World Corporate Top R&D Investors:

Shaping the Future of Technologies and of AI

European Commission

OECD
BETTER POLICIES FOR BETTER LIVES

EUR 29831 EN

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Acknowledgments: The authors are grateful to Alessandra Colecchia (OECD), Fernando Hervás Soriano (JRC), Alexander Tübke (JRC), and Giuditta De Prato (JRC) for providing input and feedback throughout the development of the report.

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JRC117068

EUR 29831 EN

PDF	ISBN 978-92-76-09669-6	ISSN 1831-9424	doi:10.2760/472704
Print	ISBN 978-92-76-09670-2	ISSN 1018-5593	doi:10.2760/16575

Luxembourg: Publications Office of the European Union, 2019

How to cite this work: Dernis H., Gkotsis P., Grassano N., Nakazato S., Squicciarini M., van Beuzekom B., Vezzani A. (2019). World Corporate Top R&D investors: Shaping the Future of Technologies and of AI. A joint JRC and OECD report. EUR 29831 EN, Publications Office of the European Union, Luxembourg, 2019, ISBN 978-92-76-09669-6, doi:10.2760/472704, JRC117068

Foreword

In modern societies, innovation and new technologies are key to growth and development and to achieving more inclusive economies and societies. In the past decades, the development and adoption of new technologies across all sectors of the economy has been characterised by unprecedented speed, scale and scope of technological change. Some of these new technologies are so pervasive that they have the potential to affect every part of economies and societies. Artificial Intelligence (AI) is one such general purpose technology that seems set to play a key role in almost every aspect of our lives.

While very widespread and deep, ongoing changes are nevertheless difficult to fully understand. The prospect for opportunities seems huge but so do the challenges, and there is the risk that the future may bring undesirable consequences - at least for some parts of society - if technological change is not steered towards enabling inclusive and sustainable outcomes, nor follows internationally agreed ethical principles. AI is a typical example of a technology having the potential to profoundly improve our lives but also to create or widen disparities. Understanding the role of all players involved in and leading technological change, also in the private sector, is key to better understand ongoing and future developments and to steer them in a direction that enhances society.

This report brings together data on patents, trademarks and scientific publications of the world's top corporate R&D investors to shed light on the role of these key players in shaping the future of technologies, and of AI in particular. As for the two previous editions, this work results from the collaborative effort of the Joint Research Centre of the European Commission (EC-JRC) and the Organisation for Economic Co-operation and Development (OECD), two organisations committed to providing solid data and analysis in support of evidence-based policy making.

The target audience of this report is quite diverse: from the scientific community to industry representatives, from practitioners to policy makers. Its aim is to provide a useful source of data and analysis to all those interested in getting a better understanding of the scientific and technological activities of key industry players, particularly in the field of AI. Most of the data underlying the analysis presented in the report are made publicly available, in an effort to spur further analysis.

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Highlights

#1 In 2016, top corporate R&D investors' headquarters and subsidiaries appear concentrated geographically. China, Germany, the United Kingdom and the United States rank among the top five locations in terms of number of both headquarters and subsidiaries

#2 Companies in medium and high-tech sectors account for significant shares of the total workforce of top R&D investors, notably in 'Computer and electronics', 'Transport equipment' and 'Machinery'

#3 'Computers and electronics' and 'Transport equipment' appear among the top 5 sectors in terms of number of companies, R&D investment, patents, trademarks and scientific publications

#4 The top 2 000 corporate R&D investors own almost two thirds of patents filed at the largest 5 IP offices worldwide; basic and applied research in AI represent a key area of their innovation activities

#5 In 2016, a large proportion of top patent and trademark owners are headquartered in Asian economies, while companies based in the United States and in Europe lead in terms of scientific publications

#6 The degree of technological diversification varies across sectors, with firms in 'IT services' and 'Telecommunications' that emerge among the most specialized

#7 Top 50 performers in terms of basic research, applied research, and products and services developments differ:

→ 'Computers and electronics', 'Machinery' and 'Wood and paper' emerge as technological development-oriented sectors

→ 'Electricity, gas and steam', 'Pharmaceuticals', and 'Transport services' are relatively more science oriented

#8 More than 80% of patents owned by 'Scientific R&D' sector protect technologies relating to *Pharmaceuticals* and *Biotechnology*, suggesting a growing importance of (highly) specialised suppliers in medical sector. This is mainly driven by companies located in the United States

#9 The distribution of registered trademarks confirms the importance of developing digital related products for a wide spectrum of sectors

#10 The scientific publications of top corporate R&D investors focus on *Engineering*, *Computer Science* and *Medicine*

#11 Firms in business and transport services are among those developing more radical inventions, whereas companies in 'Pharmaceuticals' produce a substantial number of highly-cited articles

#12 Compared to the year 2012, in 2016 pharmaceutical companies increase their presence among the top 2000 corporate R&D investors, whereas the shares of companies in 'Computers and electronics' decreases

#13 A marked increase emerges when comparing the number of patents filed by corporate R&D investors in the 'Transport equipment' in 2012-14 and 2014-16, which suggesting a potential technological upgrading of the sector

#14 Compared to 2012, Japan and China appear to have broadened the number of technological fields in which they are specializing, thus approaching the greater technological diversification exhibited by Europe and the United States

#15 Companies in ICT sector are responsible for most of the AI-related technological developments of top corporate R&D investors worldwide: Most of these firms are located in Japan, China and Korea

#16 When it comes to Artificial Intelligence, top corporate R&D investors headquartered in Europe rank relatively higher in terms of basic research than in terms of applied research and innovation or product and service development

#17 The development of AI-related patents is concentrated in few sectors: almost 50% of AI patents are filed by companies in 'Computers and electronics'. Services sectors also account for high shares of AI related patents

#18 'IT Services' and 'Computers and electronics' account for about 70% of AI-related trademarks, while AI-related publications are more evenly distributed across sectors

#19 AI–related scientific developments, measured in terms of scientific publications, are more widespread across sectors than applied research (patents) and product/service development (trademarks).

#20 'Transport equipment' companies appear particularly active when it comes to advancing the science base related to AI

#21 AI is associated with multiple technological fields, which signals both its pervasiveness and its potential prominent impact. This is especially the case of scientific publications

#22 Patents, trademarks and scientific publications tell different stories about the geographical contribution to AI:

→ Patents in AI are mostly developed by inventors located in Asia

→ In terms of AI-related trademarks, Asian economies lose ground compared to the United States and the EU-28

→ Authors located in the United States produce the bulk of AI articles published by top corporate R&D investors

#23 International collaborations appear more common in publications than in patents. Furthermore, patents and publications related to AI seem to rely on relatively larger (international) networks of authors or inventors than in the developments occurring in other scientific and technological fields

#24 The 'Computer & electronic' sector is the only one where international collaboration related to the development of AI technologies is less frequent than for other technologies. In the 'Other business services', the share of AI-related patents developed by international teams of inventors is particularly high

1. Introduction

Artificial Intelligence (AI) is gaining visibility on the agenda of businesses and policy makers alike. The fast evolution of digital technologies and their widespread adoption has modified the way we interact, generate new knowledge and organise economies and societies. Mobility, cloud computing, social networking, sensor-nets and big data analytics are only some of the forms that the digital economy is taking and that are already part of our daily lives.

Machines performing human-like cognitive functions (e.g. learning, understanding, reasoning and interacting) – the core of what is understood as artificial intelligence – have the potential to further revolutionise our economies and to contribute to tackle global challenges related to health, transport and the environment, among others (OECD, 2017).

While most seem to agree or understand what AI is or does, and the term was already coined in 1950, clearly delimiting its boundaries is t an easy task. Measuring AI is still in its infancy and different researchers and institutions have recently proposed a number of measurement frameworks (see, for example, WIPO 2019, IPO 2019) which differ along a number of dimensions. The present report relies on the experimental measurement framework developed by the OECD in collaboration with the Max Plank Institute and the OECD-led IP Statistics Task Force (see Baruffaldi et al., 2019), which proposes an operational definition of AI encompassing both core developments and key applications.

Recent advances in the field have in fact fuelled the development of AI-related applications, transforming all sectors, both Information and Communication Technologies (ICT) - and non-ICT ones, and creating value that many are trying to appropriate (Baruffaldi et al, 2019). AI is by many considered as a technology that may bring about a major technological shift like the one triggered by the World Wide Web (WIPO 2019, Craglia et al., 2018). As such, AI is not only expected to have an impact on the (technological) competitiveness of economic actors, but also to change the way people think, act and interact among each other and with machines (Gomez et al., 2018).

While discussing the possible impact of AI on economies and societies is urgent, it remains outside the scope of the present work. Here the focus is on understanding the role that top corporate R&D investors – which represent key actors in the innovation space - are playing in the development and use of new technologies. In particular, the analysis first offers a general view of the broad technological and scientific knowledge generated by these companies, to gradually narrow down its focus and investigate top corporate R&D investors' innovative activities related to AI.

This report builds on information related to the sample of the 2000 world's top R&D investors in 2016 (Hernández et al., 2017). These data are linked to other data related to patents, trademarks and scientific publications belonging to these companies, to explore the new science, technologies and products introduced by world leading corporations in key markets. These are: China, Europe, Japan, Korea and the United States in the case of patents; Europe, Japan and the United States in the case of trademarks; the whole body of scientific publications from the Elsevier's Scopus® database.

This report, in its third edition, is a result of the long-lasting collaboration between the Joint Research Centre (JRC) of the European Commission (EC) and the Organisation for Economic Co-operation and Development (OECD). It reflects their joint effort to provide up-to-date comparable data and state-of-the-art indicators and analysis in support of an evidence-base related to key policy issues. The first-time data and statistics on the innovation output of the world's top corporate R&D investors presented here aim to help shedding light on the innovative strategies of top R&D investors worldwide, and the way they contribute to shape the development of future technologies.

The publicly available database accompanying this report is meant to allow for further analysis in support of evidence-based industrial and innovation policies (see *What's next* section at the end of this report).

Some key stylised facts are already presented in this introductory part of the report, to set the scene.

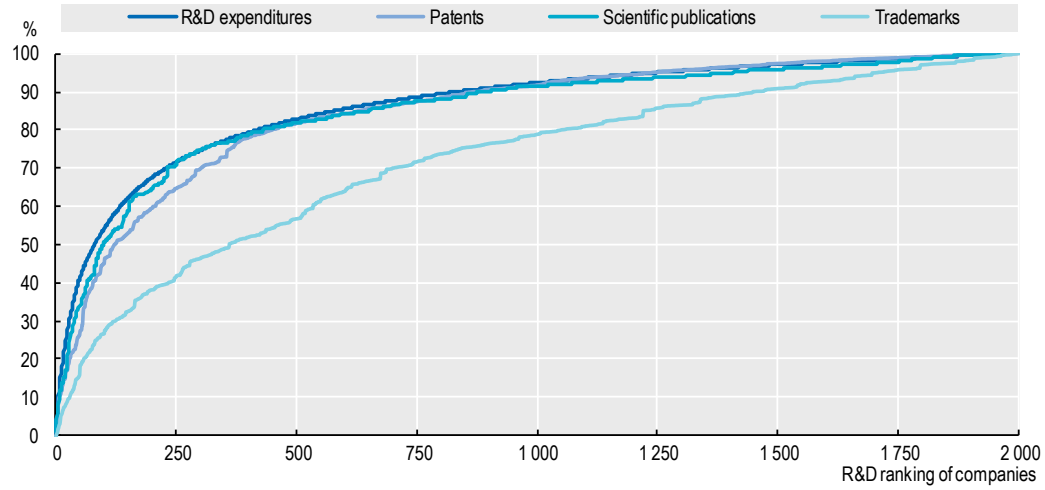
World business R&D investments are highly concentrated in a relatively small number of companies

In 2016, the top 2 000 R&D investors companies worldwide accounted for EUR 742 billion total annual R&D investment, corresponding to more than 90 % of the total business R&D investment of OECD economies plus Argentina, China, Romania, the Russian Federation, Singapore, South Africa, and Chinese Taipei (the vast majority of the world's business-funded R&D). In other words, world business R&D investments are very highly concentrated in a small number of firms. Moreover, innovation activities also appear concentrated within the sample of top R&D investors.

Figure 1.1 shows the cumulative share of R&D investment, patents, scientific publications and registered trademarks of top corporate R&D investors ranked following their investment in R&D. The cumulative share of R&D investment increases sharply until the 250th position. R&D investment, patents and scientific publications follow similar patterns, while trademarks appear less concentrated within the sample. The top 250 firms account for about 72 % of total R&D investment of the sample, 71 % of publications, 65 % of patents and only 42 % of registered trademarks.

Figure 1.1. R&D investment, publications and IP bundle of the world's top R&D investors, 2014-16

Cumulative percentage shares within the top 2000 R&D companies



Note: Data relate to companies in the top 2 000 corporate R&D sample, ranked by R&D investment in 2016. The IP bundle refers to the number of patents and trademarks filed in 2014-16, and owned by the top R&D companies, and the number of scientific articles are those published by authors affiliated in the top R&D companies during the same time-period, using fractional counts. See Box 2.1 for further details on the coverage.

Source: JRC-OECD, COR&DIP© database v.2., 2019.

A first look at the patent portfolios of top R&D investors worldwide (Figure 1.2) reveals a leading role of these firms in the development of new technologies. During the period considered (2014-16), these companies filed about 60% of the world IP5 patent families.

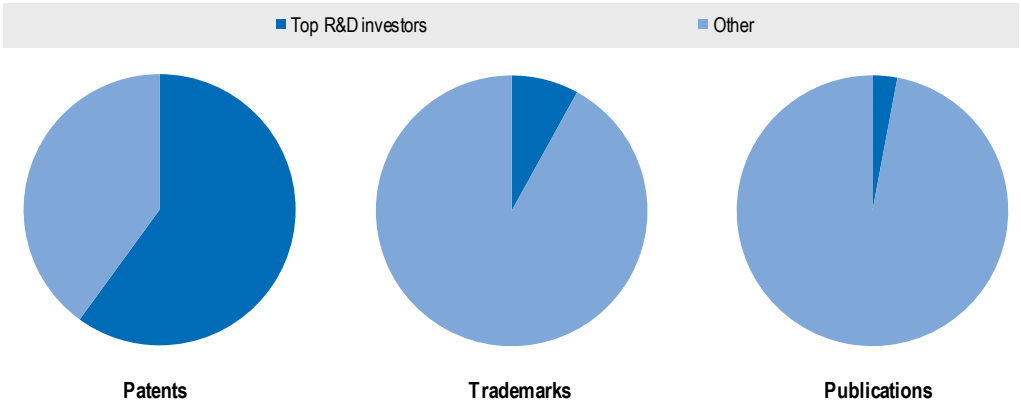
The top 2 000 R&D investors own almost two third of patents filed at the largest IP offices worldwide.

The contribution of top R&D investors in terms of registered trademarks and scientific publications is relatively low: these companies account for about 8 % of

registered trademarks at the European Union Intellectual Property Office (EUIPO), the Japan Patent Office (JPO) and the United States Patent and Trademark Office (USPTO) altogether (respectively 11%, 13% and 6%) and 3% of scientific publications. The low share of scientific publications accounted for by these companies is in line with what could be expected given the leading role of universities and other research institutions in this respect.

Figure 1.2. Patents, trademarks and publications owned by the world's top R&D investors, 2014-16

As a percentage of total IP5 patents, trademarks and publications, respectively

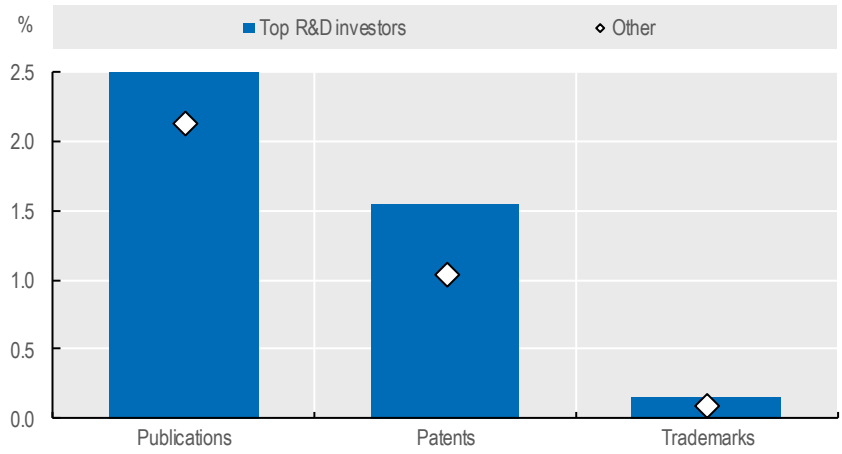


Source: JRC-OECD, COR&DIP© database v.2., 2019.

AI-related technological developments represent an emerging – albeit fast growing - field (see more about this in chapter 6). Figure 1.3 compares the proportion of AI in publications, patents and trademarks of the world's top R&D investors with those developed by all other actors worldwide. The share of AI in total scientific publications (2.5 %) of the top R&D investors is higher than that of patents (1.6 %) and trademarks (0.2%). Basic and applied research in AI seem to represent a key area of activity of top R&D performers: their share of AI-related articles, patents and trademarks is greater than the ones produced by any other actor outside the sample (2.1 %, 1 %, and 0.1 % respectively).

Figure 1.3. AI-related patents, trademarks and publications, 2014-16

Share in total patents, trademarks and publications, top R&D investors and other actors



Source: JRC-OECD, COR&DIP© database v.2., 2019.

The reminder of this publication is articulated as follows:

Section 2 offers an overview of the geographical distribution of the top corporate R&D investors worldwide and of the top 50 innovative companies, and their ranking in terms of scientific and innovative output. The analysis then moves to the sector level to show the contribution of different sectors to the overall production of patents, trademarks and publications. Evidence about the geographical and industrial specificities emerging across economies complements the picture.

Section 3 looks at the extent to which top R&D investors and their innovative activities have changed between 2012 and 2016. It compares the sample of top R&D investors in 2016 with that of 2012, focusing especially on the industrial and geographical differences that emerge. The final part of the chapter zooms into top corporate R&D investors that entered in or exited from the sample across the two waves.

Section 4 investigates the innovative competences on which the top corporate R&D investors rely. It first assesses the level of concentration in terms of scientific and technological competences and whether companies' knowledge develops in relation to well-defined core sets. The analysis allows the sector-specific competences of the top corporate R&D investors to be uncovered. It is complemented by a final focus on information and communication technologies (ICT)-related activities.

Section 5 examines the AI-related innovation activities of top corporate R&D investors worldwide. It further focuses on the top 50 companies contributing the most to AI developments, in terms of scientific publications, patents and trademarks. The analysis then moves to the sectoral and geographical level, to provide specific evidence along these two dimensions.

The final Section 6 sheds light on the way top R&D investors combine their knowledge portfolio. It first investigates the radicalness of technologies and the "quality" of the scientific outputs produced by the top R&D investors worldwide. In a second stage, the way these companies bundle basic and applied research (science and technology) is explored. Finally, a closer look is given at the pervasiveness and potential impact of the innovation activities related to AI.

2. The anatomy of innovative activities

This chapter offers an overview of the geographical distribution of the top corporate R&D investors worldwide, both in location of the headquarters and in the way subsidiaries are distributed around the globe. Additional information is provided about the top 50 innovating companies, and their ranking in terms of scientific and innovative output, with comparisons based on patent, trademark and publication-related data. The analysis then moves from the firm to the industry level, and shows the contribution of different sectors to the overall production of patents, trademarks and publications. This broad overview of the anatomy of innovative activities of top corporate R&D investors worldwide is completed by evidence about the geographical and industrial specificities emerging across economies worldwide.

2.1 The corporate structure and geographical distribution of top R&D investors

To understand innovation dynamics in the knowledge economy in the era of global value chains, we need to take a global perspective (Archibugi and Iammarino, 2002).

Companies, particularly multinational corporations (MNCs), may locate research facilities abroad to tap into new or different repositories of knowledge and capabilities, e.g. to complement their in-house technological activities, or to be able to better meet local demand and needs (Rilla and Squicciarini, 2011; Chung and Alcácer, 2002). This often translates into a geographical dispersion of multinationals' activities, and into research and development (R&D) activities being performed in certain countries or specific locations, while other activities are performed elsewhere. This is due to a number of endogenous and exogenous factors, and is shaped by herding behaviours and by local characteristics such as academic specialisation (Contractor et al., 2010; Belderbos et al., 2014; Santos‐Paulino et al., 2014).

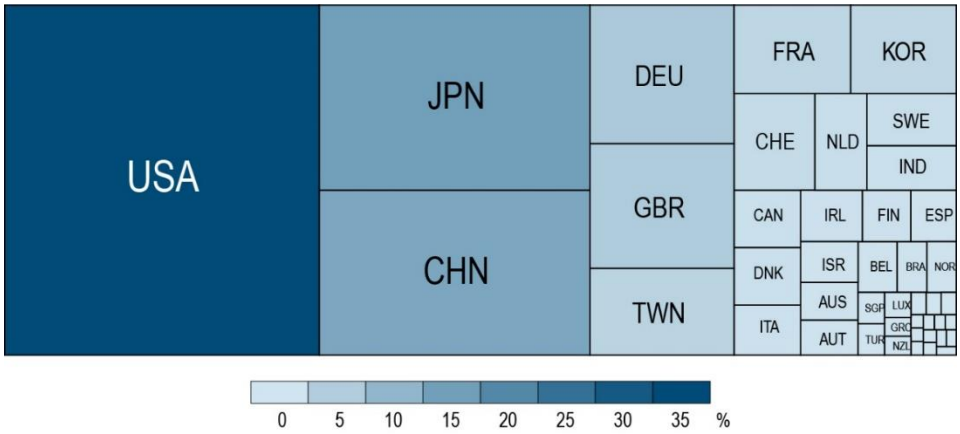
Tapping into a diversified array of scientific and technological contexts and competences, and meeting diverse consumer preferences and needs, enables MNCs to acquire and generate context-specific knowledge. This can be integrated within the broader organisation, and may lead to increased productivity and enhanced innovative capabilities (Zanfei, 2000; Castellani et al., 2017).

This section looks at the geographical location of the world's top 2 000 corporate R&D investors in 2016 (Hernández et al., 2017). These firms are either independent companies or mother companies of a number of subsidiaries or affiliates. The subsidiaries considered in this report are firms owned at least 50 % by the mother company in the sample. Altogether, almost 600 000 companies worldwide appear to belong to the world's top 2 000 corporate R&D investors.

Top corporate R&D investors worldwide are geographically concentrated: about three out of four are headquartered in only five economies

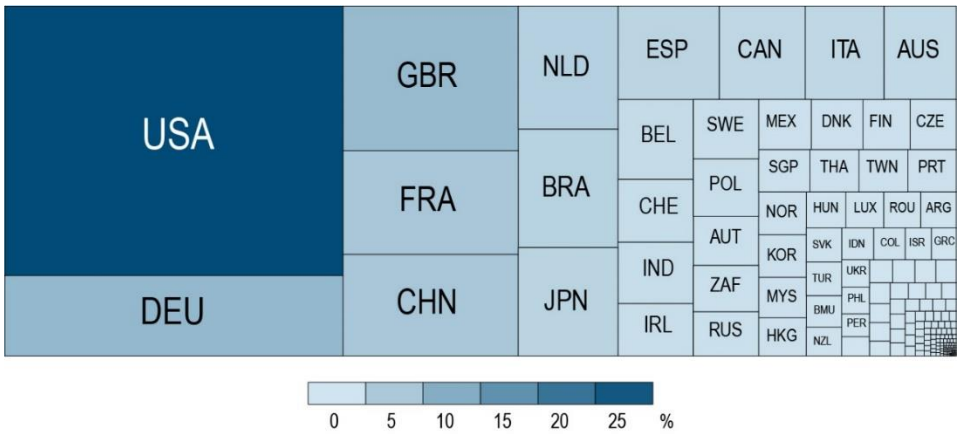
Figure 2.1 shows the share of the world's top 2 000 R&D investors according to location of the corporate headquarters. In 2016, approximately 73 % of the top R&D investors (1 458 companies) had their headquarters located in only five economies: the United States (33 %), Japan (15 %), China (13 %), Germany (6 %) and the United Kingdom (5.4 %). Another 14 % of companies were headquartered in Chinese Taipei, France, Korea, Switzerland and the Netherlands.

