub-section offers some guidance for data and methodology to be used, their limitations and result's interpretation.

3.1 What the literature says on reasons for contrasting studies' results and their impact

The literature indicates the following main reasons for discrepant results.

3.1.a Statistical norms / accounting practices

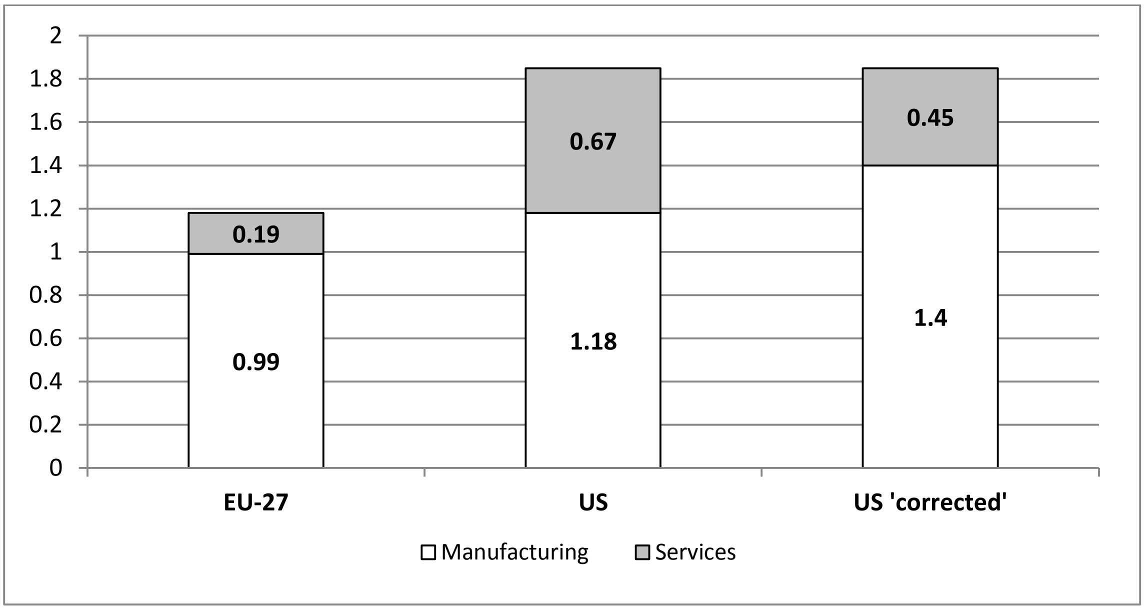
The contradictory findings regarding the causes of the R&D intensity gap between companies in the EU and the USA or other competing countries suggest that some methodological problems make it difficult to converge on generally accepted measures of structural and intrinsic effects. The decomposition of the R&D deficit into these two components has been shown to be highly sensitive to the level of data specificities.

The results of different studies seem to be highly sensitive to the level of detail at which industries are compared (Jaumotte and Pain, 2005), on whether or not service sectors are taken into consideration together with manufacturing (Erken and van Es, 2007) and on the data used and methodologies adopted (Pianta, 2005).

More importantly, in the case of studies considering both manufacturing and service sectors, the results lack robustness because of the widely recognised problems in comparing service sector R&D data between, for example, the USA and the EU, which are subject to very different statistical norms (Erken and van Es, 2007). This is confirmed by Duchêne *et al.*, 2010 who found that when it comes to the classification of multi-activity companies, the Frascati Manual recommends using the principal activity of the firm as the classification criterion, but subdividing its R&D when the activities are heterogeneous, therefore using product field information (i.e. nature or use of the product for which the R&D is conducted) in order to re-distribute the R&D activities to the manufacturing industry concerned. However, not all countries use product field data to the same extent to reclassify R&D: while, in the USA, firms are classified by principal activity only, the majority of EU Member States use product field information to re-allocate R&D expenditure.

Figure 4 below reports data from Duchene et al. (2010), which quantify such discrepancy with the usual and 'corrected' statistical figures according to different statistical approaches.

Figure 4. R&D intensity EU vs US in services and manufacturing as (BERD/GDP, 2003)



Source: Elaboration from Duchene et al. (2010), based on OECD (2006), Eurostat (2008) and NSF (2005)

3.1.b Data sources

One of the most important causes of this apparent discrepancy in corporate R&D intensity decomposition, according to the literature, is the nature of the data used, and especially the way in which data are collected. To give more explicative insides on data differences, Table 2 summarises the statistical features of data sources most frequently used in analyses of EU corporate R&D intensity decomposition.

The analysis of Table 1 suggests that the EU R&D Scoreboard data are more appropriate for the examination of the investment in R&D by a company or group of similar companies; these data give policy-makers and others some insight into companies' global R&D commitments and their relationship to firm-level economic outcomes. This focus indicates how much firms, rather than the parts of firms within particular national territories, are investing in R&D and in which industries the most R&D-active companies operate. Conversely, BERD and ANBERD data refer to all R&D activities performed by businesses within a particular territory (and therefore includes small parts of many global businesses), regardless of the location of the business's headquarters, and regardless of the sources of finance. In summary, the distinction between Scoreboard vs BERD/ANBERD/EU-KLEMS data can be seen overall as 'global corporate funding' versus 'activity within a geographical area'.

There are several studies that exhaustively discuss the detailed statistical differences between data, ranging from the definitions of R&D to the methodologies to collect the information. As this survey article is focused on the decomposition of R&D intensity, we remit to such literature for both the statistical explanation of different data and the exhaustive estimations of the extent to which these differences affect the quality of any comparison.

Table1. Summary of description of data sources most frequently used in EU corporate R&D intensity decomposition

Characteristic	EU R&D Scoreboard	BERD	ANBERD	EU-KLEMS
Monetary flows	All R&D financed by a particular company from its own funds (externally financed R&D is excluded), regardless of where that R&D activity is performed	All R&D expenditures by those parts of companies located within the country, regardless of where the funds for that R&D activity come from. R&D data refer to in-house R&D expenditure only (excluding contracted-out R&D) and only to a company's R&D performed within the national territory (and not to all parts of a company located within the country).	As BERD database but for missing data includes a number of estimations	R&D investments are considered as capital stock (and not as expenditure) and are incorporated in Gross Fixed Capital Formation ([a]); R&D is specifically considered to be a production asset
Sample	Top R&D-investing companies (only firms' R&D investment that is reported in publicly available annual reports is collected)	Collected through a census of all R&D performing companies in a country. Only some countries use stratified samples. It cover all large companies and a representative sample of smaller companies with no size threshold	Completes BERD with information from national statistical offices and with estimations and sector re-classifications for internationally comparable data	Like ANBERD (STAN), this uses additional sources such as national accounts, industry surveys, labour force surveys and capital formation surveys
Statistical Unit	Subsidiaries counted within the consolidated group; R&D systematically attributed to the registered offices	Business enterprises' subsidiaries are counted separately; R&D is attributed to headquarters or registered offices. Statistics for enterprises are compiled at national level and for local units at regional statistics level (NUTS 2 level)	As BERD	At detailed industry level per country but also provides higher-level aggregates (e.g. total economy, total market, services and total goods production)
Data collection frameworks	International Accounting Standard (IAS) 38 and national accounting standards	Frascati Manual	Frascati Manual	System of National Accounts (2008 SNA)
Geographical area	World	EU Member States and candidate Countries, EFTA Countries, Russian Federation, China, Japan, United States	34 OECD countries and six non-member economies (China, Romania, Russia Federation, Singapore, South Africa, Taipei)	25 EU countries, as well as Australia, Japan and the US
Data category	Audited company account data — companies above a minimum R&D threshold	R&D statistics via surveys of sampled companies sent by national statistical offices	R&D statistics obtained from surveys of sample companies plus a number of estimations	Extends ANBERD (STAN) with data from national accounts
Economic sectors	International Classification Benchmark (ICB)	Statistical classification of economic activities (NACE) revision 2	International Standard Industrial Classification (ISIC) revision 4	International Standard Industrial Classification (ISIC) revision 4

(a) A flow value, defined as the total value of a producer's acquisitions, less disposals of fixed assets.

Source: Own elaboration from OECD (2002, 2012), European Commission (1997, 2007, 2008, 2016a, 2016b), Azagra Caro *et al.* (2008) and O'Mahony and Timmer (2009)

Examples of authors who have investigated the statistical characteristics in depth include Potì *et al.* (2007), who compared BERD and the Community Innovation Survey (CIS), and O'Mahony and Timmer (2009), who compared the EU-KLEMS with the CIS. Azagra Caro and Grablowitz (2008) investigated the differences between BERD and the EU R&D Scoreboard, while Cozza (2010) complemented national statistical data on business R&D with EU R&D Scoreboard data.

These studies suggest that international comparison at sector and micro-level is not always possible ([19]) because of often deep methodological differences; however, different sources frequently bring an extremely useful complementarity of information ([20]).

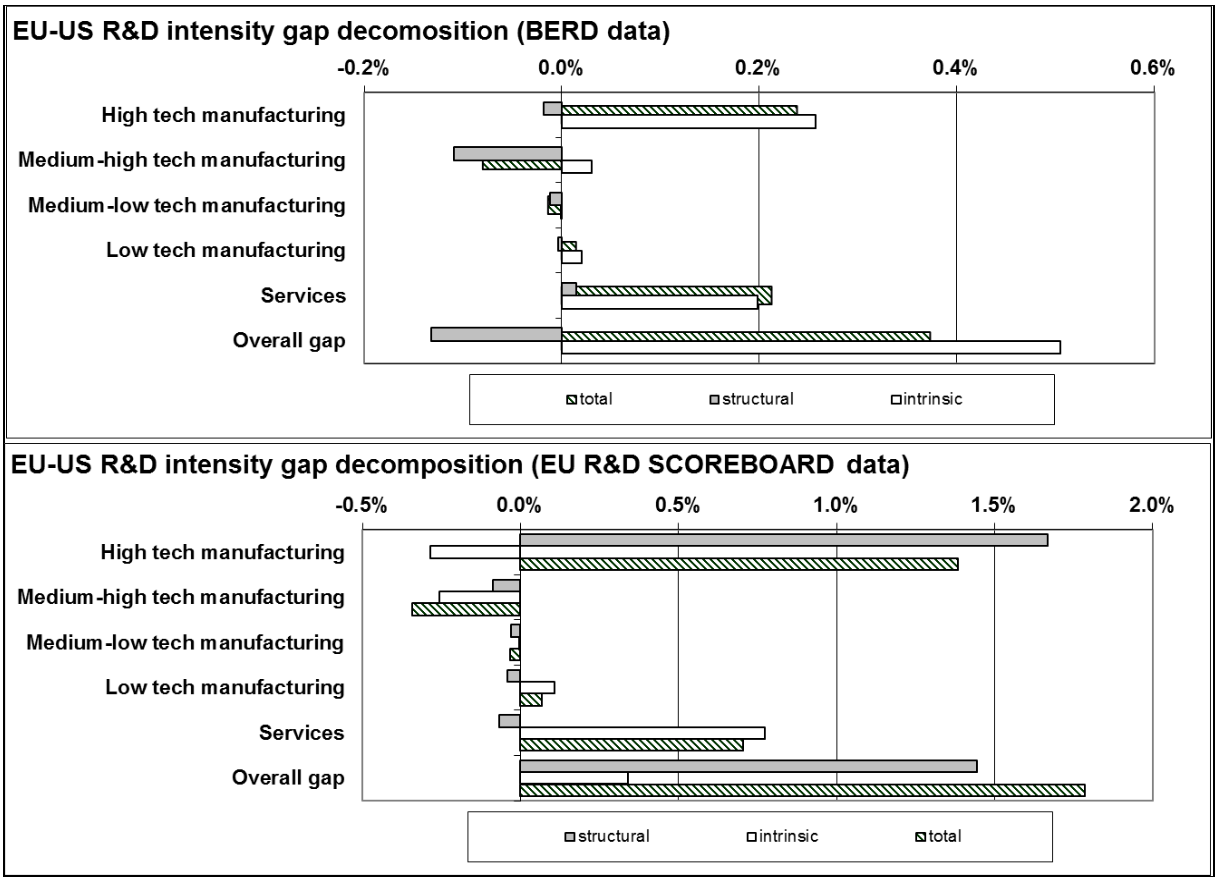
Nonetheless, to provide an example of the impact that the use of different data sources have on the final decomposition result, we report the work by Hernandez *et al.* (2013), who investigated the EU-US R&D gap by analysing BERD statistics (national intramural business expenditures in R&D) and EU R&D Scoreboard data. Figure 5 quantifies the discrepancy which derives from using these different data sources on the decomposition results of R&D intensity gap between EU and US results. It is based on data elaborated from the study of Hernandez *et al.* (2013). As can be seen, the calculations based on EU R&D Scoreboard data show that the R&D intensity performance of individual EU-based companies is similar to that of their US counterparts because of the constraints imposed by global competition. However, according to the national statistics (BERD), industrial activities located within the boundaries of the EU are much less R&D intensive than those located within the boundaries of the USA, especially in key high-tech sectors (e.g. ICT).

The authors suggest that the main reasons for such discrepant result are due to the nature of data sources and in particular due to the international inward and outward activities of the foreign controlled firms (see later in this subsection).

([19]) They argue that, for example, the distinction between national and foreign investment within the extramural R&D category, or of the actual R&D expenditures of multinationals' investment, would allow for a much better demographic distribution of data.

([20]) Recent works try to use different sources of private sector R&D data and also combine them with additional datasets to bring a previously missing dimension to the economic and policy analyses of innovation. To give a few examples, Dernis *et al. (*2015) combined EU R&D Scoreboard with patent data to disentangle the location of R&D investment (as proxy) and the technological profile of firms' R&D investment, while Alstadsæter *et al.* (2015) looked into the effects of top corporate R&D income taxation from the tax advantage of patent boxes. Amoroso *et al.* (2015) combined EU R&D Scoreboard data with the fDi Markets database to assess the ability of labour markets to attract knowledge-intensive and manufacturing greenfield FDI. Other authors combined micro-data from BERD (among others) with those from the EU's R&D Framework Programme to disentangle the delocalisation patterns in university–industry interaction (Azagra Caro *et al.,* 2013), whereas Ciriaci *et al.* (2015) matched ANBERD data with patent data from the Worldwide Patent Statistical Database (PATSTAT) and the OECD Patent Quality Indicators databases to estimate the innovation impact of knowledge-intensive business services (KIBS) into manufacturing industries. Besides, there is new, ambitious and promising institutional initiative: the 'framework regulation integrating business statistics' – FRIBS (European Commission, 2016a), which aim to harmonise statistics, establishing a common legal framework for the systematic collection, compilation and dissemination of European business statistics. Another promising initiative, still not fully complete for EU member states, concerns the Foreign AffiliaTes statistics - FATS (European Commission, 2012) which encompass inward and outward data on activities (including R&D) of foreign affiliated firms. Interesting is also the OECD DynEmp database which is based on a distributed data collection exercise aimed at creating a harmonised cross-country micro-aggregated database on employment dynamics from confidential micro-level data where the primary sources of firm and establishment data are national business registers.

Figure 5. Difference of private R&D intensity decomposition between US and EU using BERD or EU R&D Scoreboard data sources, by groups of R&D intensity sectors (2007)



Source: Own calculations based on Hernandez et al. (2013)

3.1.c International flows of R&D and business output

According to Lindmark *et al.* (2010), one factor that could explain the contradictory decomposition results is international flows of R&D and value added: companies tend to allocate a larger share of their value added and a smaller share of R&D outside their home markets. In sub-sectors with a large number of large US companies, these flows are unbalanced, and (BERD) R&D intensities are thus higher in the USA than in Europe, all else being equal. Similar results were obtained by Hernandez *et al.* (2013), who argue that the industrial activities (production and R&D) of foreign-controlled companies play a pivotal role in the discrepant results obtained using these two datasets. Therefore, we support the argument that the discrepancy in the nature of the EU-US R&D intensity gap which is found between using national statistics (national intramural data on production BERD) and using data of net sales and corporate R&D investment from the EU R&D Scoreboard is mainly due to the accounting practice for inward (or intramural) and outward (or extramural) activities of foreign-controlled firms.

To give a sense of this phenomenon, and the impact it could have on the total R&D decomposition result, we report the calculations made by Hernandez *et al.* (2013) in Table 2.

Table 2. Activities of foreign affiliates in the USA (2006)

Industrial sector	Inward* (%)	Outward* (%)
Whole manufacturing sector		
Production	21.3	36.2
R&D	14.5	13.6
Pharmaceuticals		
Production	67	77.6
R&D	22.4	14.6
Office, accounting & computing		
Production	9.1	173
R&D	0	2.8

** % of the total intramural activity performed within the USA*

Source: Hernandez et al. (2013) based on OECD globalization data on the activity of multinationals

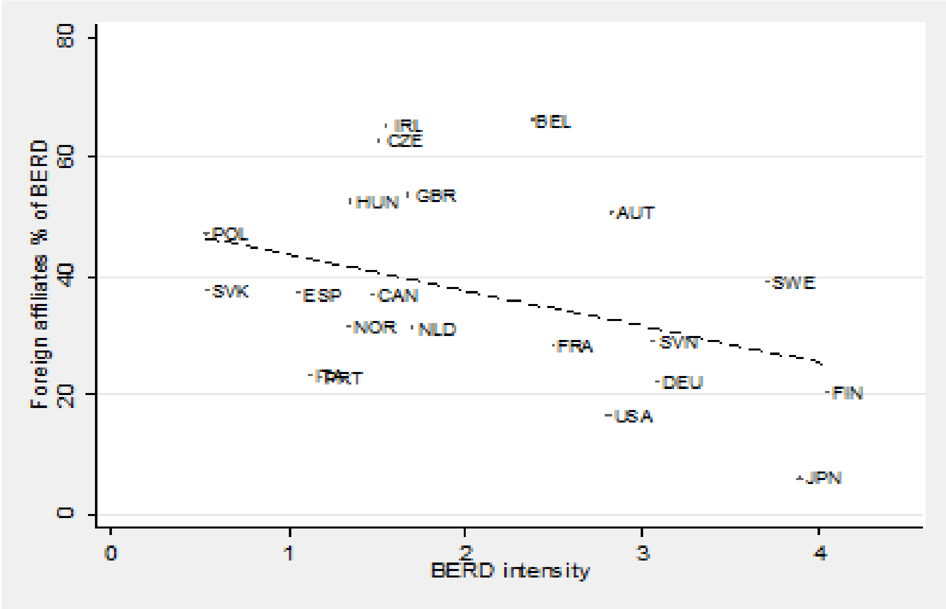
Two main messages arise from the information reported in table 2: a. companies delocalise production and research facilities in different and considerable proportions which may lead to substantial changes of the R&D intensity of both source and destination countries; b. off shoring of activities vary significantly from sector to sector. These figures also explain why the net sales of the US Scoreboard companies in high tech manufacturing sectors, especially in ICT manufacturing sectors, are much larger than the whole US production in these sectors.

Unfortunately, equivalent figures of this table for the whole EU are not fully available to make an EU-US comparison. However, according to Hernandez *et al.* (2013), data from some EU countries confirm the relevance of companies' inward and outward activities in pharmaceutical and ICT sectors that should likely affect the comparison of R&D intensities between the EU and the US.

In order to offer an appreciation of magnitude of the impact the international flows of R&D could have on the account for business R&D intensities in a given country, we analysed with the available OECD statistics the relationship between BERD intensity and the share of foreign affiliated R&D activities (inward BERD) in the total BERD of selected number of countries for the year 2013. The estimated correlation between the two variables for the overall sample considered result to be negative: 0.39, meaning that the more is the share of inward R&D activities in BERD, the less is the BERD intensity of the country. This negative correlation result confirms the findings of Dachs *et al.* (2014) who calculated it for the EU-15 countries in the years 2004-2007.

The result of our analysis by country is reported in Figure 6, where we can notice that the R&D share of BERD by foreign affiliated is higher than 50% in some EU counters as Hungary, Ireland, Belgium, Check Republic, Great Brittan and Austria. On the other hand, Japan and US that have a low share (< 20%) of R&D foreign affiliated, show higher BERD intensity.

Figure 6. Share of BERD by foreign affiliated and BERD intensity in selected countries (2013)



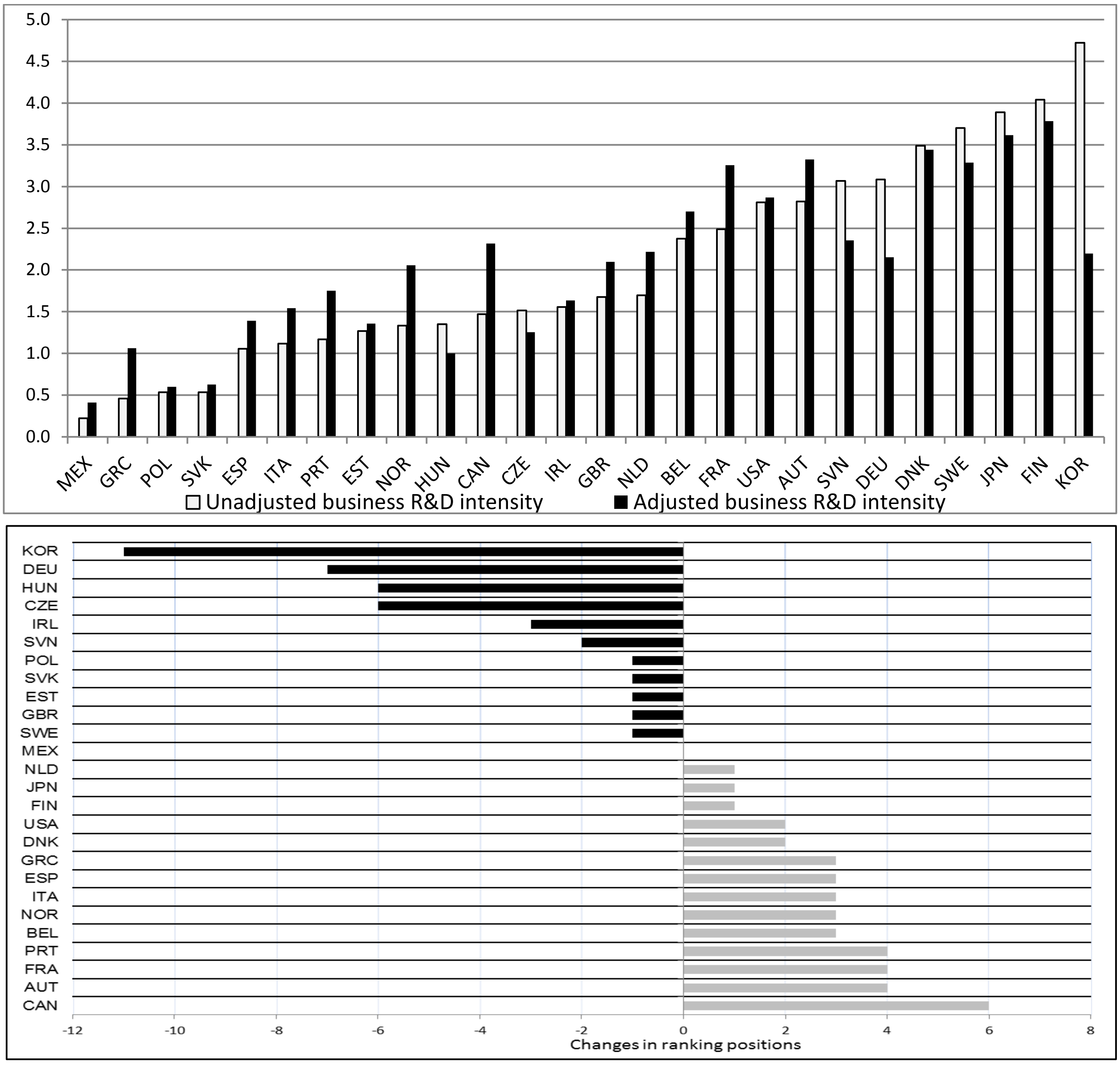
Source: own calculations based on OECD statistics (2013)

Although it is not the main objective of this survey, we would like to point out what multinational companies usually do abroad in terms of R&D differently than at home, because it could help to better understand the impact such behaviour/motivation has on R&D intensity. According to Moncada-Paternò-Castello *et al.* (2011) the determinants of the location of the R&D activities are fairly consistent whether local or international investments are considered. On the one hand, the "asset-augmenting" determinants turn out to be dominant: indeed, the access to specialized knowledge, the availability of researchers, and the legal framework rank at the top among the motives of R&D outsourcing. On the other hand, "asset exploiting" motives—such as the access to market, the cheap labour cost of researchers and the proximity to suppliers —appear to play a secondary role as drivers of R&D location abroad. Some more specific insides is given by the survey to top R&D company results by Tübke *et al.* (2015): the most frequently stated attractiveness factors among R&D sites within the EU, are the quality of R&D personnel and knowledge-sharing opportunities with universities and public organisations; comparing R&D attractiveness factors within the EU with those for the United States, the respondents point to knowledge-sharing opportunities and quality and quantity of R&D personnel as the leading factors for both world regions; comparing R&D attractiveness factors within the EU with those for China and India, the respondents reveal significant differences between the two world areas. For R&D sites in China and India, market size and growth, together with the quantity and labour cost of R&D personnel, are the main determinants of attractiveness.

3.1.d Accounting (or not) for counties' industrial structures

Even with a single data source in the same study (which, however, doesn't' decompose R&D intensity in structural and intrinsic effects), there are other cases of discrepancies in the calculation of business R&D intensities depending on the approach adopted. For example, following one of the first examples by the French Ministry for education and research (Le Ru, 2012), it is only in recent editions of the Science, Technology and Industry Scoreboard (OECD, 2015) that the OECD has recognised the role of structural differences between countries in the calculation and comparison of their R&D intensities, and overcome it by adjusting the R&D intensity using the OECD industrial structure — the sectoral share of OECD value added for the given year (2013) — as adjusted, common weights across all countries. Instead, the unadjusted measure of BERD intensity is an average based on each country's actual sector shares. The different results between the two measurements of R&D intensity are shown in Figure 7.

Figure 7. Business R&D intensity (R&D expenditure as % of value-added) in selected OECD countries adjusted and unadjusted for industrial structure (figure above), and the resulting changes in ranking positions (figure below) by R&D intensity (2013)



Source: OECD Science, Technology and Industry Scoreboard 2015 (OECD, 2015).

3.1.f. Different R&D intensity ratios

The definition of R&D intensity as an indicator of country or company performance is another important aspect to mention. First of all, the numerators and denominators could be different in nature. For example, the numerator is either firms' R&D investment or business enterprise expenditure on R&D — BERD; the former data are captured from firms' financial accounts and the latter from surveys (for detailed differences see Box 1 in the Annex).

BERD data, in contrast, are more accurate for territorial analysis of private R&D activities, although they are revealing only if the data components of inward and outward flows of R&D investment and production (added-value) are available and taken into consideration ([21]). Overall, as we indicated earlier, the focus on intramural R&D of BERD data is a key difference to the EU R&D Scoreboard data (which includes both intramural and extramural R&D). This difference complicates the comparison between the two data bases. These aspects are enormously important when drawing the correct policy implications ([22]).

Furthermore, in statistical macro- or meso-analysis for policy-makers, the denominator is either GDP or value added, whereas firms' sales or value added are used by corporate and financial analysts to benchmark their competitiveness with peers at corporate or product/service levels. The differences are substantial. Firms' sales are used by corporate and financial analysts to evaluate their level of financial effort (R&D investment) in relation to their market size (sales) and to compare this with the financial effort of their main competitors. Firms also use value added (defined as sales minus the cost of bought-in goods and services) to measure the economic health created by a company as a whole or by a given product/service and to identify differences (if any) from a competitor(s). In contrast, GDP or value added is utilised in macro- or meso-analysis by policy-makers and policy analysts as the denominator of the R&D intensity ratio to monitor territorial competitiveness. However, these measures reflect two very different aspects: GDP is measure of the value of all final goods and services produced, whereas value added in most industries consists in the value of the contribution of the factors of production - mainly capital, wages and remuneration of knowledge - and is used in macroeconomics to compare different sectors of the economy.

These differences could account for some mismatch of results when comparing aggregate R&D intensities, depending on the definition of R&D intensity and the data used in the calculation.

An example is provided by Lindmark *et al.* (2010) who calculated the ICT R&D intensities of EU and the US using both GDP and value added of ICT in 2005. The results of their calculations are provided in Table 3 showing that the US vs EU difference for the ICT R&D expenditure ratio to the VA of the ICT sector (intensity 2) is proportionally smaller (10% vs. 6%) than the ICT R&D expenditure to the GDP (intensity 1) contribution for the ICT sector in the overall R&D intensity (0.6% vs. 0.3%).

Table 3. EU vs US business R&D intensity of the ICT sectors using GDP and Value Added (2005)

	Intensity (1) **BERD ICT / GDP**	***Intensity (2)*** **BERD ICT / VA ICT**
EU 25	0.31%	6.2%
US	0,61%	9.9%

Source: Lindmark et al. 2010 based on Eurostat, OECD, EU KLEMS

([21]) In a pilot study of statistics, the European Commission (2010b) demonstrated that using data from the EU R&D Scoreboard and adding aggregate values from national business R&D statistics allows novel insights into the internationalisation of business R&D process. Unfortunately, these micro-data are not made available by the majority of statistical offices in the EU.

([22]) For example, an exhaustive explanation and empirical demonstration of the relevance of companies' cross-border activities in the evaluation of the EU–US intensity gap using BERD or the EU R&D Scoreboard data, and the apparent discrepancy of results, is provided in Ch. 7, pp. 53–62, in op. cit. as European Commission (2013).

3.1.g. Other micro- and macro-economic factors

A few more points about the use the R&D intensity as a statistical indicator need to be made. There are issues of micro- and macro-economic nature concerning the interpretation of R&D intensity indicators over time, as countries enter or leave economic cycles at different points, and grow at different but fluctuating rates (Meister and Verspagen, 2006). As we have seen in section 2.1, aggregate R&D intensity indicator is affected not only by the industrial structure, but also by characteristics (demographics, business cycle) of the pool of firms that make up that structure, and by other structural factors and intrinsic factors.

It is worth remembering that, despite policy targets and the related socio-economic objectives, companies should not be tempted to overinvest in R&D that is to invest more than their main competitors. Individual companies may lose competitiveness if they invest below the sector average, but it is by no means clear that there are positive returns for any investment above the sector average, especially in the short term.

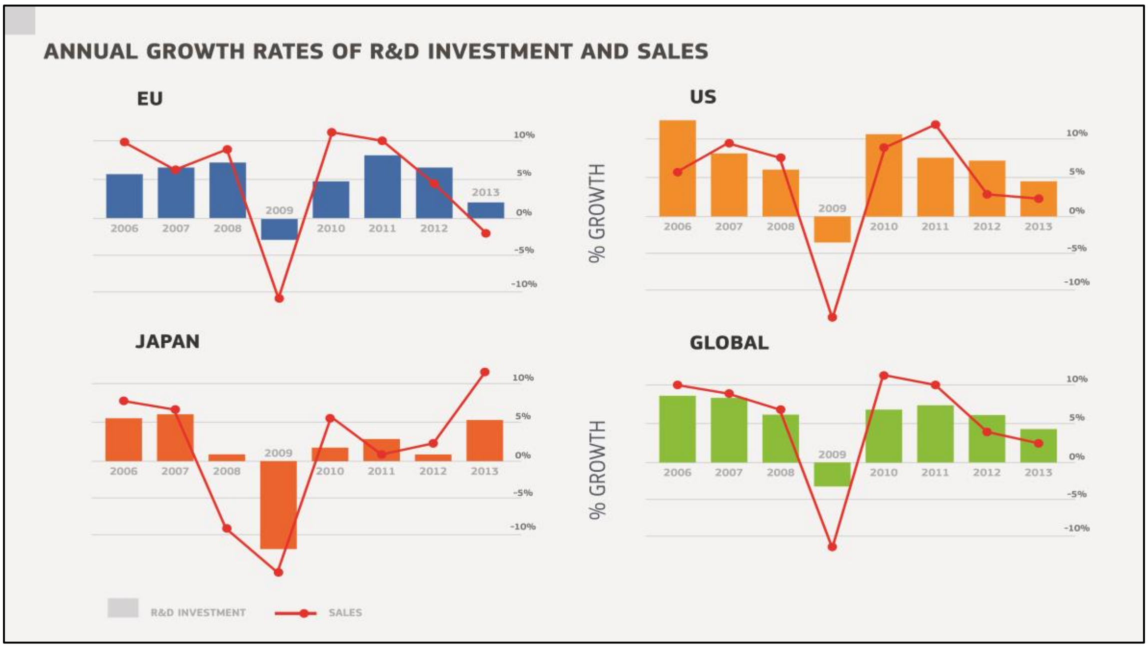
Moreover, something that the private-sector R&D intensity indicator does not consider is the complex — but important — issue of the efficiency and the effectiveness of R&D investment (Cincera *et al*., 2009). GDP accounts for economic output and the BERD/GDP measures effort (the part of private-sector economic activities devoted to R&D), not R&D efficiency or effectiveness (Godin, 2007).

Nor does private-sector R&D intensity take into account different companies' strategy, as in the case of some sub-sectors, such as the pharmaceutical or biotechnology sectors, which require firms to invest heavily in R&D but in which sales may be very low for several years until new products can be successfully introduced.

It is not surprising that fluctuations (global or country specific) in growth, together with differences in the structure of national economies and in their ability to resist the undesired effects of an economic and financial downturn, not forgetting different national economic priorities (as in developing economies, or in some new EU Member States), could lead to some turbulence in the R&D/GDP (value added or firm' sales) ratio. Such economic evolutions could either hamper or facilitate the capacity of one country relative to one to continue to invest in R&D; it could also result in a higher or lower intensity ratio simply because the value of the denominator falls or rises.

An example of fluctuations is provided in Figure 8. The analysis of the global trends in the figure since the start of the financial crisis in 2009 shows a quick recovery in terms of R&D investments in the period 2010-2012. However R&D investment growth of companies based in the EU slowed considerably in 2013; this development was accompanied by a fall in sales. The US companies appeared more reactive after the year of the financial crisis, while Japanese companies suffered the most the financial crisis which started earlier, and they hardly recovered the R&D investment levels that had before the crisis. Globally, the R&D investment growth has a pro-cyclical behaviour.

Figure 8. Annual nominal growth rates of corporate R&D investment and sales 2006-2013



Source: Data from the European Commission's EU Industrial R&D investment Scoreboard 2006-2014

3.2 Meta-analysis of the business R&D decomposition studies under inspection

Besides the analysis of the literature which point out the main reasons for contrasting results, we collected the meta-information of the studies on the decomposition of private R&D intensity that found in the literature (Table 4) and analysed them.

The two criteria for selecting studies to be considered by this survey

In our knowledge, these are the only studies in the literature that fits the central argument of this survey, therefore they all a) focus on the decomposition of corporate R&D intensity and they b) implement a comparative analysis of the determinants of R&D intensity at least at country level. These are sixteen in total, 13 of them analyse comparatively EU (seldom with the full number of member states) vs other competing countries/regions. Table A1 in the Annex offers additional information on them reporting, in particular, the basic equations used by each of these studies for the decomposition of private R&D intensity. The table also provides the main research objectives of the mentioned sixteen papers as well as more information on the results obtained.

Our analytical approach

For the analysis of the meta-information collected, we are conscious that the implementation of an empirical meta-regression analysis with results from, e.g., 40 or more studies with the different data sources would have provided a robustness check. However the result of such test wouldn't be sufficiently robust due to the too small sample of studies which implement a corporate R&D intensity decomposition analysis: they are few as 16 in total in the present literature, and only 13 of them analyse comparatively EU vs other countries. Furthermore, the country composition of the EU is heterogeneous across these studies. Therefore, following paragraphs we systematically analyse (meta-analysis) the aspects offered by the meta-information collected. The objective of the meta-analysis is to identify this common effect if the result of the R&D intensity decomposition is consistent from one study to the next as well as to identify the reason for the variation when the main result varies from one study to the next.

The analytical results are the following.

1) Research questions

Because of the focus of this research and the selection criteria of these studies, the research objective common to the sixteen papers is to analyse the effect of sector composition and intrinsic effects on private R&D expenditure investment in the EU or a given country, compared with a competing economy. Some of those studies investigate further what are the causes for dominant intrinsic and/or structural factors which determine the R&D intensity gap (e.g. Erken, 2008); others focus their analysis on one group of sectors (e.g., ICT-related in the case of Landmark et al., 2010), or centred on the manufacturing sectors (Foster-McGregor *et al*. 2013). Further research objectives look into the EU R&D intensity gap from the perspective of the age of the firms (Cincera and Veugelers, 2013). More information on research objectives are in the second column of Table A1 in the Annex.

2) Time period under investigation and geographical scope

The time period under investigation varies from one year only to a range of years; all in the time span of 1974 to 2013. The geographical scope of the comparative R&D intensity decomposition studies varies very much from comparing one to another country to comparing EU vs one to different other countries. It should be noted that the sample composition of the EU countries varies itself from seven to twenty-eight. Nonetheless, we cannot detect any communality of values among the two so heterogenic variables which could be associated to the different decomposition results of the studies investigated.

3) R&D intensity ratios

Most studies which relying on BERD, ANBERD or EU-KLEMS use the R&D expenditure to value-added ratio and some R&D expenditure to GDP ratio. The studies who rely on EU Scoreboard R&D all use R&D investment to net sales ratio. While in for the first group of studies we cannot detect any communality of values among the diverse *R&D* intensity ratios which could be associated to the different decomposition results of the studies investigated, in the case of the second group of studies both intensity ratios and result of the analyses are equal.

4) Data sources and decomposition methodologies

From the meta-analysis of the information in Table 4 and linked to part of point iii) we found an additional key reason: although the differences are not substantial in the basic calculation equations used (see Table A1 in the Annex), when relying on national statistics (BERD) or OECD ANBERD data, the result changes if the counties' industrial structures are taken into account in the calculations. In fact, the inclusion of this variable substantially affects the ranking (e.g., Sandven and Smith, 1998; see also OECD, 2015 in Table 4) or the overall result by indicating that the EU R&D intensity gap vis-a-vis mayor competing economies is mainly determined by structural factors; an opposite result from studies that have not accounted for this variable. Moreover, the meta-analysis of the empirical literature surveyed also shows a general association between the use of firm-level data from the EU R&D Scoreboard and the structural effect as the main determinant of the EU R&D intensity gap. These findings seem to be robust over the time span of the sixteen studies as in that period the aggregate industrial structure of the EU countries didn't change markedly (Foray and Lhuillery, 2010; Janger et al, 2011).

The reason why the correlation between the use of R&D EU Scoreboard data and the structural effect is always dominant has never been investigated. One possible explanation could hold on the firms' R&D investment and the sales is representative for the activity of the firms globally but not necessarily for the country of companies' registered offices.

Table 4. Synopsis (meta-information) of sixteen empirical studies on business /corporate R&D intensity decomposition

Authors	Dataset for R&D	Data years	Geographical scope	R&D intensity ratio	Additional (or specific) independent variables	Main EU (or country) R&D intensity gap determinant (intrinsic or/and structural)
Van Reenen (1997)	BERD	1974–1991	UK vs. other G7 countries,	R&D expenditures / value added (VA)		Intrinsic
Sandven and Smith (1998)	BERD	1991	8 EU countries, Norway, Australia, US and Japan	R&D expenditures / value added	Account for small vs large economies (by GDP size) and for industry	Ranking ,and in some case main determinant, changes when size and industrial structure of the economy are accounted for
Ab Iorwerth (2005)	OECD-STAN	Latest available year 1997-2000	Canada vs US	R&D expenditures / GDP	Account x industrial structure (proportion of each industry's VA to GDP)	Structural
Erken and van Es (2007)	BERD	1987–2003	EU-15 vs US	R&D expenditures / value added		Intrinsic
Erken (2008)	OECD STAN and ANBERD	1997-2001	EU vs US; The Netherlands vs other 18 OECD counties;	R&D expenditures / value added		Intrinsic
Lindmark *et al.* (2010)	BERD	2005	EU vs US	R&D investments / value added and GDP	Focus only on ICT sector	Intrinsic (structural 1/3 and intrinsic 2/3)
Moncada-Paternò-Castello et al. (2010)	EU R&D Scoreboard	2007	EU vs US and Japan	R&D investments / net sales		Structural
Mathieu and Van Pottelsberghe (2010)	OECD ANBERD	1991–2005	EU vs USA and Japan; Other 10 OECD countries;	R&D expenditures / value added	Account x industry-specific and country-specific factors	Structural
Le Ru (2012)	French MESR/SIES, Stifterverband Wissenschaftsstatistik	2001-2009	France vs Germany	R&D expenditures / GDP	Account x industrial structure (proportion of each industry's VA to GDP)	Structural
Reinstaller and Unterlass (2012)	BERD and ANBERD	2004-2007	27 EU single countries and 9 non-EU countries	R&D expenditures / value added	Account x countries structural changes over time	Intrinsic or structural, depending on countries
Foster-McGregor *et al.* (2013)	OECD ANBERD	2007–2008	7 EU countries, USA and Japan	R&D expenditures / value added	Value added exports; state aid by country	Intrinsic
Gumbau-Albert and Maudos, (2013)	EU-KLEMS	1980–2003	11 EU countries vs USA	R&D capital stock / gross value added (GVA)	*Theil index* (see Table A1 in the Annex)	Intrinsic (which largely dominate in 1980-1995; in 1995-2003 there is a structural convergence)
Cincera and Veugelers (2013)	EU R&D Scoreboard	2007	EU vs US	R&D investments / net sales	Age of firms	Structural
Stancik and Biagi (2015)	EU R&D Scoreboard	2002–2010	EU-22 vs US, Japan (and other non-EU countries)	R&D investments / net sales		Structural (but mix vs BRIC countries)
Belitz *et al*. (2015)	OECD ANBERD	2011 and 2010	Germany vs other 6 EU countries, Switzerland USA, Japan & South Korea	R&D expenditures / value added	Account x industrial structure (weighting sectors' shares to VA)	Mix (both effects strongly driven by few R&D-intensive industries)
Moncada-Paternò-Castello (2017a)	EU R&D Scoreboard	2005-2013	EU vs US, and Japan (also vs Switzerland, BRIC, Asian Tigers, rest of the word)	R&D investments / net sales		Structural

Source: Own elaboration. Note: "additional variables" are referred to be additional to the basic equation reported in section 2.2; see also table A1 in the Annex.

3.3 Hints on data and methodology to be used, their limitations and result's interpretation

The arguments of the previous sub-sections on the main reasons for discrepant results of the decomposition of the business R&D intensity found in the literature can be grouped as following i) different accounting practices and nature of data sources used, ii) R&D intensity decomposition methodology, including the possible adjustment for countries' industrial structures and the definition of the R&D intensity used, and iii) heterogeneity of countries and business structures and the timing of economic cycles analysed.

But what is the best approach to be pursued in the decomposition analysis of corporate R&D intensity?

For example, global corporate R&D investment can best be analysed using EU R&D Scoreboard data to interrogate the global R&D performance and economic competitiveness of European multinationals at the level of firms. The advantage of this micro-data source is that cover most of the private R&D worldwide (around 90%)[23], the limitation is that the denominator (usually firms' sales) doesn't not represent overall country structure of the economy, especially for services. Furthermore, another limit is the sample selection (most R&D investing firms), although the bias is homogenous over the time and geographical areas. The best use of EU R&D Scoreboard data are when similar companies are compared, and when R&D data are used with patent data to overcome the technological strategy and the localisation pitfalls of the merely data of company's global R&D investment.

BERD data are more accurate for territorial analysis of private R&D activities, although doesn't account for the outflow activities of the foreign affiliated companies in a given country. This weakness could be sorted out by the use of Foreign AffiliaTes statistics – FATS, when these data are available for the countries analysed. Furthermore, in the R&D intensity ratio, the denominator utilised in statistical macro-analysis by policy-makers is BERD/ANBERD to GDP ratio, however as R&D intensity varies very much by sectors and sub-sectors it would be opportune to analyse sector-specific R&D intensities using value added as denominator. Also, when analysts have to compare heterogeneous economies they are advised to consider that countries with high GDP tend to be more R&D intensive (Krafft *et al.,* 2014).

Corporate and financial analysts use firms' sales or value added as denominator of R&D intensity to benchmark their competitiveness against peers at the corporate or product/service level, and should be advised to account for the behaviour of multinational companies tend to allocate higher share of their value added and a smaller share of R&D outside their home market, resulting in a distorted R&D intensity (R&D expenditure to value added) result in their home counties (Lindmark, et al., 2010).

Overall, the use of BERD and EU R&D Scoreboard data can provide a better, complementary view of business R&D intensity.

Table 5 provides an outlook to guide analysts in the methodological approach to investigate business R&D intensity decomposition, show their main limitations, and offers some suggestions for interpretation considering the impact on results of such limitations.

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

Table 5. Mapping methodological approach, limitations and hints for results' interpretation of business R&D intensity decomposition using data based on national statistics and EU R&D Scoreboard data

Analysis scope & main users	***Data to use***	*Limitations & impact on results*	**Denominator of R&D intensity ratio**	*Limitations & impact on results*	**Independent variables to consider**	Possible **data complementarities** (examples)
Territorial monitoring *Policy makers / macro-economic analysts*	BERD ANBERD EU-KLEMS	Doesn't account for outward R&D flows Over-estimate service R&D in the USA Tends to overestimate intrinsic effect Variability depends on sectoral aggregation/classification Missing data are estimated, sector reclassified in ANBERD and EU-KLEMS	Value added (VA) GDP Production Productivity	Countries with high GDP tend to be more R&D intensive Multinational companies tend to allocate higher share of their VA and a smaller share of R&D outside their home market, resulting in a distorted R&D intensity (R&D expenditure to VA) result in their home counties.	Account for industrial structure (it substantially affects the country ranking or the overall decomposition result) Decouple manufacturing from service industries Test the simultaneous effects of national and industry-specific factors	FATS for inward and outward R&D expenditures of foreign affiliated companies in the EU (but not available for recent years and for all EU countries)
Firm-level monitoring *Policy-analysts* *Business-analysts*	EU R&D Scoreboard	Location of R&D investment not disclosed Mainly, large multinationals Low service industry representativeness Indicates a prevalence of structural effects in the EU R&D intensity gap vs competing economies	VA Sales Profits	VA can be calculated only for the EU-based companies Denominators do not represents overall country structure of the economy, especially for services	Higher sectoral disaggregation gives more accurate results Control for age	Patents data from PASTAT to proxy R&D localisation

Source: own elaboration, based on sixteen studies surveyed (referred in Table 1 and A1) as well as from the other sources of literature already referred in this study.

4. Concluding remarks and implications for analysts and policy-makers

Research and development (R&D) indicators are increasingly used not only to facilitation international comparisons, but also as targets for policies stimulating research. An example of such an indicator is R&D intensity. The decomposition methodology of quantifying R&D intensity was conceived with the aim of evaluation the extent to which changes in aggregate R&D intensity can be explained by a change in industrial structure (*structural effect*) or by a change within a given industry (*intrinsic effect*).

The micro–macro statistical issue is a major topic for both firms and policy-makers because of the convergence of interests in terms of outputs (i.e. private and social returns). Micro-level statistics allow evaluation of the characteristics of an economy at the unitary (firm) scale as well as at industry and macro-level when such data can be aggregated.

Despite the significance of the analytical purpose, the theoretical and methodological framework needed to decompose countries' R&D intensity has been elaborated only recently, and is still not widely used in the literature, which in turn shows rather contradictory results.

This study brings additionally to present literature in several ways.

One novelty of this study is the provision of a consistent theoretical framework of the determinants of corporate R&D intensity.

More importantly, this paper for the first time systematically identifies, analyses and discusses in detail why the findings of different studies in this subject are divergent by inspecting data and methods used. Moreover, for each of the identified main items in the use of different data and methods which are accountable for dissimilar results, this study provides examples to show the magnitude of the impact they have in the R&D intensity decomposition results.

Furthermore, the main novel outcomes of this paper by way of a meta-analysis of the sixteen references present in the literature is the identification of why some of such studies come up with different results, although most of them rely on very similar data and apply similar methods. This analysis in fact reveals that when using BERD or ANBERD data, sectorial composition (structural effect) is the main determinant of the EU business R&D intensity gap if the industrial structure of the economies is taken into account; otherwise, they indicate intrinsic effect as main determinant. Furthermore, it was found that when using the EU R&D Scoreboard data, different studies always show that the structural effect is the main determinant.

It derives that, thanks to the result of this study, there should be no more doubts but that the EU R&D intensity gap is largely determined by its sectoral composition (i.e. the smaller size of R&D-intensive sectors in relation to other sectors within the EU).

Furthermore, the study suggests which data and methods should be better approached in decomposing corporate R&D intensity. In doing so it suggests that policy-makers and analysts, depending on the question they want to address, should carefully choose the appropriate data source and methodology (being aware of their limitations), and always account for structural difference of benchmarked economies.

Additionally, there is an overall issue about the interpretation of corporate R&D intensity data. Examples have been given of the counter-cyclical or cyclical behaviour of companies and countries depending on their level of competitiveness and distance from the technological frontier. Moreover, corporate R&D intensity does not capture the efficiency and effectiveness of R&D investment, nor the business/technological characteristics or strategy of firms.

In the overall, we believe that a more accurate approach to explore is to compare the corporate R&D intensity performances of similar companies in different jurisdictions, as well as countries with comparable sectorial structure and overall economic performances, the accuracy of which would increase as more and better-quality data become available. The relevance of the methodological approach and the interpretation of results suggest that policy-makers and analysts should also rely on data from complementary sources when available.

Therefore, the results of this study show that R&D intensity as a policy target and the comparison between different characteristics of corporate R&D intensity ratios belonging to different economies should be handled with care, particularly with respect to the policy measures that result from such comparisons. Generally, if deficient R&D intensity is *intrinsic* in nature, it could be remedied by policy-makers in a relatively short period. In contrast, if the R&D intensity problem is *structural*, resulting from sectoral composition, it is much less sensitive to governmental policy and broader and deeper longer-term measures will be needed.

The findings of this first literature survey on corporate R&D intensity decomposition also indicate that further research should consider addressing the shortage of good-quality data (e.g. should provide more complete micro-data that also allow homogeneous company (and country) comparability, the shortage of investigations relying on longer time series and on longitudinal (balanced) datasets, and full data of inflows and outflows of national business R&D expenditures. Other analytical aspects to inspect are the reasons why the calculations relying on EU R&D Scoreboard data lead all the time to a structural effect as main determinant of the EU R&D intensity gap, and the study of the impact that tax regimes and subsidies have on corporate R&D intensity compared to the (un-)favourable regulatory regimes of countries. Furthermore, there is a shortage of studies that include more independent variables (which may explain more accurately the determinants of sector composition and of intrinsic effects) and investigate the development of more sophisticated statistical and econometric models.

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Appendix

Table A1. Overview of main objectives, equations and findings of 16 recent studies on private R&D intensity decomposition

Author(s), year	Research Objective(s)	Main equation	Results
Van Reenen (1997)	To break down the aggregate shifts in R&D intensity into 'between'/intrinsic and 'within'/structural effects of UK vs. competing countries and manufacturing vs. non-manufacturing industries	$\Delta r_{total} = \sum_i \Delta r_i \bar{s}_i + \sum_i \bar{r}_i \Delta s_i$ The R&D intensity r_i is the proportion value added devoted to R&D (R&D $_i$/VA $_i$) and s_i is each industry's share of total value added ($VA_i/\sum_i VA_i$) for $i = 1.\ldots N$ industries. The bars denote a time mean (average over T years). The Δ values are changes over time (for T years)	UK manufacturing industries have been slower to increase their R&D intensities than their G7 counterparts. The main reason for this is not the different pattern of industrial restructuring in the UK compared with elsewhere (either a shift away from manufacturing or shifts between industries within the manufacturing sector), but an intrinsic ('within') effect
Sandven and Smith (1998)	To identify country and sector effects in BERD intensity	$I_{m,j} = \sum_{n=1}^{n} \bar{I}_i \, w_{i,j} + \sum_{i=1}^{n} (I_{i,j} - \bar{I}_j) \cdot w_{i,j}$ $I_{m,j} = I$ stands for R&D intensity and m stands for manufacturing in country j $\bar{I}_i$ = is the typical (median) benchmark of the R&D intensity in industry i w_i = is the share (weight) of total manufacturing value added of industry i	Large countries have higher R&D intensities than small countries, and R&D intensity is affected by the industrial structure. Moreover, a strong positive association was found between economy size (GDP) and the *structure component*: the larger the economy, the more the industrial structure is favourable to a high R&D intensity in manufacturing.
Ab Iorwerth (2005)	To examine R&D intensity performance across industries between Canada and the USA	Aggregate gap is given by the sum of (a) the intensity effects: $\Sigma \left(\frac{R\&D_i^{Cnd}}{VA_i^{Cnd}} - \frac{R\&D_i^{US}}{VA_i^{US}} \right) * 1/2 \left(\frac{VA_i^{Cnd}}{GDP_i^{Cnd}} - \frac{VA_i^{US}}{GDP_i^{US}} \right)$ and (b) the structural effects, given by: $\Sigma \left(\frac{VA_i^{Cnd}}{GDP_i^{Cnd}} - \frac{VA_i^{US}}{GDP_i^{US}} \right) * 1/2 \left(\frac{R\&D_i^{Cnd}}{VA_i^{Cnd}} - \frac{R\&D_i^{US}}{VA_i^{US}} \right)$ Note: uses a Bennet decomposition following Diewert (1998)	Canada's low aggregate R&D performance hides high research intensities in some research-intensive industries. Nonetheless, the results also indicated that the smaller relative size of these industries — together with the low R&D intensities in the motor vehicle and service industries — accounted for the weak aggregate performance in Canada compared with the USA

Author(s), year	Research Objective(s)	Main equation	Results
Erken and van Es (2007)	To disentangle differences in business R&D between the EU-15 and the USA, which are broken down into a sector composition effect and an intrinsic effect	$RDI_X - RDI_Y = \sum_i RDI_{Z,i}(P_{X,i} - P_{Y,i})$ $+\sum_i P_{X,i}(RDI_{X,i} - RDI_{y,i})$ *RDI* represents the extent of private R&D intensity (R&D/VA), *P* stands for the share in the value added, *i* indicates the sector, *X* stand for country/region *X* and *Y* stands for the countries/regions with which country *X* is compared (as Van Velsen, 1988; Hollanders and Verspagen, 1998)	Differences in the structure of EU compared with the USA play only a minor role in explaining the R&D gap. Instead, the European R&D shortfall is mainly caused by a negative intrinsic effect, meaning that companies in the EU spend less on R&D than their US peers in the same sectors
Erken (2008)	(a) To analyse the effect of sector composition and intrinsic effects on private R&D expenditure in the Netherlands, OECD countries (average) and the EU-15 compared with the USA (b) To examine the *factors* that affect the *sector composition* of the Netherlands (c) To examine the *factors* that affect the *intrinsic effects* of the Netherlands.	(a) $RDI_X - RDI_Z = \sum_i RDI_{Z,i}(P_{X,i} - P_{Y,i})$ $+\sum_i P_{X,i}(RDI_{X,i} - RDI_{y,i})$ (as Erken and van Es, 2007) (b) $STR_{i,t} = \alpha + \beta\left(STR_{i,t-1} - \alpha - \sum_i f_i\, DUM_i - \varphi(LAB_{i,t-2})\right) + \gamma(INT_{i,t-1} + PUB_{i,t-1}) + \varphi(LAB_{i,t-1}) + \sum_i f_i\, DUM_i + e_{i,t}$ *STR* represents the sector composition effect as a percentage of total value added *LAB* symbolises the relative unit labour costs vis-à-vis competitors in other OECD countries *INT* represents the intrinsic effects a percentage of total value added *PUB* denotes the difference in public R&D intensity between the Netherlands and the OECD average *DUM* are country dummies. The indices *i* and *t* refer, respectively ,to countries and years (fixed effects model using OLS) (c) $RD_{i,t} = \alpha_i + \beta_i X_{i,t} + \delta_i D_{i,t} + e_{i,t}$ *RDi,t* represents the R&D intensity of countries, firms or industries (*i*) at time *t*. *RDi,t* is modelled as a function of a constant term ⍰*i*, a vector of explanatory variables *Xi,t* and dummy variables (firm-, country- or industry-specific fixed effects) *Di,t*. The error term is denoted by *ei,t*.	(a) Differences in the structure of EU compared with the USA play only a minor role in explaining the R&D gap. The European R&D shortfall is mainly caused by a negative intrinsic effect, meaning that companies in the EU spend less on R&D than their US peers in the same sectors (b) All the explanatory variables (INT, PUB and LAB) have a significant impact on the sector composition effect (c) The most important explanation behind the R&D gap (mostly intrinsic effects) is provided by institutional differences between the EU-15 and the USA

Author(s), year	Research Objective(s)	Main equation	Results
Moncada-Paternò-Castello *et al.* (2010)	To examine whether there are significant differences in private R&D intensity performance between the EU and the US and, if so, why.	$$RDI_X - RDI_Z = \sum_i RDI_{Z,i}(S_{X,i} - S_{Z,i}) + \sum_i S_{X,i}(RDI_{X,i} - RDI_{Z,i})$$ where: - X refers to one of the two samples to be compared (in our case the US the Japanese, the Switzerland's, the BRIC's, the Asian Tigers's or the Rest of the World sample) - Z is the other sample in the comparison (in our case, the EU sample) - RDI stands for R&D intensity (R&D/Y); the value of "Y" is the overall amount of net sales of companies from all sectors ($\sum y_i$) operating in a given economy - S is the share of the sector i in terms of net sales within a given economy (yi/Y).	The lower overall corporate R&D intensity for the EU is the result of sector specialisation (structural effect) —specialisation in sectors of high R&D intensity (especially ICT-related sectors) is stronger in the USA than in the EU
Lindmark *et al.* (2010)	Decomposing ICT R&D intensity of EU vs. USA by Size Factor and Intensity Factor	$$\left(\frac{R\&D^{ICT}}{GDP}\right)^{US} - \left(\frac{R\&D^{ICT}}{GDP}\right)^{EU} =$$ the US–EU deficit $$\frac{(VA^{ICT})^{US}}{(GDP)^{US}} * \left\{\frac{(R\&D^{ICT})^{US}}{(VA^{ICT})^{US}} - \frac{(R\&D^{ICT})^{EU}}{(VA^{ICT})^{EU}}\right\}$$ the deficit due to the R&D intensity factor + $$+\frac{(R\&D^{ICT})^{EU}}{(VA^{ICT})^{EU}} * \left\{\frac{(VA^{ICT})^{US}}{(GDP)^{US}} - \frac{(VA^{ICT})^{EU}}{(GDP)^{EU}}\right\}$$ the deficit due to the ICT sector size factor	The higher R&D intensity of the US ICT sector can be largely attributed to the higher US R&D intensity (intrinsic effect) compared to EU of the sub-sectors IT Equipment, Measurement Instruments and Computer Services. Therefore, no sub-sector is particularly responsible for the smaller *size* of ICT sector (the structural effect is responsible for ½ of the overall R&D intensity gap in ICT)
Mathieu and Van Pottelsberghe de la Potterie (2010)	To evaluate the extent to which national industrial structure affects country rankings based on aggregate R&D intensity	$RI_{i,jt} = \beta_{ij} + \varphi_t T$ (1) $RI_{i,jt} = \alpha_i I + \varphi_t T$ (2) $RI_{i,jt} = \beta_i J + \alpha_i I + \varphi_t T$ (3) (1) The links of country specificity to the variance in R&D intensity (2) The links of sector-specific impact on the R&D intensity (3) The simultaneous effects of national and industry-specific factors The control variables are time dummies, country dummies and/or industry dummies. *RI*, *J*, *I* and *T* are, respectively, the business R&D intensity (total R&D expenses divided by value added), country- industry- and time-specific vectors of dummy variables. β*i* and β*j* are the vectors of parameters to be estimated. Equations are estimated by the OLS method.	The econometric analysis performed on a cross-country cross-industry panel dataset suggests that accounting for industrial structure substantially affects the traditional country rankings.

Author(s), year	Research Objective(s)	Main equation	Results
Le Ru (2012)	Compare French vs German R&D intensities taking into consideration structural compositions and firms' R&D efforts	Not specified but described as basically in Ab Iorwerth (2005) or Lindmark *et al.* (2010)	Structural effects determine most of the gap, although in France firms in high-tech are more R&D intensive than German ones.
Reinstaller and Unterlass (2012)	The comparison of structural and country effects of business R&D intensities across countries *over time* (i.e. as Sandven and Smith (1998) + over time!)	$I_{m,j,t+1} = \sum_{i=1}^{n} \bar{I}_{i,t}\ w_{i,j,t} + \sum_{i=1}^{n} (I_{i,j,t} - \bar{I}_{j,t}) \cdot w_{i,j,t}$ Sector and country effects in base year *t,* $+ \sum_{i=1}^{n} I_{i,j,t} (w_{i,j,t+1} - w_{ij,t})$ change effects over time period Δt, $+ \sum_{i=1}^{n} (I_{i,j,t+1} - I_{i,j,t}) \cdot w_{i,j,t}$ changes of sectoral R&D intensities over time, and $+ \sum_{i=1}^{n} (I_{i,j,t+1} - I_{i,j,t}) (w_{i,j,t+1} - w_{ij,t})$ changes in sectoral R&D intensities (i.e. as Sandven and Smith (1998) + *over time*)	Changes in aggregate BERD figures are driven by 'within' (sectoral R&D intensity) and 'between' (structural change) effects with rather different intensity. For instance, Germany experiences structural change towards more technology-intense industries, whereas the United Kingdom experiences the inverse development pattern. Countries such as Denmark, Austria or Sweden, on the other hand, experience mostly a change in R&D intensities 'within' given industries
Foster-McGregor *et al.* (2013)	To compare the R&D intensity in the manufacturing sector as an indicator of the intensity of innovative activity, measured as the business expenditure of manufacturing firms on R&D relative to manufacturing value added	$R\&D_c^m - R\&D_w^m = \sum_i (va_{i,c} - va_{i,w}) \cdot R\&D_{i,w}$ $+ \sum_i (R\&D_{i,c} - R\&D_{i,w}) \cdot va_{i,w}$ $+ \sum_i (va_{i,c} - va_{i,w}) \cdot (R\&D_{i,c} - R\&D_{i,w})$ where $R\&D^m$ is R&D intensity in the manufacturing sector; $R\&D_i$ is R&D intensity in industry *i*. Subscript c denotes countries and subscript w denotes the global average, which for this purpose is the average of the nine countries included in the decomposition exercise. The valued added shares of manufacturing are denoted by va. (following Eaton *et al.*, 1998)	This decomposition shows that the differences in the R&D intensity of firms across the seven EU Member States and US and Japanese firms at the manufacturing level are mainly driven by the intensity effect. The industry structure (composition effect) plays a role in some of the seven Member States but is never the primary factor.

Author(s), year	Research Objective(s)	Main equation	Results
Gumbau-Albert and Maudos, (2013)	To analyse the relative importance of country effect and specialisation effect when explaining the differences and evolution in the technological effort of the USA and the EU	(a) Analysis of specialisation: $$\frac{K_t^A}{Y_t^A}-\frac{K_t^B}{Y_t^B}=\sum_{j=1}^{J}\theta_{jt}^{B}\left(\frac{K_t^A}{Y_t^A}-\frac{K_t^B}{Y_t^B}\right)+\sum_{j=1}^{J}\left(\theta_{jt}^{A}-\theta_{jt}^{B}\right)\frac{K_t^B}{Y_t^B}+\sum_{j=1}^{J}\left(\theta_{jt}^{A}-\theta_{jt}^{B}\right)\left(\frac{K_t^A}{Y_t^A}-\frac{K_t^B}{Y_t^B}\right)$$ R&D capital stock/GVA ratio, is called K/Y; A and B are the two economic areas to be analysed (USA and EU-11, respectively), t is the year and j the sector and y measures the specialisation or production structure proxied by the weight of the GVA in each sector j in total (b) Contribution of structural change: As (a) but the terms A and B are replaced by time dimensions T and 0 (initial and final year, respectively).	There was a technological gap in favour of the USA until the mid-1990s. Since 1995 a change in productive specialisation has occurred, with a significant drop in the weight of lower technology-intensive industries in the EU-11 economy, as well as a significant drop in the weight of some medium technology-intensive industries in the USA, accounting for the reduction in the technological gap between the EU and the USA. The authors also found that the differences in the productive structure of EU countries explain most of their differences in technological capital intensity
Cincera and Veugelers (2013)	To calculate exact size of the EU vs. US difference in R&D intensity between younger firms and older to determine if it is due to structural or intrinsic effects	$$RDI^y-RDI^o=\sum_i RDI_i\left(w_i^y-w_i^o\right)+\sum_i w_i\left(RDI_i^y-RDI_i^o\right)$$ RDI is the R&D intensity, defined as R&D investments divided by net sales. Superscripts y and o denote, respectively, *yollies* and *ollies*, subscript i denotes industry, w_i^y is the share of the sector accounted for by the total number of young firms and w_i^o is the share of the sector accounted for by the total number of old firms	Both structural and intrinsic effects are positive, reflecting, respectively, that, compared with *ollies*, *yollies* are more present in R&D-intensive sectors and are more R&D intensive within sectors. But the structural effect is four times greater, thus confirming the importance of the sectoral structure. The smaller of young firms in the EU accounts for about one-third of the EU–US differential in R&D intensity, while 55% of the differential is because young leading innovators in the EU are less R&D intensive than their US counterparts. Further analysis shows that this is almost entirely due to a different sectoral composition

Author(s), year	Research Objective(s)	Main equation	Results
Stancik and Biagi (2015)	To analyse R&D intensity gap decomposition on EU versus US, Japan, Asian Tigers and BRIC.	$$RDI_t^A - RDI_t^B = \sum_i (RDI_{it}^A - RDI_{it}^B) w_{it}^{AB} + \sum_i w_i (w_{it}^A - w_{it}^B) RDI_{it}^A$$ where RDI_{it}^A is the R&D intensity of sector i in year t in region A (defined as R&D investment over sales) and w_{it}^A denotes the share of sector i in year t sales within region A total sales. The first term in equation represents the intrinsic effect while the second term is the structural one. In practice, region A is always the EU-22 (which is the reference region) while region B is either, the USA, Japan, the BRIC countries or the Asian Tigers	The EU is less R&D intensive than the USA, Japan or the Asian Tiger economies, but more R&D intensive than the BRIC countries. The former result is due to structural effects, while the latter being consequence of both higher R&D intensive activities within sectors and sectoral composition. The analysis also shows that the EU is, on average, less R&D intensive than the USA (by about 2 percentage points) and that this gap has tended to increase over time
Belitz *et al.* (2015)	To analyse the difference between the private-sector R&D intensities of Germany and the OECD countries	The difference in private R&D intensity between two countries ($FI_{DEU} - FI_{Other\ country}$) is decomposed into two components, a structural component (Δ_{ST}) and a behavioural component (Δ_{VH}): $FI_{DEU} - FI_{Other\ country} = \Delta_{ST} + \Delta_{VH}$ The structural component (Δ_{ST}) captures the share of that difference that is attributable to differences in the relative sizes of industry sectors in the two countries. It is derived from the difference in sectoral weightings — measured here based on the relevant sector's share of value added and the R&D intensity of that sector in the other country. The weighted R&D intensities are aggregated across all available sectors: $\Delta_{ST} = \Sigma_i FI_{i\ Other\ country}\ (\mathrm{SHARE}_{i\ DE} - \mathrm{SHARE}_{i\ Other\ country})$ where i = sector, two-digit sector code The behavioural component (Δ_{VH}) measures the share of the total difference that is attributable to divergent R&D behaviour (R&D intensity) within a sector. It is derived from the sectoral difference in R&D intensity between two countries, which is weighted with the relevant German sector's share of value added. The weighted sectoral differences are aggregated across all available sectors: $\Delta_{VH} = \Sigma_i \mathrm{SHARE}_{i\ DE}\ (\mathrm{FI}_{i\ DE} - \mathrm{Fi}_{i\ Other\ country})$ where i = sector, 2-digit sector code. NOTE: The decomposition technique used here is based on Ronald Oaxaca and Alan Blinder's work on wage differentials. R. Oaxaca, "Male–female wage differentials in urban labour markets," *International Economic Review* 14 (3) (1973): 693–709. A. Blinder, "Wage Discrimination: Reduced Form and Structural Estimates," *Journal of Human Resources* VII (4) (1973): 436–455.	On the whole, the structural effect and the behavioural (intrinsic) effect play more or less equally important roles in explaining the differences between Germany and other countries with regard to private-sector R&D intensity. Although Germany often suffers from the behavioural effect, it usually benefits from the structural effect. Both effects are strongly driven by a few particularly research-intensive industries

Author(s), year	Research Objective(s)	Main equation	Results
Moncada-Paternò-Castello (2017a)	To investigate (i) whether the explanation for the lower overall corporate R&D intensity of the EU vis-à-vis the competing (and emerging) economies lie mainly in an "intrinsic" vs. a "structural" effect; (ii) how (if) R&D intensity gap and its main determinants has changed over the 2005-2013 period by world regions/countries.	$$RDI_t^A - RDI_t^B = \sum_i (RDI_{it}^A - RDI_{it}^B) w_{it}^{AB} + \sum_i w_i (w_{it}^A - w_{it}^B) RDI_{it}^A$$ where: - X refers to one of the two samples to be compared (in our case the US the Japanese, the Switzerland's, the BRIC's, the Asian Tigers's or the Rest of the World sample) - Z is the other sample in the comparison (in our case, the EU sample) - RDI stands for R&D intensity (R&D/Y); the value of "Y" is the overall amount of net sales of companies from all sectors $(\sum y_i)$ operating in a given economy - S is the share of the sector i in terms of net sales within a given economy (yi/Y).	The results indicated that the EU R&D investment gap is structural, that the EU gap has broadened in the last decade vs. the US; the gap is negative and with a quite stable evolution vs. Japan and Switzerland. Such EU gap is positive and with quite stable evolution vs. BRIC and Asian Tigers groups, while the companies from the rest of the world are sensibly narrowing their R&D intensity deficit. The analysis also shows that sector-by-sector within the same high and medium-high intensity sectors groups, the EU firms perform often much better (in 10/14 sectors analysed) in R&D intensity than the US ones.

Essay #2

EU corporate R&D intensity gap: What has changed over the last decade?

Pietro Moncada-Paternò-Castello (*)

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 and investigating its comparative distribution among top R&D firms, sectors and world regions/countries. It draws on a longitudinal company-level micro-dataset from 2005 to 2013, and uses both descriptive statistics and decomposition computational methods. The results confirm the structural nature of the EU R&D intensity gap. In the last decade the gap between the EU and the USA has widened, whereas the EU gap with Japan has remained relatively stable. In contrast, the emerging countries' R&D intensity gap compared to the EU has remained relatively stable, while companies from emerging economies are considerably reducing such gap. Besides, as novel contribution to the state of the art of the literature, this paper uncovers the differences between EU and US by inspecting which sectors, countries and firms are more accountable for the aggregate R&D intensity performance of these two economies, and finds a high heterogeneity of firms' R&D intensity within sectors. Finally, the study shows a high concentration of R&D in a few countries, sectors and firms, and in the EU there are fewer smaller top R&D firms that invest more intensively in R&D than in the most closed competing countries.

JEL classification: O30; O32; O38; O57

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

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(*) *Contact information: European Commission – Joint Research Centre (JRC), Growth and Innovation Directorate. Address: Edf. Expo, Calle Inca Garcilaso No. 3, 41092 Seville (Spain).*
Email: pietro.moncada-paterno-castello@ec.europa.eu

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1. Introduction

Europe is currently facing multiple challenges simultaneously: to resolve the economic crisis, to become more competitive and to create more and better jobs in a sustainable way. The Research and Development (R&D) activities of companies in the private sector are expected to be 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, namely the Lisbon strategy of 2000 and the related Barcelona target, set in 2003, which states that the EU should spend 3 %[24] of GDP on R&D, two-thirds of which should come from the private sector. The strategy was reiterated and reinforced in the more recent Europe 2020 strategy as in the related European Union Flagship initiative (European Commission, 2010). This initiative emphasises the need to support increased private research and innovation investment and to generate positive demographics (creation and growth) of companies operating in new or knowledge-intensive industries. 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 economic growth, coupled with more and better jobs (for an overview on the subject, see Sheehan and Wyckoff, 2003; Moncada-Paternò-Castello, 2010).