Figure 2.1 - Location of headquarters of world's top R&D investors, 2016
Share in top 2 000 R&D investors



Source: JRC-OECD, calculations based on EU Industrial R&D Investment Scoreboard (2017), May 2019.

Figure 2.2 - Location of subsidiaries of world's top R&D investors, 2016
Share in total subsidiaries, excluding branches



Source: JRC-OECD, calculations based on EU Industrial R&D Investment Scoreboard (2017), May 2019.

Looking at the location of the subsidiaries of the top R&D investors offers a somewhat different picture (Figure 2.2). While headquarters are distributed between 43 economies, subsidiaries can be found in more than 170 economies around the world.

Subsidiaries appear less geographically concentrated than their mother companies, suggesting that MNCs may be pursuing a number of strategies including 'home-base augmenting' and 'home-base exploiting' (see Rilla and Squicciarini, 2011, for a taxonomy). However, about half of these R&D intensive MNCs' subsidiaries are still located in only five economies: the United States (27 %), Germany (8.2 %), the United Kingdom (7.6 %), France (5.5 %) and China (5.4 %).

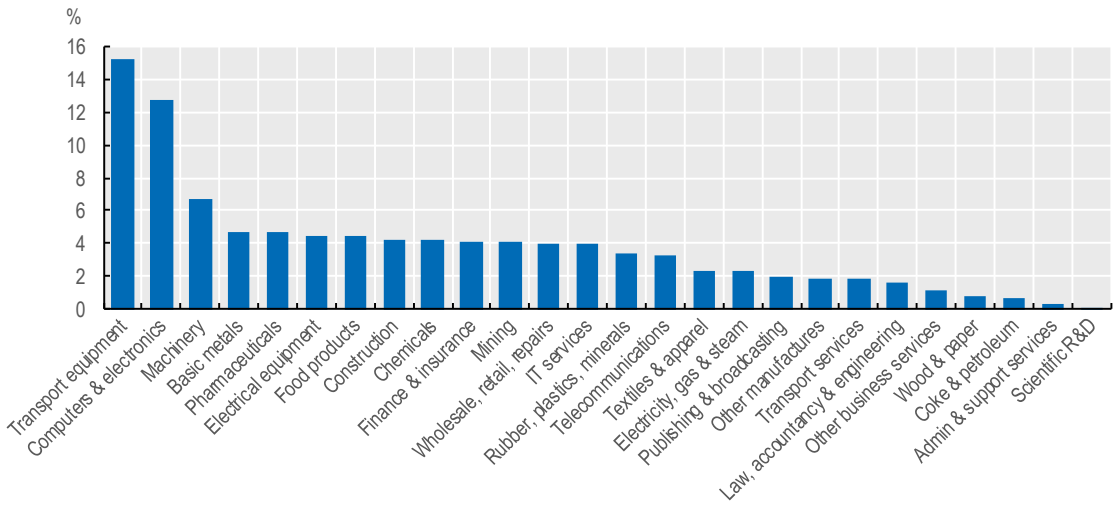
China, Germany, the United Kingdom and the United States are among the top five corporate R&D investors in terms of number of headquarters and subsidiaries

Top R&D investors mostly operate in R&D intensive sectors; about 60 % of companies operate in sectors related to Information and Communication Technologies (ICT) or health (Hernández et al., 2017). However, when considering the total workforce of the world's top R&D investors, the relative contribution of sectors changes.

Figure 2.3 shows the share of employees by industrial sector (see Annex A for classification of sectors). The chart reports only those sectors represented by at least 10 corporations in the sample. Companies operating in the 'Transport equipment' sector directly employ more than 7.5 million workers, equivalent to about 15 % of employees in the overall sample. These are followed by companies in the 'Computer and electronics' (13 %) and 'Machinery' (7 %) sectors. At the other end of the spectrum, the 63 firms in the 'Scientific R&D' sector employ only 0.03 % of the total workforce of top corporate R&D investors. This likely reflects specificities related to firm size and distribution and to skills needs.

Companies operating in medium and high-tech sectors account for significant shares of the total workforce of top R&D investors

Figure 2.3 - Total workforce of world's top R&D investors by sector, 2016
Share in terms of number of employees



Note: Data relate to sectors with at least 10 company headquarters in the top 2 000 corporate R&D sample.

Source: JRC-OECD, calculations based on EU Industrial R&D Investment Scoreboard (2017), May 2019.

2.2 Data and information used to assess the scientific and innovative output of top corporate R&D investors

Firms invest in R&D to innovate and to increase their capacity to absorb external knowledge, among other things. In addition, R&D investors often rely on intellectual property (IP) rights to protect their innovations and to better appropriate the economic returns that may accrue from their R&D investment.

IP data related to patents and trademarks provide information on the extent to which companies transform R&D investment into innovative output and protect it

While not all innovations are protected through patents, and not all patents lead to new products or processes in the market (Hall et al., 2014), patents nonetheless represent 'the only observable manifestation of inventive activity with a well-grounded claim for universality' (Trajtenberg, 1990, p. 183).

In addition, data related to trademarks - which producers and vendors use to help consumers identify (new) products and services (Ramello, 2006) - contribute better to capturing the innovative output of companies, thus allowing a better assessment. As trademarks help companies to pursue and develop their diversification strategies, they provide useful information about the innovative products and services that hit markets.

In this report, IP data are complemented by data from scientific papers related to research published by the companies in

the sample; both headquarters and affiliates (see Box 2.1 for further details on coverage of IP data and publications).

Box 2.1. IP assets and scientific publications of the top R&D investors 2016: patents, trademarks and scientific publications

Patents

To better reflect the inventive activities of top corporate R&D investors worldwide, the statistics presented here are based on families of patent applications filed at the five largest IP offices (IP5):* the European Patent Office (EPO), the Japan Patent Office (JPO), the Korean Intellectual Property Office (KIPO), the State Intellectual Property Office of the People's Republic of China (CNIPA) and the United States Patent and Trademark Office (USPTO). The definition of IP5 patent families relates to families of patent applications with members filed in at least one of the IP5, provided that another family member has been filed in any other office worldwide (see Dernis et al., 2015 and Daiko et al., 2017 for further discussion about the use of IP5 families). Families are reported according to the earliest filing date. The International Patent Classification (IPC) is used to allocate patents to technological fields (see http://www.wipo.int/classifications/ipc and Annex D).

Trademarks portfolio

Data on trademark applications relate to trademarks registered at the European Union Intellectual Property Office (EUIPO), the JPO and the USPTO. The EUIPO administers EU trademarks (EUTMs, formerly known as Community trademarks, CTMs), which are valid throughout the European Union and coexist with nationally granted trademarks. The JPO and the USPTO guarantee protection on their national markets only. For more details on USPTO trademark data, see Graham et al. (2013). Trademarks are filed in accordance with the International Classification of Goods and Services, also known as the Nice Classification (see https://www.wipo.int/classifications/nice/en, and Annex E).

Publications

The bibliometric data are based on Elsevier's Scopus® database, an abstract and citation database for peer-reviewed literature, which includes scientific journals, books and conference proceedings. Elsevier assigns each journal in Scopus to one or more subjects using its All Science and Journal Classification (ASJC). There are 27 main fields comprising 334 subjects in the classification, reported in Annex F of this report. Publication figures include only articles, reviews and conference proceedings.

Analysis period

Statistics on IP rights refer to patents or trademark applications filed in 2014-16, and owned by the top 2 000 R&D investors as well as their subsidiaries, based on the corporate structure reported at the end of 2016. The same applies for the publications, where only articles published in 2014-16 are considered.

For this report, it is assumed that the corporate structure of top R&D performers over the two years preceding 2016 (i.e. 2014-15) were sufficiently similar to that observed in 2016, and that statistics based on the three-year period 2014-16 provide an accurate enough picture of the companies' IP and publishing activities. This could not be assumed if longer timeframes were to be considered.

Furthermore, unless otherwise specified, statistics are compiled using fractional counts.

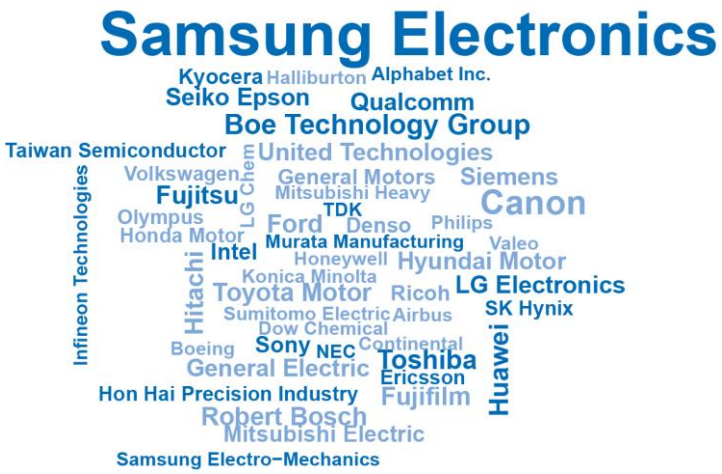
** The IP5 is a forum of the five largest intellectual property offices in the world that was set up to improve the efficiency of the examination process for patents worldwide. The IP5 offices together handle about 90 per cent of the world's patent applications. See http://www.fiveipoffices.org.*

Publishing represents a means to connect with research, to attract and display talent, and to signal scientific capabilities to the external world

While the contribution to science and scientific literature is not directly linked to (the protection of) innovation, it nevertheless mirrors firms' engagement in the creation of new knowledge and in innovative activities. Engaging in scientific publications offers firms learning opportunities and access to knowledge available in the academic community. It may further enhance companies' reputation and their attractiveness, especially when in search for the best talent. In some cases, it may help in obtaining approval for its innovative products, e.g. for new drugs in the 'Pharmaceuticals' sector (see e.g. Hicks, 1995).

Figures 2.4, 2.5 and 2.6 show the top patenting, trademarking and publishing companies among the 2 000 companies that invested the most in R&D in 2016. IP and publication data refer to the 2014-16 period.

Figure 2.4. Top 50 patenting companies, 2014-16
IP5 patent families



Note: ICT-related companies are shown in darker blue.

Source: JRC-OECD, COR&DIP© database v.2., 2019.

In particular, Figure 2.4 shows the top 50 patenting companies in terms of IP5 families. The size of the font used to display companies' name is proportional to the share of their patent portfolio in the overall patent portfolio of the top R&D investors worldwide. In addition, the name of companies in the ICT sector [1] is displayed in dark blue.

Among the top 50 patent assignees, the majority have headquarters in Asia

Out of the 50 top patenting companies, 20 corporations are based in Japan, 6 are Korean, and 4 are located in China or in Chinese Taipei. Of the remaining top 50 patent assignees, 11 are headquartered in the United States and 9 in Europe. These results are in line with previous findings on top corporate R&D investors worldwide (Dernis et al., 2015; Daiko et al., 2017), and confirm the increasing importance of Asian corporations in the global R&D landscape.

Samsung Electronics has the largest patent portfolio, owning more than 6 % of the whole IP5 patent portfolio of the top 2 000 R&D investors worldwide. The podium is completed by Canon and by BOE Technology Group, which strongly increased its patenting activities since the last edition of the report.

[1] ICT-related sectors are defined in Annex C.

The importance of ICT sector in overall patenting activities stands out clearly. Almost half of the top 50 patenting companies operate in these sectors, mainly in the 'Computers and electronics' sector.

Figure 2.5. Top 50 trademarking companies, 2014-16
EUIPO, JPO and USPTO trademarks

Note: ICT-related companies are show n in darker blue.

Source: JRC-OECD, COR&DIP© database v.2., 2019

Figure 2.5 shows the top 50 trademark registering companies at EUIPO, JPO and USPTO. The companies included in the figure are the top 50 applicants in terms of the total number of trademarks filed at the three intellectual property offices added together. Again, the centrality of Asian corporations emerges, with more than half (27) of the companies ranked in the top 50 trademark registering firms being based in Asia. More precisely, 24 of them have their headquarters in Japan, 1 in China and 2 in Korea. The rest of the companies among the top 50 trademark registering firms worldwide have their headquarters located in the United States (12) and Europe[2] (11).

The Korean LG Electronics leads, with a share of 2.5 % of the total number of trademark registrations by the top R&D investors in the three offices considered. This may reflect a pronounced branding diversification strategy by this Korean giant.

The sectoral composition of the top 50 firms is less concentrated for trademarks than for patents

Among the top 50 companies in terms of trademark registrations, 10 firms operate in the ICT sector (in dark blue), 10 in the 'Food products' sector, 9 in 'Pharmaceuticals' and 7 in the 'Chemicals' sector.

Different to patents and trademarks, most of the top publishing companies are headquartered in the United States and in Europe

Finally, the top 50 companies by number of scientific publications are shown in Figure 2.6, with those in dark blue operating in the ICT sector. Most of the companies making it to the top are headquartered in the United States (19) and Europe (18 in EU-28 countries and 3 in Switzerland). The remaining 10 companies are headquartered in Asia.

[2] For the sake of this report, Europe refers to EU-28 countries plus Switzerland (if not otherwise stated).

The top 4 publishing companies come from the United States. Microsoft leads the rank holding 2.3 % of the total publications, closely followed by IBM, Lockheed Martin and General Electrics (each accounting for about 2.0 %).

Publishing appears to be important for companies in ICT-related sectors: 15 out of the top 50 publishing companies operate in these sectors. With 11 companies among the top 50, the Pharmaceutical sector also appears to be an important contributor to the production of scientific research.

Figure 2.6. Top 50 publishing companies, 2014-16

Number of scientific publications

Note: ICT-related companies are show n in darker blue.

Source: JRC-OECD, COR&DIP© database v.2., 2019.

All in all, the three measures used in this report – patents, trademarks and scientific publications – reflect geographical, sectoral and company specificities. For example, while the top patenting companies are mostly based in Asia and operate in the ICT sector, when considering registered trademarks, Asian companies still represent the majority but the sectoral composition appears more diverse.

Finally, when considering knowledge generation that is closer to basic research, US- and Europe-based companies feature prominently in the top 50, with two companies operating in the 'Transport equipment' sector (related to aeronautics and defence) among the very top companies.

The use of several proxy measures is necessary to capture the multifaceted approaches to innovation and knowledge creation that firms may pursue

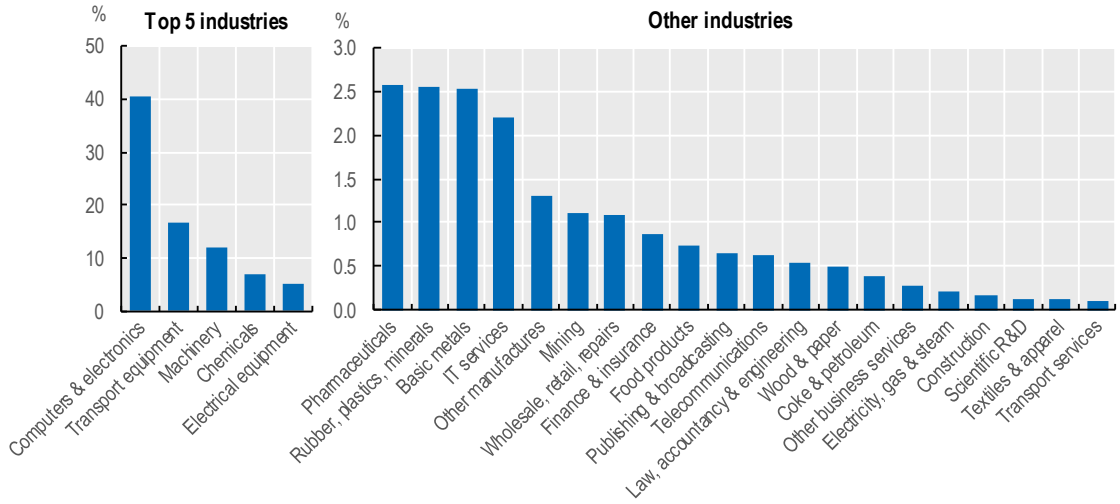
2.3 Innovative output: the industrial perspective

Having analysed general patterns, it is interesting to shed light on more specific geographical or sector-related features. Industrial sectors may be characterised by different combinations of technological opportunities, appropriability conditions, or knowledge base cumulativeness, among other things (Breschi et al., 2000).

Companies' innovative activities are partly determined by the interplay of these components, which concur to define the dominant mode of innovating within a sector (known as technological regimes – Dosi, 1982).

Figure 2.7 presents evidence of these sectoral specificities with respect to patenting activities. The top 5 sectors, in terms of share of IP5 patents, are shown in the left panel.

Figure 2.7. Patent portfolios of world's top R&D investors, by sector, ISIC rev. 4, 2014-16
As a percentage of total patents owned by top R&D investors, IP5 patent families



Note: Data relate to sectors with at least 10 company headquarters in the top 2 000 corporate R&D sample having filed patents in 2014-16.

Source: JRC-OECD, COR&DIP© database v.2., 2019.

Companies in the 'Computers and electronics' sector own about 40 % of the total IP5 patent families of the world's top corporate R&D investors. Second is the 'Transport equipment' sector with 16 %, followed by the 'Machinery' sector with a 12 % share of the total number of patents owned by the top 2 000 corporate R&D investors.

Companies operating in the top five patenting sectors own about 80 % of the whole patent portfolio of top R&D investors

With a share of patents close to 2.6 %, the 'Pharmaceuticals' sector ranks sixth and is the first one reported in the right panel of Figure 2.7. The 'Construction', 'Scientific R&D', 'Textiles and apparel' and 'Transport services' sectors were those with the lowest number of patent applications during the period considered (they each own less than 0.2 % of the overall portfolio).

Companies in the 'Computers and electronics' and 'Transport equipment' sectors are also those with the highest shares of trademark registrations, as can be seen in the left panel of Figure 2.8.

'Computers and electronics' shows a much lower share of the overall trademark portfolio compared to the case for patents. This is to be expected, given that computer and electronic products are complex products, and many technological developments protected by patents may be needed to obtain a new product or to enable provision of a certain service, signalled to consumers through only one or a few trademarks.

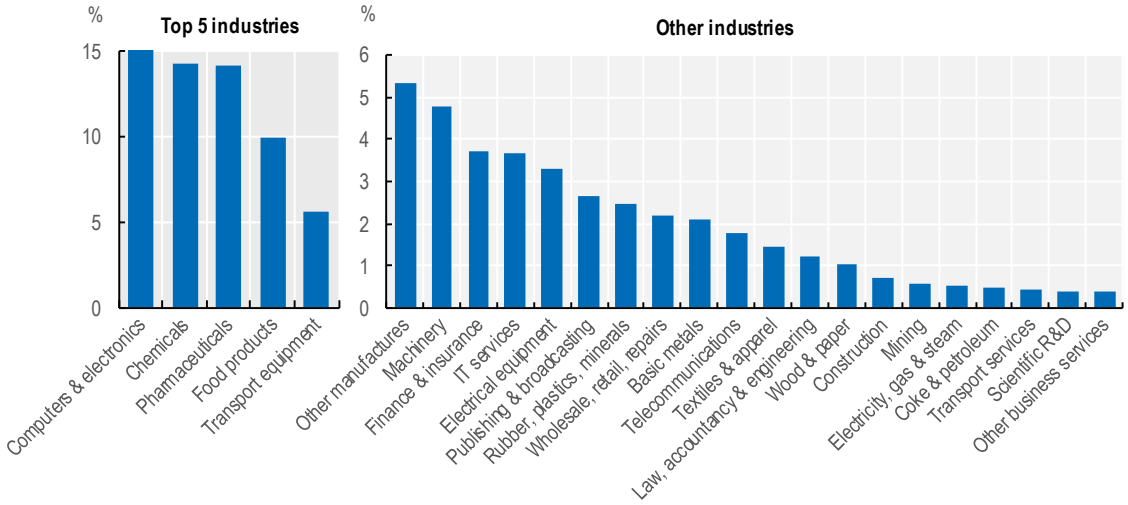
Other sectors with high shares of trademark registrations are 'Chemicals', 'Pharmaceuticals' and 'Food products'. Taken together, these five sectors register

almost 60 % of all trademarks in the sample.

Trademarks appear much less concentrated by sector than patents

Similar to patents, trademarks and related brand strategies appear to be used or implemented in different ways in different sectors, very likely also due to the nature of products and services that different sectors produce. Sectoral heterogeneity is apparent in Figure 2.8 with four sectors – 'Coke and petroleum', 'Transport services', 'Scientific R&D' and 'Other business services' – registering less than 0.5 % of the trademarks in the sample.

Figure 2.8. Trademarks portfolio of world's top R&D investors, by sector, ISIC rev. 4, 2014-16
As a percentage of total trademarks owned by top R&D investors, EUIPO, JPO and USPTO



Note: Data relate to sectors with at least 10 company headquarters in the top 2 000 corporate R&D sample having filed trademarks in 2014-16.

Source: JRC-OECD, COR&DIP© database v.2., 2019.

Scientific publications by the world's top R&D investors present a similar degree of concentration in their distribution across different sectors to the one observed for registered trademarks: the top 5 sectors publish about 60 % of the total number of scientific articles belonging to the companies in the sample (see Figure 2.9).

Firms in the 'Computers and electronics' sector again rank first among the top R&D investors in terms of publishing scientific articles, with a share of 20 % of the total scientific publications identified in this study.

Publications appear very important for companies in the 'Pharmaceuticals' and 'Transport equipment' sectors, which are responsible for about 17 % and 12 % of the total number of scientific articles in the sample, respectively. On the other hand, firms with low shares of publications are those in the 'Scientific R&D', 'Other business services', 'Admin and support services', 'Wood and paper' and 'Textile and apparel' sectors, with less than 0.5 % of publications each.

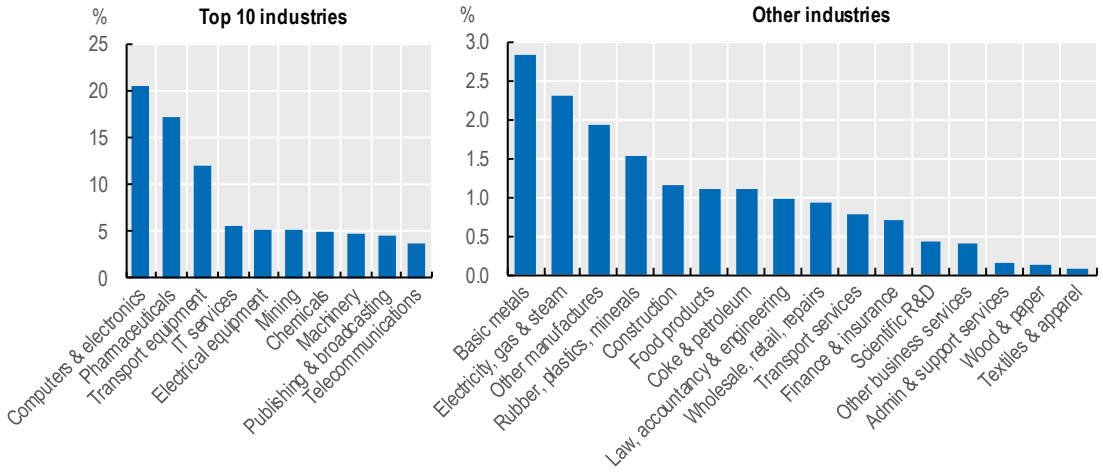
Sectors differ in their innovation patterns, as emerges from patents, trademarks and scientific publications

Some sectors – such as 'Computers and electronics' and 'Transport equipment' – rank high regardless of the measure considered. This implies that their innovative activities relate to all possible phases of innovation, from the creation of basic knowledge (as captured by scientific

publications), to practical implementation of inventions (as proxied by patents), to marketing the results of their innovative activities (through trademarks and brand strategies).

Others – such as 'Electrical equipment' and 'Pharmaceuticals' – instead couple a strong orientation towards basic research with more applied research (the former) or market placement (the latter). The 'Chemicals' sector is however oriented more towards applied research and the market than towards basic research.

Figure 2.9. Publications by the world's top R&D investors, by sector, ISIC rev. 4, 2014-16
As a percentage of total publications by top R&D investors



Note: Data relate to sectors with at least 10 company headquarters in the top 2 000 corporate R&D sample having publications in 2014-16.

Source: JRC-OECD, COR&DIP© database v.2., 2019.

2.4 Innovative output: the geographical perspective

The interaction between start-ups and incumbents, or suppliers and customers, has taken on a global dimension. Establishing relations with foreign start-ups may offer unique opportunities to tap into the repository of talented human resources located elsewhere (Rilla and Squicciarini, 2011) or to access new technological resources (Sachwald F., 2008).

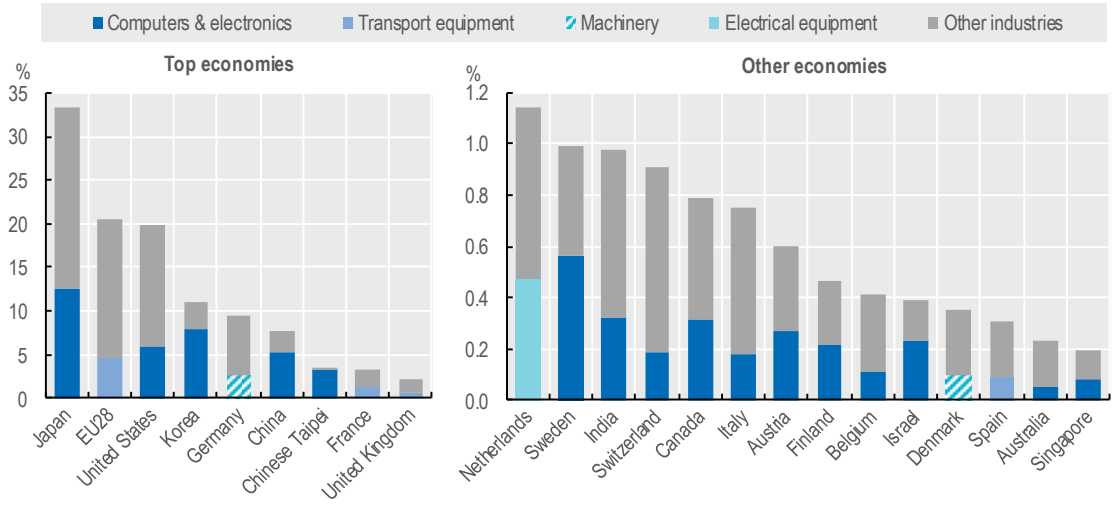
Over time, new locations have become attractive for performing R&D activities in addition to production, for a number of reasons including relative costs as well as skills availability. In other words, the interest in streamlining R&D has risen and, at the same time, the pool of viable locations for R&D has expanded.

This may pose challenges to the way innovation policies are conceived, although national innovation systems still appear important in supporting and directing the processes of innovation and learning (Lundvall, B.Å., 2016). Learning is often based on interactions for which social embeddedness is crucial. Country specificities may thus affect MNCs' decisions on the location of innovation (Ciriaci et al., 2019).

To shed some light on these issues, in what follows the innovation activities of the top corporate R&D investors worldwide are looked at from the perspective of the geographical distribution of the actual actors leading the knowledge generation process, i.e. the knowledge creators. In other words, we look at the geographical distribution of patents and publications

according to the location of inventors and authors, respectively. This is unfortunately not possible in the case of trademarks, due to lack of relevant information, so the trademark-related analysis looks at trademark applicants.

Figure 2.10. Patent portfolio of world's top R&D investors, by inventor's location, 2014-16
Share of patents by economies and top contributing sector



Note: Data relate to economies with at least 500 IP5 patent families owned by the top 2 000 corporate R&D sample in 2014-16.

Source: JRC-OECD, COR&DIP© database v.2., 2019.

Figure 2.10 show the distribution of IP5 families according to the economy of residence of the inventors. The chart further displays the top contributing sector, in terms of number of patent families developed in the economy involved (i.e. the coloured part of the bar). Only the economies with at least 500 IP5 patent families owned by the top 2 000 corporate R&D sample in 2014-16 are reported. An aggregate for the EU-28 member states is also presented in Figure 2.10.

One third of the total IP5 families have been developed by inventors residing in Japan. Inventors residing in the EU-28 member states are responsible for about 21 % of the IP5 families, followed by inventors located in the United States (20 %) and in Korea (10 %). With a share of 9.5 %, Germany is the top European country in terms of patents generated.

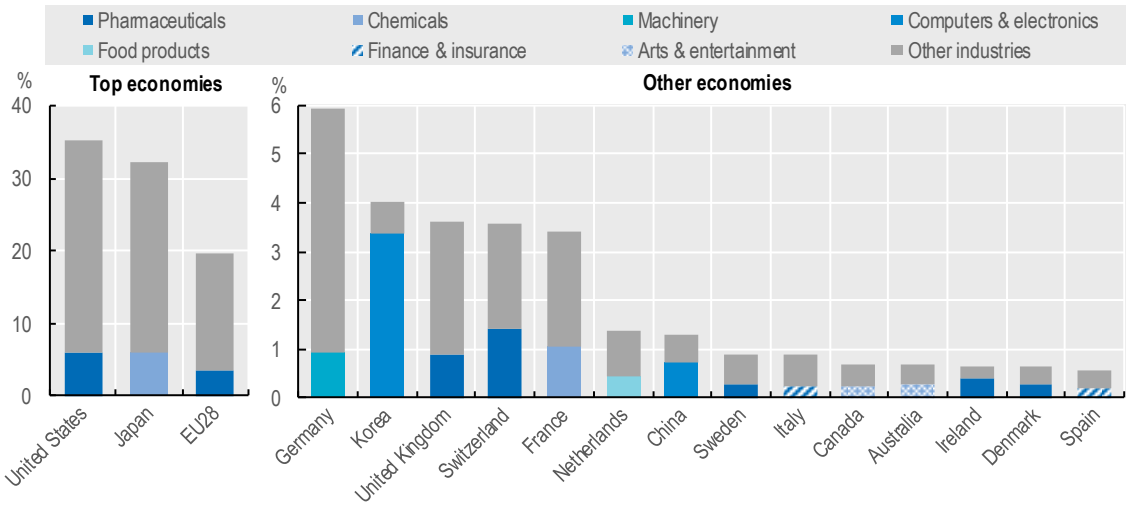
The 'Computers and electronics' sector ranks first in most of the economies considered; this is in line with the high share this sector accounts for overall (see Figure 2.7). In Japan, inventors for companies in this sector are responsible for more than one third of the total number of IP5 families developed there. In Korea (73 %), China (69 %) and Chinese Taipei (96 %), inventors in 'Computers and electronics' develop the vast majority of patents.

Inventors in Asian economies focus on technologies relevant to the 'Computers and electronics' sector

On the other hand, the top contributing sector in France, the United Kingdom and Spain is 'Transport equipment', while in Germany it is 'Machinery'.

Inventors located in the EU-28 mostly develop technologies related to 'Transport equipment'. Technological developments in EU-28 and in the United States are less concentrated in a single sector than is often the case in Asia

Figure 2.11. Trademark portfolio of world's top R&D investors, by applicant's location, 2014-16
Share of trademarks by economies and top contributing sector



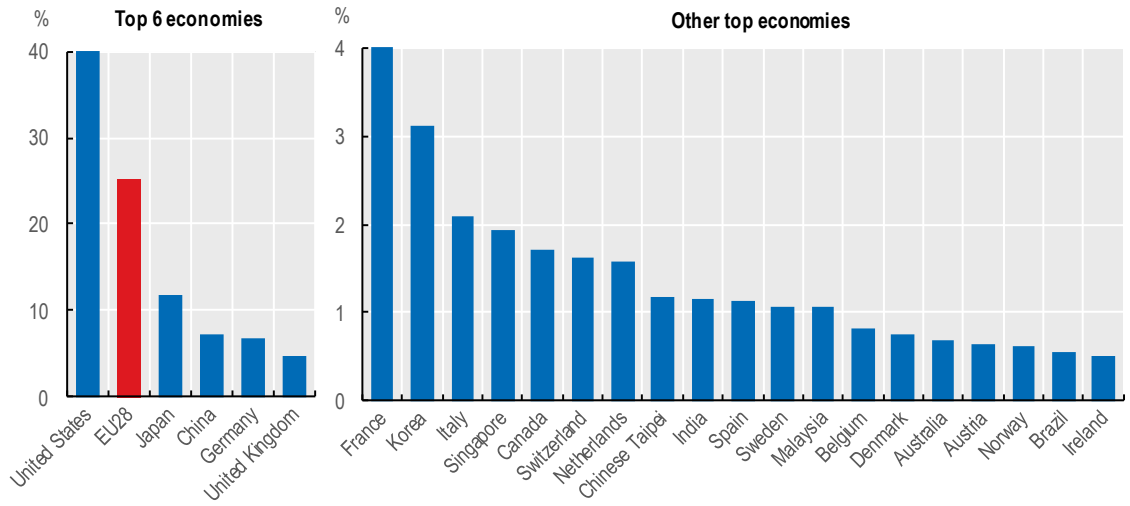
Note: Data relate to economies with at least 750 trademarks owned by the top 2 000 corporate R&D sample in 2014-16.

Source: JRC-OECD, COR&DIP© database v.2., 2019.

Figure 2.11 shows the distribution across economic areas of trademark registrations from the world's top R&D investors. Shares have been calculated based on the economy where the applicant for the registration is located. Only economies with at least 750 trademarks have been taken into account. As in Figure 2.10, the EU-28 member states have been aggregated and are presented separately.

With about 35 % of total trademark registrations, US-based companies are at the top of the list, closely followed by Japanese (32 %) and EU-28 based ones (20 %). Among the EU-28 countries, Germany is first with about 6 % of total trademarks, followed by the United Kingdom and France. Other important locations for trademark applicants are Korea and Switzerland.

Figure 2.12. Publications by world's top R&D investors, by author's affiliation location, 2014-16
Share of economies in top R&D performers, percentages



Note: Data relate to economies with over 1 000 publications by the top 2 000 corporate R&D sample in 2014-16.

Source: JRC-OECD, COR&DIP© database v.2., 2019.

Another aspect that may be interesting to look at is which sectors contribute more to trademark registrations, in different economies.

The 'Pharmaceuticals' sector is first in terms of trademark registrations in 7 out of the 17 economic areas considered

'Pharmaceuticals' emerges as the top sector contributing to trademarks in the United States, EU-28, United Kingdom, Switzerland, Sweden, Ireland and Denmark. Similar to the case for patents, in Korea and China the first sector in terms of trademark registration is 'Computers and electronics'. Meanwhile, in the case of Japanese companies, the major source of trademark registrations is the 'Chemicals' sector.

Finally, scientific publications from authors affiliated to the world top 2 000 R&D performers across the globe are shown in Figure 2.12.

Authors based in the United States are responsible for approximately 40 % of the whole number of publications in the sample. Those based in the EU-28 produce about one quarter of the publications of the top R&D investors worldwide, while the contribution from authors based in Asian economies is much lower. Those residing in Japan contribute about 12 % of overall publications, while China and Korea show much lower shares: about 7 % and 3 %, respectively.

Among the EU-28 countries, Germany is still the country with the highest share, (close to China with about 7 %), followed by the United Kingdom (4.7 %) and France (4 %).

3. On the shoulders of the giants: R&D investors 2012 vs 2016

This chapter sheds light on whether and to what extent top R&D investors and their innovative activities have changed between 2012 and 2016. It compares the sample of top R&D investors in 2016 with that of 2012, and focuses especially on the industrial and geographical differences that emerge. As the different proxy measures used capture different dimensions of the dynamics at stake, integrating them helps to provide a more general framework to read and interpret the statistics presented. First, changes in industrial and geographical distribution are analysed, followed by statistics about differences in terms of R&D investment, patents and trademarks. Patents in particular help to unveil the technological specialisation of different economic areas and how this changes over time. The final part of the chapter zooms in on those top corporate R&D investors that enter or exit from the sample between 2012 and 2016, to complete the above analysis of the industrial and geographical dynamics that have occurred.

3.1 Sectoral and geographical dynamics of top R&D investors

In a world where technological development is largely driven by the research activities performed by firms, innovation at the micro level plays an important role for aggregate economic growth (Aghion and Howitt, 1990).

R&D investment helps firms to gain competitive advantages and enhances their performance, and is thus considered a key strategic asset (Reinganum, 1985). Also, given the cumulativeness of knowledge and its path dependency (Nelson and Winter, 1982), remaining at the top requires a continuous stream of investment in R&D.

Evidence shows that the companies on the EU Industrial R&D Investment Scoreboard were responsible for about 90 % of overall corporate R&D investment worldwide in 2016. These firms have constantly increased their R&D efforts over the last period, exhibiting an increase in spending for eight consecutive years (Hernández et al., 2017). Despite being large and mostly operating on a global scale, the top R&D investors worldwide should not be seen as a monolithic block. The ranking changes every year, with new firms entering the 'club' while others exit it.

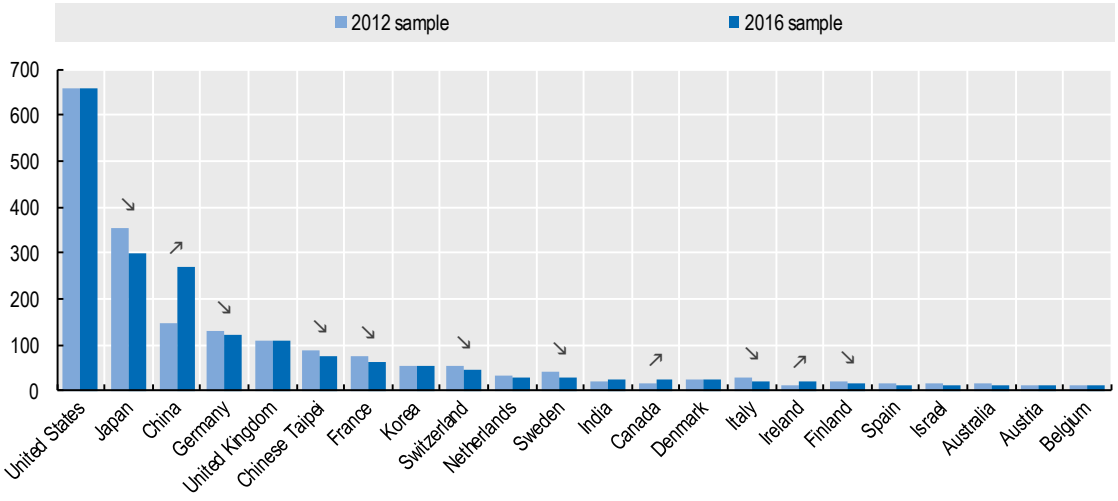
This part of the report compares the top R&D investors included in the first edition of the JRC-OECD World Corporate Top R&D Investors (Dernis et al., 2015) with those in the current edition. Although the time span considered may seem short - only four years from 2012 to 2016 - this comparison allows a number of dynamics to emerge, at both country and sector levels.

Figure 3.1 shows the geographical distribution of the top corporate R&D investors in the 2012 and the 2016 samples. Companies are assigned to the economy where their headquarters are located. US companies have the lion's share in both waves, and account for about one third of the total number of top R&D investors. Notably, their shares remain the same across the two waves, illustrating stable presence of the United States on the R&D Scoreboard.

The number of top corporate R&D investors from China almost doubled between 2012 and 2016

The number of top corporate R&D investors from China almost doubled during the four years considered (from 147 in 2012 to 268 in 2016).

Figure 3.1. Geographical distribution of the sample of world's top R&D investors, 2012 and 2016
Number of companies by location of headquarters



Note: The arrows denote a difference of 5 companies or more, between the two samples. Data relate to economies with at least 10 company headquarters in the 2012 and 2016 samples.

Source: JRC-OECD, calculations based on EU Industrial R&D Investment Scoreboard (2013 and 2017), May 2019.

This occurred to some extent 'at the expense' of companies based in Japan (-15 %) and the EU-28 (-10 %), which were pushed down the ranking[3].

A closer look at the EU-28 investors reveals that the relative ranking of economies in the EU-28 sample remained unchanged between the two waves. Germany, the United Kingdom and France continued to represent together about 60 % of the total number of top corporate R&D investors headquartered in EU-28 economies. The reduction in the number of companies headquartered in the EU-28 overall appeared to be equally distributed among economies, with two notable exceptions. The United Kingdom maintained the same number of companies across the two waves, while the number of top R&D investors in Ireland actually increased. The latter was seemingly related, at least in part, to the relocation of some US companies to Ireland (e.g. Medtronic plc, Perrigo plc).

Figure 3.2 shows the extent to which the industrial composition of top R&D investors (based on ISIC rev.4 classification, see Annex A) changed between the two waves.

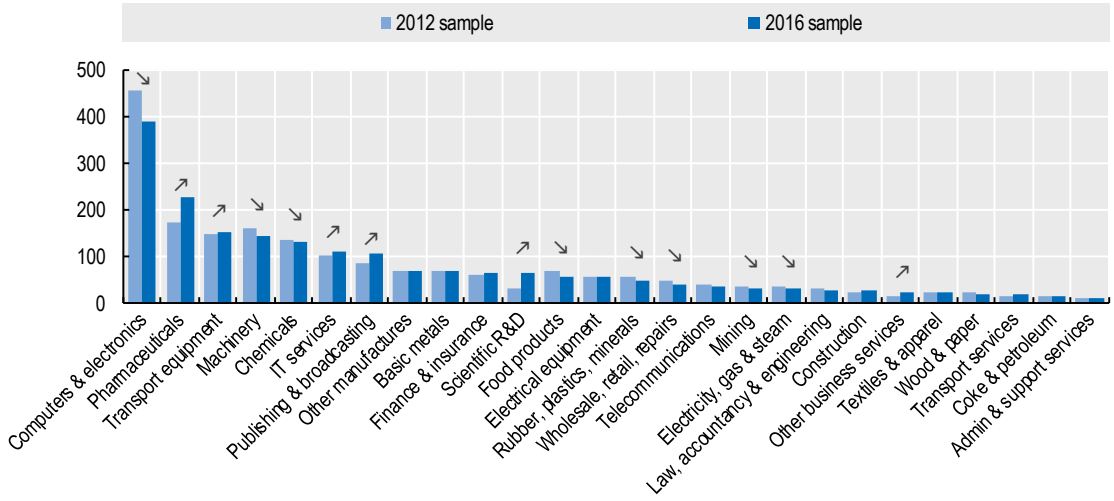
While companies in the 'Computer and electronics' sector remained the most numerous in the sample, their share decreased from 23 % to 19 % between 2012 and 2016.

Conversely, the most marked increase in absolute terms was observed in the 'Pharmaceuticals' sector, mainly due to the increased number of biotech companies in the most recent sample. Companies in the 'Scientific R&D' sector also increased significantly, more than doubling their presence in the ranking - although still accounting for only 3 % of the total 2016 sample.

Pharmaceutical companies markedly increased their presence among top R&D investors, while the share of companies in 'Computers and electronics' decreased from 23 % to 19 %

[3] Part of this considerable increase can be explained by a better coverage of Chinese companies by the data provider.

Figure 3.2. Industrial distribution of the sample of world's top R&D investors, 2012 and 2016
Number of companies by sector, ISIC rev.4



Note: The arrows denote a difference of 5 companies or more, between the two samples. Data relate to economies with at least 10 company headquarters in the 2012 and 2016 samples.

Source: JRC-OECD, calculations based on EU Industrial R&D Investment Scoreboard (2013 and 2017), May 2019.

Despite changes in the relative composition of the sample, no major changes are observed in the ranking of sectors. 'Transport Equipment' stepped onto the podium in third place, right after 'Pharmaceuticals', pushing the 'Machinery' sector down the ranking. The rise of the 'Scientific R&D' sector from 19th to 11th position suggests increased importance of specialised knowledge producers in the global technological panorama. In general, the number of sectors represented by top R&D investors decreased slightly, from 35 to 33 sectors. Despite this, the concentration of companies in the top four sectors decreased slightly (from 47 % to 45 %).

Changes in the absolute number of companies by sector are not entirely reflected in changes in the distribution of R&D investment across sectors. Figure 3.3 compares the share of R&D investment by sector between 2012 and 2016. Similar to what was observed in terms of number of companies, the R&D share for 'Pharmaceuticals' increased. 'Computers and electronics' essentially maintained its R&D investment share, while the share for 'Transport equipment' slightly decreased.

The contrasting dynamics observed in the case of 'Computers and electronics' companies, i.e. less companies accounting for an essentially unchanged R&D investment share, suggest that concentration phenomena are possibly at stake, and that for these companies R&D investment has increased more than the sample average.

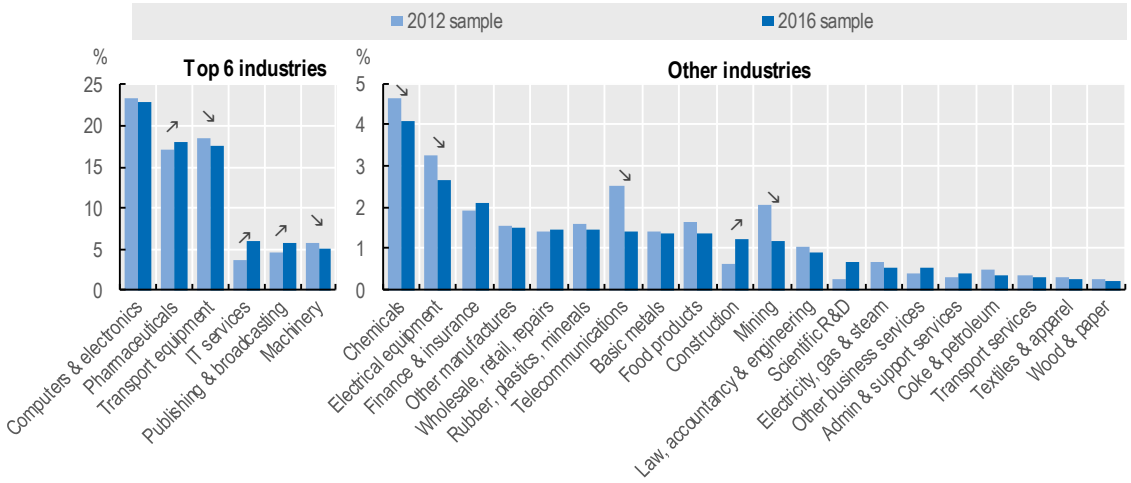
Companies in the 'Computers and electronics' sector are making relatively larger investment in R&D

By contrast, the average company in the 'Transport equipment' sector is seemingly investing less in R&D, probably due to the entry into the ranking of new specialised suppliers. Among the top five sectors, 'IT services' and 'Publishing and broadcasting' exhibit a significant increase in terms of their shares of the overall sample's investment in R&D, while decreases are registered in the 'Machinery', 'Telecommunications' and 'Mining' sectors.