The literature that deals 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 is extensive (e.g. Dosi, 1997; Pianta, 2005; Erken and van Es, 2007; Moncada-Paternò-Castello *et al.,* 2010; Cincera and Veugelers, 2013).[25] 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[26] – and reaches differing conclusions (Moncada-Paternò-Castello, 2010, 2017a). In contrast, only a limited number of studies reported in the literature have investigated the intensity of corporate R&D by combining several parameters (Ciupagea and Moncada-Paternò-Castello, 2006; Moncada-Paternò-Castello *et al*., 2010; Reinstaller and Unterlass, 2012).

This paper seeks to contribute to the literature by addressing three questions:

(i) To what extent does sector composition (the 'structural' effect) affect the aggregate EU R&D intensity gap not only in relation to the USA and Japan, but also in comparison with other competing (and emerging) economies?

(ii) Has the R&D intensity gap changed over time (2005-2013) and, if it has, how has the impact of the main factors affecting that gap changed during the time period under consideration? And which sectors, countries and firms are the most responsible for the gap?

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[24] This target was set taking into consideration the fact that, at that time, the EU was investing only 1.9 % of its GDP in R&D, whereas Japan was investing 2.7 % of GDP and the USA 2.98 % (European Commission, 2003).

[25] The first literature survey on this subject has been recently elaborated by Moncada-Paternò-Castello (2017a).

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

(iii) How has the distribution of R&D investment among top R&D-investing firms and groups of sectors changed in different world regions/countries over time?

This paper uses a novel approach by

(a) Comparing micro-data from different editions of the EU Industrial R&D Investment Scoreboard to analyse how the R&D intensity gap decomposition has changed over a long time period (2005-2013) *that includes the year(s) of economic and financial downturn;*

(b) Comparing data from firms in the EU with data from firms not only in the USA and Japan, but also in some emerging economies such as the Asian Tiger countries (Hong Kong, Singapore, South Korea and Taiwan), and the BRIC countries (Brazil, Russia, India and China);

(c) Investigating which sectors, countries and firms within the EU are accountable for most of the aggregate EU R&D intensity performance compared to its main competing economy, the USA;

(d) Addressing the concentration of corporate R&D with respect to several parameters and their evolution over time.

To our knowledge, there are no studies published in peer-reviewed scientific journals that have considered these characteristics in combination in a comparative analysis.

This study relies on company data accessible from the EU Industrial R&D Investment Scoreboard (hereafter the EU R&D Scoreboard).[27] The EU R&D Scoreboard data are collected from publicly available audited annual reports and company accounts. The main variables considered are firms' R&D investment, net sales and R&D intensity by country/region, industry (sector) and group of sectors. Based on the EU R&D Scoreboard, we compiled a database of micro-data from the EU and non-EU firms that spend the most on R&D and covering the years 2005-2013.[28]

This paper is structured as follows. Following this introduction, a review of the literature is presented (section 2). Section 3 introduces the data and samples selected for the analysis and it reports the descriptive statistics, and section 4 gives the decomposition of corporate R&D intensity. Section 5 further investigates the EU vs US R&D intensity gap. Section 6 presents the results of the analysis of the distribution of R&D among top R&D firms, sectors and countries. Section 7 summarises the findings and offers some concluding remarks.

[27] http://iri.jrc.ec.europa.eu/scoreboard.html

[28] Data are from three editions of the EU R&D Scoreboard survey, those published in 2006, 2010 and 2014, as well as a longitudinal balanced dataset spanning nine years (2005-2013) using company data from the EU R&D Scoreboard editions 2006-2014 to check the robustness of the main decomposition results using the three different Scoreboard editions.

2. Related literature

2.1 Relevance of corporate R&D investment and countries' R&D intensity differences

Theoretical studies of corporate R&D activity as a driver for economic prosperity, and the role of technological development in economic growth (Schumpeter, 1942; Solow, 1957; Romer, 1990; Hunt, 2000), suggest that firms generally invest in R&D because it provides them with an innovative rent by shifting the revenue and/or cost curve. These extra profits ensure higher overall economic growth.

Empirical evidence (e.g. Griliches, 2000; Griffith *et al*., 2004; Mohnen and Hall, 2013) broadly suggests that engaging in R&D can help firms to innovate and increase productivity, and to improve products or create new products or enter new markets that ensure competitiveness and growth, leading to both private and social benefits, thus entering into the sphere of public policy interest.

Furthermore, Hall *et al*. (2010) show that rates of return on R&D investment are likely to be in the range of 20-30 %. However, firms' returns on R&D investment in terms of innovation and competitiveness differ considerably, depending on the technology intensity of the industrial sector and the product portfolio and/or life cycle (Mairesse and Mohnen, 2005; Kumbhakar *et al*., 2012). In practice, there is an optimum level of corporate investment in R&D that very much depends on the expected returns.

Despite some fears that technological progress destroys jobs, there is firm evidence from several recent studies that, overall, this is not the case. In fact, R&D and innovation usually have a positive and significant effect on employment, and this effect is especially strong in the high-tech sector and in services, but is not significant in the traditional manufacturing sectors (Bogliacino and Pianta, 2010; Bogliacino *et al*., 2012; Harrison *et al*., 2014).

Because of this potential for private and social returns, R&D investment has become a policy target and a proxy measure that can be used to benchmark the socio-economic performance and competitiveness of an economy. In 2003, the EU set a target (to be achieved by 2010, a deadline recently extended to 2020[29]) of increasing investment in R&D from 1.9 % of GDP in 2000 to at least 3 %, of which two-thirds (2 % of GDP) is expected to be contributed by the private sector (up from 1.1 % in 2000).[30] However, more than a decade later, the situation has not improved as expected, especially in the private sector. In fact, 2013 data (same year of most recent micro-data analysed in this study) indicate that in EU-28 overall R&D intensity was still below 2 %, considerably behind that of South Korea, Japan, the USA and China (Table 1).

If we focus on R&D expenditure in the business enterprise sector (BERD) as a proportion of GDP, the result for the EU-28 in 2013 was disappointing: 1.26 %, compared with 3.09 % in South Korea, 2.60 % in Japan, 1.96 % in the USA, and 1.51 % in China. Nonetheless, in contrast to Japan and the USA, this figure did at least increase over the period 2008-2013 in the EU, although to a lesser extent than in emerging countries such as South Korea and China (with China overtaking the EU in 2013).

[29] The Europe 2020 strategy sets the objective of an R&D intensity of 3 % and most Member States have adopted this figure as their target national R&D intensity by 2020.

[30] For comparison, in 2000, the ratio of BERD to GDP (R&D intensity) was 1.8 in the USA and 2.2 in Japan.

Table 1. R&D intensity (as gross domestic expenditure on R&D) by economic sector in the EU-28 and competing economies in 2008 and 2013 – data as % of GDP

	Business enterprise sector		Government sector		High education sector		TOTAL R&D intensity	
	2008	*2013*	*2008*	*2013*	*2008*	*2013*	*2008*	*2013*
EU-28	1.17	1.26	0.24	0.25	0.43	0.47	1.84	1.98
United States	1.97	1.96	0.31	0.35	0.37	0.39	2.65	2.70
Japan	2.72	2.60	0.29	0.28	0.40	0.45	3.41	3.33
Switzerland	2.01	2.05	0.02	0.02	0.66	0.83	2.69	2.90
China	1.08	1.51	0.27	0.32	0.12	0.15	1.47	1.98
Russia	0.66	0.68	0.31	0.34	0.07	0.10	1.04	1.12
South Korea	2.53	3.09	0.41	0.47	0.37	0.41	3.31	3.97

Source*:* Own elaboration from European Commission, EUROSTAT (2015)[31]

The aim of this paper is not to determine the motivations and benefits of R&D investment, or if a particular private or policy target is appropriate. Rather, the scope (and related research questions) of the present investigation is to disentangle the main factors contributing to the EU R&D intensity gap, to identify the dynamics of the R&D investment (gap) over the period under study and to determine how (and to what extent) these factors affected the R&D intensity gap between 2005 and 2013. It also addresses the distribution of R&D investment across countries, sectors and firms. Linked to the focus of this research, the following sections present the theoretical and empirical literature on these specific aspects.

2.2 Structural versus intrinsic effects in 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).

The theoretical basis of the importance of industry composition and sector characteristics (i.e. the structural effect) in determining the aggregate corporate R&D intensity of a given economy points at the reasons why these inter-industry differences occur. For example, Pakes and Schankerman (1984), whose research is based on the theoretical work of other authors (e.g. Schumpeter, 1942; Griliches and Schmookler, 1963; Scherer, 1982), made the argument that the output of research activities (industrial knowledge) has unique economic characteristics, and they developed a theoretical model showing that R&D intensity depends on a combination of three factors: expected market size and growth in demand; appropriability differences; and technological opportunities.

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). Summarising a recent first survey of the literature in this field by Moncada-Paternò-Castello (2017a), it is apparent that some studies support the idea

[31] Extracted in June 2015 (http://ec.europa.eu/eurostat/statistics-explained/index.php/R_%26_D_expenditure).

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), while 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).

The review by Moncada-Paternò-Castello (2017a) concludes 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 – as, for example, if service sectors' data together with the heterogeneity of countries and business structures are considered, rather than to differences in the calculation model/formula used (which for instance do not vary very much in the literature). This finding confirms the results of previous investigation of these aspects by Duchêne *et al*. (2010) and Lindmark *et al*. (2010).

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; Moncada-Paternò-Castello, 2017b). 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, labour and capital markets (Aghion, 2006; de Saint-Georges and van Pottelsberghe, 2013; Veugelers, 2015).

Finally, it is important to emphasise that the structural composition of the economy has an impact on a country's overall performance in terms of corporate R&D intensity. Aggregate corporate R&D intensity performance will be lower in an economy with a relatively high proportion of low-R&D-intensity sectors than in an economy with a relatively high proportion of high-R&D-intensity sectors. However, this is not to suggest that R&D investment among firms in a country with an aggregate lower R&D intensity, whichever sector they are in, is necessarily lower than that of similar firms in a country where aggregate R&D intensity is higher.

2.3 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). The main theoretical argument underpinning this is that a high level of productivity releases resources that can be invested in new knowledge, thus completing the virtuous circle, so new knowledge/technology is the main determinant of productivity improvements and the driver of economic growth (Schumpeter, 1934; Solow, 1957; Baumol, 1986; Dosi, 1988).[32] 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 Schumpeterian (1934) view of market power and innovation, competition appears to be rather detrimental to innovation and technological progress. These theoretical

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

frameworks could explain the slower rate of productivity and innovation growth in the EU, e.g. in comparison with the USA, coinciding with the emergence of new economies, which rely increasingly on technology and human and financial capital as a basis for competitiveness (Fagerberg *et al.,* 1999; European Commission, 2013; 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 opportunities, 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; Cette *et al*., 2015; Ortega-Argiles *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 competiveness of the entire economy (Krüger, 2008; Dosi and Nelson, 2010; Perez, 2010).

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, in fact, is the case for the EU compared with the USA and emerging competitors, as confirmed by a group of empirical studies on the subject (Duchêne *et al*., 2011; Voigt and Moncada-Paternò-Castello, 2012; Veugelers, 2013; Chung, 2015).

2.4. Dispersion versus concentration of corporate R&D investment

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 and 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 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 countries, of large companies and of high R&D intensity sectors. (Ciupagea and Moncada-Paternò-Castello 2006; Moncada-Paternò-Castello *et al*., 2010; Reinstaller and Unterlass, 2012; Hirschey *et al*., 2012; Montresor and Vezzani, 2015).

In summary, in this paper we seek to update and improve our current knowledge of the characteristics and causes of, and trends in, European corporate R&D performance compared to world competitors. We anticipate that the results of our research will support help answer the three research questions posed in the introduction.

3. Data and samples selected for the analysis

3.1 Data

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 full dataset covers the years 2000-2013. The database lists the top corporate R&D investors headquartered all over the EU and R&D-investing companies headquartered outside the EU. The EU R&D Scoreboard covers about 90 % of global private R&D investment worldwide.[33] The 1 000 EU firms that invest the most in R&D together account for almost 95 % of total business expenditure on R&D in the EU.[34]

Companies in the EU R&D Scoreboard include those that are listed on a stock exchange as well as private companies and state-owned companies, but companies that are subsidiaries of another company are excluded, to avoid double counting.

In this report, data are grouped by the sector into which groups of companies are classified, following the definition of the international accounting standard Industry Classification Benchmark (ICB) at the three- or four-digit level.[35] This classification allocates a company's whole R&D investment to the country in which its registered office is located (see section A1, Box 1 in the Appendix).

The data taken from the companies' published annual accounts refer to a given financial year. The EU R&D Scoreboard data are nominal and expressed in euros. For companies reporting in a currency other than the euro, currency amounts have been converted to euros at the exchange rates of the latest Scoreboard, and the exchange rate conversion has also been applied to the historical data. In so doing, the EU R&D Scoreboard reports company results in the domestic currency, rather than as economic estimates of current purchasing parity; however, this has no impact on the kind of analyses and estimates upon which we are focusing (Montresor and Vezzani, 2015). Nonetheless, a dataset with deflated monetary values using 2000 as the reference year was analysed to check the robustness of the results obtained (see the Appendix for more information on this approach).

A discussion on caveats relating to the EU R&D Scoreboard data is provided in section 3.3 and, more extensively, in the Appendix A1.

3.2 Datasets

For the analytical purposes of this paper, two datasets from the same data source have been used.

The first comprises data from three editions of the EU R&D Scoreboard, i.e. collected in three different years: the 2006 and 2010 editions include data on 2 000 companies and the

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

34 94.7 % according to latest (2013) figures from Eurostat (€175.0bn) and the EU R&D Scoreboard (€165.8bn). The figures from the two above-mentioned statistical sources are also comparable at a global level (see Moncada-Paternò-Castello, 2017a).

35 See http://www.icbenchmark.com/.

2014 edition includes data on 2 500 companies.[36] It is worth noting that the EU and non-EU lists differ in the minimum R&D investment threshold needed to enter the rankings. Furthermore, these three editions do not contain exactly the same number of companies because of company dynamics (entry and exit behaviour to and from the ranking of top private R&D investors and mergers and acquisitions).

Therefore, in order to construct comparable sub-samples of companies from each country/region, we reduced the complete set of companies for each of the three EU R&D Scoreboard editions to approximately 1 250. In this way we could ensure that we could include a sufficient number of firms from each of the countries/regions we wanted to analyse (especially to capture firms from the BRIC and the Asian Tiger countries) and that the samples were representative and with comparable R&D investment (see Moncada-Paternò-Castello *et al*., 2010).

This approach resulted in the following sub-samples: in 2005, 1 247 companies with a minimum total R&D investment of €27.98m; in 2009, 1 247 companies with a minimum total R&D investment of €34.70m; and, in 2013, 1 242 companies with a minimum total R&D investment of €46.70m. 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. These firms account for 98 %, 97 % and 94 % of total R&D expenditure by the complete EU R&D Scoreboard sample in 2005, 2009 and 2013, respectively. Although the samples do not contain exactly the same firms (about 1060 firms - or 85% - remain the same in the three years/samples), the comparative analysis of these three datasets allows us to investigate exactly how the factors determining R&D intensity in a comparable sample of top R&D investors have changed over time. The absolute values of monetary data in the three different editions of the EU R&D Scoreboards datasets are not adjusted for inflation. In fact, there is no real need to deflate values as what we present are the ratios (basically R&D/net sales) of three different EU R&D Scoreboard editions that also differ, for instance, in the composition of included firms. Furthermore, although the values and sector composition of net sales of these companies are not perfectly representative of their economies, they are certainly representative of the sectors where these top global R&D-investing firms operate.

To check the robustness of the results of the analysis of the above-mentioned three different editions of the EU R&D Scoreboard, a second dataset with deflated monetary values was built and used. This is a longitudinal balanced dataset of nine years (2005-2013) corresponding to 1 859 enterprises worldwide taken from several editions of the EU R&D Scoreboard (see the Appendix A.3 for further details).

3.3 Main variables and caveat

The main variables considered for the analysis are the company's (R&D) investment, net sale, and sector classification at ICB three- or four-digit level. The ICB sectors have been grouped according to R&D intensity of the sector worldwide following the European Commission (2006-2014) and OECD (1997) approach: high R&D intensity; medium-high R&D intensity; medium-low R&D intensity; low R&D intensity (Box 1 in the Appendix provides further specifications).

[36] The original full sample comprised, for 2005, data from 2 000 companies with total R&D expenditure of €371bn and net sales of €11 073bn; for 2009, data from 2 000 companies with total R&D expenditure of €402bn and net sales of €12 574bn; and, for 2013, data from 2 500 companies with total R&D expenditure of €540bn and net sales of €16 723bn.

When using these EU R&D Scoreboard data, a number of factors that potentially affect the interpretation of the figures should be taken into account. In particular: i) As accounting standards permit the financial year to differ from the calendar year, the stated years can include accounts which end on a range of dates from the second part of that year until the first part of the following year. ii) The original EU R&D Scoreboard figures are nominal and expressed in euros, and deflating the monetary data of these datasets could have some drawbacks. iii) Growth in corporate R&D investment can be organic or due to acquisitions, or a combination of the two. vi) The terms ‘EU company‘, ‘US company‘, ‘Japanese company‘, etc. are used throughout this paper to refer to a company whose ultimate parent company has its registered office in that country or region.

Therefore, the EU R&D Scoreboard is a rich and accurate information source about a company’s financial effort, but is less accurate when analysing a country’s business R&D expenditure (BERD – statistics collected by national statistical offices), although the EU R&D Scoreboard shows similar results at global or a EU level (Moncada-Paternò-Castello, 2017a).

Furthermore, it is very likely that the some top R&D-investing located in some countries or regions are omitted from the EU R&D Scoreboards, for example some companies in the Asian Tiger and BRIC countries and in some of the countries in the Rest of the World (RoW) group. The reasons are mostly historical as public disclosure of companies’ data was not always mandatory, especially for companies not listed on the stock markets (e.g. Chinese firms before the privatisation wave of late 2000), and some countries were slow to adopt International Financial Reporting Standards (IFRS) (European Commission, 2014). Unsurprisingly, therefore, this deficiency is more marked in the earliest editions of the EU R&D Scoreboards. More information on the main variables considered for the analysis as well as caveats about the EU R&D Scoreboard data are reported in the Appendix A.2.

Finally, the limit of using this dataset is the selection bias because of the companies under investigation are by definition the top R&D investing firms, although this bias is homogenous over time and geographical areas. In the overall, the advantage of using this data source is that it covers the bulk of the private R&D worldwide. Therefore, although the R&D investment behaviour of top R&D firms could diverge in some respects from total world R&D investment, the differences are unlikely to be substantial considering that the EU R&D Scoreboard captures almost all global R&D investment by firms.

3.4 Descriptive statistics

Table 2 reports R&D investment and net sales as a proportion of total R&D investment by EU R&D Scoreboard for each of the years of observation, by sector group and by country/region.

Table 2. R&D investment and net sales by R&D intensity sector[37] as a proportion of total R&D investment by EU R&D Scoreboard firms in 2005, 2009 and 2013 and by country/region

R&D 2005						
	EU - 319	US - 539	Japan - 227	Asian Tigers - 66	BRIC -12	RoW - 84
high	35.3%	67.5%	40.3%	19.9%	20.9%	63.9%
medium-high	51.2%	28.7%	50.2%	70.9%	8.6%	25.2%
medium-low	6.3%	2.3%	5.5%	1.2%	0.0%	6.9%
low	7.2%	1.4%	4.0%	8.0%	70.5%	4.0%
Grand total	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
R&D 2009						
	EU - 349	US - 447	Japan - 238	Asian Tigers - 76	BRIC -44	RoW - 93
high	34.9%	69.0%	38.0%	26.3%	33.9%	62.2%
medium-high	48.2%	25.0%	52.7%	62.9%	16.0%	19.5%
medium-low	7.1%	4.5%	4.5%	3.2%	0.6%	12.1%
low	9.7%	1.5%	4.8%	7.6%	49.5%	6.2%
Grand total	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
R&D 2013						
	EU - 354	US - 409	Japan - 205	Asian Tigers - 77	BRIC -81	RoW - 116
high	32.4%	70.9%	32.4%	33.9%	27.4%	63.4%
medium-high	51.9%	23.8%	60.5%	58.5%	29.5%	24.6%
medium-low	5.6%	4.0%	4.1%	2.9%	2.0%	5.2%
low	10.1%	1.3%	3.0%	4.7%	41.1%	6.8%
Grand total	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
Net Sales 2005						
	EU - 319	US - 539	Japan - 227	Asian Tigers - 66	BRIC -12	RoW - 84
high	8.4%	26.9%	24.8%	17.4%	1.7%	18.7%
medium-high	33.9%	41.2%	47.5%	58.4%	2.9%	39.1%
medium-low	11.6%	7.0%	10.4%	4.4%	0.0%	16.6%
low	46.1%	24.8%	17.3%	19.8%	95.3%	25.7%
Grand total	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
Net Sales 2009						
	EU - 349	US - 447	Japan - 238	Asian Tigers - 76	BRIC -44	RoW - 93
high	8.0%	29.2%	19.1%	18.6%	4.3%	20.3%
medium-high	30.5%	37.0%	47.9%	59.2%	11.3%	34.1%
medium-low	12.8%	12.4%	9.1%	3.4%	3.0%	21.8%
low	48.7%	21.5%	24.0%	18.9%	81.4%	23.8%
Grand total	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
Net Sales 2013						
	EU - 354	US - 409	Japan - 205	Asian Tigers - 77	BRIC -81	RoW - 116
high	7.9%	35.7%	14.3%	21.3%	5.3%	21.2%
medium-high	34.4%	36.3%	60.3%	48.8%	17.7%	32.2%
medium-low	11.2%	12.2%	7.1%	13.4%	2.0%	14.6%
low	46.6%	15.7%	18.3%	16.5%	75.0%	32.0%
Grand total	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%

Note: Numbers adjacent to the names of countries are the number of companies included in the calculations.
Source: Computed from the EU Industrial R&D Investment Scoreboard (European Commission, 2006-2014).

In the Appendix, Table A-1 provides the monetary values of R&D investment and net sales.

[37] Defined as specified in section 3.3 and in the Appendix (Box 1).

The sectorial composition of the countries/regions analysed by sectors' groups is illustrated in Figures 1 and 2, 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 countries/regions.

Figure 1 shows that, overall, growth in R&D investment and net sales has been readily stable in the EU sample and irregular in the USA and Japan and that these two countries seem to have suffered the effects of the economic and financial crisis (the USA in 2009 and Japan after 2009).

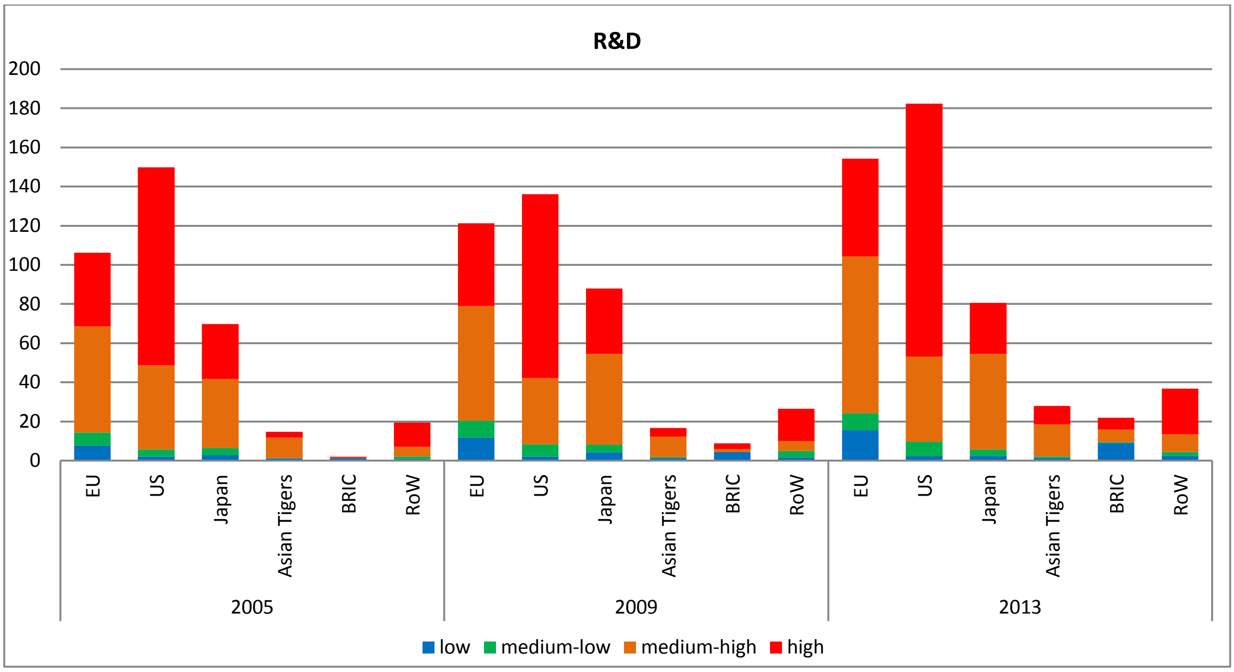
In terms of growth trends in the groups of sectors within this triad, i.e. the EU, the USA and Japan, the following can be noted. First over the period 2005-2013, US companies in the high-R&D intensity sectors' group increased their lead over other regions in both R&D investment and net sales: in this sectors' group, both R&D investment and net sales were considerably higher in 2013 than 2005 and 2009. Secondly, among EU companies, the sector group that accounted for the greatest proportion of R&D investment over the period of the study was the medium-high R&D intensity sectors' group, and investment in this sector group increased from 2005 to 2009 and from 2009 to 2013. In contrast, however, in the EU sample, the greatest proportion of net sales is accounted for by companies operating in the low-R&D intensity sectors. Finally, the pattern among Japanese companies is similar to that of EU companies, except that the medium-high R&D intensity sectors' group accounted for the highest proportion of both R&D investment and net sales.

Overall, the *structure* of the economic sectors in which top EU R&D investors operate has moderately moved towards higher R&D intensity sectors in the three years of observation. In contrast, the size of low-R&D intensity sectors has increased more considerably. This dynamic is radically different in the USA, where both R&D investment and net sales have moved towards more high-R&D intensity sectors of the economy.

Figure 2 shows R&D investment and net sales by sector of companies in the Asian Tiger countries, the BRIC countries, and the RoW. Generally, there has been a considerable increase in R&D investment, especially in the high- and medium-high R&D intensity sectors, over the three years considered. The largest R&D investment in mid-high tech sectors is made by companies from the Asian Tiger countries, and this increased considerably over the years, as did R&D investment in high-R&D intensity sectors.

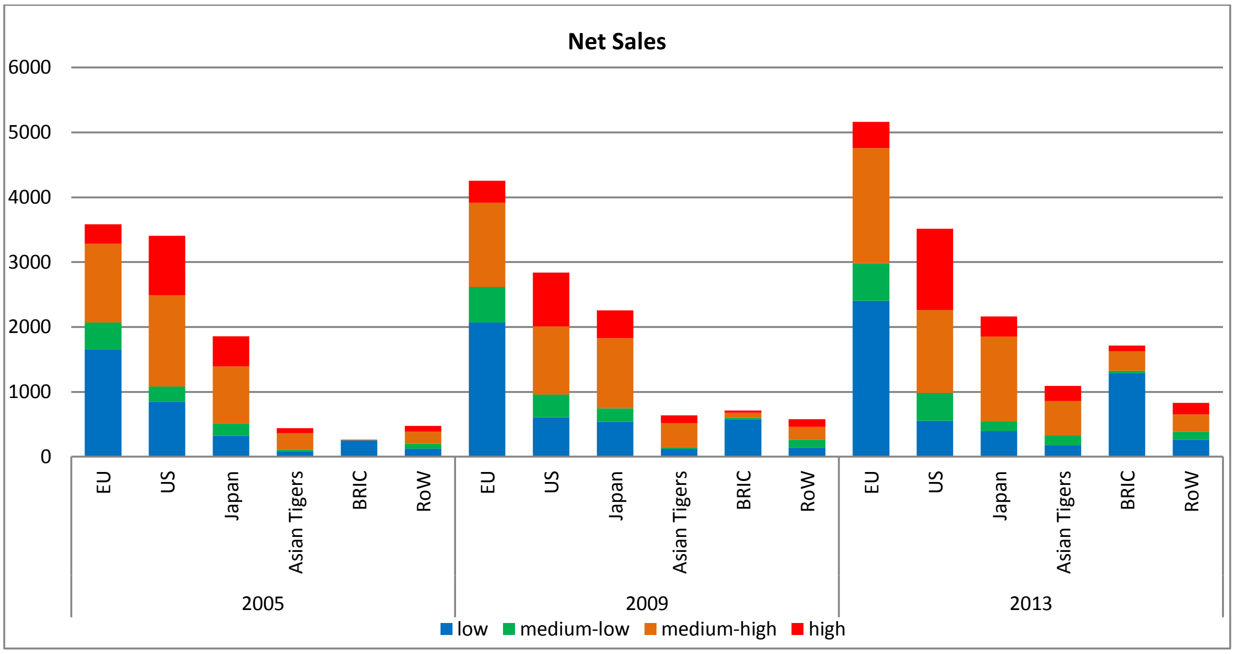
Information on the distribution of R&D expenditure and net sales by sub-sector (four-digit ICB sectors) in the EU R&D Scoreboard can be found in section 5, where it can be appreciated that the global R&D investment (and net sales) is concentrated in ICT-related sectors, in the pharmaceuticals and biotechnology sectors, and in the automobiles and parts sectors.

Figure 1. R&D investment in selected years, by countries/world regions and R&D-intensity sector group[38] (€ millions)



Source: Computed from the EU Industrial R&D Investment Scoreboard (European Commission, 2006-2014).

Figure 2. Net sales in selected years, by countries/world regions and R&D-intensity sector group[15] (€ millions)

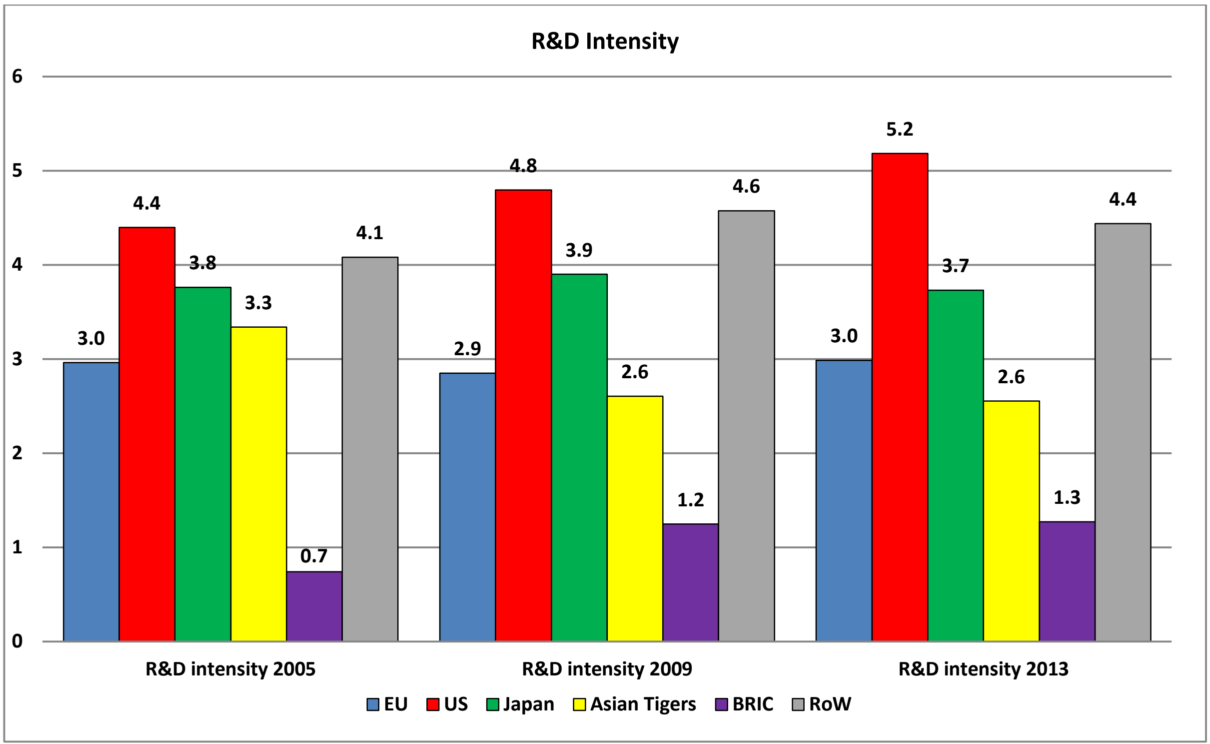


Source: Computed from the EU Industrial R&D Investment Scoreboard (European Commission, 2006-2014).

[38] Includes only companies in the top 1 250 R&D investors worldwide in terms of R&D investment and net sales (see Table 3 for details).

Data provide evidence of the large difference in net sales between the EU and the USA in the high-R&D intensity sectors, the latter, in 2013, achieving 2.5 times more net sales than the former. This means that, among the total sample of the top 1 250 R&D-investing companies worldwide, US companies are much more represented in high- R&D intensity sectors than EU companies. On the other hand, these figures also indicate that EU companies account for a higher proportion of net sales in the lower R&D intensity (medium- and low- R&D intensity sectors groups) than companies from any other countries/regions.

Figure 3. R&D intensity (R&D/net sales) in selected years by group of countries



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

There is a much larger EU sales growth (44%) from 2005 to 2013 than the USA (3%), especially in low & medium-low R&D intensity sectors (EU 44.2% and US –9.2%), a growth difference much greater than the respective countries' total R&D investment growth (45% in EU and 22% in US). These more divergent growth paths between the terms of the EU R&D intensity ratio than the USA ones have widened the EU vs US R&D intensity gap.

Therefore, the majority (by net sales) of EU companies in the EU R&D Scoreboard operate in lower-tech sector groups, and 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 sale 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 3. This figure also shows that in the EU, Japan R&D intensities remained fairly stable in the three years of observation and in the USA increased by 0.4 points.

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 rather than a lower level of firms' R&D intensity (i.e. intrinsic effects). The decomposition analysis allows the calculation of the exact size of both effects.

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 Le Ru (2012). The approach adopted in this study is also similar to those of van Reenen (1997a, b) and Sandven and Smith (1998), but uses, as a measure of output in a given economy, the share of industry (proxied by net sales - as in Cincera and Veugelers, 2013 -), rather than value added.[39] The approach is the same as that used by Moncada-Paternò-Castello *et al*. (2010)[40]:

$$RDI_{\mathrm{X}} - RDI_{\mathrm{Z}} = \sum_i RDI_{Z,i}(S_{X,i} - S_{Z,i}) + \sum_i S_{X,i}(RDI_{X,i} - RDI_{Z,i}) \quad \textbf{(1)}$$

where:

- X is the first sample (in our case the USA, Japan, the BRIC countries, the Asian Tigers countries or the RoW);

- 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.

[39] This measure of R&D intensity is not intended to be a substitute for R&D to GDP ratio. In fact, the corporate R&D investment to net sales ratio can be a useful complement, improving the overall picture of the private sector's R&D intensity.

[40] 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 (2017a) and, in particular, Appendix A1, p. 33, which includes a table summarising a survey of R&D intensity decomposition formulas.

4.2 Applying the decomposition to data of three EU R&D Scoreboard editions

We applied the R&D intensity decomposition calculations to data from three EU R&D Scoreboard editions, collected in 2006, 2010 and 2014 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 3.2. It is worth mentioning that each of these three Scoreboards contains a slightly different set of companies as countries enter and exit the ranking of top R&D investors. It provides accurate information in particular when studying the evolution of structural effects on corporate R&D intensities.