Finally, overall the distribution of R&D investment among sectors has not changed much. The first four sectors represented basically the same percentage of the total R&D (65 %) in 2012 as in 2016

(64%). In both samples, less than half the companies are responsible for almost two thirds of the total R&D investment. This means that the company-specific investment made by the corporate R&D investors in the first four sectors, i.e. those displayed on the left-hand side of Figure 3.3, is much larger (on average) than that made by the companies operating in the remaining sectors.

Figure 3.3. Distribution of R&D investment of world's top R&D investors, 2012 and 2016
Share of R&D investment in total R&D investment of world's top R&D investors



Note: The arrows denote a difference of 5 companies or more, between the two samples. Data relate to sectors with at least 10 company headquarters in the 2012 and 2016 samples.

Source: JRC-OECD, calculations based on EU Industrial R&D Investment Scoreboard (2013 and 2017), May 2019.

3.2 The changing landscape of innovative activities

Patents have long been used to proxy companies' innovative output activity (Pakes and Griliches, 1980; Acs and Audretsch, 1989) and technological strength (Narin et al., 1987). More recently, trademarks have started to complement patent-based statistics, in order to better account for, in particular, non-technological and service innovations (Mendonça et al., 2004; Gotsch and Hipp, 2012).

As shown in the previous section of this chapter, the trademark and patent portfolios of top R&D investors worldwide are fairly concentrated. What follows is a discussion of the possible changes that occurred in the concentration of patents and trademarks, by sector, between the two periods considered, and a use of patent data to investigate changes in technological specialisation in different geographical areas. Technological specialisation is here assessed using revealed technological advantage (RTA) indicators, which compare the share of patents in a given technology generated in an identified area, with the overall share of the same technology generated elsewhere. For this purpose, 2012 statistics are here compared with 2016 ones.

Figure 3.4 shows the shares of patents, by sector, for the two periods considered. As can be seen, the same sectors are at the top in the two samples, whereas significant changes can be observed in shares accounted for by the rest of the sectors.

While important differences emerge at company-specific level, changes at the aggregate sector level appear more nuanced

The relative stability of patent shares across sectors may be a reflection of persistent sector specificities.

The overall share of IP5 families filed by companies operating in 'Computers and

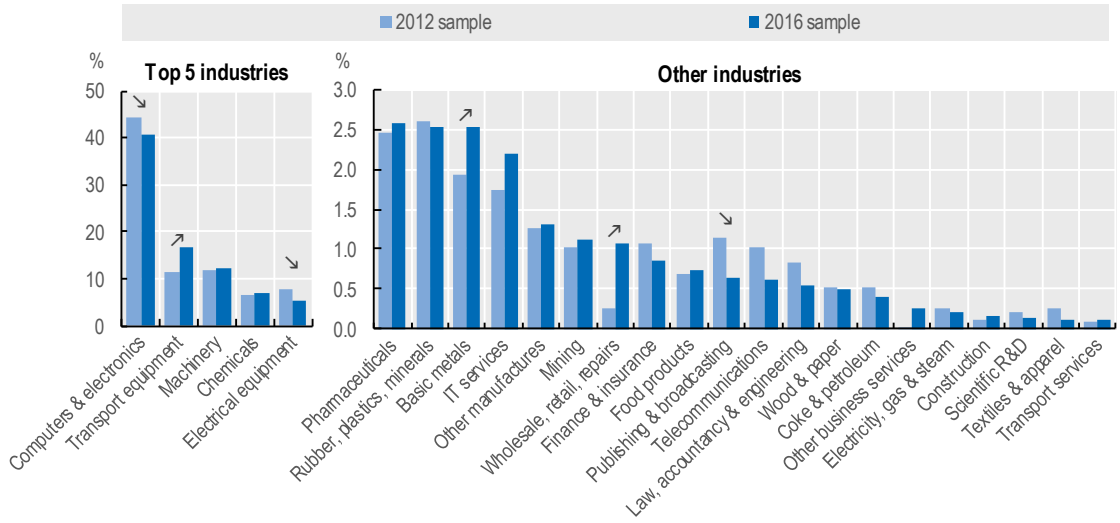
electronics' decreased between 2012 and 2016. However, companies operating in that sector remained responsible for about 40 % of total patent families owned by the top R&D investors worldwide in 2016. The 'Transport equipment' sector increased its share by five percentage points, ranking second in 2016 in terms of patenting activity.

The marked increase in patents filed by corporate R&D investors in the 'Transport equipment' sector suggests that technological upgrading may be occurring in the sector

The companies in the 'Transport equipment' sector are also responsible for the slight increase observed in the total share of patents owned by the top four sectors, i.e. 74 % in 2012 and 76 % in 2016.

Figure 3.4. Patent portfolios of world's top R&D investors, by sector, ISIC rev.4, 2012 and 2016 samples

As a percentage of total patents owned by top R&D investors in each period, IP5 patent families



Note: The arrows denote a difference of more than 0.5 percentage points between the two samples. Data cover patents owned by the top corporate R&D sample of 2012, filed in 2010-12, and patents owned by the top corporate R&D sample of 2016, filed in 2014-16.

Source: JRC-OECD, COR&DIP© database v.0, 2015 and JRC-OECD, COR&DIP© database v.2, 2019.

Figure 3.5 reports and compares trademark shares, by sector, in 2012 and in 2016. As can be seen, sectors' rankings differ depending on whether trademarks or patents are considered.

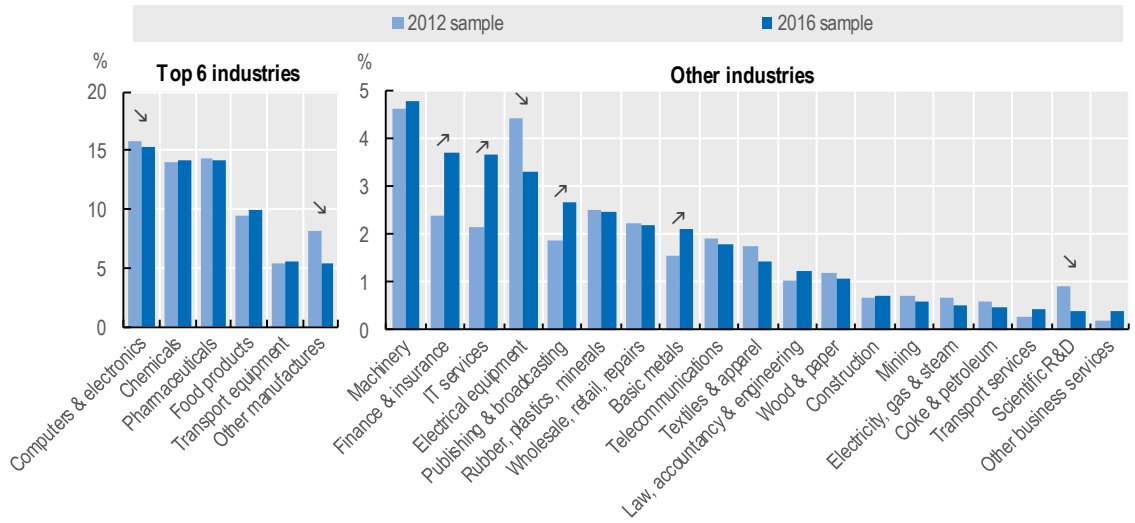
Despite the decrease observed in the relative share of trademarks between 2012 and 2016, 'Computers and electronics' remains the top trademarking sector. This sector's share of trademarks (15 %) is much lower than its share of patents (40 %) – in line with what could be expected from a sector producing complex technological goods. The 'Chemicals' and 'Pharmaceuticals' sectors conversely remain fairly stable, accounting for similar shares of registered trademarks in 2012 and 2016.

The use of registered trademarks appears more widely spread across sectors than the use of patents.

In recent years, the largest increases in terms of share of trademarks are mainly observed in sectors providing intangible goods and services, including 'Finance and insurance', 'IT services' and 'Publishing and broadcasting'. Companies in the 'Basic

Figure 3.5. Trademark portfolios of world's top R&D investors, by sector, ISIC rev.4, 2012 and 2016 samples

As a percentage of total trademarks owned by top R&D investors in each period, EUIPO, JPO and USPTO



Note: The arrows denote a difference of more than 0.5 percentage points between the two samples. Data cover trademarks owned by the top corporate R&D sample of 2012, filed in 2010-12, and trademarks owned by the top corporate R&D sample of 2016, filed in 2014-16.

Source: JRC-OECD, COR&DIP© database v.0, 2015 and JRC-OECD, COR&DIP© database v.2, 2019.

metals' sector represent an exception to this stylised fact. Their increased use of trademarks may mirror changes in their branding strategies, due for example to environmental concerns or corporate social responsibility-related branding. Finally, the slight increase in the share of trademarks registered by the 'Transport equipment' sector, and the decline in the use of trademarks in the 'Other manufactures' sector, allowed the former to appear among the top five trademarking sectors.

'Computers and electronics' and 'Transport equipment' are the two sectors remaining among the top five in terms of number of companies, and share of R&D, patents and trademarks

The relative stability emerging when comparing sectors rather than companies is similar to the one emerging when looking at the technological specialisation of different geographical areas. Radical technological change rarely occurs in short time spans. Major technological breakthroughs are rare events and it may take decades for new technological trajectories to unfold at the macro level.

Table 3.1 reports the RTA indices compiled for the major economic areas where the top R&D investors worldwide have their headquarters. The RTA index is computed using the IP5 patent families and provides an indication of relative specialisation in particular fields of technology, by the companies located in a given area. The RTA is here defined as the share of patents in a field of technology for an economic area, divided by the share of patents in the same field at the global level:

$$RTA_{it} = \frac{ps_{it}/\sum_t ps_{it}}{\sum_i ps_{it}/\sum_i \sum_t ps_{it}}$$

where ps_{it} represents the number of patents for area i in technology t. The numerator represents the share of technology t among all patents for area i, whereas the denominator represents the share of technology t among all patents. The index is equal to zero when companies headquartered in an economic area hold no patent in a given technology, and it grows with the increase of the patent

share in the given technology. An economic area is considered specialised in the given technology for values above 1, while values equal to or lower than 1 indicate no specialisation or relative de-specialisation, respectively.

Table 3.1. Revealed technology advantage (RTA) of world's top R&D investors, 2014-16

RTA and changes compared with the 2010-12 level, by field of technology and geographical location of headquarters

Field of Technology	Europe	United States	Japan	Korea	China	Rest of the World
Electrical machinery	1.0 ↗	0.7	1.2 ↗	1.2	0.5	1.1
Audio-visual tech.	0.4 ↗	0.6 ↗	1.1 ↘	1.9 ↗	1.9 ↗	1.7 ↘
Telecommunications	0.6 ↘	0.8 ↗	1.2 ↗	1.1 ↘	1.9 ↘	1.3 ↘
Digital communication	0.9 ↘	1.1	0.6	1.2 ↘	3.3 ↘	1.0 ↘
Basic communication	0.7	1.1 ↗	0.9	1.1 ↗	0.8 ↘	1.9 ↗
Computer technology	0.5	1.1 ↘	0.9 ↗	1.5 ↗	1.8 ↗	1.6 ↘
IT methods	0.7 ↘	1.6 ↘	0.9 ↗	0.8 ↘	1.4 ↗	0.8 ↘
Semiconductors	0.4	0.6 ↘	1.0 ↘	1.9 ↘	1.3 ↗	2.7 ↗
Optics	0.3 ↗	0.3 ↘	1.6	1.1	1.7 ↗	1.0
Measurement	1.4	1.2 ↗	0.9	0.5 ↗	0.5 ↗	0.7 ↘
Bio materials	1.6 ↘	1.4 ↘	0.9 ↗	0.3 ↘	0.1 ↗	0.3 ↗
Control	1.2 ↘	1.1 ↘	1.1 ↗	0.5 ↗	0.5 ↘	0.9 ↘
Medical technology	1.5	1.3 ↘	1.0 ↗	0.5 ↗	0.2 ↗	0.4 ↗
Organic chemistry	1.9	1.2 ↘	0.6 ↘	0.7 ↗	0.3 ↘	0.6 ↗
Biotechnology	1.7 ↘	1.6	0.7 ↗	0.5 ↘	0.1 ↘	0.3 ↗
Pharmaceuticals	1.8 ↘	1.6 ↘	0.5 ↗	0.3 ↗	0.2 ↗	0.8 ↗
Polymers	1.1 ↘	0.8 ↘	1.2 ↗	1.0 ↗	0.1 ↘	0.9 ↗
Food chemistry	2.3 ↗	1.4 ↘	0.5 ↘	0.3 ↗	0.1 ↗	0.2 ↗
Basic chemistry	1.3 ↘	1.3	1.0	0.6 ↗	0.2 ↘	0.4 ↗
Materials, metallurgy	1.1 ↘	0.8 ↗	1.3	0.8 ↗	0.3	0.5 ↗
Surface and coating	0.8	1.1 ↘	1.3 ↗	0.6 ↘	0.7 ↗	0.8 ↘
Micro- and nano-tech.	1.5 ↗	0.8 ↘	0.8 ↗	0.5 ↘	0.8 ↗	2.6 ↗
Chemical eng.	1.5	1.3 ↘	0.8	0.5 ↘	0.4 ↗	0.6 ↗
Environmental tech.	1.4	1.3 ↘	0.9	0.6 ↗	0.3 ↘	0.2 ↗
Handling & logistics	1.3 ↗	1.0 ↗	1.3	0.2 ↘	0.4 ↗	0.4 ↘
Machine tools	1.3 ↘	1.1	1.1 ↗	0.3 ↗	0.4 ↘	0.7
Engines, pumps, turbines	1.4 ↘	1.7	0.8	0.5 ↗	0.1 ↗	0.2
Textile and paper machines	0.6 ↗	0.6 ↗	2.1 ↗	0.1 ↘	0.1 ↘	0.1 ↘
Other special machines	1.4	1.2 ↗	1.0 ↘	0.3	0.2 ↗	0.9 ↗
Thermal devices	1.4 ↘	0.8	1.0 ↗	1.2 ↗	0.5 ↗	0.4 ↘
Mechanical elements	1.7	1.1 ↘	0.9 ↗	0.6 ↗	0.2 ↘	0.3 ↘
Transport	1.4 ↘	1.1 ↗	1.0	0.8 ↗	0.2 ↗	0.4 ↗
Furniture, games	1.5 ↘	0.8 ↘	0.9	0.9 ↗	0.9 ↗	0.6 ↘
Other consumer goods	1.8	0.9 ↗	0.5 ↘	1.6 ↗	0.7 ↗	0.4
Civil eng.	1.1 ↘	2.3 ↗	0.6 ↗	0.3 ↗	0.3 ↘	0.5 ↗

Note: Positive RTAs are highlighted in blue. The arrow denotes changes in the RTA of over 5 % compared with the 2010-12 level.

Source: JRC-OECD, COR&DIP© database v.2., 2019.

With the exceptions of *Electrical Machinery* (where it has shown positive specialisation) and *Digital Communications* (slight de-specialisation), in 2014-16 Europe[4] continued to be specialised in the same fields of technology as observed in 2010-12 (see Dernis et al., 2015). The same holds true for US-based companies, which continue to be specialised in the exact same technologies in which they were specialised in 2010-12.

Such stable specialisation patterns confirm the cumulativeness of knowledge and its path dependency, in addition to suggesting that European and US-based top R&D investors may be pursuing some form of exploitation rather than exploration strategy (March, 1991). In other words, these companies are developing innovative solutions related to technologies close to the areas in which they are already specialised, rather than exploring opportunities outside their core competences.

Notwithstanding the similarities in the technological profiles over time of companies headquartered in Europe and the United States, changes can be observed in the intensity of their specialisation (indicated by the arrows in the table). Seemingly, European and US-based companies are redistributing their R&D efforts across known fields of technology rather than opening new avenues.

The profile of top R&D investors based in Korea also remains stable, although the lower RTA index observed for *Micro- and nano-technologies* and the increased index for *Polymers* and *Thermal devices* signal changes in their research focus. The other technologies in which Korean-based companies appeared to be specialised in the first JRC-OECD remained unchanged, especially in ICT-related fields of technology.

Unlike top R&D investors based in Europe, the United States and Korea, corporations headquartered in Japan significantly changed their technological specialisation. Companies based in Japan widened their portfolio of specialisation, recently adding six technologies in which they were not previously specialised: *Control*, *Medical technology*, *Basic chemistry*, *Machine tools*, *Thermal devices* and *Transport*.

Similarly, top corporate R&D investors headquartered in China stepped up their technological capabilities in fields such as *Audio-visual tech.*, *IT methods*, *Semiconductors* and *Optics*. By contrast, in 2010-12 they appeared to be specialised in a narrow set of technologies, mostly ICT-related (*Telecommunications*, *Computer technology* and *Digital communication)*. Despite these changes, China remains the economy exhibiting the lowest number of fields in which it is technologically specialised.

In recent years, Japan and China have broadened the number of fields in which they are specialising, approaching the greater diversity already exhibited by Europe and the United States

3.3 The new members of the 'club'

Over time, new actors emerge while others may disappear from the radar screen of statistics. In this race to the top, factors such as technological and organisational capabilities (Teece et al, 1997) are key to determining firms' performance and competitiveness. This is why it is interesting not only to look at those companies and sectors that remain at the top, but also and especially to look at new entrants, to get a sense of what the future may look like.

Against the substantially unchanged pictures that emerge at sectoral and geographical level, the relative positioning of top R&D investors offers a more dynamic scenario. In what follows, the report focuses on the new entries; more

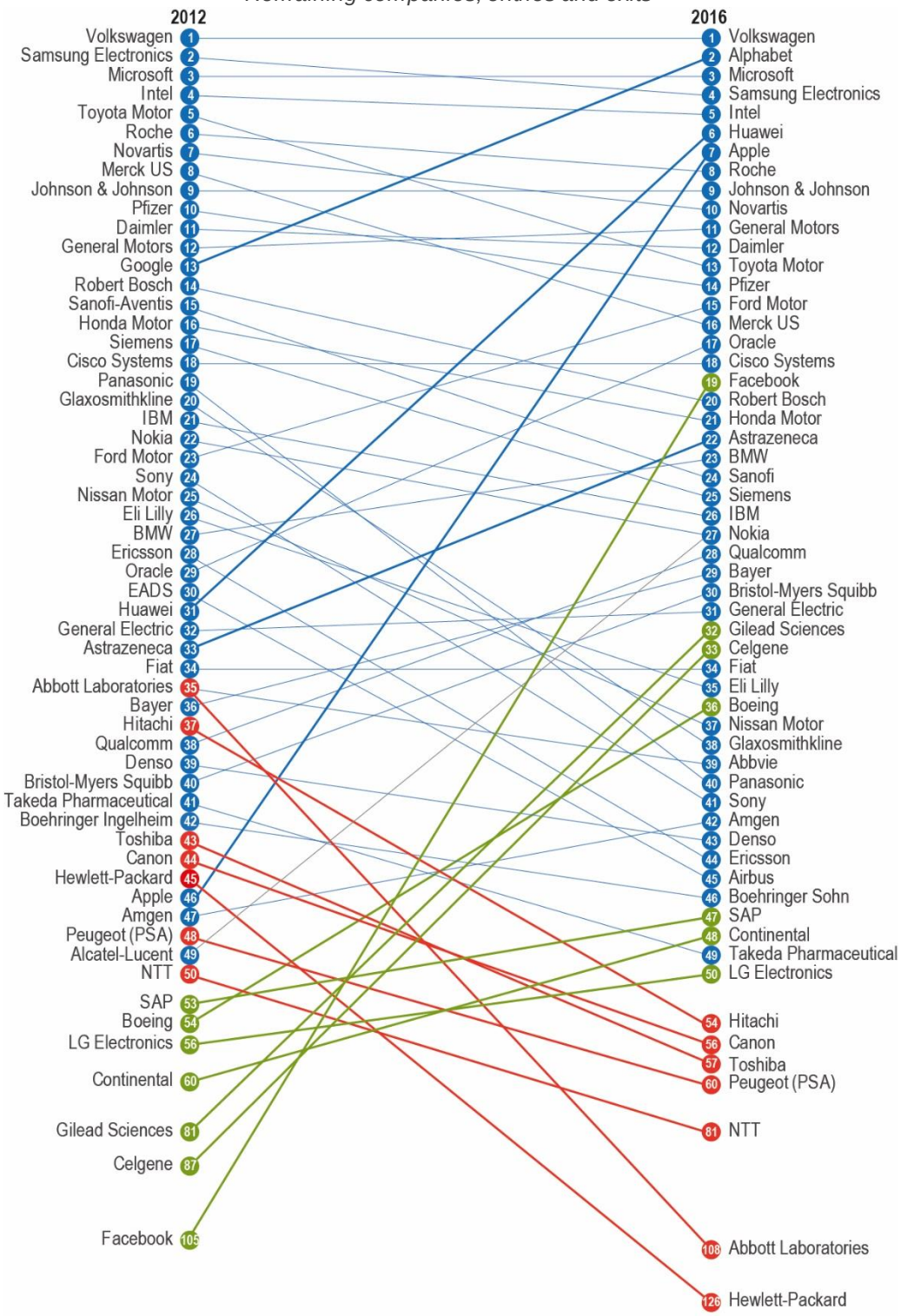
[4] For the sake of this report, Europe refers to EU-28 countries plus Switzerland (if not otherwise stated).

broadly, on changes in the companies at the very top of the ranking (top 50). The top 50 companies are responsible for about 40 % of overall R&D investment by the sample (Hernández et al., 2017). Overall mobility in the sample is further discussed by looking at the new entries (i.e. 456 companies) and their industrial and geographical distribution.

Figure 3.6 compares the ranking of the top 50 R&D investors in 2012 and in 2016. Seven companies made it to the top 50 in 2016, six of which were already present in 2012, albeit featuring in a lower part of the ranking. Facebook is the company that made the greatest leap in the last four years, climbing from 105th to 19th position. Other new entries in the top 50 are Gilead Sciences and Celgene (biotech companies), Boeing, SAP, Continental and LG Electronics. The biopharmaceutical company AbbVie is the only new company entering the top 50 in 2016 which had been outside the Scoreboard sample in 2012. However, this company is not strictly speaking a newcomer: it was founded in 2013 as a spin-off of Abbott Laboratories, which was ranked among the top 50 in 2012 and remains in the ranking (position 108). Corporate strategies and restructuring play an important role in the (measurement of the) relative positioning of companies. Indeed, the only two companies that fell from the top 50 to below 100th position are Hewlett-Packard and Abbott Laboratories, both of which experienced deep organisational restructuring. The other companies moving down from the top 50 nevertheless remained in the top 100 in 2016.

Figure 3.6. World's top 50 R&D investors, 2012 and 2016

Remaining companies, entries and exits



Note: Bold blue lines indicate an increase in ranking of more than 10 positions. The biopharmaceutical company AbbVie, founded in 2013, is a spin-off of Abbott Laboratories. Alcatel-Lucent was acquired in 2016 by Nokia.

Source: JRC-OECD, calculations based on EU Industrial R&D Investment Scoreboard (2013 and 2017), May 2019.

Looking at the whole sample, about a quarter of companies in the top 2 000 R&D investors in 2016 were not present in 2012 (see Box 3.1 for more details). In addition, more mobility can be observed when considering the overall sample than when looking only at the top 50. Despite already being a sample of global leaders, companies require particular efforts and strategies to reach and remain in the top 50 (Montresor and Vezzani, 2015).