The results of the decomposition using the EU sample for comparison are shown in Table 3 below and can be summarised as follows.

Table 3.Decomposition of R&D intensities in selected countries/regions using the EU sample for comparison (2005, 2009 and 2013)

		No. of firms	overall	structural	intrinsic
US	2005	539	1.434%	2.36%	-0.93%
	2009	447	1.944%	2.74%	-0.80%
	2013	409	2.197%	3.34%	-1.14%
Japan	2005	227	0.799%	2.23%	-1.43%
	2009	238	1.048%	1.81%	-0.77%
	2013	205	0.745%	1.52%	-0.77%
Asian Tiger	2005	66	0.376%	2.68%	-2.31%
	2009	76	-0.245%	2.82%	-3.06%
	2013	77	-0.434%	2.40%	-2.84%
BRIC	2005	12	-2.220%	-2.30%	0.07%
	2009	44	-1.605%	-1.31%	-0.29%
	2013	81	-1.714%	-1.07%	-0.65%
Row	2005	84	1.120%	1.54%	-0.42%
	2009	93	1.723%	1.91%	-0.19%
	2013	116	1.450%	1.60%	-0.15%
Note: number of EU companies 2005=319; 2009=349; 2013=354					

First, 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 USA has widened over the period under study, whereas the gap between the EU and Japan has remained stable. The EU R&D intensity gap has also widened vis-à-vis the RoW, mainly due to the presence of Switzerland in this group. In contrast, the R&D investment gap between the EU and the BRIC and Asian Tiger countries is positive, and has remained fairly stable over the three years under examination.

Secondly, the decomposition figures confirm that the EU presents an unfavourable structural effect compared with all other countries except the BRIC countries. In particular, we observe that the structural gap of the EU in comparison with the USA is, in practice, entirely and increasingly due to the structural effect.

The third, and perhaps most interesting, 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 that intrinsic R&D intensity in fact increases over the period, especially compared with firms from the USA, Japan and the BRIC countries. However, in the EU, the negative structural effect counteracts the positive effect of corporate R&D

investment efforts (intrinsic effect) to a greater extent in any of the regions/countries under examination.

Finally, the analysis of the evolution of the EU R&D intensity gap indicates that it continued to increase also in 2009 (central year of the economic and financial crisis) vs US, Japan and the RoW group while the R&D investment gap vs US and Japan was reduced during and after the crisis. The different evolution of the components of the R&D intensity is of interest in the R&D intensity path: as said in the previous section, the EU the growth in R&D investment has been stable but grew less proportionally than the 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).

To check the robustness of the results obtained by the analysis of the three different editions of the EU R&D Scoreboard (2006, 2010 and 2014), a second longitudinal dataset – with monetary data inflation adjusted – was built and used. Overall, the decomposition, when applied to the two datasets, yields very similar outputs, especially with regard to the triad. The Appendix reports the results obtained (Table A-8) and provides further information about the methodological approach. An exercise was also implemented to decompose the EU vs US R&D intensity gap for the year 2009 by using value added (VA) as denominator, as well as BERD/VA intensity and confronted these results with results obtained in this section. The methodology used, the results obtained and the discussion of them are offered in Annex A.4.

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

This section aims at analysing the gap of the EU compared to its major competing economy, the USA. It inspects the features of sectors, countries and firms within the EU and US that are "responsible" for the aggregated EU R&D intensity performance. In doing so, this novel analysis contributes to the state of the art of the literature.

5.1. Industrial sectors key in EU vs US aggregate structural R&D intensity difference

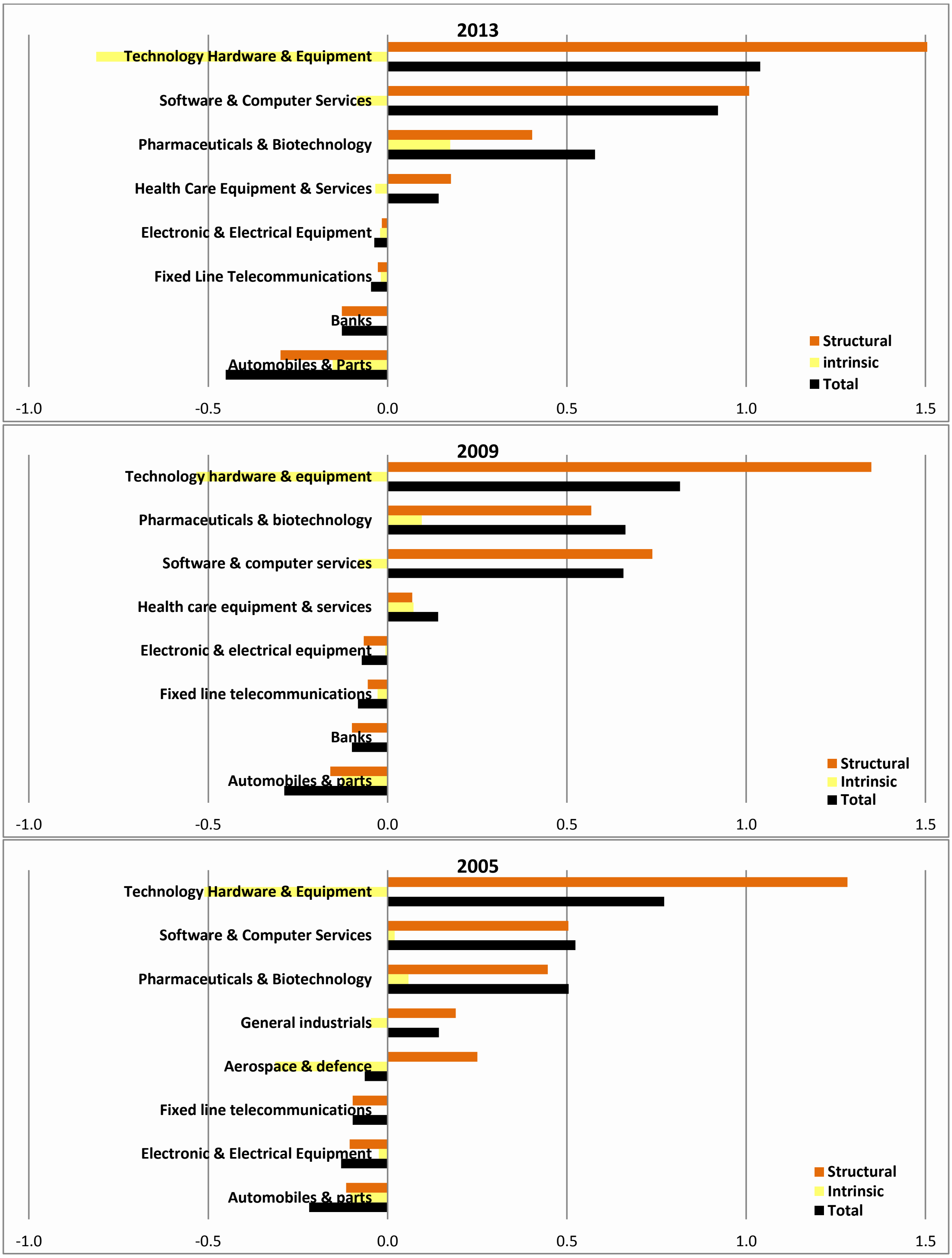
The four sectors which in 2013 and 2009 are most responsible for the structural (and the overall) EU gap in R&D intensity are, by order of relevance, Technology hardware and equipment, Software & computer services, Pharma & biotech and Health care equipment & services. The first three of them have increased the structural EU R&D intensity gap between 2005 and 2013. In 2005, General industrials sectors has been the forth sector, while Health care equipment & services in 2009 and 2013. The negative structural effects of such sectors have been alleviated by the EU firms' intrinsic effects in the same sectors and much more importantly from the EU Automobile & parts sector in the years considered (see Figure 4).

To look even more closely at the this phenomenon, Table 4 shows the sectors within the high and medium-high intensity sector groups 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 USA; a value of 2 means that R&D intensity in the EU is twice that in the USA, while a value of 0.5 means the opposite, i.e. R&D intensity in the USA is twice that in the EU.

Table 4 suggests a positive trend in R&D intensity over the period 2005-2013 among EU firms in some sectors, especially the health care, automobiles and parts, electronics and general industrials sectors, but a negative trend in some other sectors, particularly chemicals and industrial machinery.

Figure 4. EU vs US R&D intensity gap (decomposed) in selected sectors (2005, 2009 and 2013)



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

The data in Table 4 also show that overall R&D intensity was greater in the EU than in the USA (i.e. a ratio greater than 1) in 10 out of 14 sectors in 2013, for example in the software and electronic equipment sector, and in some other sectors, for example the general industrials sector, the EU outperformed in all three years although US companies have a much larger share of the market in terms of net sales. In contrast, the biotechnology sector performed much better in the USA than the EU on all parameters and all years under examination, while the opposite is true of the automobiles and parts sector.

Although the overall R&D intensity is greater in the EU than in the USA in most of the sectors represented in Table 4, the last row shows that the overall balance is in favour of the USA. Again, this is mostly because there are fewer larger companies operating in high-R&D-intensity sectors in the EU than in the USA.

An important information in Table 4 is the difference of the number of firms in each sector between the two economies. In *only* four of the fourteen medium– and high-tech sectors reported in the table, the EU firms are more numerous than the ones in the USA. This in great part explains the origin of the structural component of the of the EU R&D intensity gap: fewer EU firms very much imply a smaller overall R&D investment and size (net sale) of the EU.

Table 4. EU to US ratio of average R&D intensity and number of firms by sectors (ICB-4) within high and medium-high R&D-intensity-sector groups in 2005, 2009 and 2013

	R&D intensity			R&D investment			Size (net sales)			number of firms		
Sectors (ICB-4 classification level)	2005	2009	2013	2005	2009	2013	2005	2009	2013	2005	2009	2013
Pharmaceuticals	1.036	0.995	0.960	0.810	0.732	0.715	0.781	0.735	0.745	0.794	1.071	1.292
Software	0.852	0.983	1.047	0.906	0.679	0.736	1.063	0.691	0.703	0.178	0.349	0.267
Health care equipment & services	0.610	0.609	1.179	0.682	0.816	0.711	1.117	1.339	0.603	0.343	0.433	0.519
Biotechnology	0.634	0.736	0.573	0.361	0.431	0.273	0.570	0.585	0.477	0.262	0.238	0.355
Telecommunications equipment	1.090	0.880	1.020	2.833	3.384	2.025	2.600	3.846	1.985	0.286	0.300	0.375
Semiconductors	1.120	1.135	0.964	1.574	1.926	0.928	1.405	1.696	0.962	0.120	0.113	0.188
Aerospace & defence	2.813	1.968	1.778	1.883	1.462	1.296	0.669	0.743	0.729	0.765	0.833	1.154
Automobiles & parts	1.207	1.366	1.458	1.064	2.019	2.089	0.882	1.478	1.433	1.421	1.353	1.588
Chemicals	1.420	1.198	0.569	1.971	2.048	1.119	1.388	1.709	1.964	0.667	1.050	0.722
Commercial vehicles & trucks	1.606	1.434	1.593	1.099	1.253	1.830	0.684	0.873	1.149	0.667	0.667	0.455
Electronic equipment	0.913	0.808	1.841	0.730	0.737	0.558	0.800	0.912	0.303	0.563	0.769	0.700
General industrials	1.281	1.207	1.828	0.230	0.244	0.415	0.179	0.202	0.227	0.643	1.333	1.286
Household goods & home constr.	0.720	1.017	1.068	0.501	0.641	0.866	0.695	0.630	0.811	0.636	0.875	0.833
Industrial machinery	2.100	1.074	1.381	1.365	1.453	1.078	0.650	1.353	0.780	4.800	2.273	4.714
other sectors	0.613	0.534	0.435	0.934	0.829	0.705	1.524	1.552	1.621	0.984	1.364	1.324
Total	0.674	0.595	0.576	1.198	1.142	0.978	1.777	1.920	1.697	0.592	0.781	0.866

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

5.2. EU countries relevant for the aggregate EU structural R&D intensity result

The firm's R&D intensities by countries are analysed in this subsection. There is an important caveat to remind here: data of the EU R&D Scoreboard are not representative for many of the countries in Table 5 (e.g. the R&D investment displayed compared to R&D expenditures figures provided by BERD). Furthermore, key for the analytical outcome are the number (and size) of firms in high-tech sectors of a given country, and the sector mix of the that country.

Table 5 brings interesting information on the overall performance of the EU countries. It shows that Germany, France and UK hold the bulk of the R&D investment, net sales and number of top R&D firms across the tree years, while the other EU countries are lagging behind and are far from the three leading R&D countries. Germany more positively contributes to the overall R&D intensity of the EU. Furthermore, although France and UK are major contributions in the EU for the mentioned parameters, their R&D intensity is below the EU average, especially the UK.

Table 5. EU countries: R&D intensity, shares of R&D, net sales and number of firms; 2005-2013

2005				
Country	R&D intensity	% of R&D	% of Net Sales	% of number of firms
Croatia	10.42	0.10	0.03	0.31
Hungary	7.35	0.05	0.02	0.31
Slovenia	7.24	0.04	0.02	0.31
Ireland	6.74	0.30	0.13	0.63
Netherlands	6.37	7.63	3.55	4.70
Finland	5.05	4.44	2.61	4.70
Greece	4.69	0.03	0.02	0.31
Sweden	4.64	5.91	3.77	7.52
Denmark	4.41	1.84	1.24	5.96
Germany	4.11	35.29	25.44	22.57
Belgium	3.24	1.45	1.33	2.82
EU Total	2.96	100.00	100.00	100.00
France	2.63	19.41	21.84	16.93
Italy	2.20	4.09	5.50	5.33
United Kingdom	1.76	18.01	30.28	22.57
Austria	1.34	0.15	0.34	1.25
Spain	1.11	1.00	2.67	2.51
Luxembourg	0.65	0.27	1.23	1.25
2009				
Country	R&D intensity	% of R&D	% of Net Sales	% of number of firms
Malta	10.56	0.04	0.01	0.29
Slovenia	9.26	0.07	0.02	0.29
Hungary	8.93	0.10	0.03	0.57
Finland	6.29	4.74	2.15	3.44
Denmark	6.08	2.71	1.27	6.02
Netherlands	4.80	7.49	4.45	5.44
Sweden	4.11	4.79	3.32	6.02
Germany	3.70	34.96	26.94	26.07
Portugal	3.40	0.27	0.23	0.86
EU Total	2.85	100.00	100.00	100.00
France	2.76	19.58	20.24	15.76
Ireland	2.66	1.08	1.16	2.29
Belgium	2.30	1.66	2.05	3.15
Italy	1.93	4.84	7.16	4.87
Austria	1.89	0.37	0.56	2.01
United Kingdom	1.74	14.52	23.74	17.77
Spain	1.34	2.30	4.89	4.01
Luxembourg	0.75	0.47	1.78	1.15
2013				
Country	R&D intensity	% of R&D	% of Net Sales	% of number of firms
Hungary	11.94	0.09	0.02	0.28
Slovenia	8.10	0.06	0.02	0.28
Denmark	6.43	2.23	1.04	4.80
Finland	6.33	2.85	1.35	3.11
Portugal	5.89	0.12	0.06	0.56
Sweden	5.27	5.48	3.10	6.21
Ireland	4.13	2.34	1.69	3.67
Germany	4.13	37.67	27.27	25.71
The Netherlands	4.02	7.93	5.88	5.93
EU Total	2.99	100.00	100.00	100.00
Austria	2.74	0.37	0.40	1.98
France	2.63	17.76	20.16	16.38
Belgium	2.30	1.16	1.51	2.54
Italy	2.04	5.33	7.80	5.37
Spain	1.86	2.58	4.14	3.67
UK	1.70	13.85	24.28	18.93
Luxembourg	0.42	0.18	1.27	0.56

Note: share data in the table refers to total of the EU sample for the given year.
Source: own calculations based on the EU R&D Scoreboard 2006, 2010 and 2014.

This could be seen as main reason driving to a quick conclusion of a key negative role of France and UK in the EU R&D intensity gap. Actually, this is not necessarily the case.

These two countries are among the leading world economies and their R&D intensities reflect their (presently) healthy economic structure. It should be instead pointed out that the EU R&D intensity gap is very much due to the poorer performance of the other EU countries, as for example Italy.

The example of UK is revealing. Table 6 shows that the United Kingdom in 2013 has an assorted sector mix, and also that by number of firms, R&D investment and net sales quite concentrated in five sectors: Aerospace & defence (high-tech), Pharma and biotech (high-tech), Automobile and parts (medium-tech), Banks (low-tech) and Oil Gas (low-tech). The latter two sectors, which hold the highest levels of R&D investment and the disproportionally largest net sales, are the main responsible for lowering the overall UK's R&D intensity result.

Table 6. The R&D sector composition of UK in 2013

Sector (ICB 3 digit)	Sector group by R&D intensity	No. of firms	R&D	Net Sales
Aerospace & Defence	high	5	1296.6	43643.8
Automobiles & Parts	medium-high	6	1457.0	23966.9
Banks	low	5	2755.1	129462.5
Chemicals	medium-high	1	167.5	13320.6
Electricity	low	1	178.4	36521.9
Electronic & Electrical Equipment	medium-high	5	581.0	7056.1
Financial Services	medium-high	2	190.8	2953.4
Fixed Line Telecommunications	medium-low	1	823.9	21836.7
Food & Drug Retailers	low	1	195.8	21111.9
General Industrials	medium-high	3	215.1	331.2
General Retailers	medium-low	3	508.1	101355.6
Health Care Equipment & Services	high	1	167.5	3155.0
Household Goods & Home Construction	medium-high	1	237.6	11992.5
Industrial Engineering	medium-high	1	65.3	2081.3
Life Insurance	low	1	100.3	4040.9
Media	medium-low	1	151.7	8639.4
Mining	low	2	242.2	58380.8
Mobile Telecommunications	low	1	255.5	45789.4
Nonlife Insurance	low	1	133.7	10345.8
Oil & Gas Producers	low	3	1523.8	616198.3
Pharmaceuticals & Biotechnology	high	8	8315.3	55559.9
Software & Computer Services	high	5	637.7	4987.0
Support Services	medium-high	2	110.0	8630.0
Technology Hardware & Equipment	high	5	621.7	3645.6
Tobacco	medium-low	1	367.8	18222.2
Travel & Leisure	medium-high	1	61.9	470.0
Grand Total		**67**	**21361.4**	**1253698.6**

Source: own calculations based on the EU R&D Scoreboard 2014.

When looking inside the four sector groups that contribute most to the R&D intensity gap of the EU relative to the USA in 2013, and examining the EU countries behaviour inside, important differences arise (Table 7). Although Germany is leading in the world for R&D investment in Auto & parts - a medium-high R&D intensity sector with an overall positive impact on structural component of the EU R&D intensity gap - , is not the country with the highest R&D intensity in these four sector, except in Technology Hardware and equipment. Germany has always superior shares of both R&D and net sales compared to other EU countries. Furthermore, it can be underlined the good performance of Ireland in Health care equipment and services, of UK in Pharma and biotech, France in Software and computer services, and Finland in Technology hardware and equipment sectors.

Table 7. Main EU countries within four selected sectors in 2013: R&D intensity, share of R&D and share of net sales

ICB 3 digit name	Country	R&D intensity	% R&D	% Net sales	*No. Firms*
Health Care Equipment & Services	Italy	9.24	2.8	0.02	1
	Sweden	6.79	14.5	0.11	3
	UK	5.31	6.8	0.07	1
	Ireland	4.96	14.9	0.16	1
	Denmark	4.84	5.5	0.06	2
	Germany	3.67	49.6	0.72	5
	France	2.92	6.0	0.11	1
	EU	**4.3**	**1.6**	**1.2**	**14**
	US	**3.6**	**3.7**	**5.3**	**27**
Pharmaceuticals & Biotechnonolgy	Sweden	40.76	0.5	0.01	2
	Portugal	26.60	0.4	0.00	1
	Belgium	25.61	3.0	0.07	1
	France	15.40	22.2	0.84	4
	UK	14.97	30.8	1.20	8
	Denmark	13.62	7.7	0.33	5
	Italy	13.31	2.9	0.04	2
	Hungary	11.94	1.1	0.03	1
	Germany	11.45	29.2	1.49	6
	The Netherlands	11.22	1.0	0.02	1
	EU	**13.5**	**17.5**	**4.3**	**40**
	US	**12.4**	**19.8**	**8.3**	**55**

ICB 3 digit name	Country	R&D intensity	% R&D	% Net sales	*No. Firms*
Software & Computer Services	Denmark	21.42	1.5	0.005	1
	France	20.56	21.4	0.12	5
	The Netherlands	15.37	3.7	0.03	2
	UK	12.79	11.9	0.11	5
	Germany	12.41	47.5	0.44	4
	Spain	11.65	13.1	0.13	2
	EU	**13.4**	**3.5**	**0.9**	**20**
	US	**12.4**	**19.8**	**8.3**	**77**
Technology Hardware & Equippments	The Netherlands	18.21	18.7	0.33	4
	UK	17.05	5.1	0.08	5
	Austria	16.96	4.2	0.01	1
	France	15.77	17.0	0.34	3
	Germany	15.56	6.1	0.10	4
	Finland	14.74	23.6	0.51	1
	Sweden	13.63	24.4	0.57	2
	EU	**14.5**	**9.5**	**2.2**	
	US	**9.0**	**25.5**	**14.7**	

Note: Few countries have been dropped form the table because presented a marginal contribution to R&D, net sales and number of firms. These are, in pharma and Biotech.: Finland, Ireland, Slovenia and Spain; in Software & Computer services: Ireland; in Technology Hardware and Equipment: Denmark and Ireland.

Notes: Data in normal font refer to the share of the given country related to the sector. Data in **bold** refer to the mentioned sector in respect to the full sample (all sectors) of the EU or US. Not all EU countries are displayed.
Source: Own calculations based on the EU R&D Scoreboard 2006, 2010 and 2014.

5.3. EU and US firms key for the intrinsic R&D effects in the aggregated R&D intensity

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

The sample of the EU R&D Scoreboard represents the top R&D investors worldwide. As consequence, for this sample the answer to the question on the level of R&D intensity a firm holds and the effect it has in the aggregated results of a given sector depends not only by its level of R&D investment (it is a top R&D investor 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 quite 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. In fact, the presence in few high R&D intensity sectors of a much high number of firms in the USA sample compared to the EU one explains in large part the structural cause of the 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 imply a smaller overall R&D investment and size (net sale) of the EU compared to the USA.

To deepen the analysis at firm level even more within these four sectors, we elaborate on the covariance a firm's R&D intensity and net sales and on an index showing the impact of firm's R&D intensity and share of net sales on aggregate sector's R&D intensity.

5.3.1 Covariance of firm's R&D intensity and net sales

We have seen that the R&D intensity gap of the EU vs the USA is dominated by the structural effects and in particular in four high R&D intensity sectors. The aim is to calculate the joint variability (covariance) of R&D intensity and net sales of a firm operating in a given sector to observe statistically if these two variables tend to show similar or opposite behaviours (positive and negative covariance, respectively).

We follow Olley and Pakes (1996) and Andrews *et al.* (2015), and modify their cross sectional *productivity* decomposition equation by considering a moment of the firm's R&D intensity distribution (the unweight mean) and a joint moment with the size distribution reflecting the extent to which the firm also has a larger or smaller relative size, i.e. the share of firm' net sales in the sector sample as weight. Hence, the equation to compute the *covariance of R&D intensity and net sales of a firm* i *or* $Cov\ (\Theta_{ij},\ RDI_{ij})$ defined as the average of firm-level R&D intensity weighted by net sales, can be written as follows:

$$Cov\ (\Theta_{ij}, RDI_{ij}) = \sum_{i\in j}(\Theta_{ij} - \overline{\Theta}_j) * (\mathrm{RDI}_{ij} - \overline{\mathrm{RDI}}_j) \qquad \textbf{(2)}$$

where $\overline{\mathrm{RDI}}_j = 1/N_j * (\Sigma_{i\in j}\ \mathrm{RDI}_i)$ is the un-weighted sector R&D intensity mean, θ_i is a measure of the relative size of each firm (e.g. the share of firm's net sales) and $\bar{\theta}_j = 1/N_j$ is the average share of firms' net sales at the sector level, and $\Sigma_{i\in j}\ (\theta_i - \bar{\theta}_j)(\mathrm{RDI}_i - \overline{\mathrm{RDI}}_j)$ is the allocative firms' covariance of R&D intensity and net sales $[Cov\ (\Theta_{ij}, RDI_{ij})]$.

The resulting firm's covariance result has a substantially different meaning compared to the result of the cross sectional *productivity* decomposition in Olley and Pakes (1996) and Andrews *et al.* (2015). In fact, here the RDI_C_i is not the measure of the covariance between so straight input-output values (as productivity and sales are). For example, the *negative* $Cov\left(\Theta_{ij}, RDI_{ij}\right)$ value could simply mean that the firm was able to invested in R&D at lowest level and at the same time succeed in the market by reaching the highest shares in net sales compared to the mean of other firms of the sector in the sample; it could also mean that the firm holds a lower net sale share and a higher R&D intensity compared to the respective average of the firms in the sector. In the case of a *positive* $Cov\left(\Theta_{ij}, RDI_{ij}\right)$ value, the greater value of R&D variable mainly corresponds to the greater value of the net sales, and the same holds for the lesser values of both variable; these latter cases do not necessarily indicate a positive business performance of the firm.

5.3.2. INDEX of the impact of firm's R&D intensity and share of net sales on aggregate sector's R&D intensity.

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 RDI, there may be two groups of firms that have a different contribution to the final aggregate sectoral RDI. Indeed, as net sales, are the denominator of the RDI, therefore, the more R&D intensive firms with larger shares of net sales are responsible for the larger positive impact on the aggregate sectoral R&D intensity. Another group, the firms with lower R&D intensities and larger shares of net sales, are responsible for the larger negative impact on the 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 firm's *impact Index* = Θ_{ij} RDI_{ij}, can be written as:

$$Impact\ INDEX = \Theta_{ij} * (\mathrm{RDI}_{ij} - \mathrm{RDI_j}) \quad \textbf{(3)}$$

where $\mathrm{RDI}_j = \Sigma_{i \in j} \frac{\mathrm{RD}_i}{\mathrm{NS}_i}$ is the aggregate sectoral R&D intensity; Θ_i is the measure of the firm's relative size as share of the firm net sales to the 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[41].

5.3.3 Results

Table 8 (8a for the year 2005; 8b for the year 2013) shows the firms in the four mentioned sectors both for the EU and US which hold the highest and the lowest levels of R&D intensity compared to the average in the EU or US *together* with their highest R&D investment shares and shares of net sales within each of the sectors considered. It includes the values of covariance and the impact Index as defined earlier. Furthermore, we assess such firms for their behaviour in 2005-2013 period 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[42]. A possible drawback to take into consideration is the effect of mergers and acquisitions on firms' trend or country/region performance that could have a considerable impact, as is the case Meditronic, a firm formerly from the USA, based in the EU (Ireland) since 2016.

[41] $\sum_i \theta * (RD_i - RD_j) = \sum_i \left(\frac{RD_{ij}}{Y_{ij}} - \frac{\sum_i RD_{ij}}{\sum_i Y_{ij}}\right) * \frac{Y_{ij}}{\sum_i Y_{ij}}$ 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 $\frac{RD_j - RD_j}{Y_j} = \emptyset$

[42] We retain from calling these firms "laggards" and "leading" because, as already said, they are top R&D investors in their respective sector by the sample construction.

Table 8a. Key EU and US firms for the intrinsic R&D effects in the aggregated R&D intensity results in selected sectors (at ICB-3 digits level of classification) in 2005

Sector	YEAR 2005	R&D intenity	% R&D	% Net Sales	Cov.	Impact Intex	# firms
Health Care Equip. & Services	**EU**	**4.5**	**1.1**	**0.9**			**12**
	Carl Zeiss	10.4	19.5	8.4	0.0	46.9	
	Essilor International	4.7	9.6	9.2	0.0	-0.7	
	B Braun Melsungen	3.2	8.3	11.4	-0.1	-17.7	
	Gambro	2.9	6.7	10.2	-0.1	-18.9	
	Fresenius	1.9	12.6	29.8	-0.8	-85.6	
	USA	**7.3**	**3.4**	**2.0**			**35**
	Boston Scientific	10.8	11.4	7.7	0.1	27.2	
	Medtronic	9.9	18.7	13.9	0.2	35.5	
	Baxter International	5.4	9.0	12.1	-0.3	-22.8	
	Becton Dickinson	5.0	4.6	6.6	-0.1	-15.1	
Pharmaceuticals & Biotechnology	**EU**	**14.8**	**17.6**	**4.3**	**0.0**	**-2.0**	**38**
	Schering	18.6	5.3	4.2	-0.6	16.2	
	Novo Nordisk	15.1	3.7	3.6	-0.4	1.0	
	Sanofi-Aventis	14.8	21.7	21.6	-7.6	0.8	
	GlaxoSmithKline	14.5	24.5	25.0	-9.0	-7.3	
	Boehringer Ingelheim	14.3	7.3	7.5	-2.0	-3.8	
	AstraZeneca	14.1	15.4	16.1	-5.5	-10.6	
	Merck DE	12.1	3.8	4.6	-0.9	-12.2	
	USA	**15.7**	**23.3**	**6.6**			**76**
	Eli Lilly	20.7	7.3	5.6	-10.3	27.8	
	Amgen	18.6	5.6	4.7	-8.3	14.0	
	Merck US	17.5	9.3	8.4	-17.3	15.3	
	Pfizer	14.5	18.1	19.5	-45.3	-22.7	
	Johnson & Johnson	12.5	15.3	19.2	-44.9	-60.6	
	Abbott Laboratories	8.2	4.4	8.5	-18.3	-63.7	
Software & Computer Services	**EU**	**10.5**	**2.4**	**0.8**			**18**
	Dassault Systemes	27.7	10.1	3.8	65.6	65.6	
	SAP	12.8	42.3	34.7	80.0	80.0	
	Sage	10.5	4.6	4.6	0.1	0.1	
	Indra Sistemas	7.1	3.3	4.9	-16.3	-16.3	
	Amdocs	7.1	4.8	7.0	-23.9	-23.9	
	Wincor Nixdorf	4.5	3.0	7.1	-42.7	-42.7	
	LogicaCMG	1.4	1.4	10.9	-99.0	-99.0	
	USA	**10.8**	**13.6**	**5.5**			**80**
	Microsoft	14.9	27.5	20.1	2.6	80.7	
	Oracle	13.0	7.8	6.5	0.6	14.1	
	Yahoo!	11.2	2.5	2.4	0.1	0.8	
	Google	9.8	2.5	2.8	0.1	-3.0	
	IBM	5.9	22.5	41.3	1.9	-204.2	
Technology Hardware & Equipments	**EU**	**13.7**	**11.9**	**3.1**			**22**
	Infineon Technologies	18.4	9.8	7.4	0.0	34.3	
	STMicroelectronics	17.5	10.4	8.2	0.0	30.9	
	Ericsson	16.9	21.6	17.6	0.0	55.5	
	ASML	13.9	0.8	0.8	0.1	-2.0	
	Alcatel	13.6	14.2	14.3	-0.3	-1.2	
	Nokia	11.6	31.5	37.2	-1.8	-77.8	
	Oce	7.2	1.5	2.9	0.2	-19.0	
	USA	**9.4**	**36.1**	**11.9**			**145**
	Texas Instruments	15.0	4.5	2.8	0.0	15.7	
	Cisco Systems	13.4	7.4	5.2	-0.2	20.5	
	Intel	13.3	11.4	8.1	-0.3	31.0	
	Motorola	10.0	8.2	7.7	-0.5	4.3	
	Xerox	4.9	1.7	3.2	-0.3	-14.5	
	Hewlett-Packard	4.0	7.7	18.1	-2.2	-98.0	
	Apple Computer	3.8	1.2	2.9	-0.3	-16.3	
	Dell	0.8	1.0	11.7	-1.8	-100.6	

Notes: Data in regular font refer to the given firm related to the sector where the firm operate. Data in bold refer to the mentioned sector in respect to the full sample (all sectors) of the EU or the USA.
Legend: firms highlighted in green and in read hold R&D intensity above and below the average respectively in the given sector and region (EU or US).