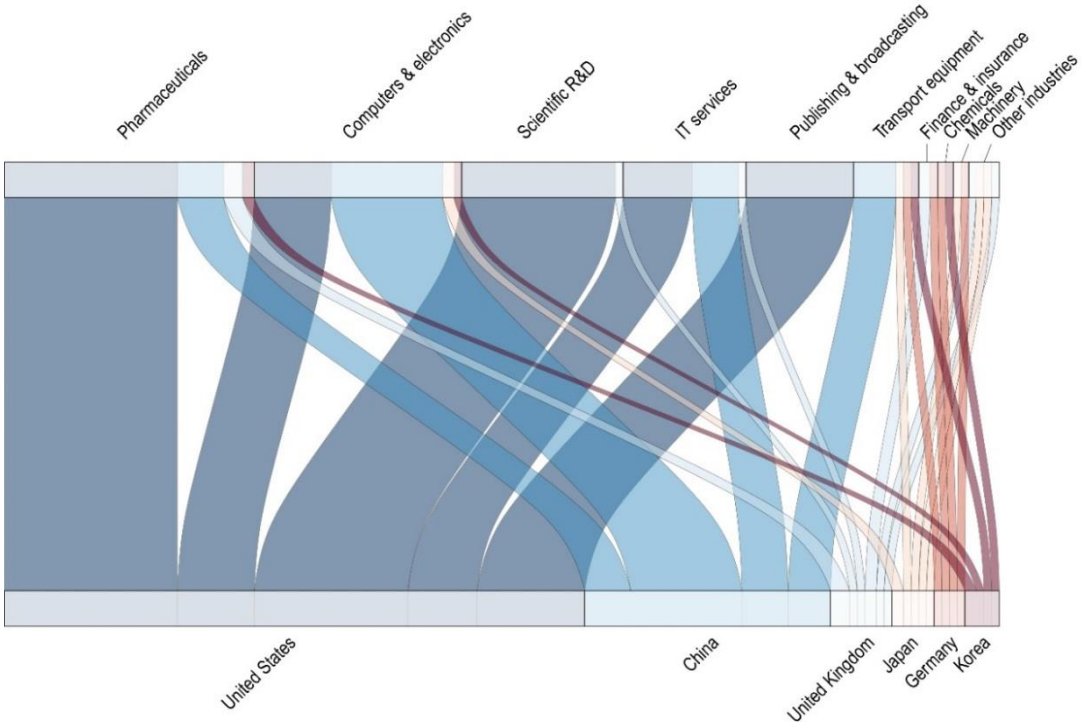
Figure 3.7 combines information about the location of the headquarters and the sector to which new entrants belong, to assist in their profiling. Most new companies come from either the United States or China. The entrance of a number of Chinese-based companies is in line with descriptive statistics presented in section 3.1. While the total number of US companies in the two samples is the same, the fact that there are so many new entrants headquartered in the United States conveys the idea of the US being characterised by competitive and dynamic environments. It may further reflect the extent to which old companies are replaced by new ones and new innovative ventures are created. A close look at sectors corroborates this interpretation. The majority of the new top corporate R&D investors are active either in 'Pharmaceuticals' (many of which are biotech companies) or in ICT-related sectors.

The growing importance of the 'Scientific R&D' sector is mostly driven by US-based companies

It should be noted that new entrants altogether account for less than 8 % of total R&D investment by 2016 Scoreboard companies. Therefore, the substantial stability across waves observed throughout the chapter is only marginally changed by the entrance of the numerous new companies. More pronounced changes would emerge if considering a longer time span. Four years may indeed not be long enough to appreciate major changes in the structure of the top R&D investors worldwide, which are very large and innovative due to their nature.

Figure 3.7. New world top R&D investors, by sector and headquarters' location, 2016 sample

Main geographical and industrial origin of companies not also present in 2012 sample



Note: Data relate to economies with at least 10 company headquarters entering the top 2 000 corporate R&D sample in 2016. Only the top sectors by economies are shown in the figure.

Source: JRC-OECD, calculations based on EU Industrial R&D Investment Scoreboard (2013 and 2017), May 2019.

Box 3.1: The 'new kids on the block' - companies entering the 'club' of top R&D investors

Of the top 2 000 R&D investors in 2016, 1 428 where already among the top R&D investors in 2012. Altogether, these companies accounted for 91.4 % of total R&D performed by the sample in 2016.

An additional 116 companies (accounting for 1.1 % of total R&D for the sample in 2016) were already present in the 2012 ranking but featured between 2 001 and 2 500 in terms of position.

This leaves 456 firms (representing 7.6 % of the total R&D in 2016) which were not present in the ranking four years previously.

Only 45 of these new companies entered in a significant position (top 500) in the most recent ranking considered. Many of these new entrants are not strictly speaking new companies, but are either the result of major company transformations (mergers and acquisitions, spin offs, etc.) or companies that went public during the period between the two samples.

The top three entrants are a clear example of this. AbbVie (position 39) and Hewlett Packard Enterprise (position 62) are the results of a spin-off (of Abbott Laboratories) and a split of Hewlett-Packard into two companies: HP and Hewlett Packard Enterprise. The third top entrant is Dell Technologies (position 51). Dell went private in 2013 (hence did not publish audited accounts) and disappeared from the ranking (included in the R&D Scoreboard edition of 2012). The following year the company went public again and reappeared in the ranking for the 2014 edition.

The new entrants not due to a major company operation or to a long-established company going public are mainly companies in ICT-related sectors.

The main example of this is Twitter: founded in 2006, it has traded since 2013 and entered the ranking of top 2 000 R&D investors in the 2014 edition.

4. The variety of innovation activities

This chapter investigates the innovative competences on which the top corporate R&D investors rely. Firstly, the extent to which these competences are concentrated (or not) is assessed and secondly, whether companies' knowledge develops in relation to well-defined core sets is investigated. Thirdly, whether industry specificities emerge along the innovation process, and fourthly, whether industries differ in the importance they give to basic research compared to technology, product, and service development are examined. This analysis uncovers the industry-specific competences of the top corporate R&D investors. Finally, additional stylised facts about the information and communication technology (ICT) activities of top corporate R&D investors, given the important role that these technologies play in the digital era, are presented.

4.1 Concentration of innovative competences by top R&D investors

The technology-related knowledge that companies master often centres on (relatively) narrow and well-identified sets of core competences. These allow companies to enter, position themselves, and compete in their target markets and distinguish themselves from their competitors.

The stylised facts highlighted in previous chapters align with a long-standing literature showing that the technological competences of firms tend to remain relatively stable, at least in the short term. The technological profile of companies and their evolution go hand in hand with the way their product market space develops (Patel and Pavitt, 1997) and with their ability to bring new ideas onto the market successfully (Dosi et al., 2017). In addition, the very same set of technologies may help develop a range of (also very different) products. This explains why companies may appear to be more diversified in terms of products they produce than in terms of their technological specialisation (Dosi et al., 2017).

Furthermore, companies operating in the very same markets or sectors may share a number of commonalities in their R&D and innovation strategies (Cohen and Klepper, 1992). What distinguishes them is firstly the specific combination of the technological opportunities they pursue. Secondly, the cumulativeness, and more in general, the way they build, nurture, and upgrade or diversify their knowledge base. Lastly, the competition and appropriability conditions under which they operate (Breschi et al., 2000).

To shed light on these features, the present section shows the extent to which the innovative competences of top R&D investors throughout the world are concentrated (or not) around a distinctive core of technologies or knowledge areas. For this purpose, concentration ratios, i.e. CR_4 indexes, have been separately compiled on the portfolio of patents and trademarks of, and the scientific publications produced by top corporate R&D investors. The indexes mirror the cumulative share of the four most represented technological classes covered in the patents owned by a given sector, i.e. $CR_{4,I} = \sum_{n=1}^{4} s_n$.

The CR_4 indexes shown here rely on 35 technological fields in patents, 45 product and service classes of trademarks, and 27 scientific fields in publications. More information about the taxonomies on which indexes are based and what they contain is provided in Box 4.1. Further details about the relevant taxonomies can be found in Appendices D-E-F of this publication.

Given that the different intellectual assets considered, i.e., patent, trademarks, and scientific publications are not grouped in the same way nor do groups include the same underlying number of subcategories or items, it is not possible to compare concentration indexes across assets. While it is perfectly reasonable to compare the

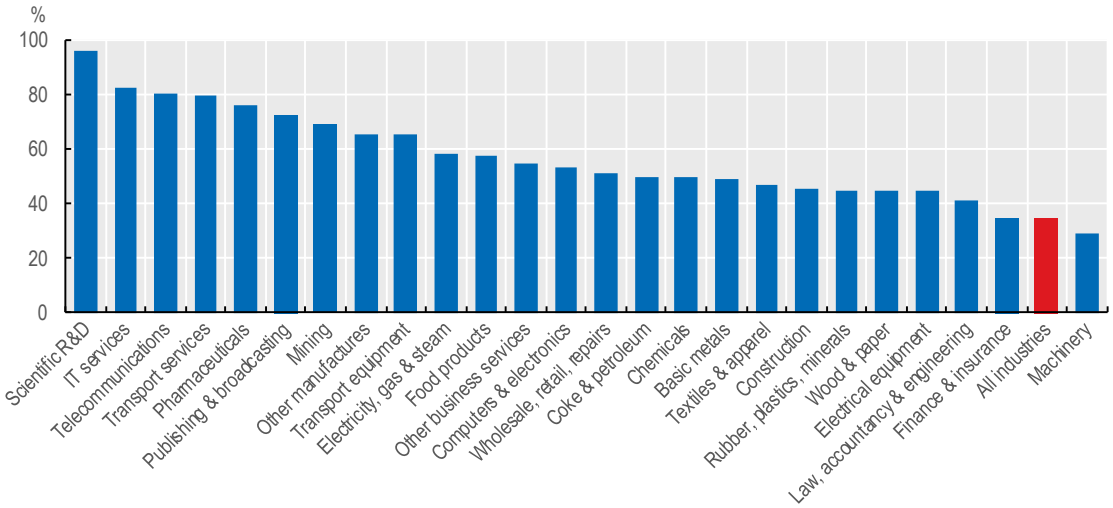
extent to which sectors differ in their technological focus, it is not possible to say that a CR_4 of 70 % observed in the case of patents is greater than a CR_4 of 65 % observed in the case of trademarks or scientific publications. Comparisons can nevertheless be made in general terms, especially for the relative positioning of sectors in the rankings.

Figure 4.1 shows the concentration indexes computed on the patent portfolios of sectors featuring at least 10 of the top 2000 R&D investors worldwide.

The degree of technological specialisation varies across sectors. 'IT services' and 'Telecommunications' are amongst the most specialised and focus 80 % or more of their patenting activity in only four technology areas

Figure 4.1. Technological concentration in patent portfolios of the world's top R&D investors by sector, ISIC rev. 4, 2014-16

Share of top four technological fields in total IP5 patent families owned by sector



Note: Data relate to sectors with at least 10 company headquarters in the top 2 000 corporate R&D sample that filed patents in 2014-16.

Source: JRC-OECD, COR&DIP© database v.2., 2019.

With about 97 % of their patent portfolios concentrated in four technological fields only, top corporate R&D investors in the 'Scientific R&D' sector emerge as having the most concentrated technological knowledge. Companies operating in this sector are active in basic research, applied research, and/or experimental development, and are part of the so-called knowledge intensive business services, which play a key role in the knowledge-based economy (Hertog, 2000).

Other sectors characterised by patent portfolios that emerge as being particularly concentrated around a core set of technology areas are 'ICT services' and 'Telecommunications' (both above 80 %).

At the other end of the spectrum lies the 'Machinery' sector which displays a highly diversified set of competences. The top four most frequent technologies developed in this sector only account for approximately 30 % of the patents. The concentration ratio in the 'Machinery' sector is even lower than that obtained on the whole sample, based on pooling together the patent portfolios of companies operating in different sectors.

Companies in the 'Scientific R&D' sector focus on a narrow set of technological competences whereas those in 'Machinery' rely on a more diversified technology base

Taken overall, the trademark portfolios of top corporate R&D investors worldwide appears to be concentrated in a similar way to patents. As can be seen from Figure 4.2, approximately 36 % of the trademarks belonging to the top corporate R&D investors are filed in four Nice classes. These are: *Instruments and Computers*, *Pharma products*, *R&D and Software*, and *Cleaning products* (for an exact description of the Nice classes, see https://www.wipo.int/classifications/nice/nclpub/en/fr/).

Similarly to the concentration analysis of patents, 'Scientific R&D' emerges as a sector whose companies focus on a relatively narrow set of product and service classes. The 'Pharmaceuticals' sector follows, in line with what could be expected from the particular type of business models characterising these companies.

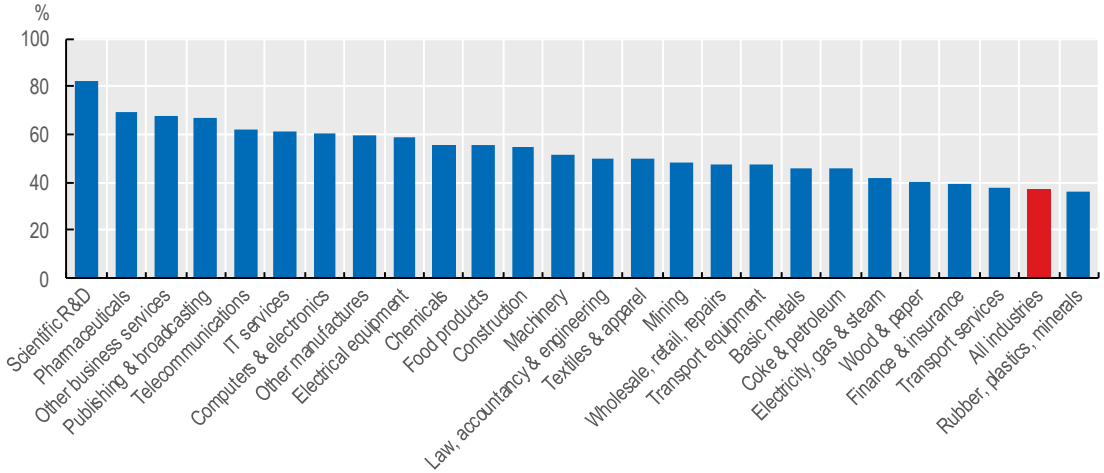
Comparing the relative degree of concentration of technological developments and trademarking activities provides some interesting insights. Some sectors appear to be more focused on a small number of technology fields than the range of products and services they trademark. For instance, this is the case with 'Telecommunications' and 'ICT services', which rank second and third in terms of technological specialisation but fifth and sixth in terms of trademark concentration.

On the other hand, companies in sectors such as 'Computers and electronics', 'Chemicals', 'Electrical equipment', and 'Machinery' exhibit a seemingly higher specialisation in a limited set of product and service classes than in technological fields. In other words, the technologies developed by these sectors may result in a relatively narrower set of complex products and services. Equivalently, a broader technological base and a wider array of technological developments are required to bring a smaller set of (often complex) products and services onto the market. This can be seen by comparing the position of these sectors in the ranks respectively displayed in figures 4.1 and 4.2.

Differences in the complexity of products and in branding strategies contribute to the differences in technological and market concentration observed across sectors

Figure 4.2. Product and service class concentration in trademarks owned by the world's top R&D investors by sector, ISIC rev. 4, 2014-16

Top four trademark classes in company portfolios, EUIPO, JPO, and USPTO



Note: Data relate to sectors with at least 10 company headquarters in the top 2 000 corporate R&D sample that filed trademarks in 2014-16.

Source: JRC-OECD, COR&DIP© database v.2., 2019.

An analysis of the breadth of the scientific base that top corporate R&D investors contribute to developing and rely upon also reveals significant differences across sectors, as shown in Figure 4.3. On average, approximately 57 % of the scientific publications made by authors affiliated to the top corporate R&D investors only relate to 4 out of 27 of the main fields listed in the Elsevier classification of scientific articles. Generally speaking, this means that more than half of the scientific production of each company in the dataset concern a relatively narrowly set of scientific developments.

Box 4.1. Classifying IP rights and publications

Patents and trademarks are classified by Intellectual Property offices during the examination procedure (in the case of patents) or the registration process (for trademarks) according to internationally-agreed classifications. Bibliographic experts group scientific publications into main subject areas.

Patent examiners attribute **International Patent Classification (IPC)** codes to patents to denote the technology domains to which inventions belong (see http://www.wipo.int/classifications/ipc). The IPC classification groups technologies into eight main sections, which in total feature approximately 70 000 subdivisions. In the present report, IPC codes are aggregated into 35 technological fields according to the concordance proposed by WIPO (2013, revised in 2018). The list of technology fields is provided in Appendix D.

Trademarks applications are filed following the **International Classification of Goods and Services** which is also known as the Nice Classification (NCL). This classification consists of 34 classes covering a wide range of goods and 11 classes relating to services (see: http://www.wipo.int/classifications/nice/en/, and Appendix E).

Bibliometric data are classified according to the **All Science and Journal Classification** (ASJC). Elsevier assigns each journal in Scopus (which is one of the largest abstract and citation databases of peer-reviewed literature) to one or more subjects using ASJC. There are 27 main fields comprising 334 subjects in the classification, as detailed in Appendix F of this publication (see also: https://service.elsevier.com/app/overview/scopus).

Analysis of applied research and product development reveals that 'Scientific R&D' sector is the most concentrated. About 85 % of scientific articles authored by employees affiliated to the companies operating in this sector are in four scientific fields (*Medicine*; *Biochemistry, Genetics, and Molecular Biology*; *Pharmacology, Toxicology and Pharmaceutics,* and *Immunology and Microbiology*).

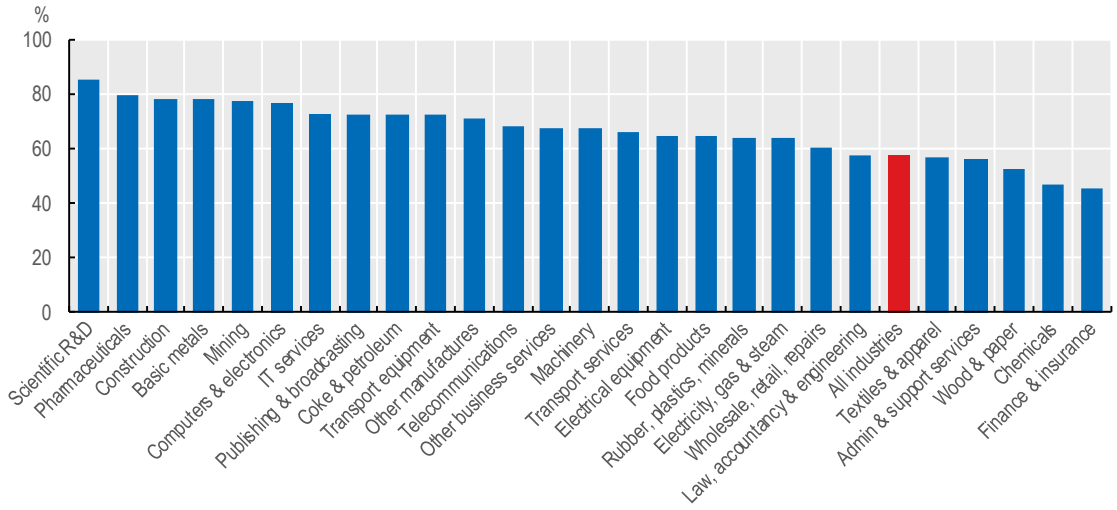
As in the case of trademarks, the 'Pharmaceuticals' sector ranks second with a concentration index related to scientific publications of almost 80 %. At the other end of the spectrum, 'Chemicals' and 'Finance and insurance' are the sectors reporting the lowest degrees of scientific specialisation, as shown by CR_4 ratios being slightly below 50 %.

Taken together, the specialisation indexes proposed tell a story of sector specificities. The way companies innovate and bring their innovative products and services onto the market differs depending on the sectors in which these companies operate. Basic research, applied research, and product and service development - as captured by scientific publications, patents, and trademark registrations, respectively – play a different role in different sectors. Some sectors, such as 'Scientific R&D', are highly specialised in their production of basic and applied research as well as in the type of product and services they develop while other sectors present varying degrees of specialisation in the core set of competences they rely upon during the innovation process.

Basic research, applied research, and product and service development play a very different role in companies competing to be at the top in different sectors

Figure 4.3. Scientific concentration in the publication portfolios of the world's top R&D investors by sector, ISIC rev. 4, 2014-16

Share of top four scientific fields in publications by sector



Note: Data relate to sectors with at least 10 company headquarters in the top 2 000 corporate R&D sample with publications in 2014-16.

Source: JRC-OECD, COR&DIP© database v.2., 2019.

4.2 Top competence areas by sector

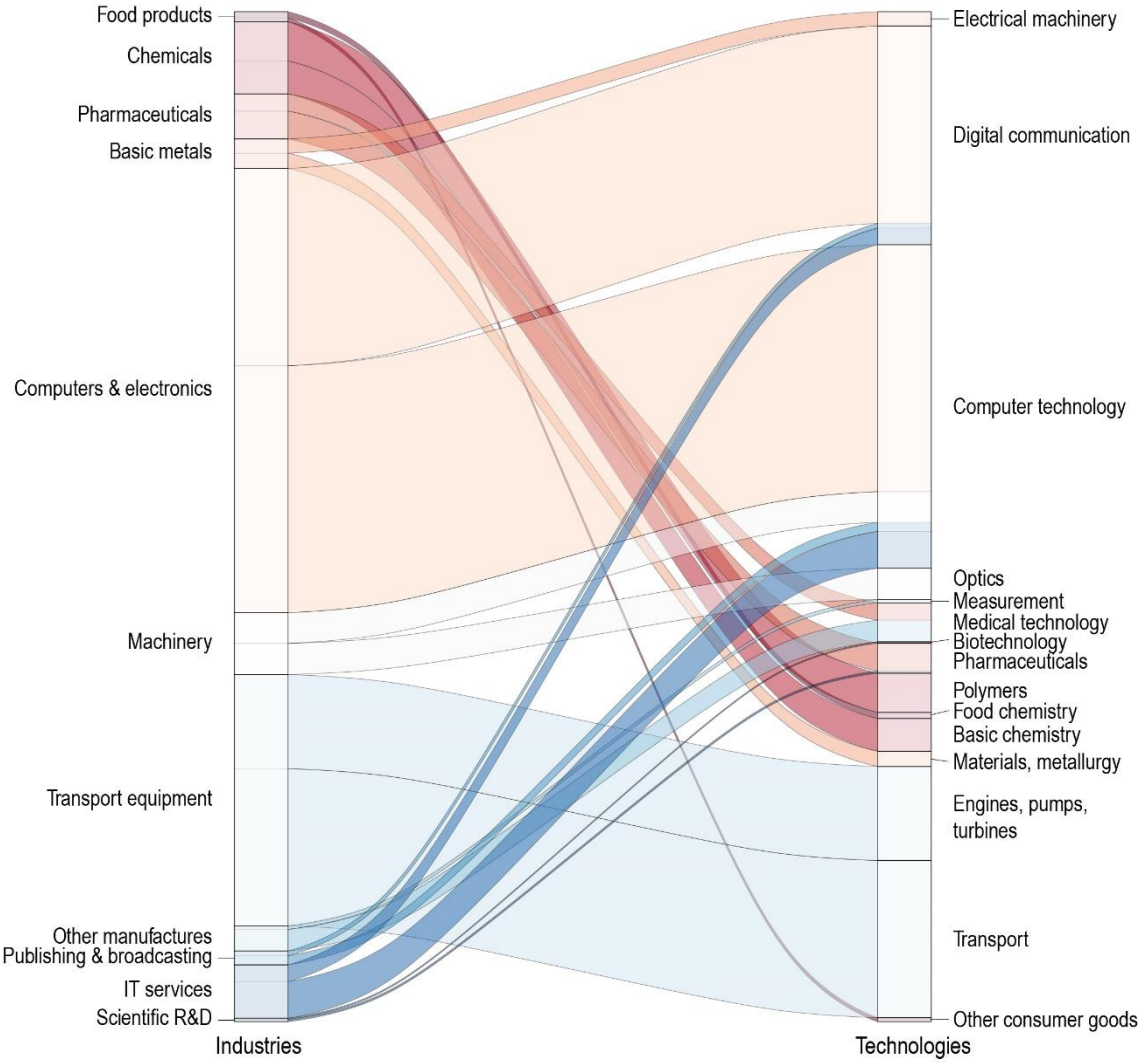
The technological capabilities of companies often show regularities that allow them to be grouped and competition in technological markets to be characterised (Gkotsis et al., 2018). For example, recent evidence shows that the development of environmental-related innovations in the automotive sector has led to patents being applied in relation to three main technological trajectories: green internal combustion engines, electric/hybrid, and mixed/complex technologies (Faria and Andersen, 2017).

In attempting to shed light on the key scientific technological and product developments on which top corporate R&D investors focus, the three figures that follow show the sectors on the left-hand side and on the right-hand side the type of output considered, which companies contributed to developing (i.e., patents, trademarks, and scientific publications, respectively). The size of the bars on the left-hand side denotes the proportion of the overall innovative output generated by the sector considered. Conversely, the size of the bars on the right-hand side mirrors, for example, the way patents in considered technology are filed by the top corporate R&D investors, as a proportion of their overall patent portfolio. Furthermore, two flows depart from each sectors listed on the left hand side, each corresponding to the top two technology fields, product and service class, or scientific fields to which they contribute. Again, the relative size of these flows mirrors the relative importance of these developments in the sector considered.

Figure 4.4 shows the top two technology fields that sectors focus the most on. As previously mentioned, this figure may be read from different perspectives. These include considering the shares of top technologies (right axis) developed overall or the extent to which different sectors contribute to develop different technologies, (the flows between the left and the right axis) may be examined to see the most significant contributors in different technology fields.

Figure 4.4. Top two technologies patented by sector, ISIC rev.4, 2014-16

Share in total IP5 patent families owned by the world's top R&D investors



Note: Data relate to sectors with at least 50 company headquarters in the top 2 000 corporate R&D sample that filed patents in 2014-16.

Source: JRC-OECD, COR&DIP© database v.2., 2019.

The majority of patents filed by top corporate R&D investors relate to *Computer Technology* and *Digital Communication*, both fields related to ICT technologies and digitalisation. These inventions mainly originate from companies operating in the 'Computers and electronics' and 'ICT services' sectors. Interestingly, *Computer Technology* (together with *Optics*) is also the technology most frequently developed by the 'Machinery' sector, a fact which highlights the importance of digitalisation and automation for the sector. Similarly, technological developments related to *Electrical Machinery* appear to be highly relevant for the 'Basic Metal' sector.

Transport and *Engines, pumps, turbines* are the two main technological fields in which companies in the 'Transport equipment' sector file for patents, and together they represent approximately 43 % of the patent portfolio of this sector.

Medical and chemical related technologies are also highly patented by companies in the overall sample. These technologies are among those that are most developed by a number of selected sectors, including 'Food products', 'Chemicals', 'Pharmaceuticals', and 'Other

manufactures'. Figure 4.4 also characterises the patent portfolio of companies operating in 'Scientific R&D', with approximately 51 % being filed in *Pharmaceuticals* and 30 % in *Biotechnology*.

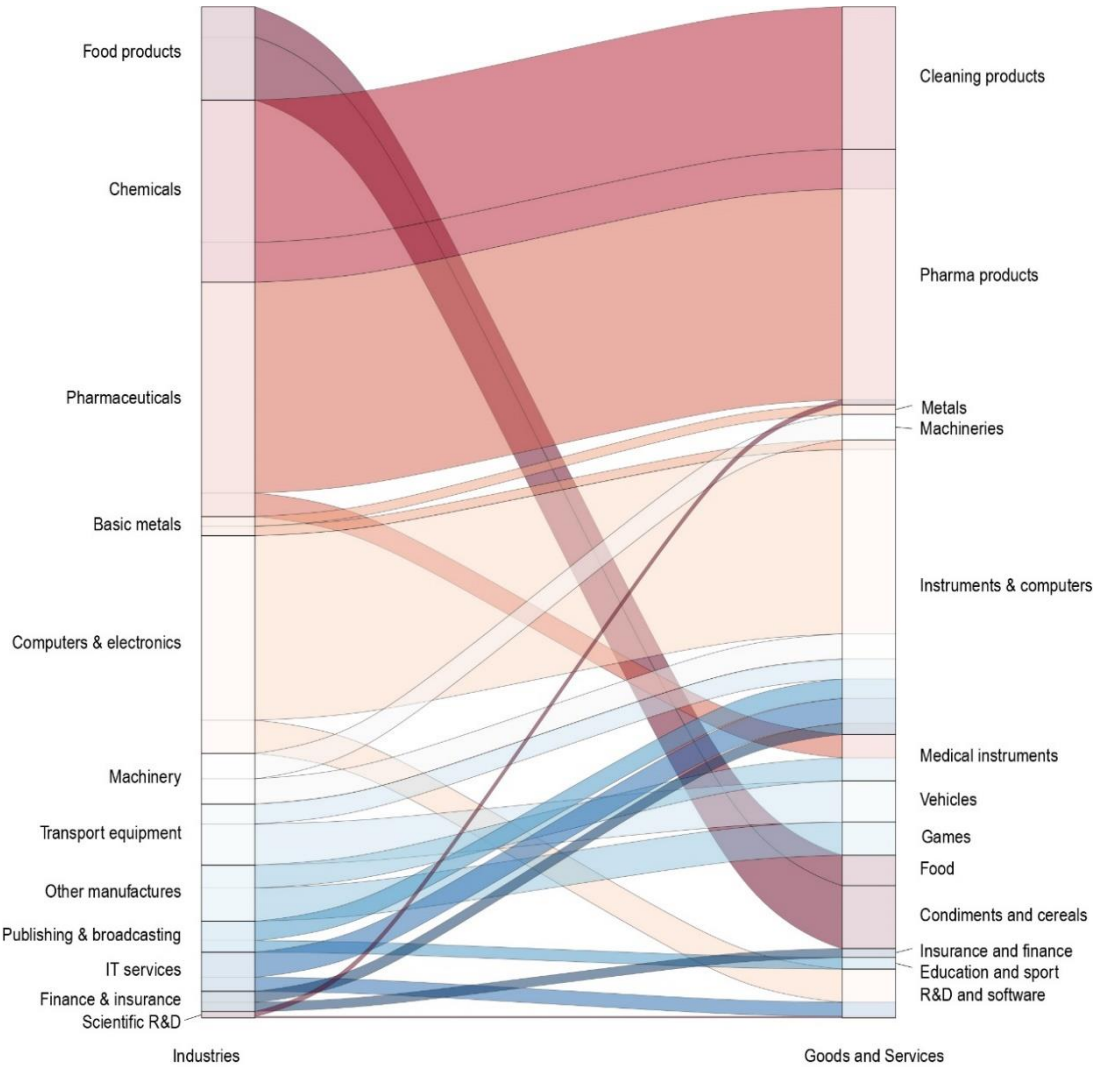
More than 80 % of patents owned by 'Scientific R&D' sector relate to *Pharmaceuticals* and *Biotechnology*, suggesting a growing importance of (highly) specialised suppliers in the medical industries

Figure 4.5 offers a picture similar to that shown in Figure 4.4, but applied to the two product and service trademark classes most frequently registered by the top R&D investors worldwide by sector.

Similar to patents, registered trademarks are broadly consistent with the type of products and services that the sectors considered could be expected to specialise in. Most trademarked products and services directly relate to the industrial classification of companies although some peculiarities worth noticing do emerge.

Figure 4.5. Top two goods and services registered by sector, ISIC rev.4, 2014-16

Share in total trademarks owned by the world's top R&D investors



Note: Data relate to sectors with at least 50 company headquarters in the top 2 000 corporate R&D sample that filed trademarks in 2014-16. Class titles correspond to short labels based on the Nice Classification. For an exact description of the classes, see https://www.wipo.int/classifications/nice/nclpub/en/fr/

Source: JRC-OECD, COR&DIP© database v.2., 2019.

Firstly, the top trademarked products by 'Chemicals' companies fall in the *Cleaning* and *Pharma products* classes. The former is a broad product category also including non-medicated cosmetics and toothpastes, toiletry preparations, perfumery, essential oils, bleaching preparations, and other substances. Therefore, it should not be seen as strictly related to cleaning products and this is confirmed by the fact that it is among the top 4 classes protected by 'Pharmaceuticals' companies.

Secondly, *Instruments & computers* is among the two most frequent classes used by several non-ICT sectors: 'Basic metals', 'Machinery', 'Transport equipment', 'Other manufactures', 'Publishing and broadcasting', and 'Finance and insurance'.

Registered trademarks confirm the importance of developing digitally related products for a wide spectrum of industrial sectors

Finally, the most frequent product and services developed by 'Scientific R&D' companies are *Pharma products* and *R&D and software*. This evidence helps to further characterise this group of companies in the top corporate R&D sample and also highlights the importance of digitalisation in the discovery and commercialisation of new drugs.

Figure 4.6 shows the two most frequent classification fields to which the scientific publications authored by staff affiliated to the top R&D investors worldwide belong.

It is worth noting that publications by the top R&D corporate investors in the world broadly fall into seven main scientific classes. This confirms some of the stylised facts proposed so far and suggests the importance of a somewhat specialised knowledge base for the development of a relatively wider array of technological solutions. Scientific publications further appear to relate to scientific fields that are directly related to the industrial classification of companies.

Top corporate R&D investors focus their scientific publications in *Engineering*, *Computer Science,* and *Medicine*

Approximately, 16 % of the total number of publications belonging to the firms in the sample is classified as *Engineering*- related publications. Companies in the 'Computers and electronics' sector are responsible for 6.3 % of total publications in this field, which represents 31 % of the sector's total publications. A considerable amount of *Engineering*-related publications is contributed by firms in 'Transport equipment', which hold 4.5 % of total publications in this field. This represents almost 39 % of total publications from firms in the sector, the second most important field being *physics and Astronomy* with 12 %.

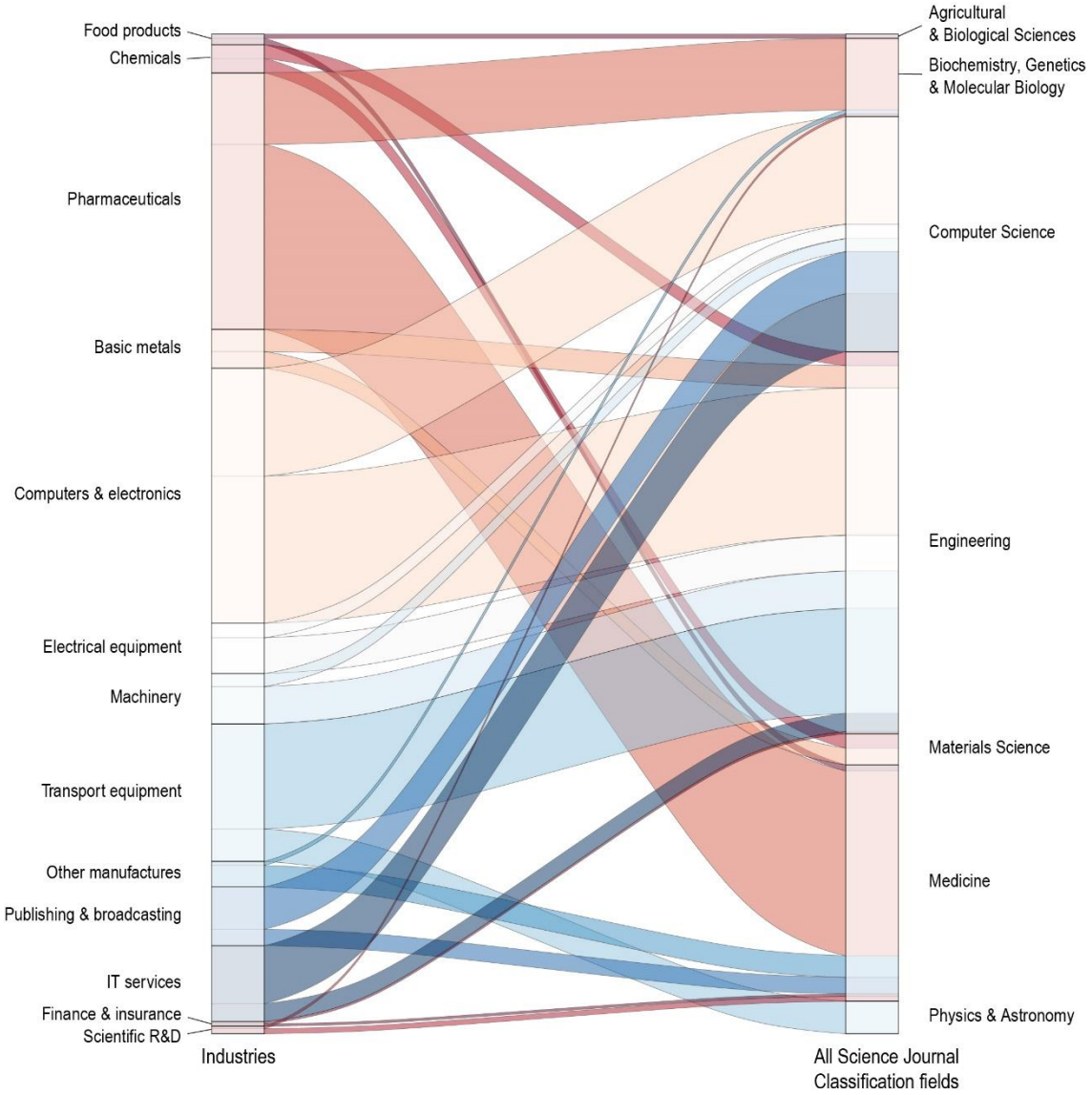
Engineering also emerges as being highly important in the research performed by companies in sectors such as 'Electrical equipment', 'Machinery', and 'Basic metals', where this scientific field represents more than 30 % of publications. *Computer Science* is the second most important field for 'Electrical equipment' and 'Machinery', while 'Basic metals' is active in the *Material Science* field.

On the other hand, *Medicine* and *Computer Science* related publications represent 10 % each of the total number of publications in the sample.

The majority of the *Medicine*-related publications (7.9 %) come from firms in the 'Pharmaceuticals' sector, which appear to focus 43 % of their total publications in this field. Conversely, another 17 % relate to *Biochemistry, Genetics and Molecular Biology.*

The main body of *Computer Science*-related publications in the sample comes from companies in the 'Computers and electronics' sector (4.6 %) and in the 'IT services' sector (2.5 %).

Figure 4.6. Top two All Science Journal Classification fields by sector, ISIC rev.4, 2014-16
Share in total publications by the world's top R&D investors



Note: Data relate to sectors with at least 50 company headquarters in the top 2 000 corporate R&D sample with publications in 2014-16.

Source: JRC-OECD, COR&DIP© database v.2., 2019.

4.3 The digital competences of top R&D investors

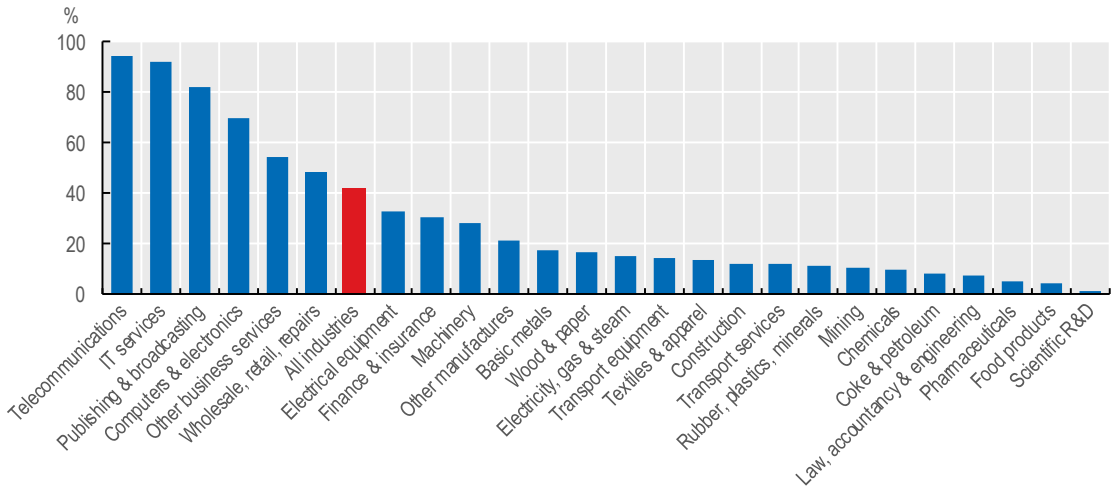
Examining the ICT-related patents developed by companies in different sectors helps shed light on the importance and penetration of the digital transformation in the economy.

Overall, ICT-related patents emerge as being highly relevant to many sectors

They represent 42 % of total IP5 families in the sample, as can be seen in Figure 4.7.

Over 80 % of the patents owned by the top corporate R&D investors in the 'Telecommunications', 'IT services', and 'Publishing and broadcasting' sectors belong to ICT. A high degree of ICT specialisation is also observed in sectors such as 'Computers and electronics' and 'Other business services'.

Figure 4.7. ICT patents owned by the world's top R&D investors by sector, ISIC rev. 4, 2014-16
Share in IP5 patent families by sector



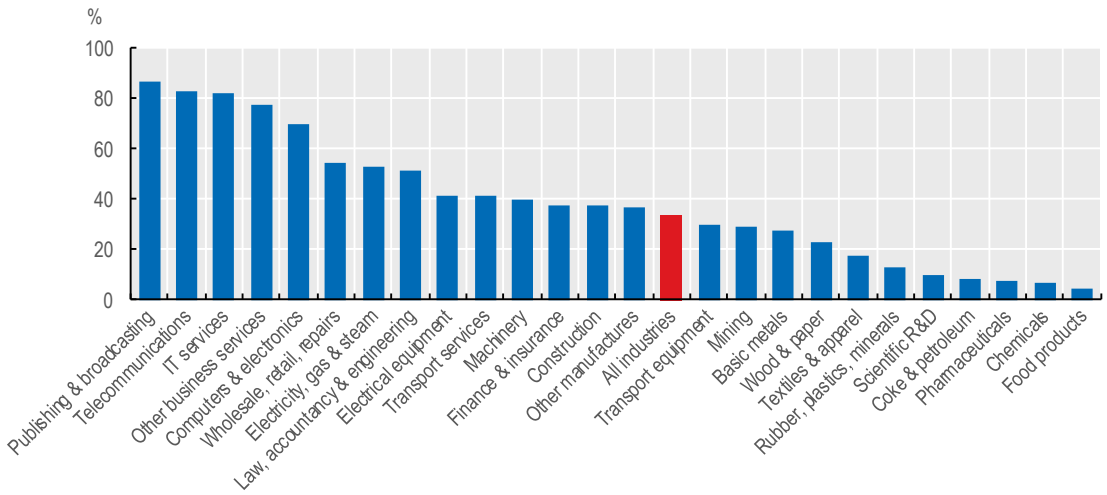
Note: Data relate to sectors with at least 10 company headquarters in the top 2 000 corporate R&D sample that filed patents in 2014-16.

Source: JRC-OECD, COR&DIP© database v.2., 2019.

At the other end of the spectrum 'Pharmaceuticals', 'Food products', and 'Scientific R&D' firms have the lowest shares of ICT patents in their portfolios, with ICT patents that respectively account for approximately 5 %, 4 %, and 1 % of their overall portfolio.

Figure 4.8 shows the ICT-related trademarks registered at EU IPO, JPO, and USPTO by the top R&D investors as a share of the total number of trademarks in their portfolio, with statistics that are displayed at the sector level. This figure only displays the statistics for those sectors with at least 10 firms in the top 2 000 list.

Figure 4.8. ICT-related trademarks owned by the world's top R&D investors by sector, ISIC rev. 4, 2014-16
Share in total trademarks by sector, EUIPO, JPO, and USPTO



Note: Data relate to sectors with at least 10 company headquarters in the top 2 000 corporate R&D sample that filed trademarks in 2014-16.

Source: JRC-OECD, COR&DIP© database v.2., 2019.

Firms in the 'Publishing and broadcasting' sector have the highest share of ICT related trademarks in their portfolio, with almost 87 % of their registrations classified as ICT. A high share of ICT trademarks (more than 82 %) is also found in the portfolios of 'Telecommunications' and 'IT services' companies. On average, 33.6 % of the trademarks in the sample are for ICT goods and services.

In general, ICT related trademarks appear to be important in a wide array of sectors, although not as important as patents

A relatively low share, below 10 %, of ICT trademarks is found in the portfolio of firms in 'Scientific R&D', 'Coke and petroleum', 'Pharmaceuticals', 'Chemicals', and 'Food products' sectors.

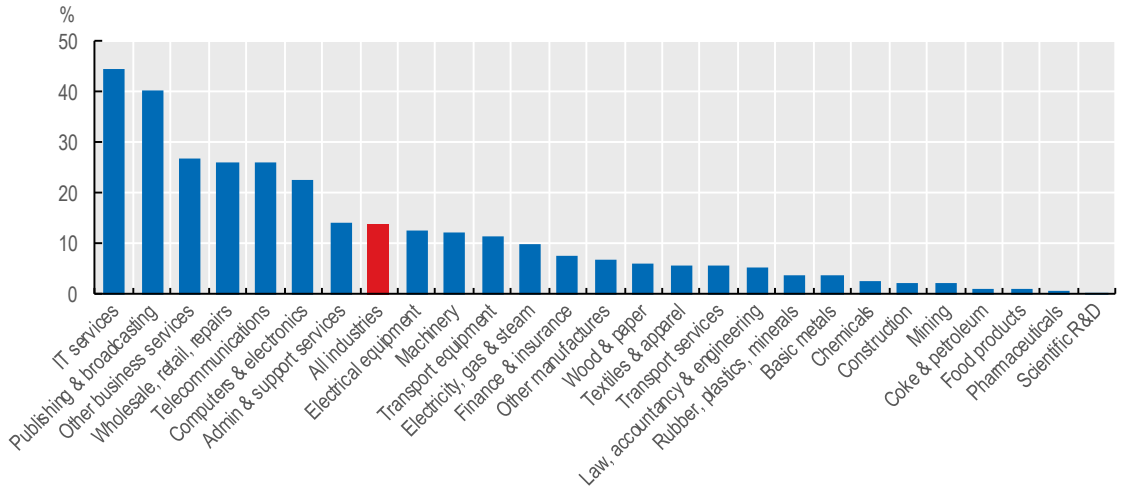
Developing science in relation to information and communication technologies also appears to be important for top corporate R&D investors. Looking at the share of ICT-related scientific publications in the portfolio of these companies (Figure 4.9) shows the great relevance of ICT for firms in 'IT services' (44.5 %), 'Publishing and broadcasting' (40.2 %), 'Other business services' (approximately 27 %), 'Wholesale, retail, repairs' and 'Telecommunications' (approximately 26 %).

Conversely, 'Pharmaceuticals' and 'Scientific R&D' are the sectors where ICT-related publications represent less than 1 % of total publications.