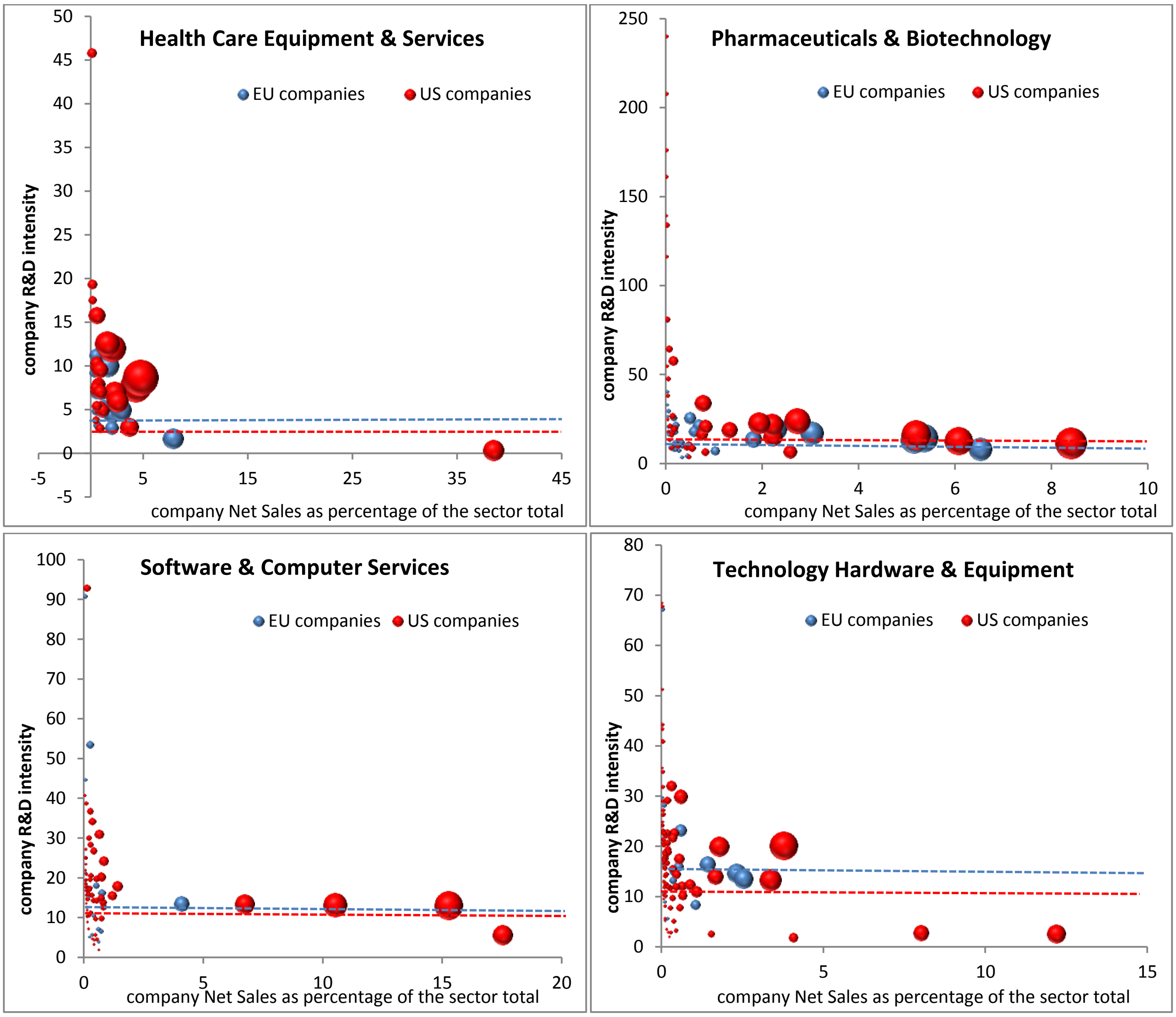
Table 8b. Key EU and US firms for the intrinsic R&D effects in the aggregated R&D intensity results in selected sectors (at ICB-3 digits level of classification) in 2013

Sector	YEAR 2013	R&D intenity	% R&D	% Net Sales	Cov.	Impact Intex	# firms / growth
Health Care Equip. & Services	**EU**	**4.3**	**1.6**	**1.2**			**14**
	CARL ZEISS	10.0	17.0	7.2	0.0	37.4	
	COVIDIEN	5.0	14.9	12.8	-0.1	1.2	
	B BRAUN MELSUNGEN	4.4	9.3	8.9	0.0	-4.0	▲
	ESSILOR INTERNATIONAL	2.9	6.0	8.8	0.0	-17.1	▼
	FRESENIUS	1.7	14.1	35.2	-1.2	-111.2	
	USA	**3.6**	**3.7**	**5.3**			**27**
	MEDTRONIC	8.7	1.8	6.7	0.0	33.8	▼
	BAXTER INTERNATIONAL	7.7	2.1	6.0	0.1	24.3	▲
	BECTON DICKINSON	7.0	2.3	3.2	0.0	10.5	
	MCKESSON	0.4	5.4	54.0	-4.6	-176.4	
Pharmaceuticals & Biotechnology	**EU**	**13.5**	**17.5**	**4.3**			**40**
	BOEHRINGER INGELHEIM	19.5	10.2	7.0	-115.8	42.2	
	ASTRAZENECA	17.2	11.9	9.3	-174.5	34.3	▲
	SANOFI-AVENTIS	14.4	17.6	16.5	-357.9	15.6	▼
	NOVO NORDISK	14.0	5.8	5.6	-79.3	2.8	▼
	MERCK DE	13.6	5.6	5.5	-78.0	0.4	▲
	GLAXOSMITHKLINE	13.1	15.4	15.8	-341.4	-5.8	▼
	BAYER	8.1	12.1	20.1	-451.3	-107.9	
	USA	**16.0**	**21.4**	**6.9**			**55**
	ELI LILLY	23.9	10.3	6.9	-32.9	54.6	▲
	AMGEN	21.9	7.6	5.6	-24.4	32.6	▲
	MERCK US	16.2	13.3	13.1	-74.2	2.4	▲
	PFIZER	12.7	12.2	15.4	-89.4	-50.5	▼
	JOHNSON & JOHNSON	11.5	15.2	21.2	-128.5	-95.8	▼
	ABBOTT LABORATORIES	6.6	2.7	6.5	-31.2	-60.8	▼
Software & Computer Services	**EU**	**13.4**	**3.5**	**0.9**			**20**
	DASSAULT SYSTEMES	18.2	7.0	5.2	0.0	24.8	
	AMADEUS	16.3	9.5	7.8	-0.1	22.5	
	SAP	13.6	42.7	42.2	-2.4	7.3	▲
	SAGE	10.5	3.2	4.1	0.1	-11.9	
	AMDOCS	7.2	3.3	6.1	-0.1	-37.8	▼
	INDRA SISTEMAS	6.7	3.7	7.3	-0.3	-48.9	▼
	WINCOR NIXDORF	4.0	1.8	6.2	-0.2	-58.1	▼
	USA	**12.4**	**19.8**	**8.3**			**77**
	ORACLE	13.5	10.4	9.5	-0.4	10.5	▲
	GOOGLE	13.2	15.9	14.9	-0.7	12.9	▲
	MICROSOFT	13.1	22.9	21.6	-1.1	16.2	▲
	SUNGARD DATA SYSTEMS	9.9	0.8	1.0	0.0	-2.5	
	IBM	5.7	11.3	24.8	-3.0	-166.2	▼
Technology Hardware & Equipments	**EU**	**14.5**	**9.5**	**2.2**			**22**
	STMICROELECTRONICS	23.2	9.3	5.8	0.1	135.3	▲
	ALCATEL-LUCENT	16.4	16.2	14.3	-0.2	235.7	▲
	ASML HOLDING	16.0	5.7	5.2	0.0	83.4	▲
	NOKIA	14.7	23.6	23.3	-0.7	57.2	▼
	ERICSSON	13.6	23.8	25.5	-1.1	-24.7	▼
	NXP SEMICONDUCTORS	13.3	3.2	3.5	0.1	-4.4	
	SEAGATE TECHNOLOGY	8.4	6.1	10.5	-0.6	-64.3	
	USA	**9.0**	**25.5**	**14.7**			**93**
	INTEL	20.1	16.5	7.4	0.1	82.3	▲
	CISCO SYSTEMS	13.4	9.8	6.6	-0.3	28.7	▲
	TEXAS INSTRUMENTS	12.5	2.4	1.7	0.0	5.9	▼
	MOTOROLA	12.1	1.6	1.2	0.0	3.8	▼
	HEWLETT-PACKARD	2.8	4.9	15.8	-2.4	-98.1	▼
	APPLE	2.6	7.0	24.0	-3.8	-153.5	▼
	XEROX	2.6	0.9	3.0	-0.3	-19.3	▼
	DELL	1.9	1.7	8.0	-1.2	-57.0	

Notes: Data in regular font refer to the given firm related to the sector where the firm operate. Data in bold refer to the mentioned sector in respect to the full sample (all sectors) of the EU or the USA.
Legend: firms highlighted in green and in read hold R&D intensity above and below the average respectively in the given sector and region (EU or US). The sign ▼ refers to firms which have had a negative trend (2005-2013) primarily in R&D intensity and then also in other two variables, whereas ▲ refers to firms with positive trend.

Figure 5 reports the R&D investment size of EU and US firms and their distribution by R&D intensity and net sales in the four sectors that are main responsible for the overall EU R&D intensity gap in the year 2013.

Figure 5. R&D investment size of EU and US firms and their distribution by R&D intensity and net sales in selected sectors in 2013



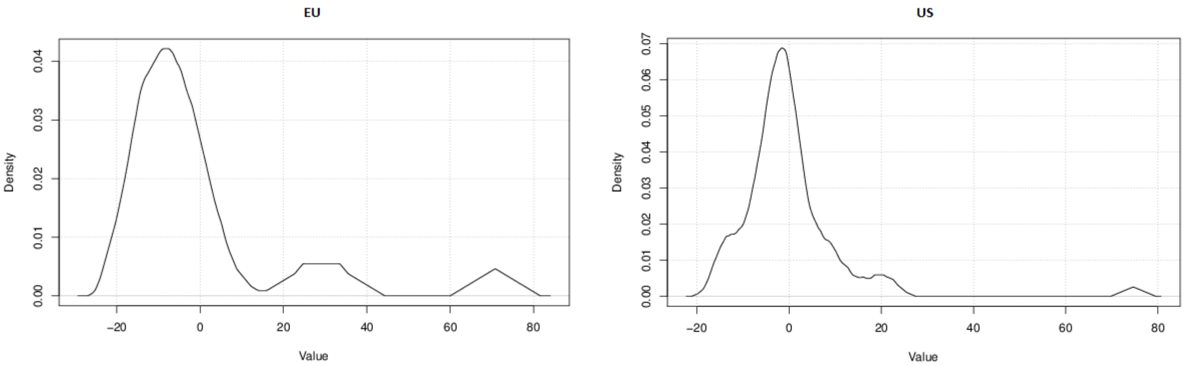
------- average R&D intensity US companies in the sector; ------- average R&D intensity EU companies in the sector

Note: The size of the bubbles is proportional to the share of EU or US firm's R&D investment in the sector (full sample)

Figure 5 shows that there is a larger number of both larger and smaller R&D investors in the US samples than in the EU ones.

To appreciate in details the difference between EU and US as well as the possible firms' heterogeneities in R&D intensity and net sales within the same sectors in both economies, we provide an illustrative example for the Software and Computer Service sector in 2013 by computing a Kernel density distribution of the difference between R&D intensity of the firm and the average of the R&D intensity of the sector (Figure 6), the distribution of both the differences of the firms' R&D intensity and net sales with the respective average values of the sector (Figure 7), and in Figure 8 the Normal distribution of the Impact Index.

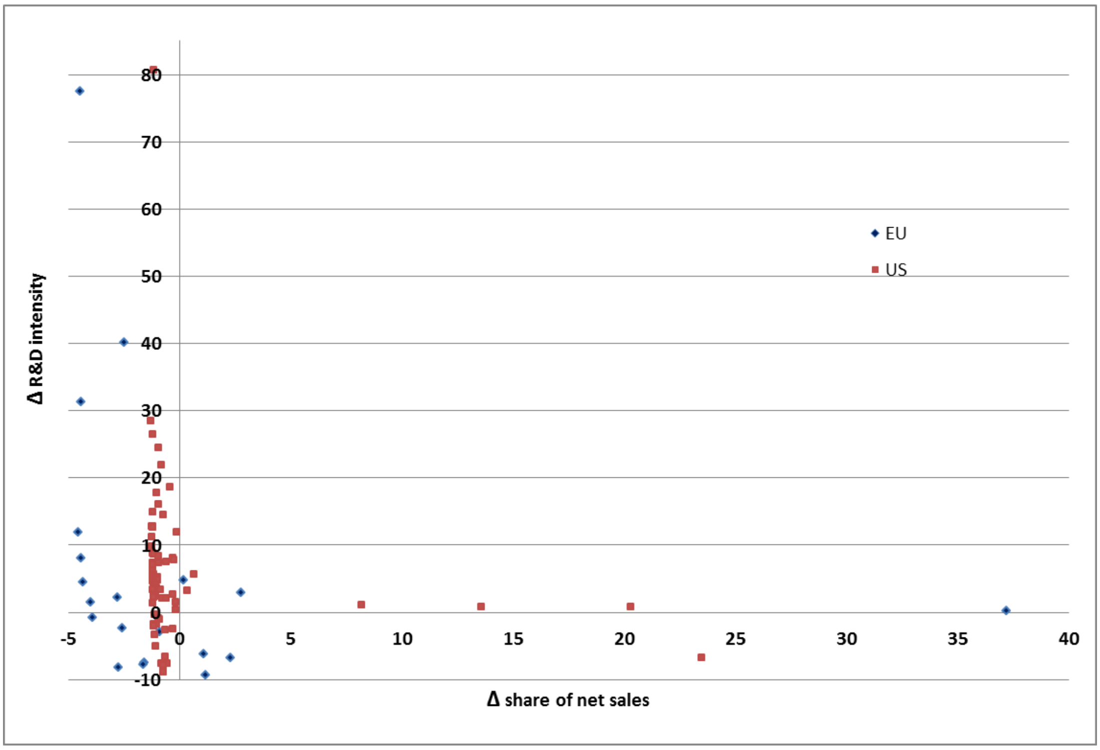
Figure 6.Triangular Kernel density distribution[43] of the difference between R&D intensity of the firms and the average R&D intensity of the Software and Computer Service sector, EU and US (2013)



Interesting from Figure 6 is that the highest density of the shape of this distribution function f for the EU sample is centred in the negative x value, which is not the case for the USA; on the other hand, the quite high density f values for both the EU and US denotes a high firms' heterogeneities in R&D intensity in both EU and USA samples of firms.

Figure 7 indicates that few large (by net sales) firms are very much responsible for differences in R&D intensities in both the in EU and US samples.

Figure 7. Δ[44] of firm' average R&D intensity and share on net sales in the Software and Computer Service sector, EU and US (2013)

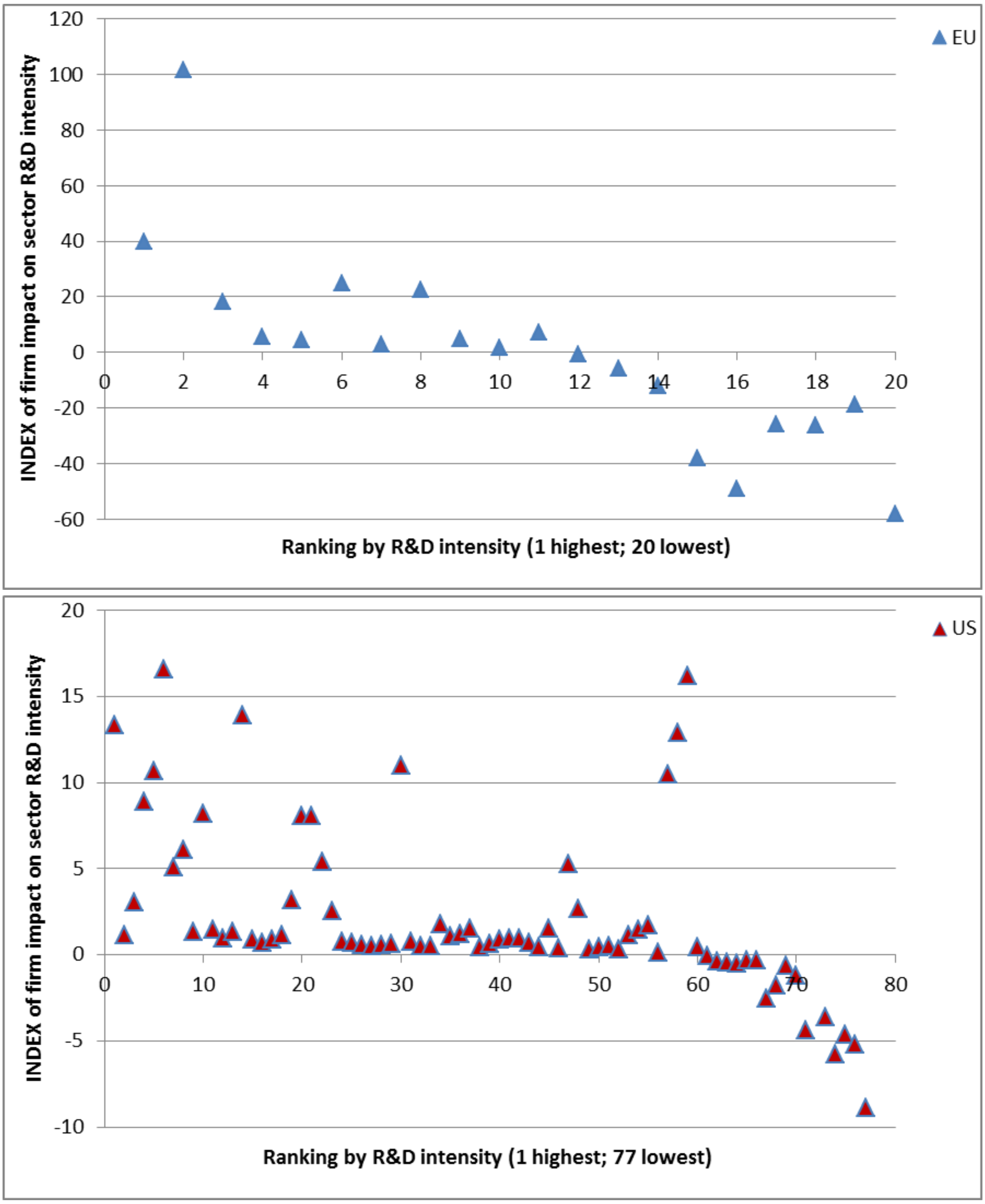


[43] Computed in the Free Statistics Software (version 1.1.23-r7) of the Office for Research Development and Education, see Wessa (2015)

[44] $\Delta\ R\&D\ intensity = \mathrm{RDI}_i - \overline{\mathrm{RDI}}_j$; $\Delta\ share\ of\ Net\ Sales = \theta_i - \overline{\theta}_j$

The Index reported in Figure 8 confirms EU and USA samples show quite similar heterogeneous behaviour of firms, although in the US firms, beside an outlier (IBM, see note of the figure), the Index ranges in a narrower array of values compared to the EU firms.

Figure 8. Distribution of the firm impact INDEX on the R&D intensity by their R&D intensity ranking in Software and Computer Service sector, EU and US (2013)



Note: for graphical representation purposes, within he US sample the figure doesn't report the value of IBM (Index: - 166,2; R&D intensity ranking: 72/77).

5.3.4 Discussion

Three main analytical results that could be point out as follows:

a) The firm's distribution of R&D intensity within sector reveals (Figure 5) that compared to US ones, the EU firms i) are less numerous, ii) there are less large firms (by R&D investment), iii) there are less small firms (by R&D investment), iv) less large R&D investors that hold a high share of net sales, and v) the secor's R&D intensity is superior, except in pharma & biotech sector.

b) As the EU holds a much lower number of companies than the USA in the four key sectors analysed, the EU holds a lower overall share of net sales and share of R&D investment compared with the full sample (all sectors)[45], especially in Technology Hardware and equipment and in Software and computer services.

a) 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. These are very much the same companies in the two years considered.

c) There is not a clear path of single firm or group of these top R&D firms within the four sectors and in both economies examined that dominate a common trend behaviour. Also because of the nature of the sample (are all top R&D investors), we cant's spot that there is a clear problem of lower R&D intensity firms in these four sectors that are not catching up, nor that the firms with higher R&D intensity are underperforming (likewise Andrews *et al.*, 2015 found for firms' productivity). The case of, for example, Fresenus in health care equipment and services sector is revealing: the firm R&D intensity is considerably below EU average in the sector with a negative trend for this value between 2005 and 2013. However, at the same time the firm grew greatly in both shares of R&D investment and net sales in the sector! In general, most of the firms that were in the top and in the bottom of the R&D intensity ranking in 2005 remained unchanged in 2013.

d) The result of the previous point together with the high heterogeneity R&D intensity of firms within the same sector (confirming recent findings by Coad, 2017) shows that there is a coexistence of firms with different R&D investment strategies and efficiencies. That is, the firms with large market share can enjoy their dominant position, with a high R&D efficiency, because of high appropriability and high cumulativeness and high economy of scale in the exploitation of R&D results (Schumpeter 1943; 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 bear in mind that the relative impact of top R&D investing firms on the overall EU R&D intensity gap depends very much on their presence in the *high-R&D intensity sectors* and their *size*. Of course, the larger is the number of firms and their aggregate size in *high-R&D intensity sectors*, the bigger is 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 and country performances to R&D intensities in few EU and US firms, as well as they reveal a general high heterogeneity of R&D intensity within the same sector in both regions.

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[45] This finding is in line to the one of the main results of the main section 6 which follows on the distribution of R&D across firms, sectors and countries.

6. Distribution of R&D across firms, sectors and countries

This section aims to investigate the comparative distribution of R&D investment among the firms in the sample by three main variables[46]: the size of a firm's R&D investment, the sector of activity and the country/world region.

The distribution of R&D intensity by company's R&D size (i.e. the cumulative average R&D intensity) is calculated by summing the R&D investment from the largest to the smallest R&D investors in each country/region and dividing it by the sums of sales. The results are shown in Figure 6.[47]

Figure 6 shows that the cumulative corporate R&D intensity is asymmetrically distributed, with a significant difference in the degree of concentration between the USA, Japan, the EU and the rest of the countries/regions examined. This suggests that differences in overall R&D intensities also reflect business R&D demographics, i.e. the size of R&D investment by companies. That is, the bigest R&D investors are more R&D-intensive than the smaller ones.

In the case of the highest ranking companies (the ~10 largest R&D investors in each country) R&D intensity by US firms outperform all firms from its competing economies. In addition, as we move down the rankings, we find a larger group of smaller (by R&D investment) US companies investing more strongly in R&D (by R&D intensity), and in a more consistent way than EU firms, thus raising the overall R&D performance of US firms.

A comparison of the graphs for 2005, 2009 and 2013 (Figure 9) reveals three general points of interest. The first is that the top 40 R&D investors account for the highest cumulative average R&D intensity. Secondly, the cumulative average R&D intensity of US companies increased in 2013 relative to 2005 and 2009, especially in companies in the top 40 rankings, but also in each of the companies in the ranking from about the 110th place down. In contrast, EU companies in 2013 showed roughly the same behaviour in 2005, resulting in a greater difference in cumulative average R&D intensity between these two years in favour of US companies. Thirdly, in 2013, BRIC companies – with a greater representation than in 2005 – show the lowest cumulated average R&D intensity. Furthermore, moving down the rankings (by R&D investment), companies from the Asian Tiger countries invested more strongly in R&D (by cumulated average R&D intensity) in 2005 than in 2013.

Figure 9 is very telling in two aspects.

First, over the period the curve becomes increasingly skewed towards the origin of the two axes, confirming that R&D intensity is highly concentrated in the top-ranked R&D-investing companies. This also means that the highest ranked R&D investors are likely to operate in sectors of high-high R&D intensity (these sectors have a R&D intensity greater than 5 %).

Secondly, and perhaps even more importantly, the curves from the ranking of 60 on the *x*-axis to the right-hand side of the figure show that there is a much smaller proportion of high R&D intensity companies in the EU sample compared to the US one, resulting in an increase in the gap in cumulative average R&D investment.

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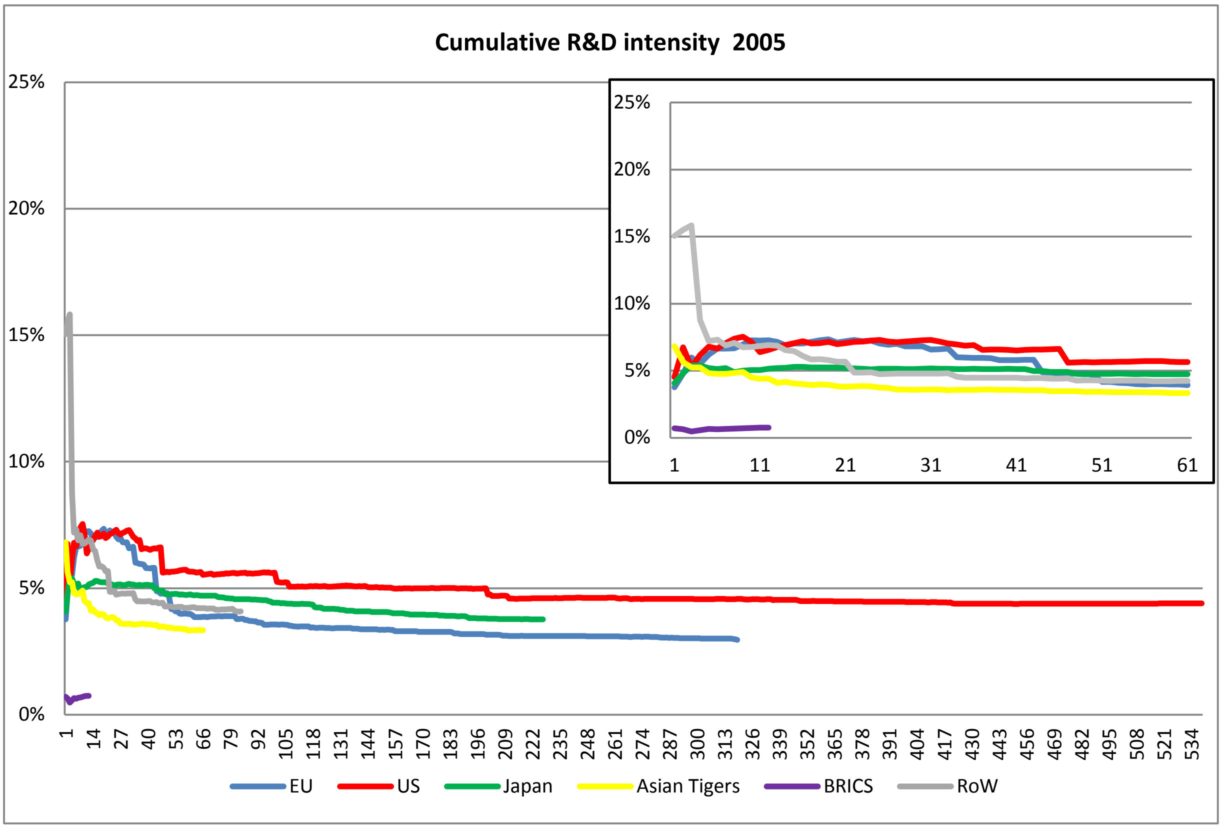
[46] We acknowledge that firm age is another interesting variable affecting R&D concentration. For the related arguments and results, see García-Quevedo *et al.* (2014) and Moncada-Paternò-Castello (2017b).

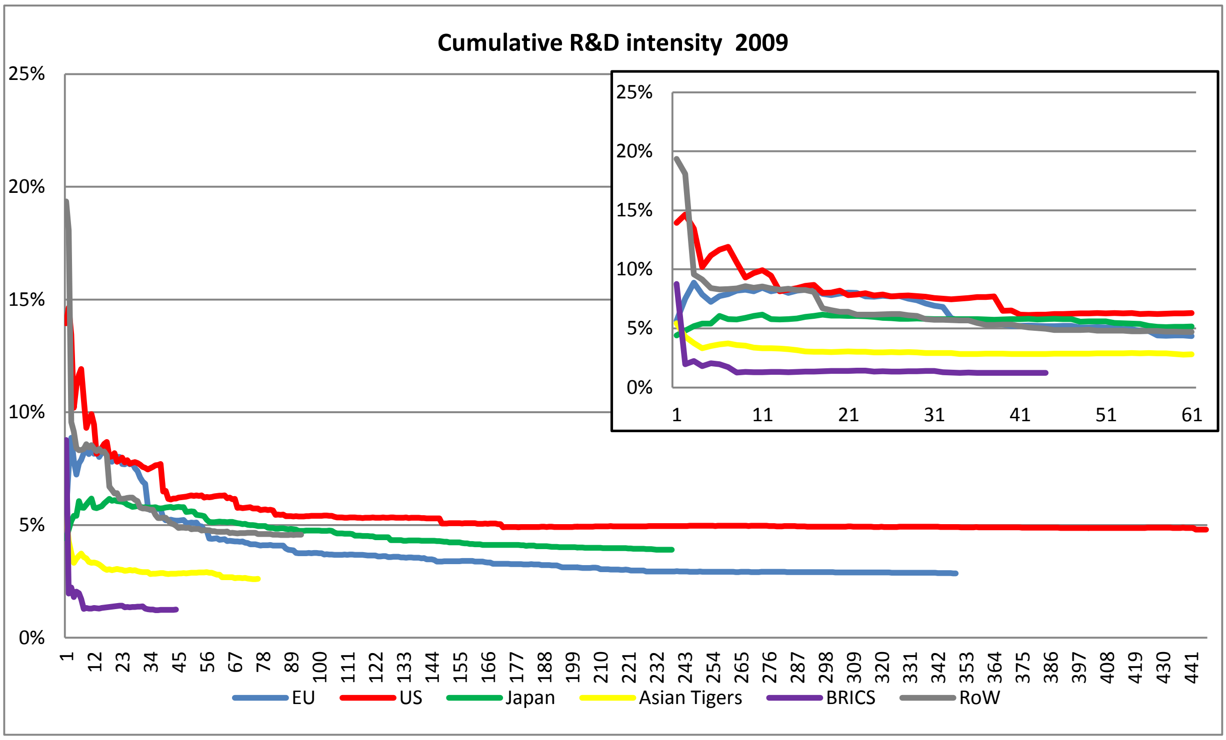
[47] In 2005, as the sample analysed includes only 12 BRIC companies, the graph for BRIC companies stops at 12 on the horizontal axis, while 84 for the RoW, 66 for the Asian Tigers, 227 for Japan, 319 for the EU and 539 for the USA. In 2009, as the sample analysed includes only 44 BRIC companies, the graph for BRIC companies stops at 44 on the horizontal axis, while it goes up to 93 for the set of companies from the RoW, 76 for the Asian Tigers, 238 for Japan, 349 for the EU and 477 for the USA. In 2013, as the sample analysed goes up to 77 for the set of companies from the Asian Tigers, 116 for the RoW, 81 for the BRIC countries, for 205 for Japan, 354 for the EU and 409 for the USA.

Figure 9(a). Cumulative average R&D intensity of the samples of EU R&D Scoreboard companies in 2005 by country/region (%)



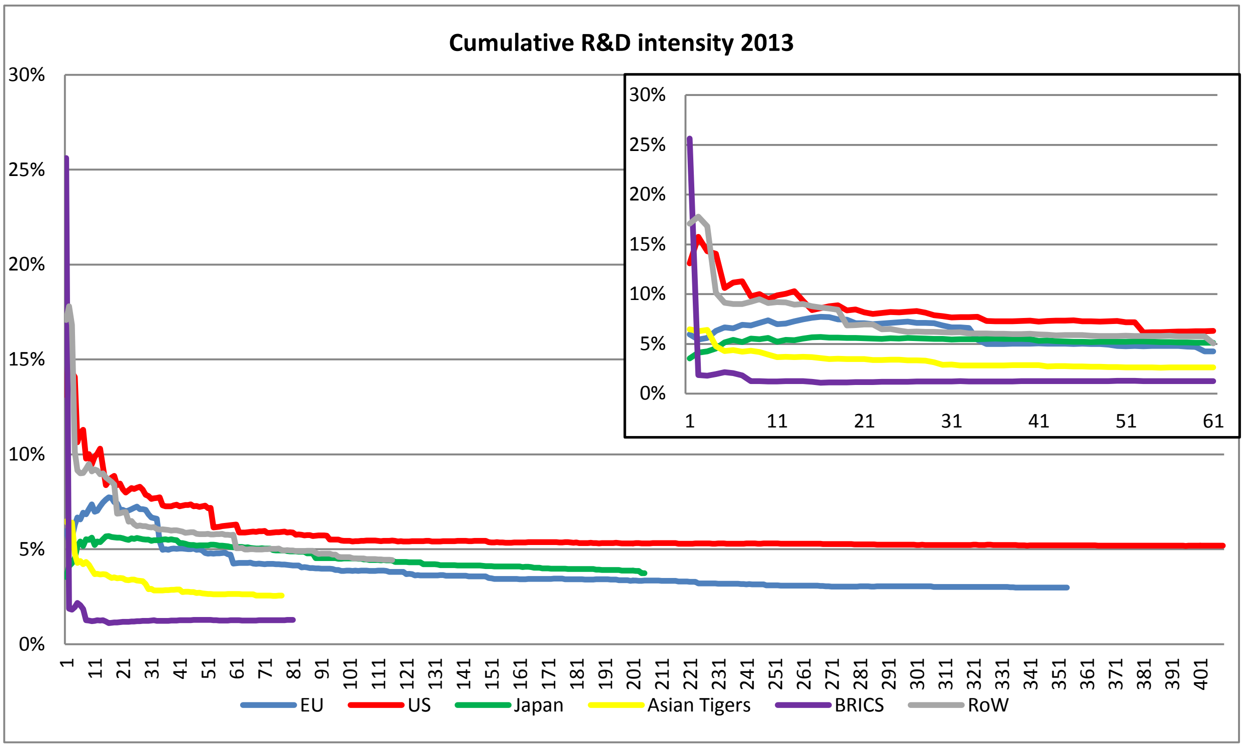
Note: The value on the *y*-axis is the cumulative R&D intensity; the value on the *x*-axis is the firm's rank according to its R&D investment; more details are given in footnote 20. *Source*: Computed from the EU Industrial R&D Investment Scoreboard (European Commission, 2006).

Figure 9(b). Cumulative average R&D intensity of the examined samples of EU R&D Scoreboard companies in 2009 by country/region (%)



Note: The value on the *y*-axis is the cumulative R&D intensity; the value on the *x*-axis is the firm's rank according to its R&D investment; more details are given in footnote 19. *Source*: Computed from the EU Industrial R&D Investment Scoreboard (European Commission, 2010).

Figure 9(c). Cumulative average R&D intensity of the examined samples of EU R&D Scoreboard companies in 2013 by countries/regions (%)



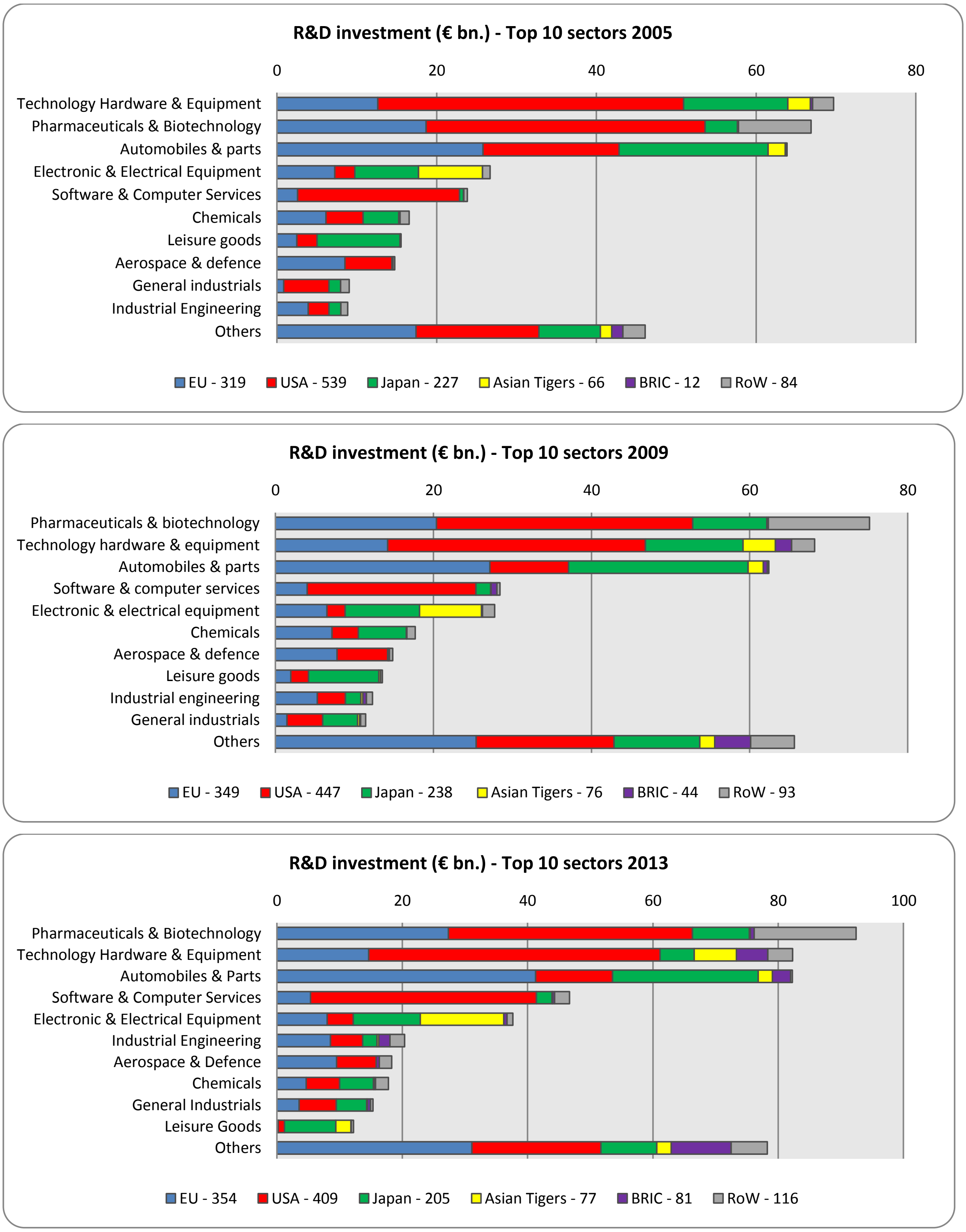
Note: The value on the *y*-axis is the cumulative R&D intensity; the value of the *x*-axis is the firm's rank according to its R&D investment; more details are given in footnote 19. *Source*: Computed from the EU Industrial R&D Investment Scoreboard (European Commission, 2014).

This means that the EU sample includes more companies with lower R&D intensity than, for instance, the US and Japanese samples. In other words, Figure 9 shows that, compared with the EU and Japan, the US sample includes a greater proportion of smaller R&D investors that invest more strongly in R&D (i.e. by R&D intensity): most of US companies holds a cumulative R&D intensity above 5 % in the last two years analysed (i.e. 2009 and 2013), which means that, in contrast to similar EU and Japanese firms, these smaller US R&D investors are mostly operating in high-tech sectors.