Overall, the statistics shown above suggest that a number of sectors, including 'IT services', 'Telecommunications', and 'Other business services' focus an important part of their activities on ICT-related developments and activities.

Figure 4.9. ICT-related scientific articles of the world's top R&D investors by sector, ISIC rev. 4, 2014-16

Share in total scientific publications by sector



Note: Data relate to sectors with at least 10 company headquarters in the top 2 000 corporate R&D sample with publications in 2014-16. The All Science Journal Category (ASJC) field "Computer Science" is used as a proxy for ICT-related articles.

Source: JRC-OECD, COR&DIP© database v.2., 2019.

5. Shaping AI development: The role of Top R&D investors

This chapter sheds light on Artificial Intelligence (AI)-related developments by top corporate R&D investors worldwide. The analysis encompasses scientific publications, patents, and trademarks, and additional information is also provided about the top 50 companies that most contribute to developing artificial intelligence in terms of scientific and innovative output. The analysis then moves from the firm to industry level, and shows the contribution of different sectors to the overall production of AI related patents, trademarks, and publications. Further insights into the geographic location where basic research and applied research on AI are pursued and products/services are developed are also presented.

5.1 Top innovators in Artificial Intelligence

Artificial Intelligence (AI) is high on the agenda of both businesses and governments (EC COM (2018)237). AI is expected to have far-ranging societal and economic repercussions in the near future (OECD 2018). Although the term was initially coined in 1950, recent advances in the field have further fuelled the development of AI-related applications also transforming non-ICT related sectors and creating value that many are trying to appropriate (Baruffaldi et al, 2019).

Many consider AI to be a general purpose technology, one which may bring about a major technological shift like the one triggered by the World Wide Web (WIPO 2019, Craglia et al., 2018). As such, AI is not only expected to have an impact on the (technological) competitiveness of economic actors, but it is also expected to change the way people think, act, and interact between each other and with machines (Gomez et al., 2018).

While discussing the possible impact of AI on economies and societies is interesting, it remains outside the scope of the present work. Here the focus is on understanding the role that top corporate R&D investors are playing in the development and use of AI given that they represent key actors in the innovation space. The analysis presented in this chapter aims to shed light on basic and applied research, and AI product and service development that top corporate R&D investors worldwide are responsible for.

Measuring AI is still in its infancy and various researchers and institutions are developing a number of measurement frameworks (for example, see WIPO 2019, IPO 2019, or the EC AI Watch Knowledge Service to monitor the Development, Uptake and Impact of Artificial Intelligence for Europe). The operational definition of AI used in the present report relies on the experimental measurement framework developed by the OECD in collaboration with the Max Plank Institute and the OECD-led IP Statistics Task Force (see Baruffaldi et al., 2019, and Box 5.1).

Figure 5.1 displays the top 50 companies with the largest share of AI related inventions in their patent portfolio. The size of the font with which the names of companies are written is proportional to the share of relevant patents owned by these companies. Names in dark blue font correspond to companies in ICT-related sectors.

The majority of the top corporate R&D investors which contribute the most to develop AI-related technologies appear to be headquartered in Japan (21), in the United States (12), in China (6), and in Korea (4). When it comes to top AI developers, only 4 companies are headquartered in Europe (2 in Germany, 1

in Ireland, and 1 in the Netherlands). These top corporate R&D investors, which can be called top AI developers for the sake of brevity, operate in eight industrial sectors. As can be expected, given that AI is ultimately about algorithms and software, most of these companies belong to 'Computers and electronics' (19) and to other ICT-related sectors, such as IT services (8).

Companies in ICT sectors are responsible for most of the AI-related technological developments by top corporate R&D investors

Other top AI-patenting companies operate in the 'Transport equipment' (9) and 'Machinery' (5) sectors, therefore suggesting that sectors including automotive and machinery are striving to innovate and evolve by leveraging the new opportunities triggered by AI-related technologies. Examples of AI-related applications include highly sophisticated vehicles such as autonomous cars and drones.

The Japanese company Canon ranks at the very top. It alone is responsible for 10.6% of patents in AI-related technologies belonging to the top corporate R&D investors worldwide, followed by the Korean based Samsung Electronics (7.9 %), the Japanese Fujitsu (3.6 %), and the US Alphabet Inc. (3.4 %).

31 out of the top 50 top corporate R&D investors contribute the most to developing AI-related technologies are located in Japan, China, and Korea

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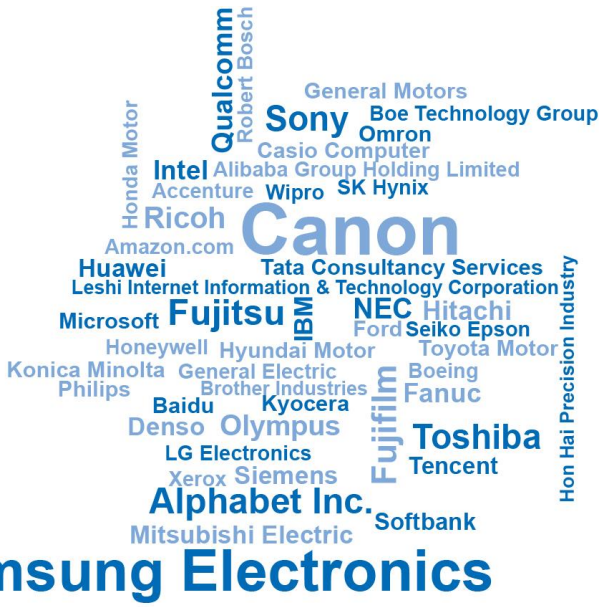
Figure 5.1. Top 50 companies with AI patents, 2014-16
IP5 patent families in AI-related technologies



Note: ICT-related companies are show n in darker blue.

Source: JRC-OECD, COR&DIP© database v.2., 2019.

The names of the companies registering the highest numbers of trademarks related to AI are displayed in Figure 5.2. As seen in the case of patents, it is also in the case with trademarks that most of the companies leading AI product and service developments are headquartered in the United States and Japan. An important difference nevertheless emerges with respect to patents: Japan and the United States feature equally at the top as they each host the headquarters of 14 of the top corporate R&D investors leading developments in AI-related products and services. In addition, 10 corporations headquartered in EU-28 countries also

belong to the top 50 companies registering AI-related trademarks.

Alphabet Inc. leads the ranking, and account for 9.5 % of all AI-related trademarks filed at the three offices altogether (EUIPO, JPO, and USPTO). NEC and LG Electronics, respectively headquartered in Japan and Korea, follow in the AI-related trademarks ranking.

As happens with patents, AI-related trademark registrations are mostly made by companies in ICT sectors, i.e. 32 out of the top 50 companies operate in ICT.

ICT companies play an even more prominent role in AI-related registered trademarks than in patents

AI-related products and services are not only important for ICT sectors, but also for other sectors. Among the top 50 companies trademarking AI-related products and services, six belong to the 'Transport equipment' sector and three to the 'Wholesale, retail, repairs' sectors. This confirms what has already emerged from patents: automotive and more generally transport-related companies are investing a lot in the technological and market developments of AI-related technologies.

Figure 5.2. Top 50 companies with AI-related trademarks, 2014-16
AI-related trademarks: EUIPO, JPO, and USPTO

Note: ICT-related companies are show n in darker blue.

Source: JRC-OECD, COR&DIP© database v.2., 2019.

Based on the findings shown above, it is interesting to examine the science underlying the technological and market developments observed so far.

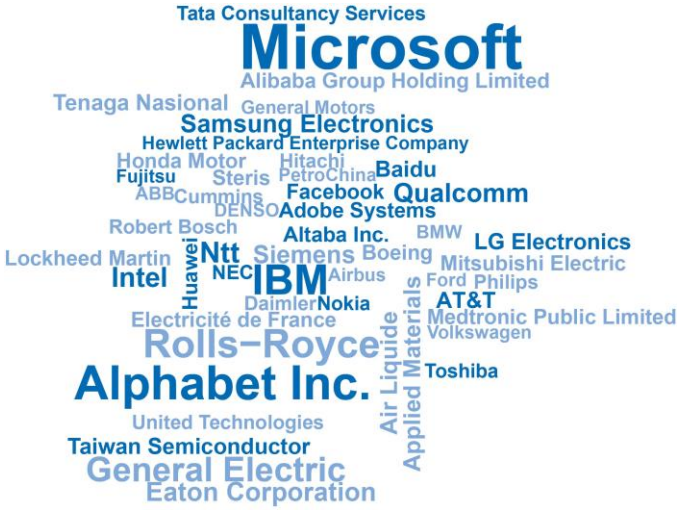
For this purpose, Figure 5.3 shows the top 50 companies among the world top R&D investors that are responsible for the highest shares of AI-related publications. These firms are rather uniformly distributed across the United States (18), and Asia (17, among which 8 in Japan, 4 in China, 2 in Korea, 1 in Chinese Taipei, 1 in India, and 1 in Malaysia) and Europe including Switzerland (15).

Top corporate R&D investors headquartered in Europe rank higher in basic research related to AI than in applied research and innovation or product development

At the top of the list ranks the US based Microsoft, a company to which the authors of about 9 % of the scientific publications in AI-related fields belong. This virtual podium is complemented by another two US companies: Alphabet Inc. (6 %) and IBM (5 %), both operating in the 'IT services' sector.

Figure 5.3. Top 50 companies publishing AI articles, 2014-16

AI-related articles



Note: ICT-related companies are show n in darker blue.

Source: JRC-OECD, COR&DIP© database v.2., 2019.

AI –related scientific developments are wider spread across sectors than applied research and product/service development

In terms of scientific publications, ICT-related sectors are those with most companies at the top (23). Noteworthy is the fact that 13 firms in the 'Transport equipment' sector also make it to the top 50, confirming the importance of AI-related technologies for companies operating in this sector

'Transport equipment' companies appear to be particularly active when it comes to advancing the AI science base

Overall, when considering AI-related patents, trademarks, and scientific publications 13 companies always feature among the top 50. These AI- leaders are (in alphabetical order): Alphabet Inc., Denso, Fujitsu, General Electric, Hitachi, Honda Motor, Huawei, IBM, Intel, LG Electronics, Microsoft, NEC, and Samsung Electronics. These companies are active in the various stages of the AI innovative process from basic research to product development. Ten of these companies operate in ICT-related sectors while the remaining three belong to the 'Transport equipment' sector.

Box 5.1: Identifying Artificial Intelligence patents, trademarks, and scientific publications

Artificial intelligence (AI) is a term used to describe machines performing human-like cognitive functions (e.g., learning, understanding, reasoning, and interacting). It refers to machine-based systems that are capable of influencing the environment by making recommendations, predictions, or decisions for a given set of objectives (OECD, 2019).

The boundaries between AI and other innovations are at times blurred and constantly evolving. AI developments began in the 1950s+ when pioneers in computing, mathematics, psychology, and statistics set out to solve some concrete problems in order to make machines that can "think" (Turing, 1950). These included playing games, classifying images, and understanding natural language.

Detecting the development of AI is therefore challenging. The OECD jointly with the Max Planck Institute for Innovation and Competition (MPI), and benefitting from the support of the experts belonging to the OECD-led IP Statistic Task Force,* devised a three-pronged approach to identifying and measuring developments in AI. The approach relies on exploring developments in science as captured in scientific publications; technological developments, software especially open source software, and as proxied by patents... It involves identifying documents (publications, patents, and software) that can be unambiguously related to AI as well as using expert advice (for details see Baruffaldi et al., 2019).

AI Articles

AI-related documents are identified using a list of AI-related keywords to search scientific documents, especially abstracts and titles. These keywords were selected on the basis of an analysis of word frequencies and co-occurrence patterns, with the starting point being the frequency patterns of the terms used in journals classified as being AI-focused in the Elsevier's SCOPUS © database. To avoid over-identification and to account for the fact that some AI-related terms may also be used in non-AI settings, only documents with two or more keywords were considered as being AI-related.

AI-related patents

An experimental approach – based on patent classification codes, keywords obtained from the analysis of AI-related scientific publications, and a combination of these two – was taken to search patent documents in order to identify AI-related inventions contained in patent applications. This patent-based approach, initially developed by the OECD and MPI, was further refined through work carried out under the aegis of the OECD-led Intellectual Property (IP) Statistics Task Force, benefitting in particular from the advice of experts and patent examiners at selected IP offices.

AI-related trademarks

Trademark registrations for AI-related products or services are identified using keyword searches performed on text describing items protected by registered trademarks. The list of keywords derives from those obtained from the publication analysis, and has been refined using advice from IP experts. No class-based approach is implemented in the case of trademarks as no AI-specific codes could be identified in the list of goods and services contained in the NICE classification.

** OECD IP data activities are carried out in close co-operation with the members of the IP Statistics Task Force, which gathers representatives from about 20 IP offices worldwide (see http://oe.cd/ipstats). The work on AI measurement specifically benefitted from useful inputs from experts and patent examiners from IP Australia, the Canadian Intellectual Property Office (CIPO), the European Patent Office (EPO), the Israel Patent Office (ILPO), the Italian Patent and Trademark Office (UIBM), the National Institute for Industrial Property of Chile (INAPI), the United Kingdom Intellectual Property Office (UK IPO), and the United States Patent and Trademark Office (USPTO)*

5.2 Innovative activities in AI: the industrial perspective

As already shown in chapter 4, the way innovative activities are performed is highly heterogeneous across firms and often depends on sector specificities. This heterogeneity is well captured in Figure 5.4 which displays the share of AI patents, trademarks, and scientific publications that belong to the 5 sectors that emerge as being most active in the field.

The development of AI-related patents is concentrated in a few sectors: almost half AI patents by top R&D investors are filed by companies in 'Computers and electronics'

Almost 91 % of the AI-related patent families are filed in only 5 sectors by the top R&D investors worldwide, of which 46% are owned by companies operating in 'Computers and electronics', followed by 'Machinery' (18 %).

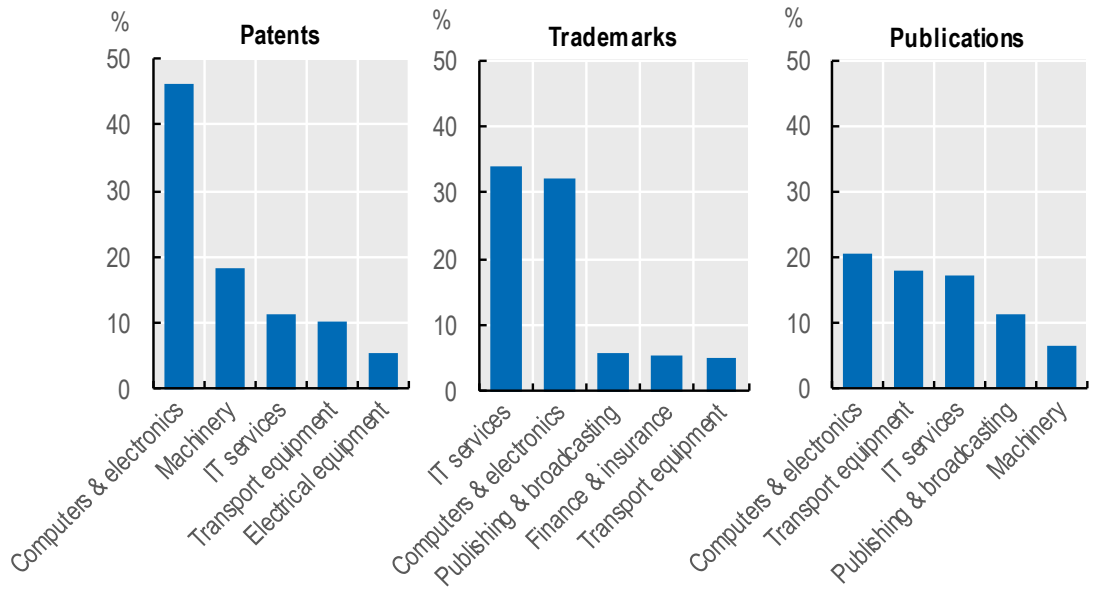
'IT Services' and 'Computers and electronics' account for about 70 % of AI-related trademarks while AI-related publications are more evenly distributed across sectors

The top 5 sectors are responsible for 82 % of the total AI-related trademark registrations. 'IT services' companies register the highest share of AI-trademarks (34 %) closely followed by those operating in the 'Computer and electronics' sector (32 %).

The generation of new scientific AI knowledge is relatively less concentrated than patents and trademarks. The top 5 sectors that contribute the most to advancing AI-related scientific developments account for approximately 73 % of these publications.

Companies in 'Computer and electronics', 'Transport equipment', and 'IT services' each publish about one fifth of all AI-related documents published by the top R&D investors worldwide. These three sectors feature among the top 5 sectors generating AI patents, trademarks, and scientific publications as shown in Figure 5.4.

Figure 5.4. Top 5 sectors in Artificial Intelligence, ISIC rev.4, 2014-16
Patents, trademarks, and publications



Source: JRC-OECD, COR&DIP© database v.2., 2019.

Taken together, the stylised facts displayed above suggest that while ICT-related sectors are at the forefront of AI developments, other sectors, such as 'Transport equipment', are also very active and exploit and develop the potential of AI.

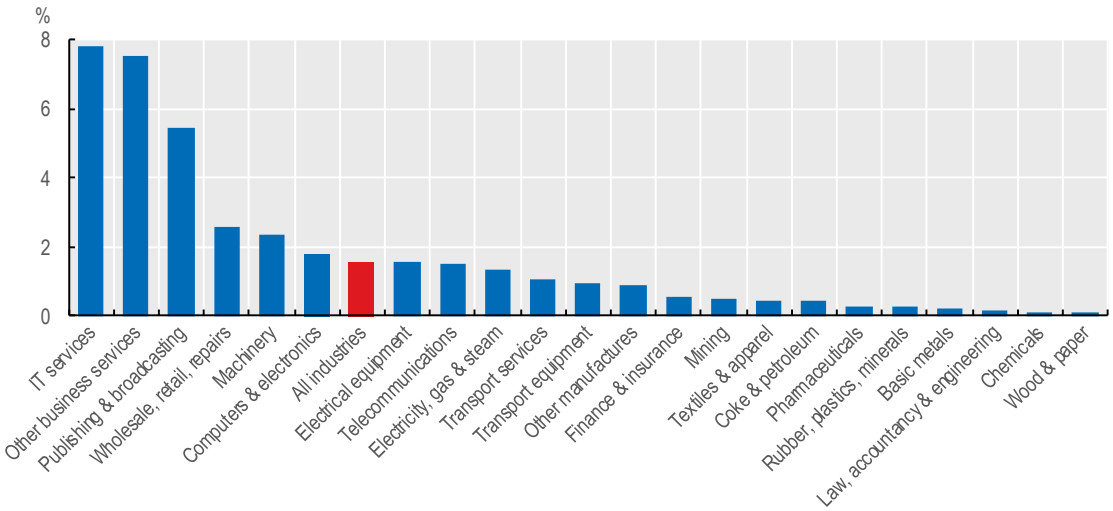
The relative intensity of AI-related patents filings by sectors is presented in Figure 5.5. This shows AI-related patents as a share of the total number of patents in the portfolio of top corporate R&D investors by sector.

Overall, approximately 1.6 % of the sample's patent portfolio relate to AI technologies. 'IT services' (8 %), 'Other business services' (7.6 %), and 'Publishing and broadcasting' (5.5 %) are by far the most AI-intensive sectors in patent filings.

Companies in service sectors account for a high share of AI related patents

'Wholesale, retail, repairs', 'Machinery', and 'Computer and electronics' also display above average shares in AI-related patents.

Figure 5.5. AI-related patents of world's top R&D investors by sector, ISIC rev. 4, 2014-16
Share in IP5 patent families by sector



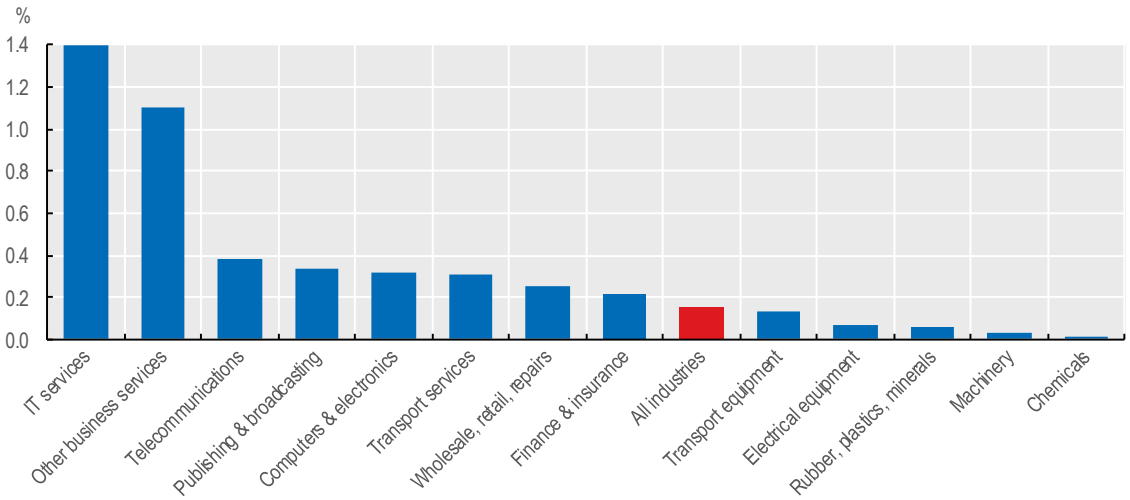
Note: Data relate to sectors with at least 10 company headquarters in the top 2 000 corporate R&D sample that AI filed patents in 2014-16.

Source: JRC-OECD, COR&DIP© database v.2., 2019.

Similar to the patent figure above, Figure 5.6 displays the proportion of AI trademark registrations owned by the top-2 000 R&D investors worldwide as a share of total trademarks owned, by sector.

Similar to patents, companies in the 'IT services' sector are those reporting the highest share of AI-related trademarks, albeit smaller than that of patents (1.4 %), followed by 'Other business services' (1.1 %). Overall, the number of AI-related trademarks remains low in all of the sectors considered.

Figure 5.6. AI-related trademarks of the world's top R&D investors by sector, ISIC rev. 4, 2014-16
Share in total trademarks by sector, EUIPO, JPO, and USPTO



Note: Data relate to sectors with at least 10 company headquarters in the top 2 000 corporate R&D sample that filed for AI-related trademarks in 2014-16.

Source: JRC-OECD, COR&DIP© database v.2., 2019.

The shares of AI-related articles in total publications by sector are reported in Figure 5.7. Among the three measures considered in this report, publications are those featuring the highest share of AI related contributions.

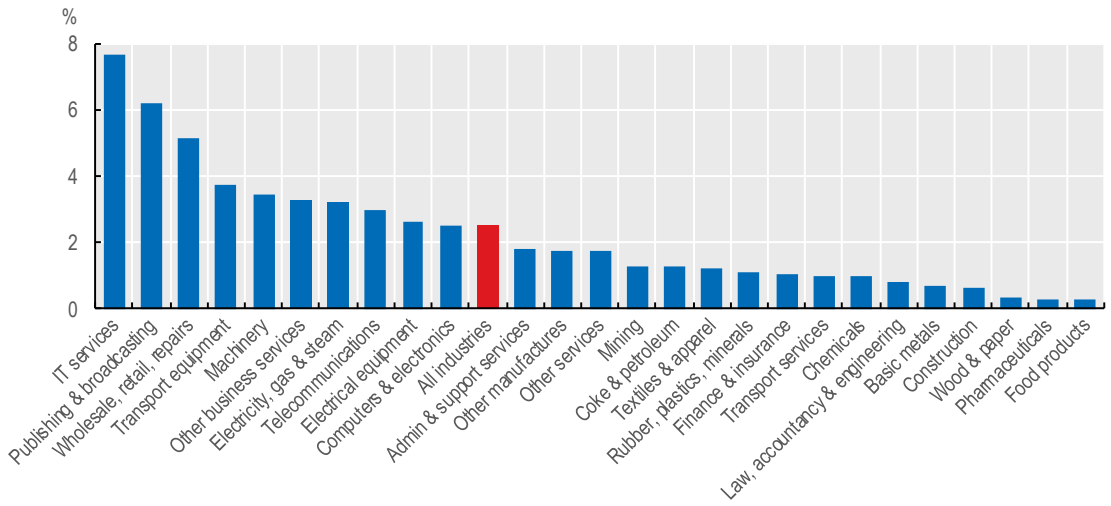
Top corporate R&D investors are shaping AI-related scientific developments in a significant way, and more than patents and trademarks

Again, the 'IT services' sector ranks first in scientific publications with 7.7 % of articles focusing on AI-related developments.