Another aspect of note is that only a relatively small number of companies contribute to the total business R&D investment worldwide: of the 2 500 companies included in the EU R&D Scoreboards (editions 2006 to 2014), only a relatively small number account for between 80 and 90 % of global business enterprise expenditure (European Commission, 2006-2014). For example, in 2013 almost half (i.e. 1 247) of the original total sample of 2 500 companies accounted for 94 % of the total R&D investment of the whole sample. Furthermore, despite the rise in R&D investment in emerging economies from 2005 to 2013, only 968 US, EU and Japanese firms together contributed the bulk of R&D investment worldwide in 2013: these 968 firms accounted for €407bn (or 83 %) of the total global figure of €504bn contributed by the 1 242 firms in our sample. However, from 2005 to 2013 there is a decreasing trend of R&D investment concentration held by the Triad by both number of firms (from 1085 in 2005 to 968 in 2013) and R&D investment share (from 90% in 2005 to 83% in 2013).

Finally, a global R&D investment is concentrated in ICT-related sectors, in the pharmaceuticals and biotechnology sectors and in the automobiles and parts sectors. A quick analysis shows that top four sectors in terms of global R&D investment accounted for 62.8 %, 58.9 % and 60.3 % of R&D investment in 2005, 2009 and 2013, respectively (Figure 10). It is interesting to note that, among these four sectors, the EU leads R&D investment in automobiles and parts, which is the only medium-tech sector; the other three are high-tech sectors and investment in these sectors is led by the USA.

Figure 10. The 10 sectors (ICB-4) with the highest global corporate R&D investment concentration by country/region (2005, 2009, 2013)



Source: own calculations based on the EU R&D Scoreboard 2006, 2010 and 2014 (sectors at ICB-3 level of classification).

7. Summary and conclusions

This paper seeks to increase our understanding of how and why R&D intensity differs in different regions of the world. It confirms that differences in the structural composition of economies play a major role in the R&D intensity gap; it suggests that concentration of R&D investment is an important factor, and it provides new findings. This study is innovative in the methodological approach undertaken and in the results obtained. The research is based on a longitudinal dataset of micro-data for the period 2005-2013 and uses both descriptive statistical analysis as well as a decomposition computation method. These analyses aim to contribute to the literature on the determinants of the EU corporate R&D intensity gap by testing the decomposition effects of several parameters, providing an examination of these phenomena over a nine-year period and giving empirical support to researchers and decision-makers by showing the significance of structural and intrinsic effects as well as the comparative distribution of R&D investment and intensities among top R&D-investing firms, sectors and world regions/countries (the EU, the USA, Japan, the BRIC countries and the Asian Tiger countries).

6.1 Main research findings

(i) The extent the sector composition (the ‘structural’ effect) affects the aggregate EU R&D intensity gap

Firstly, our analysis shows that R&D investment and net sales growth rates remained steady for the EU sample during the period 2005-2013. The analysis also indicates that, in 2009, annual growth in corporate R&D investment suffered the effect of the economic and financial crisis in most regions/countries, apart from the EU. The effect of the crisis was most evident in the case of the USA, where recovery to the 2005 annual growth level was still proving difficult in 2013. Despite this, in the years considered, US companies show the highest R&D investment figures, followed by companies in the EU and Japan, as a result of which the USA led R&D investment in the high-tech sector group during these years.

Secondly, the R&D intensity gap between the EU and both the USA and Japan was found to be negative and due to the structural composition of the economy (in line with the findings of Moncada-Paternò-Castello *et al*. (2010) and Cincera and Veugelers (2013). However, the main reason for the widening of the EU intensity gap during the period 2005-2013 is the much larger growth in total net sales (especially in the low and medium-low tech sectors) of the EU compared to the US, which is greater than the growth difference between the respective regions/countries' total R&D investment.
The findings also found a negative gap held by BRIC countries compared to the EU and that in the years studied due especially to ‘structural effects’. The EU has a negative gap compared to the RoW group (driven by the presence of Switzerland) due to ‘structural effects’. Relative to the EU, the Asian Tigers show a negative R&D intensity gap in the first year and a positive R&D intensity gap in the last two years of observation, in all cases mainly due to ‘intrinsic effects’.

(ii) The dynamics of the R&D intensity gap (including of its two main determining factors), and the sectors, countries and firms main responsible for the gap.

The third main finding is that the R&D intensity gap between the EU and its main competitors has in part widened in the last nine years (ratifying results by Duchêne *et al*., 2011; Voigt and Moncada-Paternò-Castello, 2012 and Veugelers, 2013). As an original contribution to the literature, this study indicates that the overall evolution of the R&D investment gap of the EU in comparison an increase in the negative gap with the USA, and a quite stable negative gap compared with Japan. Furthermore, the EU shows a decreasing positive R&D investment gap compared with the BRIC group of countries over the three years considered. The Asian Tigers have shifted from a negative R&D intensity gap in comparison with the EU in 2005 to a positive gap in 2009 and an even more positive one in 2013.

The fourth key finding is that in terms of the 'intrinsic effect' EU firms outperform all their competing economies, and even improve their comparative performance over the period of time examined, especially in comparison with firms from the USA, Japan and the BRIC countries. However, the structural effect outweighs the positive effect of EU corporate R&D investment effort (intrinsic effect) in comparison with all regions/countries considered. In this context, this study shows that within the high and medium-high intensity sector groups, EU firms in individual sectors often perform much better (in 2013, 10 out of the 14 sectors analysed[48]) in terms of R&D intensity than US companies. As these findings are new in the literature, we also checked the robustness of the above results by implementing a decomposition of the R&D investment gap using a longitudinal balanced dataset (2005-2013) built from several editions of the EU R&D Scoreboard. This further analysis largely confirms and validates the main output of our investigation.

The fifth key finding of the paper, as novel contribution to the state of the art of the literature, is the identification of the sectors, countries and firms which are most "responsible" for the EU R&D intensity performances and the differences with the US group of firms. Technology hardware and equipment, Software & computer services, Pharma & biotech and Health care equipment & services account for the bulk of the negative EU structural R&D intensity gap. On the other hand EU automobile & parts sector counter-balance the negative structural effects of such sectors. Furthermore, France and UK, although they are the second and third larger EU countries in R&D investment, they have an industrial structure less concentrated in high-R&D intensity sectors. This has an overall (negative) impact in the aggregate EU R&D intensity gap. On the other hand, German firms contribute most positively to the overall R&D intensity of the EU because of their shares in both R&D and market shares in medium-high and high R&D-intensity sectors. There is a concentration in few EU and US companies by R&D intensity, R&D investment share and share of net sales which determine the aggregate intrinsic R&D effects in the EU vs US R&D intensity gap. The key top R&D firms in both economies and the four mentioned sectors are very much the same across the years considered without showing appreciable different growth paths within sectors. However the key difference is the number of top R&D investors present in such high-R&D intensity sectors, with US which sometimes duplicates or triplicates the number of the EU companies. This study found that there is a high heterogeneity distribution of R&D intensity of firms *within* the same sector, indicating the coexistence of firms with different R&D investment strategies and efficiencies. Furthermore, most of the firms within the selected sectors that were in the top and in the bottom of the R&D intensity ranking in 2005 remained unchanged in 2013.
A key analytical consideration is that the large share of R&D investment in the EU is held by few leading R&D countries with a R&D specialisation mostly in medium- and low-R&D intensity sectors. Other EU countries, even if are strong world economies (e.g. Italy, Spain), are lagging behind these EU R&D leaders. Linked to this fact is that EU holds a much lower number of companies than the USA in the four sectors that are key in the EU structural R&D intensity gap, resulting in considerable lower shares of net sales and R&D investment compared to the USA especially in Technology Hardware and equipment and in Software and computer services.

[48] The four sectors in which EU companies performed worse than US companies in 2013 are biotechnology, chemicals, pharmaceuticals and semiconductors.

(iii) The distribution of R&D investment *across* top R&D-investing firms and groups of sectors dynamics in different world regions/countries

The sixth relevant finding is that, in the years considered, corporate R&D is asymmetrically distributed, differing significantly between EU and non-EU companies. Overall, the study confirms that the bulk of global private R&D investment is concentrated in high and medium-high sector groups (especially the pharmaceutical and biotechnology, technology hardware and equipment, and automobiles and parts sectors, and software and computer services), in a few countries/regions (especially the USA, the EU and Japan) and in a few companies, confirming our third research hypothesis. The trend analysis indicates a decreasing concentration for both number of companies and R&D investment share of the Triad and an overall rather stable share of R&D investment held by the four top sectors. Interestingly, R&D intensity is highly concentrated in a small group of the largest R&D-investing firms. These results largely confirm the findings of Ciupagea and Moncada-Paternò-Castello (2006), Moncada-Paternò-Castello *et al.,* (2010) and, in part, Reinstaller and Unterlass (2012), and show that US companies with high cumulative R&D intensity, as is typical of high-tech sectors (i.e. R&D intensity above 5 %), dominate the full range of R&D investment ranking. The analysis of the evolution of the cumulative average R&D intensity of the examined samples represents a novel contribution to the literature. It shows that the bulk of the smaller top US R&D investors improved their cumulative R&D intensity in 2013 with respect to 2005. In contrast, the one of the smaller top EU R&D investors remained largely unchanged. Moreover, this parameter continues to be lowest in the BRIC region, but in the Asian Tiger countries increased from 2005 to 2013.

6.2 Concluding remarks

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 2003, 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 there have been no signs of the changes necessary to achieve the EU policy target for 2020 (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 the associated company demographics with the socio-economic and policy framework conditions are the most important reasons. For example, Mathieu and Pottelsberghe (2010), Foray and Lhuillery (2010) and Moncada-Paternò-Castello (2010) argue that there have been more dynamic changes in the structure of the US economy than in the EU economy in the last two decades. The economy in the USA moved in favour of higher-R&D-intensity sectors in particular, in ICT-related sectors, to a larger extent than in the EU, and this, in turn, was a major contributor in the difference in overall R&D intensity between the EU and the USA.

The findings of this study clearly show that EU companies have only a weak presence, in terms of market and R&D investment shares, in the high-tech sectors compared with their most direct competitors; most of these sectors have been created in the last few decades (e.g. biotech, software, internet) by new smaller R&D-intensive firms, as argued by Cincera and Veugelers (2013) and Moncada-Paternò-Castello (2010, 2017b).

Therefore, when taking action to decrease the EU R&D intensity gap, policy-makers should not consider only horizontal policy options across all sector and firm typologies. Tailored policies that address the technology development and diffusions as well as barriers to entering (and/or creating of new high risk and oriented to solve societal problems) R&D and innovation-intensive sectors and smaller R&D-intensive companies (also favouring new/young entrants) should be also considered.

This study shows that the EU corporate R&D investment mostly in medium-R&D intensity sectors (which dominated structure of the EU economy) is less sensitive to a global economic and financial downturn. Furthermore, larger European companies in lower and more traditional R&D intensity sectors (such as automobiles and parts and industrial engineering and machinery) have to be acknowledged for their capacity to compete (and lead) on a global level. Hence, EU policy measures should be also directed towards firms operating in less R&D-intensive sectors to enable them not only to carry quality R&D themselves but also to absorb R&D results from other, more R&D intensive, sectors. In doing so these companies will be better prepared to exercise a key leading role in the development process of the next technological generations and in the creation of the future knowledge-intensive industries.

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Appendix

A.1 - Caveats of the EU R&D Scoreboard data[49]

Before introducing the variables used in this study, we must point out that when using the EU R&D Scoreboard data for comparative analyses there are a number of factors that should be taken into account because they potentially affect the interpretation of the figures. In particular, the following should be borne in mind:

i) The EU R&D Scoreboard figures are nominal and expressed in euros, with all foreign currencies converted at the exchange rate prevailing on 31 December of the reporting year. Financial indicators consolidated from companies' activities in different currency areas are influenced by fluctuations in exchange rates. This has an impact on firms' relative placing in the world rankings based on these indicators. Moreover, the ratios between indicators or the growth rate of an indicator may be affected.

ii) Deflating the monetary data of these datasets has some drawbacks. It should be noted that, in practice, most firms in the EU R&D Scoreboard dataset are multinational; therefore, they have operations and sales in many countries all over the world. These firms' R&D investments are, in general, largely executed in their home countries (essentially, at the location of the company headquarters). In this context, if a deflator such as percentage of GDP of the firm's home country is applied for a given year equally to R&D investment, sales and profits, additional elements of data distortion are introduced. However, if the variables are not deflated, a different problem arises as all variables would increase over time (i.e. all variables will have a common trend due to inflation).

iii) Growth in corporate R&D investment can be organic, due to acquisitions, or a combination of the two. Consequently, mergers and acquisitions may explain sudden changes in the R&D growth rates and rankings of specific companies. They are likely to have less effect on R&D intensities since most acquisitions involve companies in the same sector.

iv) Other important factors to take into account are differences in the various countries' (or sectors') business cycles, which may have a significant impact on companies' investment decisions as well as the adoption of the International Financial Reporting Standards (IFRS).[50] It should also be noted that, although the accounting standards lead to a certain standardisation in the data reported, companies still have some choice over what they declare as R&D. This can have important impacts.

v) Company location versus R&D investment location: The terms 'EU company', 'non-EU company', 'US company', 'Japanese company', etc., are used throughout this report to refer to a company whose ultimate parent has located its registered office in that country or region. In fact, the EU R&D Scoreboard does not show where exactly the R&D investment is executed. It is a rich and accurate information source about a company's financial effort, but is less accurate when analysing a country's business R&D expenditures (the business

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[49] Source: European Commission (2006-2014).

[50] Since 2005, the European Union has required all listed companies in the EU to prepare their consolidated financial statements according to IFRS (see: Regulation (EC) No 1606/2002 of the European Parliament and of the Council of 19 July 2002 on the application of international accounting standards at http://eurlex. Available at: europa.eu/LexUriServ/LexUriServ.do?uri=CELEX:32002R1606:EN:HTML).

enterprise expenditures in R&D – BERD – statistics collected by national statistical offices[51]), although it shows similar overall results at EU level. An extensive discussion on these and other aspects of using the EU R&D Scoreboard compared with other data sources is offered by Moncada-Paternò-Castello (2017a).

A.2 - Description of the main variables considered for the analysis

The selection of variables is motivated by the research goals – i.e. answering the research questions/testing the above-mentioned hypotheses – and is supported in the literature, e.g. Lindmark, Turlea and Ulbrich (2010), Moncada-Paternò-Castello *et al.* (2010) and Cincera and Veugelers (2013). The main variables considered in the study are:

(i) Corporate research and development (R&D) investment. According to the EU R&D Scoreboard methodology, this is the cash investment funded by companies themselves. It excludes R&D undertaken under contract for customers such as governments or other companies. It also excludes the companies' share of any associated company or joint venture R&D investment. Disclosed in the company's annual report and accounts, it is subject to the accounting definitions of R&D. For example, a definition is set out in International Accounting Standard (IAS) 38 'Intangible assets' and is based on the OECD (2002) 'Frascati' manual.[52]

(ii) Net sales follow the usual accounting definition of sales, excluding sales taxes and shares of sales of joint ventures and associates. For banks, sales are defined as the 'Total (operating) income' plus any insurance income. For insurance companies, sales are defined as 'Gross premiums written' plus any banking income.

(iii) Sectors' classification: ICB (Industry Classification Benchmark) at the three-digit level, corresponding to sectors in which each company states its main activity lies. The ICB is an industry classification taxonomy launched by Dow Jones and FTSE in 2005 and now owned solely by FTSE International. It is used to segregate markets into sectors within the macro-economy. The ICB is used globally (though not universally) to divide the market into increasingly specific categories, allowing investors to compare industry trends between well-defined sub-sectors. We grouped industrial sectors according to R&D intensity, and following the European Commission (2006-2014) and OECD (1997) approach (see Box 1).

[51] For a comparison between EU R&D Scoreboard with BERD statistics, see Box 1 (p. 26) in Moncada-Paternò-Castello *et al*. (2010).

[52] Research is defined as original and planned investigation undertaken with the prospect of gaining new scientific or technical knowledge and understanding. Expenditure on research is recognised as an expense when it is incurred. Development is the application of research findings or other knowledge to a plan or design for the production of new or substantially improved materials, devices, products, processes, systems or services before the start of commercial production or use. Development costs are capitalised when they meet certain criteria and when it can be demonstrated that the asset will generate probable future economic benefits. Where some or all of R&D costs have been capitalised, the additions to the appropriate intangible assets are included to calculate the cash investment and any amortisation eliminated.

Box A-1. Grouping of industrial sectors according to R&D intensity of the sector worldwide.

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; and leisure and goods.

Medium-high R&D intensity sectors (R&D intensity between 2 % and 5 %) include, for example, aerospace and defence; automobiles and parts; electronics and electrical equipment; industrial engineering and machinery; chemicals; personal goods; household goods; general industrials; and support services.

Medium-low R&D intensity sectors (R&D intensity between 1 % and 2 %) include, for example, food producers; beverages; travel and leisure; media; oil equipment; electricity; and fixed line telecommunications.

Low R&D intensity sectors (R&D intensity less than 1 %) include, for example, oil and gas producers; industrial metals; construction and materials; food and drug retailers; transportation; mining; tobacco; and multi-utilities.

Source: European Commission (2014) following the OECD (1997) approach.

Note: In contrast to the approach to the data taken in the 2014 edition of the EU R&D Scoreboard, the aerospace and defence sector has been classified as medium-high as its global R&D intensity results averaged less than 5 % over the three years considered. In fact, this sector was in the medium-high sector group in the 2006 and 2010 editions of the EU R&D Scoreboard.

For this study, Hong Kong, Singapore, South Korea and Taiwan have been grouped as ‘the Asian Tigers’, with Brazil, Russia, India and China as the ‘BRIC.’ countries; RoW denotes ‘Rest of the World’.

Table A-1. R&D investment and net sales by country/region of the sample analysed with regard original samples of the three EU R&D Scoreboards editions (2005; 2009; 2013)

Country/region (No. of firms) **2005**	R&D investment (%)	R&D investment (€ bn)	Net sales (%)	Net sales (€ bn)
EU (319)	94.0%	106.2	79.5%	3583.3
US (539)	99.1%	149.8	98.2%	3406.8
Japan (227)	99.6%	69.8	98.3%	1855.7
Asian Tigers (66)	100.0%	14.6	100.0%	438.4
BRIC (12)	97.3%	2.0	93.6%	263.5
RoW (84)	98.4%	19.4	97.6%	475.8
Grand Total* (1247)	**97.6%**	**361.8**	**90.5%**	**10023.6**
Country/region (No. of firms) **2009**	R&D investment (%)	R&D investment (€ bn)	Net sales (%)	Net sales (€ bn)
EU (349)	93.3%	121.3	78.7%	4254.3
US (447)	98.6%	136.1	98.5%	2837.3
Japan (238)	99.3%	88.0	97.3%	2256.5
Asian Tigers (76)	98.1%	16.6	98.9%	638.4
BRIC (44)	98.3%	8.9	97.5%	710.5
RoW (93)	99.0%	26.5	98.1%	578.9
Grand Total* (1247)	**97.1%**	**397.3**	**89.7%**	**11275.9**
Country/region (No. of firms) **2013**	R&D investment (%)	R&D investment (€ bn)	Net sales (%)	Net sales (€ bn)
EU (354)	95.1%	154.3	87.4%	5164.5
US (409)	94.2%	182.3	91.6%	3516.4
Japan (205)	94.1%	80.6	81.9%	2160.2
Asian Tigers (77)	89.9%	27.9	80.3%	1092.7
BRIC (81)	85.1%	21.8	88.8%	1715.6
RoW (116)	91.6%	36.8	79.4%	828.5
Grand Total* (1242)	**93.6%**	**503.6**	**86.6%**	**14477.9**

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

*The total of the truncated sample as a proportion of the total of the original full sample.

Note: The original full sample comprised, for 2005, data from 2 000 companies with a total R&D expenditure of €371bn and net sales of €11 073bn; for 2009, data from 2 000 companies with a total R&D expenditure of €402bn and net sales of €12 574bn; and, for 2013, data from 2 500 companies with a total R&D expenditure of €540bn and net sales of €16 723bn.

For information, taking as reference the overall sample of 2 500 firms in 2013, the R&D investment is distributed as follows: EU 30.1 %, USA 36 %, Japan 15.9 %, together totalling 82 %. The RoW represented 18% of the global R&D investment (of which Switzerland, 4.3%; South Korea 3.8 %; China 3.7 %; Taiwan 1.8 %; Canada 0.7 %; and other countries 3.7 %).

A.3 - Decomposition using a longitudinal dataset (2005-2013)

<u>The dataset</u>

To check the robustness of the results obtained by the analysis of the three different editions of the EU R&D Scoreboard (2006, 2010 and 2014), a second dataset was built and used. The dataset was built by building the dataset with 2 500 firms listed in the 2014 EU R&D Scoreboard edition (2013 data) and keeping only those firms that had in each and every previous edition of the EU R&D Scoreboard both R&D and net sales data back to the edition of 2006 (2005 data) as well as the ORBIS-Bureau van Dijk database.

This balanced dataset allowed us to capture how the R&D investment of individual companies changed over the nine-year period of observation. The monetary data in this balanced dataset were adjusted for inflation. The deflation was done using the GDP deflators published by World Bank[53] and using 2000 as the reference year, taking the same approach used by Montresor and Vezzani (2015)[54] on a dataset these authors built from the same data source (i.e. the EU R&D Scoreboard).

In the end, complete data for each of the nine years were available for 1 859 firms, and the longitudinal dataset includes most of the companies present in the three samples, one for each of the EU R&D Scoreboard editions of 2006, 2010 and 2013 used for the analysis shown in section 3 of the paper. More exactly, in this sample of 1 859 firms, there are 907 companies from the 2006 EU R&D Scoreboard (73 %), 995 companies from the 2010 EU R&D Scoreboard (80 %) and 1 023 companies from the 2014 EU R&D Scoreboard (82 %). Therefore, differences are due to missing data for at least one of the nine years considered because of the different composition of the EU R&D Scoreboard editions.

Tables A-2 and A-3 and Figure A-1 show descriptive statistics of the balanced dataset.

Figure A-1 shows the global R&D investment and net sales annual growth rates of the longitudinal dataset 2005-2013, marked by a decrease in 2009 in both parameters due to the financial and economic downturn.

[53] http://data.worldbank.org/indicator/NY.GDP.DEFL.KD.ZG/countries/all?display=default

[54] See page 384, footnote 7 of the mentioned authors

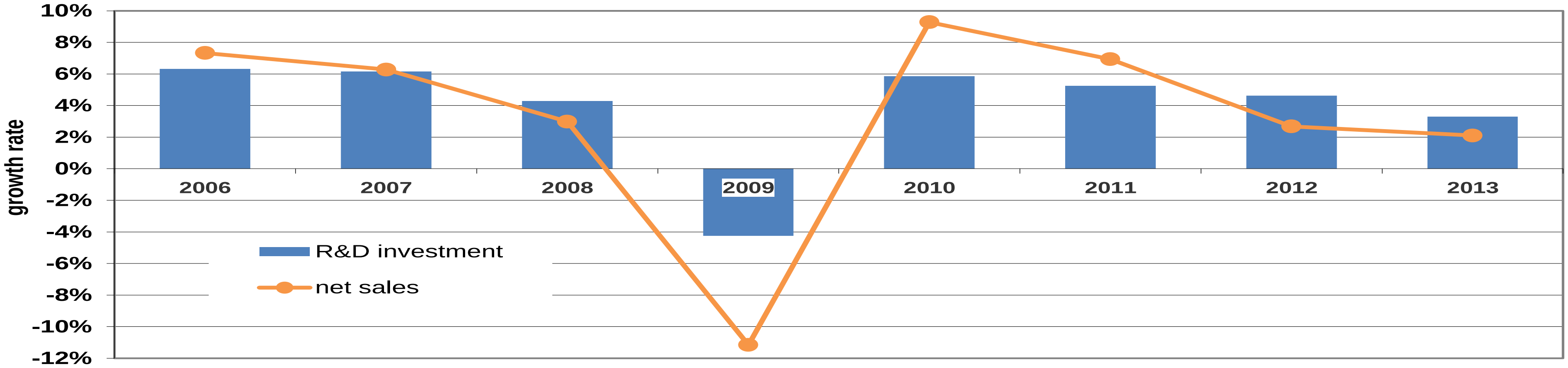
Table A-2. Descriptive statistics of the sample by main world regions/countries – balanced dataset 2005-2013

	all firms		EU		US		Japan		BRIC		Asian Tigers		RoW	
	mean	std dev	mean	std dev	mean	std dev	mean	std dev	mean	std dev	mean	std dev	mean	std dev
R&D	213.1	642.7	231.6	665.5	216.3	623.4	261.6	695.7	109.2	183.7	141.3	630.8	155.2	650.4
Net sales	6339.2	17343.2	8255.9	21177.3	4390.0	14507.4	7960.3	16954.4	10854.3	30288.3	5687.9	13435.4	3521.7	9183.7
R&D intensity	1.08	27.22	2.53	48.79	0.89	9.06	0.04	0.05	0.05	0.07	0.04	0.04	0.06	0.06
number of firms	1859		473		619		366		68		156		177	

Table A-3. Descriptive statistics of the sample by R&D intensity sectors – balanced dataset 2005-2013

	all firms		high R&D intensity		medium-high R&D intensity		medium-low R&D intensity		low R&D intensity	
	mean	std dev	mean	std dev	mean	std dev	mean	std dev	mean	std dev
R&D	213.1	642.7	254.2	707.7	204.1	682.3	153.0	277.1	113.1	162.4
Net sales	6339	17343	2938	8206	5951	15065	10562	15635	19813	37691
R&D intensity	0.85	23.17	1.93	35.48	0.06	0.34	0.03	0.04	0.01	0.01
number of firms	1859		792		760		124		183	

Figure A-1. Global R&D investment and net sales annual growth rates – longitudinal dataset 2005-2013



Applying the decomposition to the longitudinal dataset of EU R&D Scoreboards

We applied the decomposition to the data for three years (2005, 2009 and 2013) from the longitudinal balanced dataset of nine years (2005-2013), which comprised data for 1 859 enterprises worldwide taken from several editions of the EU R&D Scoreboard. Overall, when comparing the data of the three 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 three different EU R&D Scoreboards.

The balanced dataset, however, allows us to capture how the R&D investment of individual companies has changed over the nine-year period of observation, thereby providing accurate information that is particularly useful for studying the evolution of the 'intrinsic effect' in the R&D intensity gap.

Table A-4 provides the result of this decomposition calculation. Comparing the data for the USA and the EU, we can confirm that the reason for the R&D intensity gap remains structural and very little changes over the years (as one would expect – the data come from the same companies competing in the same sectors of operations) and that the order of magnitude of the R&D intensity gap is in most cases very similar to what was reported in Table 3 (section 4.2). Moreover, the decomposition of this longitudinal dataset confirms that, in terms of 'intrinsic effects', EU companies outperform all of their competing economies, apart from the RoW group where Switzerland dominates.

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. For the other country groups, the results are also generally similar, although sometimes sample variations lead to changes in the results.

In fact, in contrast to the results in section 4.2 and the data in Table 3, in Table A-4 the 'intrinsic effect' advantage of EU companies is slightly improved over time when compared with Japan and BRIC. There are a number of possible reasons for this, but they mainly stem from the different characteristics of the two datasets (e.g. the number of companies in the dataset, their size and sectorial composition, the use of nominal as opposed to real values, and so on).

Table A-4. Decomposition of R&D intensities in selected countries/regions using the EU sample for comparison and applied to three years of the longitudinal dataset (2005-2013)

		n. of companies	overall	structural	intrinsic
US	2005	619	1.347	2.505	-1.159
	2009	619	1.867	2.990	-1.124
	2013	619	2.121	3.325	-1.204
Japan	2005	366	0.512	1.714	-1.202
	2009	366	0.758	1.680	-0.923
	2013	366	0.481	1.600	-1.119
Asian Tigers	2005	156	-0.250	2.770	-3.020
	2009	156	-0.654	2.741	-3.396
	2013	156	-0.321	2.461	-2.782
BRIC	2005	68	-2.130	-0.877	-1.253
	2009	68	-1.762	-0.809	-0.953
	2013	68	-1.799	-1.016	-0.783
RoW	2005	177	0.501	1.203	-0.702
	2009	177	1.401	1.709	-0.308
	2013	177	1.601	1.900	-0.299
Note: number of EU companies: 473					

A.4 - Decomposition of EU vs US R&D intensity gap using different definitions of R&D intensity

The EU R&D Scoreboard data used in R&D intensity decomposition leads to indicate that the EU gap is mainly due to a structural effect. This result could be due to the sample composition: in fact, the decomposition is based on the small number of EU and US leaders in terms of R&D - although representative of up to 90 % of the total private R&D in the full sample of 2500 firms - but these companies represent a small share of the total economy (GDP= denominator globally, or Value Added – VA - contribution at sector level). Such bias could explain the difference in the decomposition result (i.e. intrinsic effect as main determinant) when using BERD in the numerator whit GDP or VA at the denominator (see Moncada-Paternò-Castello, 2017a). Therefore, we tested the result of EU vs US decomposition of this paper (section 4.2, page 16) using the R&D intensity as the share of EU Scoreboard R&D (SB_R&D) to firms' net sales (NS), and compare it with the decomposition results using other R&D intensity ratios, namely, SB_R&D/VA and BERD/VA.

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

The 2009 year was the only most recent year of the three years referred in the R&D intensity decomposition of this paper (i.e. 2005, 2009 and 2013) for which is possible to get VA data with the same classification (ISIC rev. 4). The coverage of the EU countries in EU KLEMS (for the VA) and OECD-ANBERD[55] (for BERD) of the 2009 is limited to the following EU countries' coverage: Belgium, Sweden, Finland, The 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 USA R&D intensity values of R&D and net sales at ICB – 3 digit as well as ICB-4 level sector classification of the EU R&D Scoreboard were converted into ISIC rev. 4 sector classification for comparability reasons. Also, all monetary values were converted in € million using the exchange rate of the 31 December 2009, following the EU R&D Scoreboard methodology.

The overall result is shown in the following Table A-5:

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

Table A-5. Decomposition of different R&D intensities ratios in EU and US using the EU sample for comparison (2009)

2009	**overall**	structural	intrinsic
SB_R&D/NS (ICB3)	**1.944%**	2.74%	-0.80%
SB_R&D/NS (ICB4)	**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 at the value of the fraction, differ substantially in the overall R&D intensity gap as well as we compared totally heterogeneous data 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 to net sales output which 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 USA include the portion of VA coming from multinationals (the non-EU foreign affiliated operating in the EU countries), while the NS of EU R&D Scoreboard companies arise both from national as well as international markets.
- The mismatch of the two &D intensities decompositions as well as the causes (intrinsic vs structural) of the EU vs US gap is very likely to be due to where the R&D and 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 the entire R&D activities within the USA, while the bulk of their production and VA is performed abroad (Lindmark *et al*., 2010; Hernandez *et al.*, 2013); this lower very much the denominator for the USA firms in these sectors with a clear consequence of rising very much the R&D intensity of the US firms in the share *SB_R&D/VA.*
- The higher sectoral aggregation at ISIC.4 of the R&D intensity values of firms is very likely to be one of the main reasons for the discrepant results: it doesn't allow to appreciate/reduce very much the differences between sub-sectors as it was in the decomposition of *SB_R&D/NS* intensity using a the lower possible aggregation (as discussed in Lindmark *et al*., 2010) that the availability of data allow.

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, as reported by Moncada-Paternò-Castello (2017a), the R&D share of BERD by foreign affiliated in 2013 is higher than 50% in some EU countries as Hungary, Ireland, Belgium, Check Republic, Great Brittan and Austria. On the other hand, Japan and US that have a low share (< 20%) of R&D foreign affiliated, show higher BERD intensity.
- Furthermore, although very high representative for the R&D EU and US R&D investment, 1247 firms, represents 83% of the global BERD. If it is then divided by the VA of the full economy, this will alter substantially the final results and make them

even less comparable of BERD / VA or with R&D / the net sales of the EU R&D Scoreboard companies. In practice, the value of the numerator will be decreased by about a 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 to the result of a Report authored by a report by ETEPS (2008)[56] which concludes with the following sentence: "*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*". The results are also consistent to the findings of the paper of Moncada-Paternò-Castello (2017a) which points out most of the arguments introduced above.

Differences in decomposition results between SB_R&D/NS (ICB3) and SB_R&D/NS (ICB4)

- Explanations for such (small) differences are basically due to the different level of sectoral aggregations (ICB-3 vs ICB-4), where the firms from a major aggregation drop in a sub aggregation (in line to Jaumotte and Pain, 2005; Erken and van Es, 2007; Lindmark *et al*., 2010).

Overall, the results of the R&D intensity gap decomposition using the R&D investment and the sector composition (structure) represented by the companies of the EU R&D Scoreboard in the sample are reliable. This paper, in fact, doesn't assume that the R&D sectors mix 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 provide complementary information and it is not comparable to the *SB_R&D/VA* or to *BERD/GDP* or *BERD/VA* ratios. Nor there is a rational in mixing data of such different nature for the R&D intensity ratio which obviously brings contradicting decomposition results; that is, it is meaningless to arbitrarily mix company and territorial data (e.g. the ratio SB_R&D/territorial VA). In the future, it would be possible to do so by first converting the EU R&D Scoreboard data into territorial data by using, for example, patent information of EU R&D Scoreboard companies' subsidiaries as a proxy.

Finally, it can be recall that the *SB_R&D/NS* intensity decomposition is an approach taken by all the decomposition studies in the literature that use the EU R&D Scoreboard data (e.g.: Moncada-Paternò-Castello *et al*., 2010; Lindmark *et al*., 2010; Cincera and Veugelers, 2013; Stancik and Biagi, 2015).

[56] 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 Center for Economic Studies, Romania). "Impact of industrial R&D on business performance: Evidences from quantitative analyses based on company data and official statistics".No.150083-2005-02-BE. Final Report. Brussels (BE), 10 March 2008 (unpublished. Available upon request).

Essay #3

Sector dynamics, specialisation and R&D growth of top innovators in the global economy

Pietro Moncada-Paternò-Castello (*)

Abstract

This paper investigates the sectoral dynamics and the resulting specialisation of the major economies during the last decade through the lens of the top R&D investors worldwide and their drivers for R&D investment growth across sectors. 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. Also, the EU has an even broader technological specialisation than its already broad industrial R&D sector specialisation, while the USA leads by number of technological fields mostly belonging to the industrial R&D sectors of its specialisation. 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. The paper investigates as well the effects of R&D intensity, capital intensity and profitability on R&D investment growth of the firms across sectors. The result indicates that firms make a complementary use of capital expenditures and R&D intensity for their R&D investment growth strategies and, new to the literature, it reveals the there are differences in their use between firms' age classes across sectors. This implies that to reach a more positive R&D dynamics, the EU should aim at a different sector mix with larger presence of firms in newer R&D-intensive sectors.

JEL classification: O30; O32; O38; O57

Keywords: Corporate R&D, EU R&D intensity deficit, sector dynamics and specialisation, technology specialisation, IPR, firms' age, R&D growth performance.

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(*) Contact information: European Commission — Joint Research Centre (JRC), Growth and Innovation Directorate. Address: Edf. Expo, Calle Inca Garcilaso No. 3, 41092 Seville, Spain.
Email: pietro.moncada-paterno-castello@ec.europa.eu

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[57], some aspects of the relationship between innovative firms, industrial dynamics, technological development/specialisation, and R&D investment growth 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' age, size and dynamic (capacity for rapid growth) as key factors influencing this deficit (e.g. Bartelsman *et al*., 2005; O'Sullivan, 2006; García-Manjón and Romero-Merino, 2012; Cincera and Veugelers, 2013; Ciriaci *et al*., 2014). Other authors have investigated the use of firms' financial resources for their R&D activities (Martínez-Ros and Tribó, 2006; Hall and Lerner, 2010; Wang *et al.,* 2016), also under their financial constraints (Czarnitzki and Hottenrott, 2011; Cincera *et al.,* 2012 and 2016; Hall *et al.,* 2016). However, despite its relevance, little attention has been given on the internal financial factors which affect firms' R&D growth performance across sectors and the possible differences across firm characteristics.

In this paper we analyse the R&D sectoral dynamics in the major world economies, the resulting industrial R&D sectoral and technological specialisations, and the use of firms' internal resources for R&D investment growth strategies across sectors by some specific firm' features. The resulting specificities could broaden our understanding of the sector dynamics and the R&D intensity gap.

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)[58]. These are mainly multinational companies which operate in several sectors and countries. 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).

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 impact of firms' economic and financial factors to their R&D investment growth across sectors, we do it by grouping the firms by their combined R&D growth and age characteristics.

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

[57] 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.'

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

specialisation. By doing so, we disentangle the technological transformation paths (if 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 industrial ICT sectors. A further analysis of the patent portfolio of these top R&D firms suggests that in the Triad there is even broaden technology specialisation by patent application in a large number of sectors.

Second, the 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. These aspects have little coverage in the present literature.

Third, as we find a weak link between sectorial dynamics and aggregate R&D investment patterns, we investigate the R&D investment growth and the age at the micro-level, besides the traditional sectoral classifications. As original contribution to the literature, we found that the capital intensity is more important for younger firms which hold a high R&D investment growth patterns than for older firms. This suggests that such young companies use fixed capital and R&D as complementary sources of investment. Moreover, the effect of R&D intensity on R&D investment is always positive and significant for younger firms. This result also confirms the findings of Cincera and Veugelers, 2013 who indicate that young leading innovators, particularly in high-tech sectors, play a pivotal role in countries' R&D performance, as newer (smaller) firms have their own strategic incentives to invest in R&D at higher levels than incumbents (Schumpeter, 1934).

Our findings reveal that to achieve a more positive R&D investment dynamics, the EU should aim at a different sector mix with larger presence of firms' younger firms in new(er) R&D-intensive sectors. This would have the effect of increasing the EU R&D investment and the R&D intensity gaps vis-à-vis its main competitor(s).

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 on sector composition, firms' R&D performance and age. Section 3 describes the dataset and variables used. Section 4 provides the analytical results, and section 5 concludes.

2. Literature

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.

The corporate R&D intensity decomposition literature has been analysed from a theoretical, methodological and empirical angle by a dedicated study authored by Moncada-Paternò-Castello (2017b), which reveals that recent studies mainly point at structural composition and dynamics as the main factors determining the EU R&D investment gap. Furthermore, a new empirical article by Moncada-Paternò-Castello (2017a) confirms the structural nature of the EU R&D intensity gap and uncovers the differences between the EU with main competitors and emerging countries by inspecting which sectors and EU countries and firms are more accountable for the aggregate EU R&D intensity performance over time.

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 the R&D investment dynamics of developed economies and emerging ones. Third, we investigate the R&D investment growth associated to the age at the micro-level, besides the traditional sectoral classifications. In doing so, we show that the recent emphasis on the importance of increasing the R&D investment by the presence of younger firms 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[59]. 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 country's private R&D

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 several scholars, such as Sachwald (2008), Mathieu and van Pottelsberghe (2010) and Moncada-Paternò-Castello (2017a), 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, analysing patents 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 the EU.

The **first research question** this study will aim at answering is the following: What are the country/world regions specificities in the change of R&D investment across sectors and their resulting industrial R&D sector and the technological specialisation?

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.

[59] *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).

But, what happened to the R&D investment and its trend of countries/world regions with different sectoral (R&D) specialisations? Which of those shows more stable R&D investment patterns during the economic crisis? This represents the **second research question**.

2.3 Firm's R&D investment performance across sectors

The previous sub-section introduced the literature of dynamics of sectors' related to R&D investment. To fully understand the phenomenon, we surveyed the literature to detect if there are commonalities among firms in their R&D investment behaviour which go beyond the sectoral perspective. As result, we found that there is a stream of the economic literature which shows that there could be a high heterogeneity of firm's R&D intensity and investment across and within sectors. Differences between sectors are likely due to a not simultaneous transformation of the business model and by the rise of different competitiveness and technological frontier levels; differences between firms within the same sector are likely due to their different capacity, efficiency and/or business strategy and the expected returns (i.e., Moncada-Paternò-Castello, 2017a; Coad, 2017, Mairesse and Mohnen, 2005).

The expectation of a higher demand/sales (Grabowski, 1968), returns (Pollack and Adler, 2014) are only some examples of economic and financial factors that influence the firm's R&D growth. Recently Kumbhakar *et al.* (2012) show that R&D activities affect firms' productivity by shifting the production frontier and increasing efficiency in high-tech sectors. On the other hand, physical capital stock results in higher productivity especially in low-tech and service sectors. To the extent that firms are more productive and profitable, they grow faster; on the other hand, capital investment may represent an alternative avenue to firms' growth.

Furthermore, in some firms there is a R&D growth path dependency where the R&D is considered a fixed cost, either because of R&D infrastructure or (especially) because of creating a new product (Romer, 1990). In other cases, there is a coexistence of firms with different R&D investment strategies and efficiencies. That is, the firms with large market share can enjoy their dominant position, with a high R&D efficiency, the so called 'creative accumulation'[60], because of high appropriability and high cumulativeness and high economy of scale in the exploitation of R&D results (Schumpeter's Mark II theory - Schumpeter 1942; Becker and Hall, 2013). On the other hand, there are smaller (*new*) firms which rise their R&D investment to introduce innovations into the market in order to put pressure on, and displace, the incumbents, according to Schumpeter's Mark I theory (Schumpeter, 1934). Arrow (1962) and Jovanovic (1982) extend this theoretical setting by arguing that a firm's growth depends on its age / the entrepreneurs' ability to learn over time[61].

Following this theoretical framework, one stream of empirical literature indicates a correlation between firm *age* and their R&D investment growth. One part of this literature indicates that R&D investment growth is associated to smaller newer companies as they have their own strategic incentive to increasingly invest in R&D because, despite the more moderated economies of scale in R&D activities, it causes higher profit returns than in established (incumbent) firms (Meza and Tombak, 2009; Matsumura and Matsushima, 2010; Schneider and Veugelers, 2010). Another part of the literature shows that less concentrated industries, industries with fewer sunk costs and industries in the early stages of the life cycle favour the

[60] 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).

[61] 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).

appearance of new (young) small innovative firms (Utterback, 1996; Malerba, 2004; Fort *et al.*, 2013; Audretsch *et al*., 2014).

Furthermore, a few studies have found that young leading innovators, particularly in high-tech sectors, play a pivotal role in countries' R&D performance. Cincera and Veugelers (2011, 2013) for example 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[62].

We notice that, despite its relevance, there is still a lack of empirical literature addressing the use of the financial and economic sources by the top R&D firms to determine their R&D investment dynamics across sectors when analysing the evolution of the EU R&D compared to the one of the USA and the other major world economies. Therefore, to inspect with more deepness the corporate R&D investment growth besides the traditional sectoral or R&D intensity classifications, and taking into account the above literature, this study will address the following **third research question**: What financial and economic factors affect firms' R&D growth performance across sectors? Are these factors different across firm age?

In particular, in this paper 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 link such macro-dynamics to micro- evidence by explaining to what extent the use of financial and economic resources by top R&D firms showing particularly good performances boost their own R&D investment growth.

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[63].

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

[62] The reason for the low dynamism in new 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.

[63] 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.

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, 2017b). We supplement the information in the EU R&D Scoreboard by age of companies (the year of foundation), which we obtained from different sources[64]. The main sources of this additional information are companies' annual reports and other publicly available official documents and the ORBIS database (Bureau Van Dijk).

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- and medium-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[65].

The dataset used in this study 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. In the case of section 4.3, firms data are complemented with patent information from the COR&DIP database[66] for technological specialisation analysis; in section 4.5, data of world top 2000 R&D firms of the EU R&D Scoreboard are used for a cross sectional analysis.

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 this study focuses mainly on the distribution of R&D across sectors and countries within a given year, the use of nominal values doesn't affect its results. The approach adopted in this respect by this study follows

[64] 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.

[65] 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%.

[66] EC-JRC/OECD's COR&DIP© (Corporate R&D Intellectual Property database): https://survey.oecd.org/Survey.aspx?s=7d7469b2122144fa811c5f3b13d1cb79

that of many other scholars[67]. Moreover, the low or absent inflation rates in the last decade lay off the need for adjusting the monetary values.

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 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[68] 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[69]. 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).

[67] 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).

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

[69] 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.

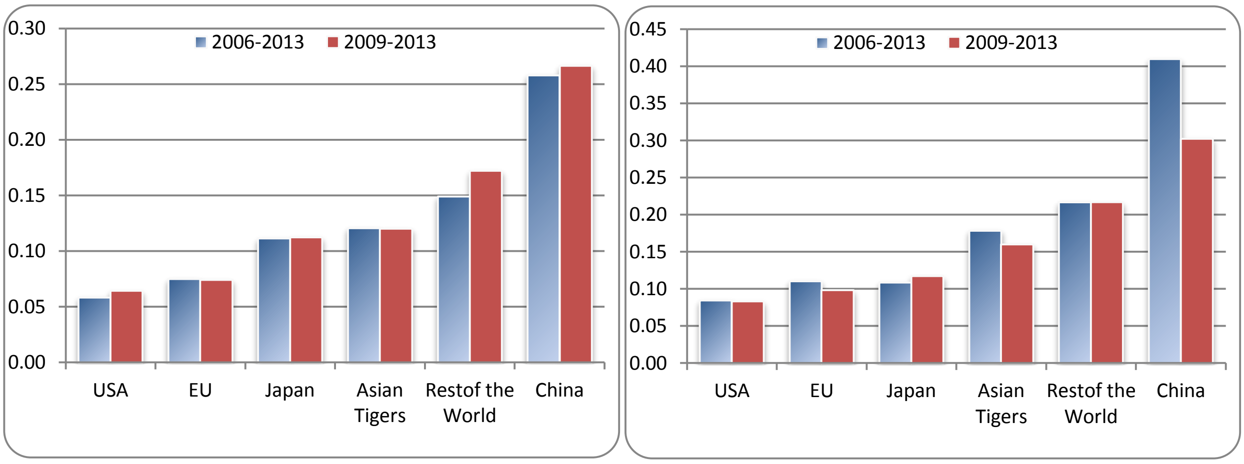
However, Jajuga (1987) and Lee *et al.* (2011) suggest that the usual *Euclidean* distance measure cannot be used to specify the distance between sequences because a sequence consists of ordinal values while the *Manhattan* distance metrics has been used by several authors in innovation studies, e.g. 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)[70]. 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.

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 (Atkinson and Ezell, 2012).

[70] 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.

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 (Oulton, 2012). Another possible explanation is the use of different methodological approaches by Mowery (2009) and by Foray and Lhuillery (2010)[71]. Finally, emerging economies show a higher capacity to change their R&D profile, especially considering the shift in company distribution.

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.

[71] 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 Scoreboard, as in the present study - see Moncada-Paternò-Castello (2017b) 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.
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%
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%
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%
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%				
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%

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.

'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).

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.

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

where P_{ijt} 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, and even less in a large number of the 35 ICB-3 sectors. Averages over groups of 3-5 years in the R&D_RCA calculations are not expressly used here because this would basically hide the variance, which in turn is the central point of analytical interest. In fact, we are looking for the sectoral changes from the beginning to the end of the period (i.e. 2005 and 2013) of EU R&D Scoreboard firms in respective sectors. Also, such firms in the EU R&D Scoreboard do not change very much from one year to the other and such averaging approach would be not telling very much.

The value of the R&D_RCA index for 2013 (Table 2a) reveals that EU firms consolidated their comparative advantage in R&D investment, especially in medium-tech sectors, for example in '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.

Table 2a. 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 and/or 2013.

ICB-4 digits sectors	R&D intensity group	EU 2005	EU 2013	USA 2005	USA 2013	Japan 2005	Japan 2013	Asian Tigers 2013	China 2013	Rest of the World 2013
Aerospace & defence	H	1.9	1.7	1.0	1.0	0.0	0.0	0.0	0.0	1.6
Alternative energy	M-L	0.0	2.6	0.0	0.5	0.0	0.0	0.0	0.0	0.0
Automobiles & parts	M-H	1.4	1.6	0.6	0.4	1.5	1.8	0.5	0.6	0.2
Banks	L	3.2	2.6	0.0	0.0	0.0	0.0	0.0	1.4	1.9
Beverages	M-L	0.0	0.8	0.0	1.1	4.9	2.3	0.0	0.0	0.0
Chemicals	M-H	1.3	0.9	0.7	0.8	1.3	1.9	0.1	0.0	1.5
Construction materials	L	1.1	0.6	0.3	0.2	2.2	0.6	0.0	18.2	0.3
Electricity	M-L	1.5	2.2	0.0	0.0	1.9	0.6	3.8	0.0	0.0
Electronic equipment	M-H	1.0	0.7	0.2	0.3	1.5	1.8	6.7	0.3	0.2
Finance insurance	M-H	2.4	1.7	0.7	0.6	0.0	0.7	0.0	0.0	2.0
Fixed line telecom	M-L	1.7	1.7	0.0	0.4	1.8	1.4	1.3	1.2	0.2
Food producers	M-L	1.4	1.3	0.2	0.5	0.6	0.6	0.2	0.0	3.6
Food retailers	M-L	1.7	3.2	1.2	0.0	0.0	0.0	0.0	0.0	0.0
Forestry paper	L	1.4	2.3	0.7	0.0	1.4	1.7	0.0	0.0	0.0
General industrials	M-H	0.3	0.8	1.6	1.1	0.9	2.0	0.1	0.9	0.3
General retailers	M-L	0.0	0.7	2.2	2.2	0.7	0.0	0.0	0.0	0.0
Health care equipment	H	0.7	0.8	1.9	1.8	0.1	0.5	0.0	0.0	0.4
Household goods	M-H	0.7	1.2	1.7	1.7	0.4	0.1	0.0	0.0	0.0
Industrial engineer	M-H	1.5	1.4	0.7	0.7	0.8	0.7	0.2	2.5	1.3
Industrial metals	L	1.2	1.1	0.3	0.1	1.6	2.0	2.5	3.2	0.7
Industrial transport	M-L	1.7	2.3	0.0	0.0	1.2	0.0	0.0	8.6	0.0
Leisure goods	H	0.5	0.0	0.4	0.2	3.4	4.2	3.7	0.0	0.4
Media	M-L	2.2	2.3	0.3	0.3	0.9	1.1	0.0	0.0	0.0
Mining	L	0.0	1.0	0.0	0.0	0.0	0.0	0.0	0.0	8.7
Mobile telecom	L	1.2	1.9	0.0	0.6	0.0	0.0	0.0	0.0	2.3
Oil equipment	L	0.0	0.4	2.6	1.8	0.0	0.0	1.3	1.0	1.4
Oil gas producers	L	1.4	0.9	0.6	0.4	0.1	0.2	0.5	7.9	2.9
Personal goods	M-H	0.9	1.4	1.0	0.5	0.9	1.4	0.9	0.0	1.2
Pharma & biotech	H	0.9	1.0	1.3	1.2	0.3	0.6	0.0	0.0	2.3
Software & computer s.	H	0.4	0.4	2.2	2.1	0.1	0.3	0.0	0.0	0.7
Support services	M-H	0.5	1.2	1.6	1.1	0.3	0.4	0.0	0.0	2.2
Technology hardware	H	0.6	0.6	1.3	1.6	1.0	0.4	1.4	1.9	0.6
Tobacco	M-L	0.2	1.0	1.7	1.0	1.3	2.1	0.0	0.0	0.0
Travel & leisure	M-H	1.0	0.3	1.2	0.2	0.7	4.1	0.0	2.7	1.3
Utilities	L	1.7	2.7	0.2	0.2	1.0	0.6	0.0	0.0	0.0
Total No. of sector specialization		*19*	*19*	*13*	*11*	*12*	*13*	*7*	*9*	*14*
↑ Sect. special. 2005-13 (No.)		*8*		*1*		*7*				
↓ Sect. special. 2005-13 (No.)		*7*		*7*		*2*				
New Sect. special. 2005-13 (No.)		*4*		*1*		*4*				
De-specialization 2005-13 (No.)		*4*		*3*		*3*				

Source: Own elaboration. Note: Highlighted cells correspond to sector specialization.

Table 2.b Overview of total sector specialisations (R&D Revealed Comparative Advantage index) by R&D intensity groups and countries/regions – 2005 and/or 2013.

R&D intensity group	EU 2005	EU 2013	USA 2005	USA 2013	Japan 2005	Japan 2013	Asian Tigers 2013	China 2013	Rest of the World 2013
H	1	1	4	4	1	1	1	1	2
M-H	5	6	5	3	3	6	1	2	6
M-L	6	7	3	3	5	4	3	2	1
L	7	5	1	1	3	2	2	4	5
Total	*19*	*19*	*13*	*11*	*12*	*13*	*7*	*9*	*14*

Source: Own elaboration. Note H, M-H, M-L and L are abbreviations for High, Medium-High, Medium-Low, and Low R&D intensity sector groups respectively

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'.

Focusing on the Triad economies, between 2005 and 2013, the EU strengthened further its specialisation in 8 sectors (all low- and medium-low R&D intensity sectors, but one: auto & parts), while reduced the strength of its specialisation in 7 sectors (all high or medium-high R&D intensity sectors); moreover the EU showed equal number of *new* sectors of specialisation (three of medium-high and one of medium-low R&D intensity) and of sectors of *de-specialisation* (two low- and two medium-high R&D intensity). In the same period, the US strengthened in one high-R&D intensity sector of specialisation, decreased its specialization in seven sectors with different R&D intensity, specialised in one *new* low-medium sector and *de-specialised* in three sectors (two medium-high and one medium-low). Japanese companies shown a positive balance between *new* sector specialisations (4) and sectors *de-specialisation* (3) resulting in additional specialisation of medium-high R&D intensity sectors (Table 2a and 2b).

In the overall, the EU maintained the number of sectors of specialisation (19 in both 2005 and 2013), but at the advantage of medium-low R&D intensity sectors (Table 2a and 2b). The USA decreased from 13 to 11 the total number of sectors of specialisation in the same time span by falling down two medium-high R&D intensity sectors. Japan increased strongly the number of sectors specialisation in medium-high R&D intensity and decreased the number of sectors of specialisation in all the others groups of R&D intensity sectors except in one high-tech sector (Leisure goods). The results shown in this subsection confirm 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' (this latter sector because of firms from Switzerland) sectors.

4.3 Technological specialisation of countries/regions

The specialisation resulting from the industrial R&D sectoral dynamics analysed in the previous sub-section doesn't reveal the technological profiles of the companies. Holding this information permits going beyond R&D and directly inspecting what technical profile it generated. According to Dernis *et al.* (2015), the patent data allow identifying the main technological fields in which top corporate R&D investors focus their inventive activities. These authors used the technology classes in which patents are filed as a proxy for technological specialisation and thus to identify the technological competences at the basis of companies' output and performance.

The analysis of technological profiles of firms, therefore, can shed light on i) which technological field countries specialise due to their corporate R&D investment, ii) what is the degree of technology specialisation within a given industrial R&D sector and iii) if there is a difference between the technology specialisation and the industrial R&D sector specialisation as emerged from sub-section 4.2. In fact, a company or group of companies in a country/world region could be specialised in one or a few technological fields (concentrated specialisation) within a particular industrial (ICB) sector or it could be specialised in a large number of technological fields (diffused specialisation); furthermore, a firm that belongs to one industrial sector in the stock exchange can also invest in technological fields that are far from such sectoral classification. This is for example the case of Siemens Company, which is classified under the Electric and electronic equipment sector, invests very much in R&D in other technological fields (sectors) such as wind turbines (Alternative energy) and medical imaging systems (Health care equipment)[72].

To measure firms' technological specialisation, we examined the portfolio of patent applications of the 1000 top world R&D investors in the year 2013 (EU R&D Scoreboard, 2014 edition) and considering the OECD-European Commission (2015) database[73]. Patent data of EU R&D Scoreboard firms have been built using the ownership structure of companies and considering those patents filed over 2010-2012 at European patent office (EPO) and at the US Patent and Trademark Office (USPTO) during 2010-2012[74].

The choice of analysing a relatively short period of time (three years) is driven by lack of information about the pre-2013 corporate structure of top R&D performers: overall, the top R&D investors considered had several thousand of 'controlled' subsidiaries (defined as firms owned for more than 50% by the parent) in 2013. As Dernis *et al.* (2015) suggest, the ownership structure of such EU R&D Scoreboard companies over two-three years remains similar and the related statistics based on this period of time provides an accurate picture of their patent-related activities, while the same might not be true if longer time frames were to be considered.

The INPADOC (as adopted by EPO and the world intellectual property office - WIPO)[75] technological classification of patent families has been used. Using the concordance between International Patent Classification (IPC) classes and the technologies (WIPO, 2013; Dernis *et al.,* 2015), the technology classes where the patents are filled were grouped in 35

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[72] Source: Siemens (2015): http://www.siemens.com/press/en/events/2015/corporate/2015-11-innovation.php

[73] To access the EC-JRC/OECD COR&DIP© database, v.0. 2015: Access to COR&DIP©

[74] Methodological specifications are described in Dernis et al. (2015), pp 20-25.

[75] https://www.epo.org/searching-for-patents/legal/inpadoc.html#tab1

technological fields. These 35 technological fields can be in theory held by each of the ICB-3 industrial sectors.

Nine hundred and one companies out of 1000 top world R&D investors in the year 2013 resulted to hold patent applications. The distribution of the 901 companies with patents filled in by world region is the following: EU 214; US 309; Japan 167; Asian Tigers 57; China 37; RoW 117. The remaining 99 without a patent filled in are mainly from the USA (17) and UK (14).

The R&D Revealed Comparative Advantage (R&D_RCA) index introduced in the previous sub-section was adapted for calculating the *Technology Revealed Comparative Advantage - TECH_RCA* - based on the mentioned patents data and technological classification by country/wold region in 2013.

Table 3.Share of patents applications in a particular technological field relative to the share of the global patents applications in all technological fields in different countries/regions (Technology Revealed Comparative Advantage index) in 2013

TECHNOLOGY FIELD	EU	US	Japan	Asian Tigers	China	Rest of the World
Electrical machinery, apparatus, energy	0.89	0.58	1.17	0.99	0.88	0.86
Audio-visual technology	0.50	0.73	1.15	1.70	0.95	0.67
Telecommunications	0.62	0.90	1.04	1.57	2.66	0.87
Digital communication	0.78	1.09	0.88	1.75	4.82	0.81
Basic communication processes	0.62	0.89	1.11	1.33	0.79	0.80
Computer technology	0.63	1.28	0.96	1.44	0.80	0.87
IT methods for management	0.88	1.82	0.73	1.27	0.58	1.16
Semiconductors	0.59	0.80	1.16	1.34	0.82	0.61
Optics	0.58	0.81	1.16	1.18	1.09	0.69
Measurement	1.19	1.09	0.95	0.67	0.62	1.31
Analysis of biological materials	1.58	1.77	0.55	0.44	0.56	2.71
Control	1.01	0.88	1.07	0.75	0.31	1.12
Medical technology	1.63	1.88	0.63	0.33	0.63	1.35
Organic fine chemistry	2.39	1.55	0.53	0.18	0.35	1.92
Biotechnology	1.70	2.01	0.47	0.33	0.55	2.61
Pharmaceuticals	1.72	2.12	0.38	0.17	0.30	3.44
Macromolecular chemistry, polymers	1.75	1.12	0.88	0.48	0.47	0.78
Food chemistry	1.74	2.05	0.42	0.08	0.05	3.39
Basic materials chemistry	1.99	1.37	0.73	0.26	0.32	1.17
Materials, metallurgy	1.34	0.69	1.09	0.46	0.51	1.01
Surface technology, coating	1.09	0.88	1.05	0.84	0.66	0.86
Micro-structural and nano-technology	1.09	1.21	0.82	1.34	3.68	0.99
Chemical engineering	1.66	1.11	0.83	0.56	0.70	1.40
Environmental technology	1.38	0.69	1.12	0.33	0.30	0.80
Handling	1.50	1.01	0.92	0.49	0.54	1.32
Machine tools	1.55	0.98	0.93	0.54	0.17	1.18
Engines, pumps, turbines	1.44	0.87	0.98	0.30	0.17	1.67
Textile and paper machines	0.72	0.80	1.29	0.27	0.49	0.35
Other special machines	1.79	1.03	0.89	0.43	0.35	0.92
Thermal processes and apparatus	1.27	0.61	1.11	0.84	0.40	0.70
Mechanical elements	1.56	0.71	1.03	0.61	0.25	0.90
Transport	1.10	0.47	1.27	0.34	0.14	0.61
Furniture, games	1.87	1.36	0.56	1.09	0.29	2.42
Other consumer goods	1.54	1.24	0.72	1.70	0.41	0.97
Civil engineering	1.16	2.76	0.44	0.35	0.43	1.70

Source: Own elaboration. Note: the highlighted cells correspond to sector specialization.

The result is shown in Table 3 which reveals that there is an even more diffused technology specialisation in EU compared to R&D industrial (sectoral) specialisation. This in part is also the case for the USA, but not for the Japanese group of companies. Interesting to note is that US companies show highest technological specialisation not only in the expected fields (i.e., ICTs, Biotech, …), but also in others like Food chemicals.

While Table 3 allows seeing in which technological fields EU R&D Scoreboard companies are specialised and in which they are not, Table 4 shows the number of technological fields only in which the region/country is specialised within each industrial sector (ICB-3). It also reports the average TECH_RCA index of the fields that belong to a given industrial sector and country/region. The technological fields that did not reach the TECH_RCA index's unit were dropped from the calculation of the country/region average specialisation.

A high number of technological fields within a given industrial sector (ICB-3) in Table 4 is thus a strong signal of a country/region with high technological specialisation which in addition is highly diversified because the patents from firms in the specific industrial sector cover a broader range of technological fields/applications in the sector compared to patents from firms from different countries/regions in the same industrial sector. The TECH_RCA index average provides additional information on this as it indicates the comparative strengths of such technological specialisation in the given industrial sector. Therefore, Table 4 allows appreciating the degree of technology specialisation within a given industrial R&D sector, as well as the differences between the technology specialisation of Table 3 and the industrial R&D sector specialisation of Table 2 (sub-section 4.2).

The results show a quite expected general technology specialisation, in line with the industrial R&D sector specialisation emerged from section 4.2.

There are, however, some interesting aspects that arise especially related to the triad. First, the EU, USA and Japan hold the highest and the broaden technology specialisation by industrial sectors worldwide, China and Asian Tigers follow by very far. The rest of the world group denotes a high specialisation is some utility sectors, but also in other high-tech sectors as mobile telecommunications. Second, there are some unexpected technological fields of specialisation in industrial sectors as in the case of Software and computer services in Japan which holds in this sector much more technological fields of specialisation than the US, with a much higher average of specialisation index. Other similar cases are for example the Pharma and biotech sector in the EU and Japan compared to the US. This phenomenon holds when pharma and biotech subsectors are analysed separately: pharma companies patent in more fields than the biotech ones (i.e. there could be heterogeneity within the same sector at a higher level of aggregation). It could be also due to the difference between the country where the company is based and the country where the R&D is executed and the patent office where the patent is filled / submitted.

Finally, the USA leads in most of the industrial sectors it specialises by number of technological fields, while the EU has a more diffused high technology specialisation across industrial sectors. The general more broadened specialisation in industrial sectors by technological fields compared to Table 2 of sub-section 4.2 is probably due to the fact that the same patent field can be filled in different industrial sectors for different applications[76].

[76] It worth mentioning that different quality of patent systems influence the patenting and licencing behaviour of innovative firms (Saint-Georges and van Pottelsberghe de la Potterie, 2013).

Table 4. Number of specialised technological fields and mean of specialisation (TECH_RCA index) grouped by industrial sectors and country/region

INDUSTRIAL SECTORS	EU		USA		Japan		Asian Tigers		China		Rest of the world	
	No. of Fields	mean Spec.	No. of Fields	mean Spec.	No. of Fields	mean Spec.	No. of Fields	mean Spec.	No. of Fields	mean Spec.	No. of Fields	mean Spec.
Aerospace & Defence	13	1.42	18	1.38	0	NA	0	NA	0	NA	15	1.45
Alternative Energy	18	1.17	13	3.93	0	NA	0	NA	0	NA	0	NA
Automobiles & Parts	15	1.34	21	1.48	19	1.17	16	1.38	10	2.05	8	1.75
Banks	18	1.51	0	NA	0	NA	0	NA	0	NA	17	1.22
Beverages	11	5.21	9	5.24	23	1.07	0	NA	0	NA	0	NA
Chemicals	20	1.64	21	1.70	14	1.18	11	2.63	0	NA	13	2.56
Construction & Materials	22	1.62	11	2.73	13	1.19	0	NA	16	2.93	6	4.26
Electricity	19	2.43	0	NA	17	1.14	10	1.98	0	NA	3	9.27
Electronic & Electrical Equipment	20	2.18	17	3.65	18	1.08	12	1.30	6	3.27	14	1.46
Financial Services	2	7.99	23	1.13	0	NA	0	NA	0	NA	12	4.31
Fixed Line Telecommunications	7	1.76	19	6.04	21	1.17	7	2.35	6	9.46	5	2.50
Food & Drug Retailers	14	1.09	0	NA	0	NA	0	NA	0	NA	3	8.34
Food Producers	9	2.11	8	2.66	23	1.55	0	NA	0	NA	13	1.89
Forestry & Paper	16	3.90	0	NA	19	1.10	0	NA	0	NA	0	NA
Gas, Water & Multi-utilities	20	1.12	13	2.56	12	4.38	0	NA	0	NA	0	NA
General Industrials	20	2.39	22	2.01	13	1.09	9	5.41	14	5.67	21	4.86
General Retailers	12	11.02	12	1.07	0	NA	0	NA	0	NA	10	18.74
Health Care Equipment & Services	17	1.57	22	1.34	8	1.75	0	NA	0	NA	4	2.15
Household Goods & Home Construction	5	2.14	29	1.23	0	NA	0	NA	0	NA	8	2.30
Industrial Engineering	16	1.53	21	1.64	15	1.49	7	1.99	13	2.91	10	1.86
Industrial Metals & Mining	17	3.57	9	5.01	17	1.03	15	4.54	0	NA	6	6.30
Industrial Transportation	14	2.88	0	NA	0	NA	0	NA	21	1.18	0	NA
Leisure Goods	12	5.56	12	3.51	20	1.09	11	2.18	0	NA	11	2.56
Life Insurance	0	NA	0	NA	0	NA	0	NA	0	NA	10	1.00
Media	8	2.15	19	1.21	18	3.60	0	NA	0	NA	4	2.52
Mining	0	NA	0	NA	0	NA	0	NA	0	NA	35	1.00
Mobile Telecommunications	0	NA	9	2.69	0	NA	0	NA	0	NA	26	1.07
Nonequity Investment Instruments	0	NA	0	NA	24	1.00	0	NA	0	NA	0	NA
Nonlife Insurance	0	NA	0	NA	0	NA	0	NA	0	NA	6	1.00
Oil & Gas Producers	10	1.43	17	2.56	16	1.54	10	2.66	8	3.16	13	2.86
Oil Equipment, Services & Distribution	14	3.11	7	1.26	0	NA	26	2.21	11	6.23	0	NA
Personal Goods	7	3.05	18	2.21	16	1.29	6	6.44	0	NA	8	4.08
Pharmaceuticals & Biotechnology	17	1.46	13	1.18	16	2.94	5	1.75	0	NA	12	1.81
Real Estate Investment & Services	0	NA	0	NA	0	NA	0	NA	0	NA	3	1.00
Software & Computer Services	18	2.03	8	1.37	23	1.24	3	33.98	0	NA	8	3.53
Support Services	9	2.71	7	11.55	24	1.15	0	NA	0	NA	6	7.65
Technology Hardware & Equipment	9	1.36	24	1.15	23	1.50	6	1.30	4	1.82	5	1.89
Tobacco	0	NA	14	3.68	20	1.08	0	NA	0	NA	8	4.50
Travel & Leisure	11	3.93	6	3.65	27	1.23	0	NA	0	NA	5	2.99

Source: Own elaboration. Note: Only specialised field (i.e. TECH_RCA > 1) are reported. Sectors are at ICB-3 digit level. Highlighted cells in green indicate the strongest comparative specialisation, while in salmon colour are the values indicating an appreciable high specialisation.

4.4 Country differences in private R&D investment capacity

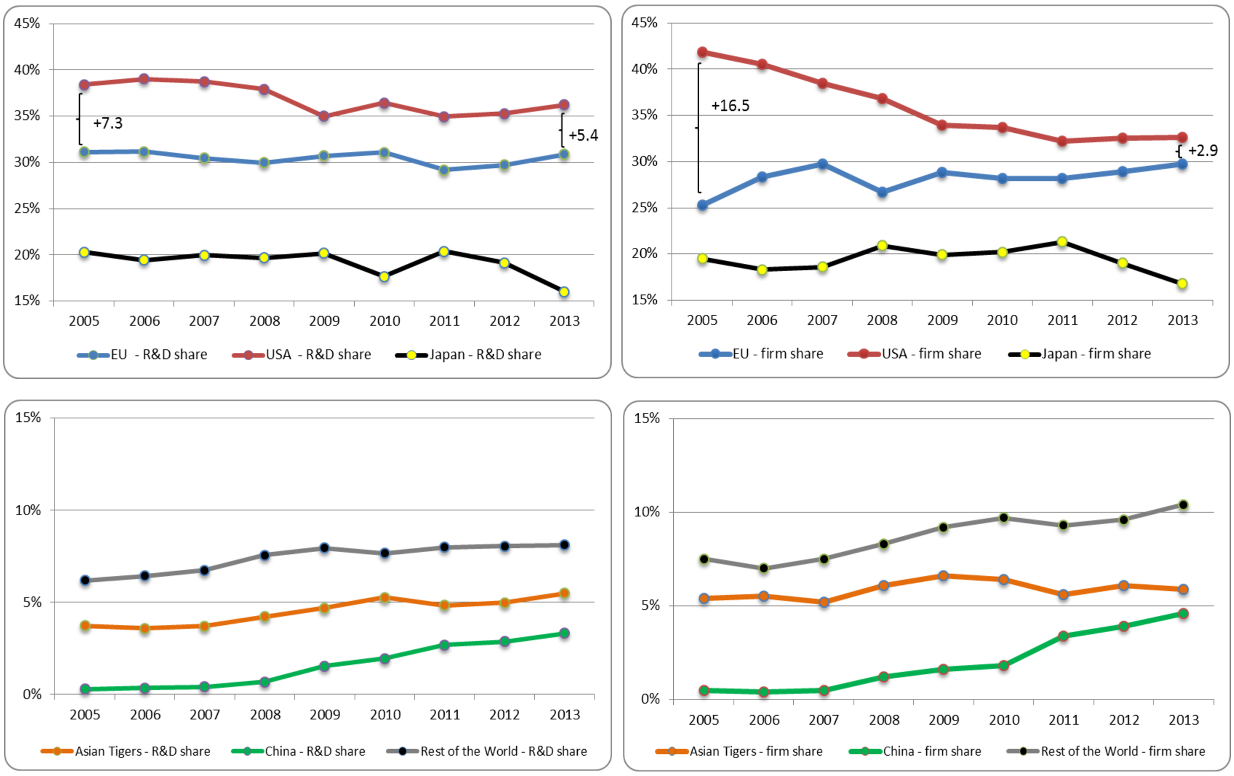
Given the sectoral pattern discussed above, the general argument that economies moving towards more R&D-intensive sectors are expected to also increase their overall R&D investment capacity does not seem to provide us with a clear expectation on the relative performances of the economies considered. 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 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 the 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.

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).

Figure 2. Shares by economic area: R&D investment (left) and number of firms (right), 2005-13



Source: Own elaboration

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).

4.5 R&D investment growth performance of firms across sectors

This subsection investigates the effects of R&D, fixed capital and profit intensities on R&D investment growth of the firms across sectors and by their combined R&D growth and age characteristics.

The literature reviewed suggests that **R&D investment** can foster **technical change, sectoral dynamics and competitiveness** (section 2.1 and 2.2). Moreover, according to one stream of the recent literature **young leading innovators**, particularly in high-tech sectors, play a pivotal role in countries' R&D performance (section 2.3), as newer (smaller) firms have their own strategic incentives to invest in R&D at higher levels than incumbents.

In so far, **this paper has shown** that countries/regions differ when considering both sectoral R&D dynamics (section 4.1) and sectoral specialisation (section 4.2), especially when comparing EU and US. However, such dissimilarities are not reflected in the overall R&D investment trends, which remain quite stable along time (see EU vs US in section 4.4).

Together we find a weak link between sectorial dynamics and aggregate R&D investment patterns. It is therefore of interest to directly look at the two dimensions discussed earlier when reviewing the literature: R&D investment growth and the age at the micro-level, besides the traditional sectoral classifications. **What factors affect firms' R&D growth performance across sectors? Are these different across firm age classes?**

To answer to this question we first **group firms according to their relative R&D growth between 2010 and 2013 and their age**. Data are drawn from the top 2000 R&D corporate investors as reported in the 2014 EU R&D Scoreboard, we rely to the latest full panel available in order to increase the number of observations and to exploit the time dimension in our analysis[77]. In particular, we group firms according to two main characteristics: those with an R&D growth above (below) the sample average[78] and the age above (below) the sample average[79]. The partitioning give rise to four groups of firms as reported in Table 5. The groups are built by taking the average growth of each firm from 2010 to 2013.

Table 5.Groups with combinations of firms above and below the average of age and R&D investment growth (2010-2013)

Average R&D growth

Average age

	HG *(High R&D investment Growth)*	*LG* *(Low R&D investment Growth)*
young	"**Greyhounds**"	"**slow Yorkshires**"
old	"**fast Labradors**"	"**Neapolitan Mastiff**"

Acknowledging the heterogeneity of firms within sectors and across them (ref.: section 2.3), the characterisation of firms belonging to these four groups is strived hereafter.

"**Greyhounds**" (28.1 % of the sample; e.g.: Sap, DE; Google, USA; Edenred, FR) are typically young firms that either are earlier entries in new high-tech sectors and / or those that invest in R&D at higher levels to be able to enter and compete in more established sectors.

"**Slow Yorkshires**" (33.7 % of the sample; e.g., Sumco, JAP; Dong, DK; Qisda, Taiwan) are typically these younger firms encountering financial constraints or that are exploiting their improved efficiency in R&D investment.

[77] We limit the analysis of R&D growth to the 2010-2013 period. In fact, four years is a sufficient business time span to robustly answer our research question, and the 2010-2013 period avoids considering the first effects of the financial crisis, which can blurred the relationships under scrutiny. To implement the estimates, we rely on a cross-section data with more than 1,530 observations after filtering for missing data from the initial 2000 top R&D investing firms.

[78] The average of R&D growth rate between 2010 and 2013 is 33.9 % (in line to the average annual rate of 7%).

[79] The average age of the firms is 45 years between 2010 and 2013 (median, 27 years).

"**Fast Labradors**" (7.3 % of the sample; e.g. Volkswagen, DE; SNAM, IT; Barklays, UK) are established firms that after an economic/financial downturn are recovering their former level of R&D or/ need to invest higher levels of R&D because are in a transformative innovation process, i.e., the so called firm's *structural upgrading* (ref.: section 2.1).

"**Neapolitan Mastiff**" (30.9% of the sample; e.g.; Vattenfal, SK; Upm-Kymmene, FI; China Railway, China) represent the mature firms in traditional sectors which do not feel that have to grow in R&D investment because not justified by the expected returns, or because enjoy their dominant position as well as their high appropriability and cumulativeness and high economy of scale in the exploitation of R&D results (ref.: section 2.3).

In a second step we run **a multinomial logit regression model** to estimate in a *cross-section* of data the probability that a given company belongs to the four groups identified. In particular, we are interested in the extent to which capital intensity, R&D intensity and profitability influence these probabilities. The reason justifying this choice is the theoretical Schumpeterian-based (Shumpeter, 1942) virtuous circle starting with 1) Knowledge & new technology generation, which is able to open new (successful) markets and to 2) improve firm's productivity (Romer 1990; Griliches, 1988 and 2000; Mohnen and Hall, 2013) , this in turn causes 3) the rise of profits Hall *et al.,* 2010); higher profits make available additional financial resources which are then 4) (re-)invested in knowledge (Grabowski and Mueller, 1978; Amoroso *et al*., 2017).

In a multinomial framework, the probability to belong to a specific group is estimated with respect to a reference category (base) and can be written as:

$$\ln\frac{P(y_i = g)}{P(y_i = base)} = \alpha_g + \beta_{g1} cap\_int_i + \beta_{g2} rd\_int_i + \beta_{g3} prof\_int_i + \delta_g ind + \gamma_g country + u_1$$

where the main variables are capital intensity, R&D intensity and profitability (following the approach of Tang, 2006; Brenner and Schimke, 2015). Moreover, we include a set of industry fixed effects and control for countries/regions differences. The LG & older group has been used as baseline in the estimates, an average variance inflation factor (VIF) of 1.10 indicates that there are no multicolinearity issues. It should be noted that growth groups are built on the 2010-2013 R&D dynamics, where the regressors are levels of the variables considered for the 2010 as it allows to observe the changes in subsequent years following the initial one; this 'growth regression framework' rules out endogeneity issues.

Table 6 reports the **regression results** of three different specifications including an increasing number of explanatory variables.

Table 6. Multinomial regression for probability of belonging to a specific R&D growth/age group.

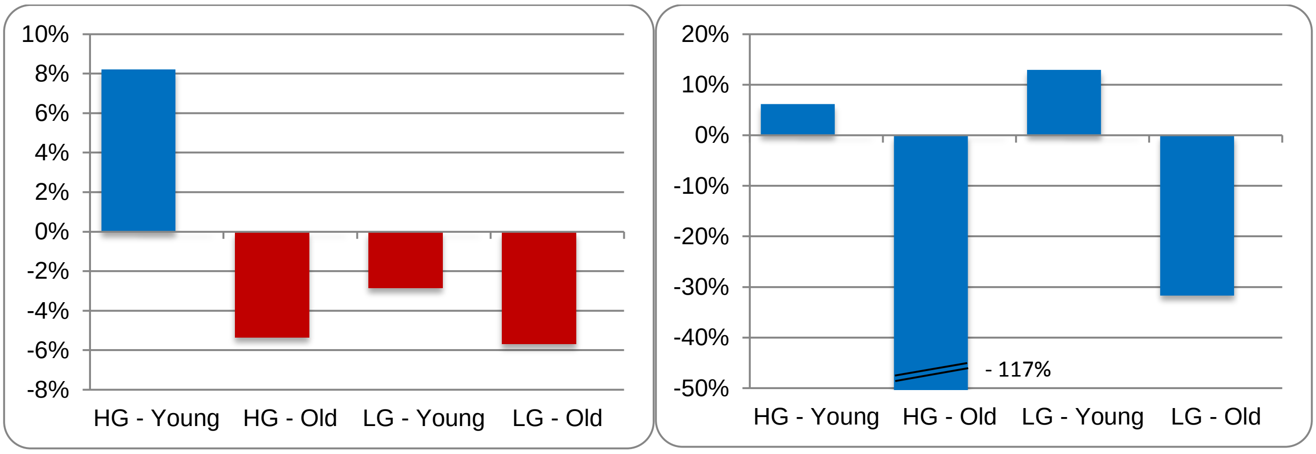
	Baseline group = LG old			Baseline group = LG old			Baseline group = LG old		
	HG_young	HG_old	LG_young	HG_young	HG_old	LG_young	HG_young	HG_old	LG_young
Capital intensity	9.147**	-0.891	3.368	7.870**	0.663	1.792	8.273**	0.201	1.685
	(3.943)	(6.342)	(3.927)	(3.821)	(5.933)	(3.887)	(3.921)	(6.052)	(3.978)
R&D intensity				17.900***	-37.336***	19.573***	16.573***	-37.157***	19.541***
				(4.626)	(14.253)	(4.575)	(4.784)	(14.314)	(4.713)
Profitability							-0.255	1.690	-0.166
							(0.430)	(1.406)	(0.431)
Asian Tigers as baseline									
China	16.298	28.643	15.270	16.156	28.817	15.119	15.927	28.289	14.874
	(692.821)	(1,423.138)	(692.821)	(697.204)	(1,398.285)	(697.204)	(616.495)	(1,230.231)	(616.495)
EU	-2.393***	14.650	-1.740***	-2.611***	14.996	-1.985***	-2.577***	14.709	-1.986***
	(0.539)	(1,243.109)	(0.509)	(0.542)	(1,212.067)	(0.513)	(0.542)	(1,064.614)	(0.513)
Japan	-4.497***	13.421	-3.330***	-4.649***	13.758	-3.529***	-4.615***	13.530	-3.533***
	(0.601)	(1,243.109)	(0.517)	(0.603)	(1,212.067)	(0.521)	(0.603)	(1,064.614)	(0.521)
Rest of the World	-0.520	15.018	-1.274**	-0.664	15.226	-1.440***	-0.637	14.892	-1.438***
	(0.563)	(1,243.109)	(0.551)	(0.564)	(1,212.067)	(0.552)	(0.564)	(1,064.614)	(0.552)
USA	-0.807	13.887	-0.939*	-1.143**	14.236	-1.322***	-1.116**	13.933	-1.322***
	(0.525)	(1,243.109)	(0.506)	(0.530)	(1,212.067)	(0.512)	(0.531)	(1,064.614)	(0.512)
Industry fixed effects[80]	*0.000****	*0.000****	*0.000****	*0.000****	*0.000****	*0.000****	*0.000****	*0.000****	*0.000****
Constant	-1.047	-15.739	0.516	-0.725	-16.024	0.887	-0.764	-15.919	0.929
	(1.115)	(1,243.109)	(0.987)	(1.107)	(1,212.067)	(0.979)	(1.116)	(1,064.614)	(0.985)
Observations	1,540	1,540	1,540	1,540	1,540	1,540	1,537	1,537	1,537
LR chi^2	888.7	888.7	888.7	938.9	938.9	938.9	939	939	939
Pseudo R^2	0.226	0.226	0.226	0.238	0.238	0.238	0.239	0.239	0.239
Log-Likelihood	-1525	-1525	-1525	-1500	-1500	-1500	-1496	-1496	-1496

*Standard errors in parentheses - *** p<0.01, ** p<0.05, * p<0.1 - Industry fixed effects reports the result of an F-test on ICB3digit industrial dummies jointly equals zero.*

Giving that the results of multinomial logistic regressions are not straightforward (coefficients report differences with the baseline), in Figure 3 we also report **the resulting elasticities** for each of the groups considered.

[80] Industry fixed effects reports the result of an F-test. The STATA results report 3 decimals places of accuracy for the P-value. Therefore, a value of 0.000 means that the P-value is less than 0.0005. This leads to the decision that the null hypothesis of a zero coefficient can be rejected at any reasonable significance level (such as 0.10, 0.05 or 0.01).

Figure 3. Elasticity of capital intensity (left) and R&D intensity (right) by R&D growth/age groups



Note: *red bars indicate that the estimated elasticity is not statistically significant*

The **analysis of econometric results** can be summarised as follows:

i. The effect of *profitability* does not seem to be statistically significant. This could be due to the fact that the sample is made of top R&D investing firms in which their R&D investment is less volatile than profitability because of internal constraints, such as the cost of research personnel and infrastructure and the need to face competition in the innovation field (Gharbi *at al*., 2014).

ii. The effect of *capital intensity* is positive and significant for the younger & faster R&D growing firms ("Greyhounds"). This suggests that capital intensity is important for Greyhounds firms, and that such top R&D companies treat fixed capital and R&D as complementary types of investments. In fact, firms can innovate by investing either in R&D or fixed capital which often involves buying in innovation from outside. Such argument confirms the finding of Ciupagea (2005) and underlining the strategic investment choice the firms should face (Castellani, *et al.* 2016)[81].

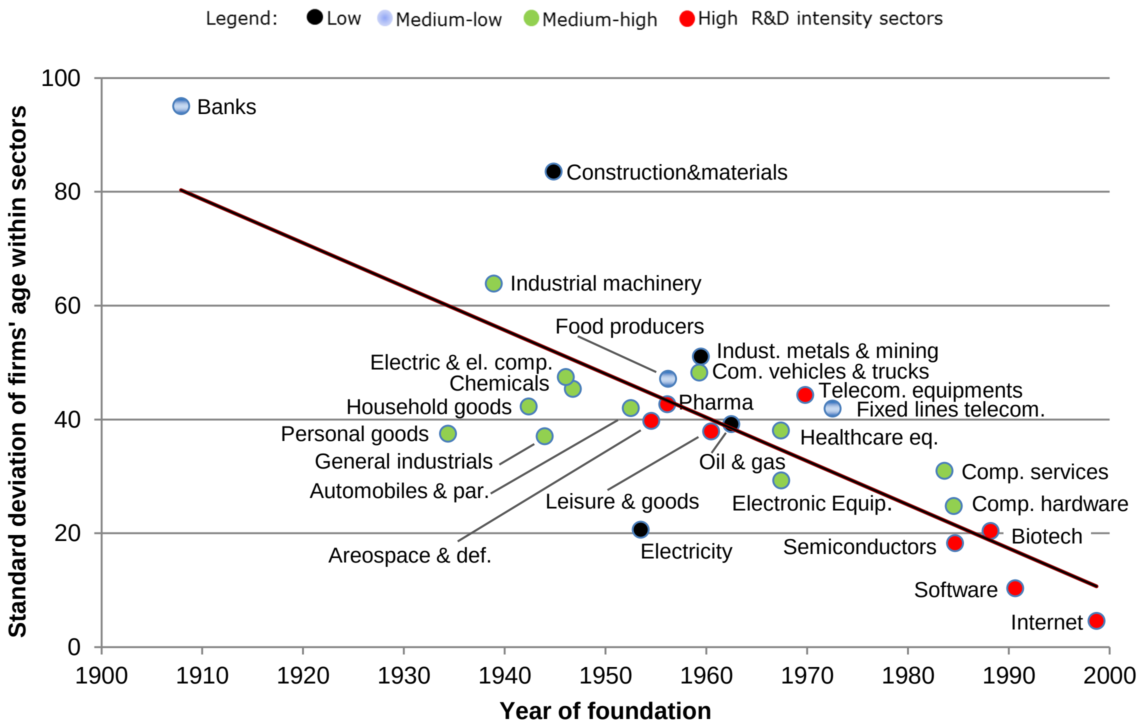
iii. The effect of *R&D intensity* on R&D investment growth is always statistically significant, but the positive (negative) signs are associated to the younger (older) firms to the two (higher or lower) R&D investment growth paths. This result indicates that R&D intensity is much more related with the age of the firms than to subsequent R&D investment growth. Such outcome suggests that the youngest firms may be concentrated in the new high R&D intensity sectors, i.e., Internet, Software, Biotech and Semiconductors -, all these sectors are high-R&D intensive and all of them are led by US firms (Moncada-Paternò-Castello, 2017a).

iv. *Countries differences* are notables, with the Japan and the EU firms less performant that US and Asian Tigers (baseline). This could reinforce the previous findings, as the effects reflect the differences in the age classes between the mentioned countries (Asian Tiger the youngest, Japanese the oldest).

[81] This is also explained because, despite their moderated economies of scale in R&D activities, higher R&D investment causes higher profit returns than for established (incumbent) firms, and also because it could be the only way to compete with incumbents and displace them (Schumpeter, 1934 - Mark I theory- , Meza and Tombak, 2009; Matsumura and Matsushima, 2010; Schneider and Veugelers, 2010).

Figure 4 reports the age differences across industrial sectors **helping to complement the econometric finding disentangling the *industrial effects* on firms' R&D growth performance by observing, as expected, that younger firms are concentrated in the newer *high R&D intensity* sectors** as suggested earlier in point iii.

Figure 4.Average year of sectors (by top R&D firms) and their variation



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 reports the sectoral average year of foundation of top R&D investors disaggregated at ICB-4 digit level for some sectors (horizontal axis) versus its standard deviation. It reveals a high degree of heterogeneity of firms' age across sectors.

As expected, the average year of top R&D investors in recent technologies-based sectors, i.e., Internet', 'Software' and 'Biotechnology', is the lowest of the sample considered. In fact, new firms have a key role in developing technological breakthroughs and in creating new technology-based sectors and markets. In contrast, large established firms are less dynamics in such novel technological and sectoral development.

Figure 4 also shows that other traditional sectors, as the 'Banks', 'Construction and materials' and 'Industrial Machinery' combine high values of average firm age with high firm age heterogeneity within-sector (more details can be found in Table A2 in the Annex). For the first mentioned sector, such heterogeneity is mainly due to the abundant mergers in the recent years, and for the second mentioned sector largely because of the emergence of new Chinese firms in this sector.

Observing the sectors with the younger average years of foundation in Figure 4, 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.

In sum, firms make a complementary use of capital expenditures and R&D intensity for their R&D investment growth strategies, and there are differences in their use between firms' age classes across sectors. Younger firms are able to better exploit (or more in need of) than older firms their capital expenditure in their high R&D growth, while they better exploit their R&D intensity in both higher and lower R&D growth. This result could also indicate a simultaneous phenomenon - or an alternative different cause - in which established large firms with relatively low R&D intensity have increased their R&D investments as much as their more R&D intensive counterparts. In these years without major breakthroughs, there is a general increase in R&D investment across industries and companies, as higher competitiveness moves forwards the knowledge/technological frontier faster than in the past.

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, and the response to competitiveness threats by mature established companies fully exploiting their R&D investment capacity and efficiency. Therefore, such competitiveness tensions drive at the same time the sectoral dynamics and the firms' R&D investment growth strategies.

5. Conclusions

This paper provides a new analysis of the sectoral dynamics of the major economies during the last decade through the lens of the top R&D investors worldwide, and it also looks at their drivers for R&D investment growth across sectors and firms' age groups. In doing so, indirectly complements the literature on the EU corporate R&D intensity gap.

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. Besides, 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. The analysis of the firms' patent portfolio suggests a broaden technology specialisation by patents' application in a large number of sectors by the Triad.

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.

As we find a weak link between sectorial dynamics and aggregate R&D investment patterns, the R&D investment growth and the age at the micro-level have been also investigated besides the traditional sectoral classifications. As original contribution to the literature, this research has found that younger firms are able to better exploit than older firms their capital expenditure while they are in high R&D growth patterns, while younger firms rely on R&D intensity in both higher and lower R&D growth paths. As expected, that there is a sectoral (industrial) effect on firms' R&D growth performance, as younger firms are concentrated in the newer high R&D intensity (growing) sectors[82].

These findings reveal that to achieve a more positive R&D investment dynamics, the EU should aim at a different sector mix with larger presence of younger firms in new(er) R&D-intensive sectors. This would have the effect of reducing both the EU R&D investment and the R&D intensity gaps vis-à-vis its main competitor(s).

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. What really matters is the competitiveness of firms, in which their R&D investment growth strategies together with their capacity to turn innovation into value added plays a key role. The open question is whether the present EU industrial R&D and competitiveness model is sustainable in the long run.

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[82] This result also confirms the findings of Cincera and Veugelers, 2013 who indicate that young leading innovators, particularly in high-tech sectors, play a pivotal role in countries' R&D performance, as newer (smaller) firms have their own strategic incentives to invest in R&D at higher levels than incumbents (Schumpeter, 1934).

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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 are 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 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

Summary of output

1. Main results

The results of the research conducted in the framework the Thesis clearly show (ref.: **first paper** – i.e. the survey of theoretical and empirical issues of corporate R&D intensity decomposition studies) that R&D intensity as a policy target and the comparison between different characteristics of corporate R&D intensity ratios belonging to different economies should be handled with care, particularly with respect to the policy measures that result from such comparisons. For example, global corporate R&D funding can best be analysed using EU R&D Scoreboard data to interrogate the global R&D performance and economic competitiveness of European multinationals at the level of firms. BERD data are more accurate for territorial analysis of private R&D activities, although doesn't account for the outflow activities of the foreign affiliated companies in a given country. Furthermore, in the R&D intensity ratio, the denominator utilised in statistical macro- or meso- analysis by policy-makers is either GDP or value added, whereas corporate and financial analysts use firms' sales or value added to benchmark their competitiveness against peers at the corporate or product/service level.

Additionally, there is a key issue about the interpretation of corporate R&D intensity data. Examples have been given of the counter-cyclical or cyclical behaviour of companies depending on their level of competitiveness and distance from the technological frontier. Moreover, corporate R&D intensity does not capture the efficiency and effectiveness of R&D investment, nor the business/technological characteristics or strategy of firms.

One of the novelties of this study is the provision of a consistent theoretical framework of the determinants of corporate R&D intensity. Furthermore, this research for the first time systematically identifies, analyses and discusses in detail why the findings of different studies in this subject are divergent by inspecting data and methods used. Moreover, for each of the identified main items in the use of different data and methods which are accountable for dissimilar results, this study provides examples to show the magnitude of the impact they have in the R&D intensity decomposition results.

The main outcome of this study is the clear identification of why different studies come up with different results, despite most studies rely on very similar data and apply a similar method: when using BERD or ANBERD data, academic studies reveal that the sectorial composition (structural effect) is the main determinant of the EU business R&D intensity gap if the industrial structure of the economies are taken into account; otherwise, they indicate the intrinsic effect as main determinant; when using the EU R&D Scoreboard data, different studies always show that the structural effect is the main determinant.

It derives that, thanks to the result of this study, there should be no more doubts but that the EU R&D intensity gap is largely determined by its sectoral composition (i.e. the smaller size of R&D-intensive sectors in relation to other sectors within the EU). The study also suggests which data and methods should be better approached in decomposing corporate R&D intensity depending on the analytical aim and how much reliable the results are, and provides some hints for their interpretation.

Turning the attention to the **second paper** (on EU corporate R&D intensity gap) its research findings can summarised as follows.

(i) The extent the sector composition (the 'structural' effect) affects the aggregate EU R&D intensity gap

Firstly, the analysis shows that R&D investment and net sales growth rates remained steady for the EU sample during the period 2005-2013. The analysis also indicates that, in 2009, annual growth in corporate R&D investment suffered the effect of the economic and financial crisis in most regions/countries, apart from the EU. The effect of the crisis was most evident in the case of the USA, where recovery to the 2005 annual growth level was still proving difficult in 2013. Despite this, in the years considered, US companies show the highest R&D investment figures, followed by companies in the EU and Japan, as a result of which the USA led R&D investment in the high-tech sector group during these years.

Secondly, the R&D intensity gap between the EU and both the USA and Japan was found to be negative and due to the structural composition of the economy (in line with the findings of Moncada-Paternò-Castello et al. (2010) and Cincera and Veugelers (2013). However, the main reason for the widening of the EU intensity gap during the period 2005-2013 is the much larger growth in total net sales (especially in the low and medium-low tech sectors) of the EU compared to the US, which is greater than the growth difference between the respective regions/countries' total R&D investment.

The findings also found a negative gap held by BRIC countries compared to the EU and that in the years studied due especially to 'structural effects'. The EU has a negative gap compared to the RoW group (driven by the presence of Switzerland) due to 'structural effects'. Relative to the EU, the Asian Tigers show a negative R&D intensity gap in the first year and a positive R&D intensity gap in the last two years of observation, in all cases mainly due to 'intrinsic effects'.

(ii) The dynamics of the R&D intensity gap (including of its two main determining factors), and the sectors, countries and firms main responsible for the gap.

The third main finding is that the R&D intensity gap between the EU and its main competitors has in part widened in the last nine years (ratifying results by Duchêne *et al.*, 2011; Voigt and Moncada-Paternò-Castello, 2012; Veugelers, 2013). As an original contribution to the literature, this study indicates that the overall evolution of the R&D investment gap of the EU in comparison an increase in the negative gap with the USA, and a quite stable negative gap compared with Japan. Furthermore, the EU shows a decreasing positive R&D investment gap compared with the BRIC group of countries over the three years considered. The Asian Tigers have shifted from a negative R&D intensity gap in comparison with the EU in 2005 to a positive gap in 2009 and an even more positive one in 2013.

The fourth key finding is that in terms of the 'intrinsic effect' EU firms outperform all their competing economies, and even improve their comparative performance over the period of time examined, especially in comparison with firms from the USA, Japan and the BRIC countries. However, the structural effect outweighs the positive effect of EU corporate R&D investment effort (intrinsic effect) in comparison with all regions/countries considered. In this context, this study shows that within the high and medium-high intensity sector groups, EU firms in individual sectors often perform much better (in 2013, 10 out of the 14 sectors analysed) in terms of R&D intensity than US companies. As these findings are new in the literature, we also checked the robustness of the above results by implementing a decomposition of the R&D investment gap using a longitudinal balanced dataset (2005-2013) built from several editions of the EU R&D Scoreboard. This further analysis largely confirms and validates the main output of our investigation.

The fifth key finding of the paper, as novel contribution to the state of the art of the literature, is the identification of the sectors, countries and firms which are most "responsible" for the EU R&D intensity performances and the differences with the US group of firms. Technology hardware and equipment, Software & computer services, Pharma & biotech and Health care equipment & services account for the bulk of the negative EU structural R&D intensity gap. On the other hand EU automobile & parts sector counter-balance the negative structural effects of such sectors. Furthermore, France and UK, although they are the second and third larger EU countries in R&D investment, they have an industrial structure less concentrated in high-R&D intensity sectors. This has an overall (negative) impact in the aggregate EU R&D intensity gap. On the other hand, German firms contribute most positively to the overall R&D intensity of the EU because of their shares in both R&D and market shares in medium-high and high R&D-intensity sectors. There is a concentration in few EU and US companies by R&D intensity, R&D investment share and share of net sales which determine the aggregate intrinsic R&D effects in the EU vs US R&D intensity gap. The key top R&D firms in both economies and the four mentioned sectors are very much the same across the years considered without showing appreciable different growth paths within sectors. However the key difference is the number of top R&D investors present in such high-R&D intensity sectors, with US which sometimes duplicates or triplicates the number of the EU companies. This study found that there is a high heterogeneity distribution of R&D intensity of firms within the same sector, indicating the coexistence of firms with different R&D investment strategies and efficiencies. Furthermore, most of the firms within the selected sectors that were in the top and in the bottom of the R&D intensity ranking in 2005 remained unchanged in 2013.

A key analytical consideration is that the large share of R&D investment in the EU is held by few leading R&D countries with a R&D specialisation mostly in medium- and low-R&D intensity sectors. Other EU countries, even if are strong world economies (e.g. Italy, Spain), are lagging behind these EU R&D leaders. Linked to this fact is that EU holds a much lower number of companies than the USA in the four sectors that are key in the EU structural R&D intensity gap, resulting in considerable lower shares of net sales and R&D investment compared to the USA especially in Technology Hardware and equipment and in Software and computer services.

(iii) The distribution of R&D investment across top R&D-investing firms and groups of sectors dynamics in different world regions/countries

The sixth relevant finding is that, in the years considered, corporate R&D is asymmetrically distributed, differing significantly between EU and non-EU companies. Overall, the study confirms that the bulk of global private R&D investment is concentrated in high and medium-high sector groups (especially the pharmaceutical and biotechnology, technology hardware and equipment, and automobiles and parts sectors, and software and computer services), in a few countries/regions (especially the USA, the EU and Japan) and in a few companies, confirming our third research hypothesis. The trend analysis indicates a decreasing concentration for both number of companies and R&D investment share of the Triad and an overall rather stable share of R&D investment held by the four top sectors. Interestingly, R&D intensity is highly concentrated in a small group of the largest R&D-investing firms. These results largely confirm the findings of Ciupagea and Moncada-Paternò-Castello (2006), Moncada-Paternò-Castello *et al.,* (2010) and, in part, Reinstaller and Unterlass (2012), and show that US companies with high cumulative R&D intensity, as is typical of high-tech sectors (i.e. R&D intensity above 5 %), dominate the full range of R&D investment ranking. The analysis of the evolution of the cumulative average R&D intensity of the examined samples represents a novel contribution to the literature. It shows that the bulk of the smaller top US R&D investors improved their cumulative R&D intensity in 2013 with respect to 2005. In contrast, the one of the smaller top EU R&D investors remained largely unchanged. Moreover, this parameter continues to be lowest in the BRIC region, but in the Asian Tiger countries increased from 2005 to 2013.

Finally, the **third paper** (on R&D sectorial dynamics, specialisation and growth) complements the literature on the EU corporate R&D intensity gap.

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, this research finds 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. Besides, 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. The analysis of the firms' patent portfolio suggests a broaden technology specialisation by patents' application in a large number of sectors by the Triad.

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.

As it finds a weak link between sectorial dynamics and aggregate R&D investment patterns, the R&D investment growth and the age at the micro-level have been also investigated besides the traditional sectoral classifications. As original contribution to the literature, this research has found that younger firms are able to better exploit than older firms their capital expenditure while they are in high R&D growth patterns, while younger firms rely on R&D intensity in both higher and lower R&D growth paths. Moreover, the study confirms, as expected, that there is a sectoral (industrial) effect on firms' R&D growth performance, as younger firms are concentrated in the newer high R&D intensity (growing) sectors.

2. Conclusions and policy implications

a) The **first study** (the survey of literature on corporate R&D decomposition), points out at the relevance of the methodological approach and the interpretation of results which suggest that policy-makers and analysts should also rely on data from complementary sources when available. A more accurate approach to explore would be to compare the corporate R&D intensity performances of similar companies in different jurisdictions, as well as countries with comparable sectorial structure and overall economic performances, the accuracy of which would increase as more and better-quality data become available.

Therefore, the results of this study show that R&D intensity as a policy target and the comparison between different characteristics of corporate R&D intensity ratios belonging to different economies should be handled with care, particularly with respect to the policy measures that result from such comparisons. Generally, if deficient R&D intensity is intrinsic in nature, it could be remedied by policy-makers in a relatively short period. In contrast, if the R&D intensity problem is structural, resulting from sectoral composition, it is much less sensitive to governmental policy and broader and deeper longer-term measures will be needed.

b) The **second study** on the EU corporate R&D intensity gap, 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 2003, was based. It confirms that the reason for the EU R&D investment gap, especially relative to the USA, Japan and Switzerland, is mainly structural, and there have been no signs of the changes necessary to achieve the EU policy target for 2020 (van Pottelsberghe, 2008; Voigt and Moncada-Paternò-Castello, 2012).[83]

The findings of this study clearly show that EU companies have only a weak presence, in terms of market and R&D investment shares, in the high-tech sectors compared with their most direct competitors; most of these sectors have been created in the last few decades (e.g. biotech, software, internet) by new smaller R&D-intensive firms, as argued by Cincera and Veugelers (2013) and Moncada-Paternò-Castello (2010, 2017). However, the high heterogeneity distribution of R&D intensity of firms within the same sector found by this study, indicating the coexistence of firms with different R&D investment strategies and efficiencies should be duly considered by policy makers.

Therefore, when taking action to decrease the EU R&D intensity gap, policy-makers should not consider only horizontal policy options across all sector and firm typologies. Tailored policies that address the technology development and diffusions as well as barriers to entering (and/or creating of new high risk and oriented to solve societal problems) R&D and innovation-intensive sectors and smaller R&D-intensive companies (also favouring new/young entrants) should be also considered.

[83] Other sources of literature can help us to understand why this phenomenon occurs. Many authors suggest that dynamic changes in the structure of the economy and the associated company demographics with the socio-economic and policy framework conditions are the most important reasons. For example, Mathieu and Pottelsberghe (2010), Foray and Lhuillery (2010) and Moncada-Paternò-Castello (2010) argue that there have been more dynamic changes in the structure of the US economy than in the EU economy in the last two decades. The economy in the USA moved in favour of higher-R&D-intensity sectors in particular, in ICT-related sectors, to a larger extent than in the EU, and this, in turn, was a major contributor in the difference in overall R&D intensity between the EU and the USA.

This study shows that the EU corporate R&D investment mostly in medium-R&D intensity sectors (which dominated structure of the EU economy) is less sensitive to a global economic and financial downturn. Furthermore, larger European companies in lower and more traditional R&D intensity sectors (such as automobiles and parts and industrial engineering and machinery) have to be acknowledged for their capacity to compete (and lead) on a global level. Hence, EU policy measures should be also directed towards firms operating in less R&D-intensive sectors to enable them not only to carry quality R&D themselves but also to absorb R&D results from other, more R&D intensive, sectors. In doing so these companies will be better prepared to exercise a key leading role in the development process of the next technological generations and in the creation of the future knowledge-intensive industries.

c) The **third study** - which investigates the sectoral dynamics with the resulting sectoral and technological specialisations, and it also looks at their drivers for R&D investment growth across sectors and firms' age groups of top R&D firms - reinforces the previously suggested implications for research and innovation policy, and proposes some new ones.

That is, EU policies should also address the barriers to enter R&D-intensive sectors and consider identifying and targeting new promising R&D-intensive sectors (potentially more risky), favouring companies that enter (including smaller R&D-intensive companies and start-ups) and growth 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" along with the traditional focus on young innovative firms independently from the sector in which they operate.

The second and third study also show that the EU corporate R&D investment mostly in medium-R&D intensity sectors (which dominated structure of the EU economy) is less sensitive to a global economic and financial downturn. Furthermore, larger European companies in lower and more traditional R&D intensity sectors (such as automobiles and parts and industrial engineering and machinery) have to be acknowledged for their capacity to compete (and lead) on a global level. Hence, EU policies, if necessary, should be also directed towards established (large/medium) firms operating in less R&D-intensive sectors to enable them not only to carry quality R&D themselves but also to absorb R&D results from other, more R&D intensive, sectors. In doing so these companies will be better prepared to exercise a leading role in the development process of the next technological generations and in the creation of the future knowledge-intensive industries.

Such R&D policy strategy which combines the support of the emergence of new innovative sectors and of a mayor absorption capacity of mature firms would have the effect of reducing both the EU R&D investment and the R&D intensity gaps vis-à-vis its main competitor(s).

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. What really matters is the competitiveness of firms, in which their R&D investment growth strategies together with their capacity to turn innovation into value added plays a key role. The open question is whether the present EU industrial R&D and competitiveness model is sustainable in the long run.

Yet, 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.

3. Limitations and avenues for further research

There are some limitations and potential avenues for further extension of these three studies that are briefly indicated hereafter.

The first paper could be extended in the future to implement some additional computations work to further disentangle the statistical differences between data, ranging from the definitions of R&D to the methodologies to collect the information and the relative analyses output to unscramble even further to what the extent these differences affect the values and quality of any comparison.

The limitation of the second and third paper regards the data source. In particular, the country of the R&D investment actually expended could be different from the country where the office of the mother company is registered. To overcome this problem, future studies should consider combining data from the EU R&D Scoreboard with data from other sources.

Further researches in this field should consider addressing the shortage of good-quality data (e.g. should provide more complete micro-data – like firms of smaller size/SMEs and localisation of subsidiaries of MNEs -) that also allow homogeneous company and country comparability, the shortage of investigations relying on longer time series and on longitudinal (balanced) datasets, and full data of inflows and outflows of national business R&D expenditures.

Furthermore, the follow up of these studies could benefit from the study of the casual relationship and include more independent variables, as firm size, and controlling for other parameters as firm cash flow, and GDP variation. One additional avenue could be to implement a corporate R&D decomposition exercise for some industries at different levels of disaggregation (e.g. 2, 3 and 4) to investigate if and how much the decomposition result change (i.e., robustness check).

Moreover, there is a shortage of studies that include more independent variables (which may explain more accurately the determinants of sector composition and of intrinsic effects) and investigate the development of more sophisticated statistical and econometric models.

Another further research stream to explore would be to examine how (if) mergers & acquisitions, and the R&D policy measures impact the sector composition and its dynamics, together with the aggregate R&D intensity and the firms employment growth. Finally, it would worth studying how such R&D investment shift across sectors has impacted the firms' productivity and profitability.

Would be also interesting to investigate the reasons for the heterogeneity of R&D intensity of firms within the same sectors to understand if is due to methodological issues or to different business models.

Other analytical aspects to inspect are the reasons why the calculations relying on EU R&D Scoreboard data lead all the time to a structural effect as main determinant of the EU R&D intensity gap, and the study of the impact that tax regimes and subsidies have on corporate R&D intensity compared to the (un)favourable regulatory regimes of countries.

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