Other sectors significantly engaged in basic research related to AI are: 'Publishing and broadcasting' (6.2 %), 'Wholesale, retail, repairs' (5.1 %), 'Transport equipment' (3.7 %), and 'Machinery' (3.4 %).

Figure 5.7. AI-related articles of the world's top R&D investors by sector, ISIC rev. 4, 2014-16

Share in total scientific publications by sector



Note: Data relate to sectors with at least 10 company headquarters in the top 2 000 corporate R&D sample with publications in AI in 2014-16.

Source: JRC-OECD, COR&DIP© database v.2., 2019.

5.3 Innovative activities in AI: the geographical perspective

The geographical distribution of the AI-related innovation activities of the world top 2000 corporate R&D investors provides additional insights into developments in AI.

As mentioned in chapter 2, innovation strategies adopted by companies and their decisions to locate their innovation activities in different geographical areas are influenced by a number of factors, including the presence of specific competences and technological capabilities (Rilla and Squicciarini, 2011).

The location of the very actors - i.e. the human capital, the inventors – contributing to developing the AI-related inventions detailed in patent documents helps illuminate the repository of knowledge that companies tap into.

For this purpose, Figure 5.8 shows the distribution of IP5 families in AI by location of the inventors contributing to them. Approximately 92 % of AI-related patents are developed by inventors residing in 5 areas, namely: Japan, United States, EU-28, China, and Korea.

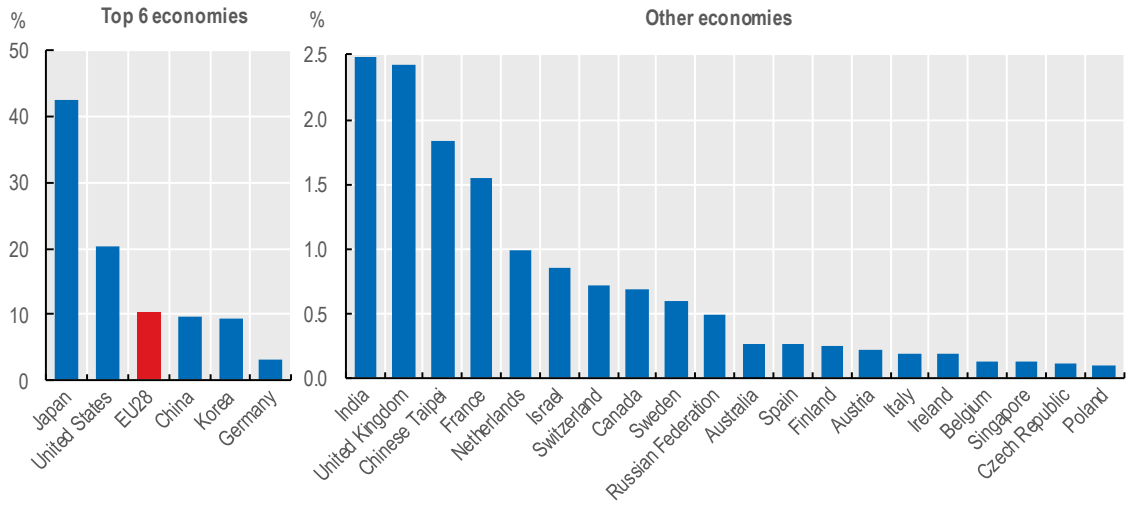
Inventors located in Japan contribute to the development of about 43 % of the AI related patents in the sample. With about 20 %, US-based inventors rank second in terms of patent developments. Inventors from the EU-28, China, and Korea in turn contributed about 10 % of AI-patents each. Germany is the EU-28 economy contributing the highest share of AI-related patents when considering location of

inventors. Despite the small number of Indian-based companies among the top corporate R&D investors worldwide, Indian inventors contributed to developing 2.5 % of AI-related inventions, more than the United Kingdom (2.4 %), Chinese Taipei (1.8 %), and France (1.5 %).

Two thirds of AI-related patents are developed by inventors residing in Asia (approximately 43 % in Japan, 10 % in China, and 10 % in Korea)

Inventors located in Asia are leading technological developments in AI, confirming the strong specialisation of Asian economies in the development of ICT innovations in general, and of AI in particular.

Figure 5.8. AI-related patents of the world's top R&D investors by inventor's location, 2014-16
Share in AI-related IP5 patent families



Source: JRC-OECD, COR&DIP© database v.2., 2019.

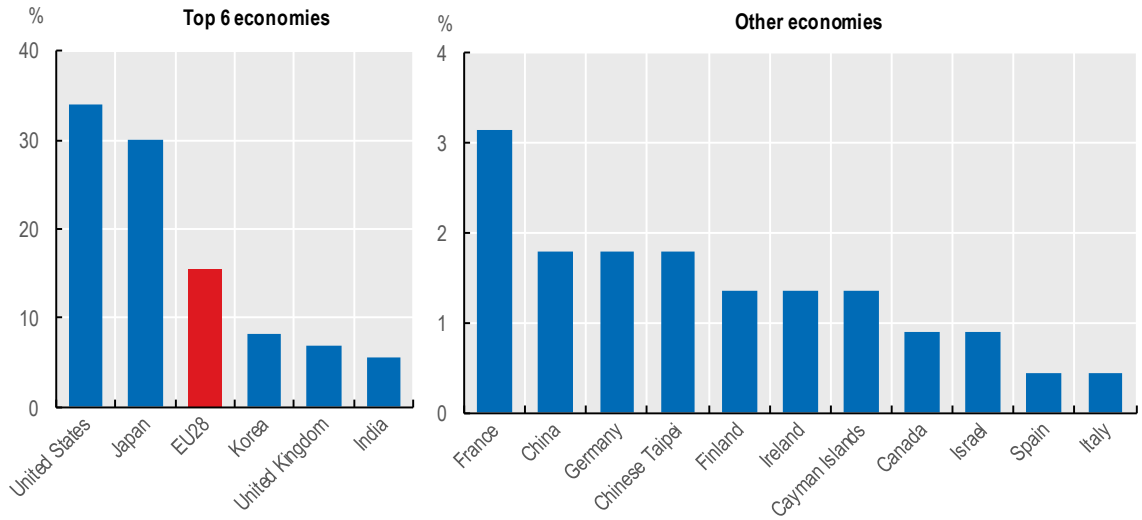
In contrast, a different picture emerges when registered trademarks protecting products and services in AI are considered. Figure 5.9 shows the distribution of AI trademarks according to the location of their applicants. The United States is the economy registering the most AI related trademarks with about 34 % of AI owned by companies' affiliates located in the US. Japan ranks second (30 %), followed by the EU-28 (16 %), and Korea (8 %). Lastly, Chinese affiliates own a small portion of AI-related trademarks (1.8 %).

When considering AI related trademarks in the sample, applicants from Asia are behind compared to the United States and the EU-28

The United Kingdom takes the leading position within EU-28 economies, with about 7 % of AI-trademarks registered by affiliates located in the country. Indian firms are also relatively active in protecting AI-related products and services.

As in the case of AI related patents, AI trademarks are also highly concentrated geographically with the first two economic areas together summing over 60 % of the total number of trademark registered by the top corporate R&D investors worldwide. In both cases, the top two economies are Japan (first when considering patents) and the United States (first for trademarks registrations). This can be taken as an indication of the special and successful focus put on AI technological and commercial developments in these economies.

Figure 5.9. AI-related trademarks of the world's top R&D investors by location of applicant, 2014-16
Share in AI-related trademarks



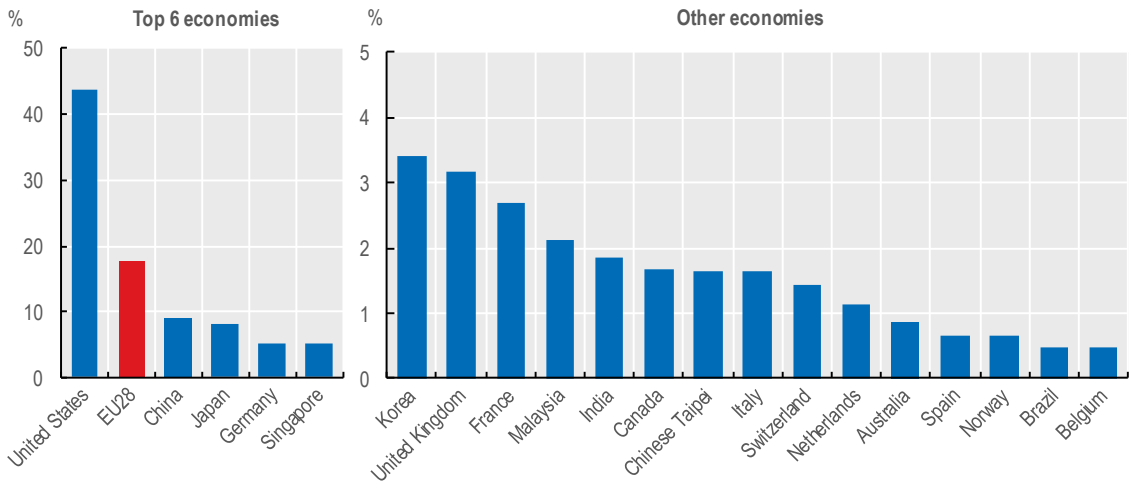
Source: JRC-OECD, COR&DIP© database v.2., 2019.

The United States also emerges as playing a leading role when looking at basic AI research developments as proxied by scientific publications. Figure 5.10 reports the share of AI-related publications with statistics compiled according to the location of the author(s).

Researchers located in the United States contributed approximately 44 % of the total AI-related publications of the world's top R&D investors. EU-28 economies show a relative strong position, ranking second with approximately 18 % of AI-related publications. On the other hand, China and Japan based researchers emerge as each being responsible for less than 10 % of publications in the field.

Authors based in the United States produce the bulk of AI related publications in the sample. The EU-28 ranks second with a share of AI related publications double that of China or Japan

Figure 5.10. AI-related articles of the world's top R&D investors by author's location, 2014-16
Share in AI-related articles



Source: JRC-OECD, COR&DIP© database v.2., 2019

6. Organising innovation to mould the future

This chapter sheds light on the scientific, technological and economic value (i.e., the "quality") of the innovative portfolio of top corporate R&D investors worldwide and also examines the way companies bundle different types of outputs. For this purpose, indicators of the radicalness of technologies and the "quality" of the scientific output produced by companies are followed by an exploration of the way companies bundle scientific and technological developments and the extent to which companies are active in basic and applied research activities. A closer look at the pervasiveness and potential impact of the AI innovation activities of top corporate R&D investors is then presented by looking at the way AI is combined in patents, trademarks, and scientific publications. Finally, this chapter provides several insights into the collaborative networks underpinning the generation of knowledge.

6.1 Leading the knowledge generation process

In a world where firms are "knowledge-integrating institutions" (Grant, 1996), knowledge production and management are key factors for firms to stay at the forefront of the competition race (DeCarolis and Deeds, 1999). In fact, what matters is not just the production of knowledge but also and especially the production of "good" knowledge (Soo et al., 2004).

Indicators built on publications and on patents can be used to proxy and evaluate the "quality" and "value" of the basic and applied knowledge produced by various actors (McMillan and Hamilton III, 2000; Park and Park, 2006). However, the longstanding discussion concerning the definition and measurement of patent "quality has led to the development and use of a plethora of indicators that rely on different metrics (see Squicciarini et al., 2013, for a compendium). While the definition of scientific excellence also poses serious conceptual challenges, the number of citations received by scientific publications is frequently used to evaluate scientific research.

This section proposes an initial assessment of the quality or value of the basic and applied knowledge generated by the top corporate R&D investors worldwide in the sample. The prospective technological and economic value of patents is assessed using the radicalness index, which aims to capture the extent to which an invention differs from its predecessors. As proposed by Shane (2001), the concept of patent radicalness relies on the idea that inventions built on paradigms that differ from that to which the considered patent belongs, represent a greater, better, or different type of advancement, i.e., are more radical than inventions relying on similar knowledge (see Box 6.1 for various methodological details). The radical index proposed here is based on the number of technological domains to which the patents cited in the focal patent's document belong to, minus the fields covered by the focal patent itself.

In the case of articles, the measure of scientific quality and relevance considered here is a distribution-based one whereby the top 10 percent of most cited articles by scientific field are considered as being high quality or leading scientific contributions (Schubert and Braun, 1986).

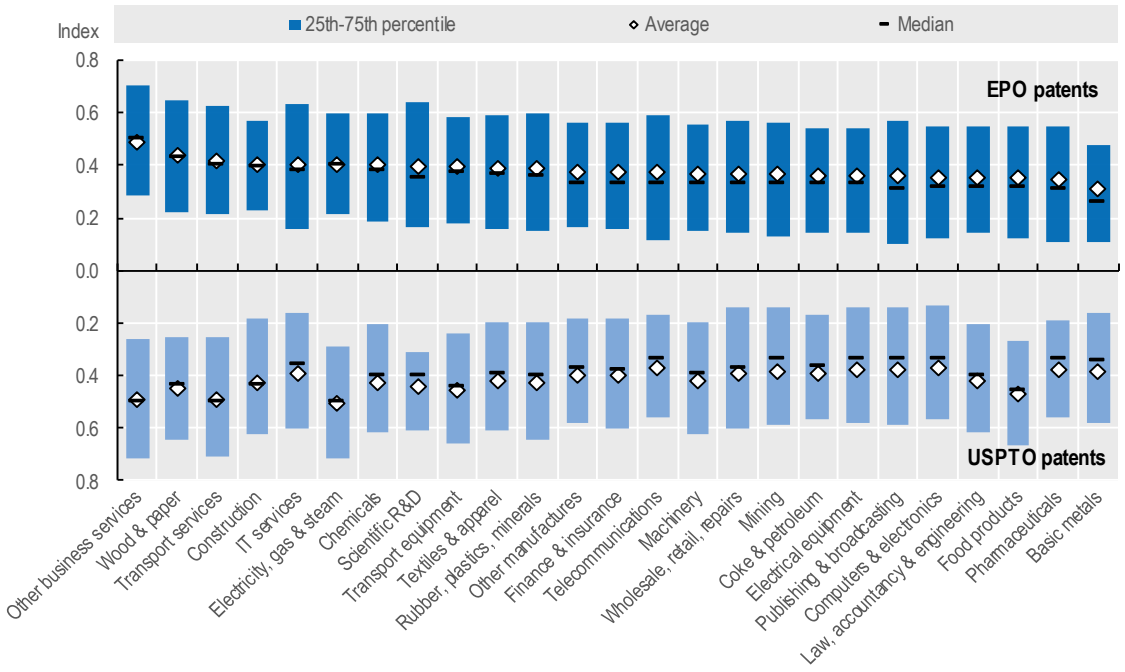
Figure 6.1 shows the value of the radicalness index at the sector level. Due to the unavailability of citation data for all IP5 patent families, the radicalness index is only shown for patents filed at the EPO (top panel) and the USPTO (bottom panel) that belong to IP5 patent families. Furthermore, and in consideration of the different way patent citations are dealt with at the EPO and the USPTO, and the different prior knowledge disclosure requirements at the two offices considered (OECD, 2009), direct comparisons of the index across the two offices should not be made.

Looking at indicators based on EPO patents (top panel), 'Other business services', 'Wood and paper', and 'Transport services' emerge as the sectors featuring the highest average values of the radicalness index. Firms operating in these sectors seemingly tend to rely on a more diversified array of technological knowledge when developing new solutions. In these sectors, more than 42 % of the technological domains cited in EPO patents differ from those to which the citing patents belong.

'Other business services' and 'Transport services' also rank at the top when USPTO patents are considered, with 'Electricity, gas & steam' among the top three sectors developing radical inventions. Overall, the relative rankings of sectors in terms of radicalness appear to be quite similar across the two patent offices considered.

Figure 6.1. Radical inventions by the world's top R&D investors by sector, ISIC rev. 4, 2014-16

Distribution of the patent radicalness index, EPO and USPTO patents



Note: Data relate to sectors with at least 10 companies in the top 2 000 corporate R&D sample that filed patents in 2014-16. Only EPO and USPTO patents that belong to IP5 patent families are considered.

Source: JRC-OECD, COR&DIP© database v.2., 2019.

'Other business services' and 'Transport services' are among those developing more radical inventions

Indicators based on EPO and USPTO patents differ when looking at the dispersion of the radicalness of technological knowledge within sectors. To some extent this may reflect specificities in the EU and the United States' (technological) markets. This heterogeneity within sectors can be seen by looking at the interquartile range, i.e. the 25th-75th percentile, of the radicalness indexes thus constructed (the height of the bars in Figure 6.1). The larger the bar, the greater the heterogeneity of the quality of the inventions patented in the sector.

'IT services', 'Scientific R&D', and 'Telecommunications' at the EPO are the sectors reporting the highest degree of heterogeneity. In the case of USPTO patents, companies operating in 'Other business services', 'Wholesale, retail, repairs', and 'Transport services' feature the largest heterogeneity.

In turn Figure 6.2 presents the share of publications that are among the top 10 percent cited in their respective scientific fields, broken down by sector. The three sectors featuring the greater proportion of highly cited papers are 'Pharmaceuticals', 'Computers and electronics', and 'Transport equipment'.

Altogether companies in these three sectors produced 54 % of the total number of highly cited academic papers authored by individuals belonging to the companies in the sample. The same sectors also feature in the top three positions in terms of share of total number of scientific publications (see Figure 2.9 in chapter 2).

Comparing the ranking related to the way different sectors contributing to generating scientific publications overall (Figure 2.9 in chapter 2), ordering sectors on the basis of their production of highly cited papers, identifies those sectors making significant contributions to scientific development in terms of both quantity and quality.

Companies in 'Pharmaceuticals' 'Computers and electronics', and 'Transport equipment' rank top in terms of highly cited papers and share of total number of scientific publications

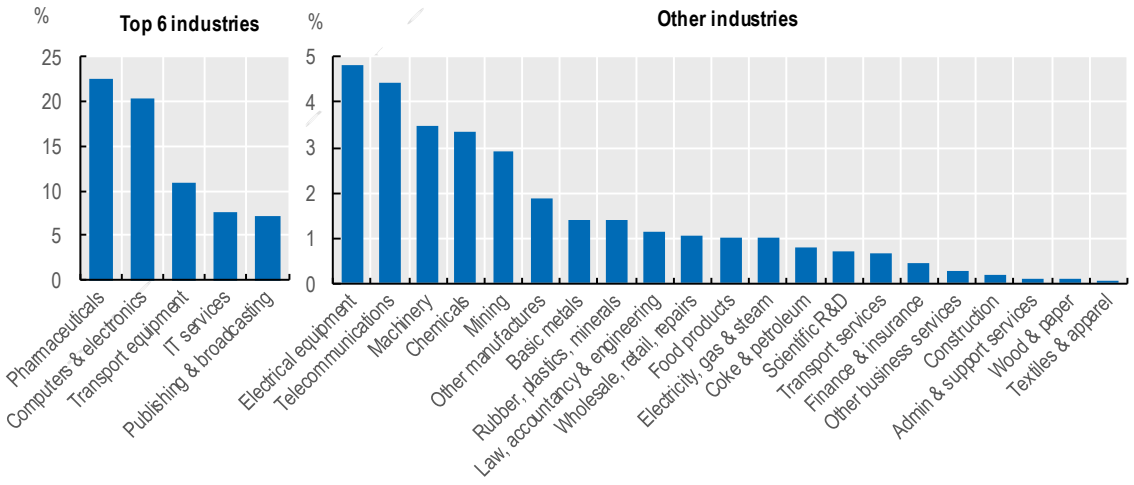
In addition, 'Pharmaceuticals', 'Publishing and broadcasting', and 'IT services' are sectors producing basic research of relatively higher quality than other sectors as they account for relatively higher shares of top cited articles (22.7 %, 7.1 %, and 7.6 %) than total publications (17.2 %, 4.6 %, and 5.5 % respectively).

This is in line with the literature showing how these firms produce both high numbers of and high quality publications (Camerani et al., 2018).

Other sectors, such as 'Chemicals', 'Mining', and 'Basic metals' feature lower shares of top 10 percent cited papers (2.9 %, 3.3 %, and 1.4%, respectively) than shares of total publications (5.1 %, 4.9 %, and 2.8 %).

Figure 6.2. Top cited articles of the world's top R&D investors by sector, ISIC rev. 4, 2014-16

Share of the top 10 % cited publications



Note: Data relate to sectors with at least 10 companies in the top 2 000 corporate R&D sample with publications in 2014-16.

Source: JRC-OECD, COR&DIP© database v.2., 2019.

Box 6.1. Radicalness and scientific excellence

Quality-based measures shed light on the scientific, technological, and prospective economic value of the patents and publications in the portfolios of the world's top corporate R&D investors. Two indicators are used in the present report to account for the quality of patents and of scientific publications, which are:

Radical patents

Inventions often build on and combine knowledge existing in different technological fields. The extent to which this knowledge (re)combination occurs can be inferred from looking at the technological fields patents cited in a focal patent belongs. The OECD radicalness index derives from the one proposed by Shane (2001) in which the radicalness of a patent is measured as a time invariant count of the number of technology classes in which the patents cited by the given patent are classified, but in which the patent itself is not classified. The more a patent cites previous patents in classes other than those it is in, the more the invention should be considered radical as it builds on paradigms that differ from the one it is applied to (Squicciarini et al, 2013).

The indicator of radicalness *à la Shane* is defined as:

$$Radicalness_P = \sum_j^{n_p} CT_j / n_p \; ; \; IPC_{pj} \neq IPC_p$$

where CT_j denotes the count of IPC (4 digit codes) IPC_{pj} of patent *j* cited in patent *p* that is not allocated to patent *p*, out of *n* IPC classes in the backward citations counted at the most disaggregated level available. The higher the ratio, the more diversified the array of technologies the patent relies upon on.

Top cited articles

The indicator of scientific excellence - top cited articles - provides information about the quality of the research output, building on the number of citations a given article receives. It refers to the amount (in %) of a unit's scientific output that is part of the set of the 10 % most-cited papers in their respective scientific fields (OECD and Scimago Research Group, 2016). Scientific articles in the top 10 % highly cited publications are stratified by ASJC field and publication year. Only documents with a fixed number of citations above the threshold are included. Documents with the same number of citations as the threshold are sorted according to the *Scimago Scientific Journal Rankings (SJR)* value of the journal in which they were published. In this case, those with the highest scores enter the 10 % pool.

6.2 Bundling competences

The relationship between science (i.e. basic research) and technology (i.e. applied research) has long been debated and continues to be at the core of both the policy and academic debate (Dasgupta and David, 1994).

Some scholars have questioned the reasons why firms should engage in science (Rosenberg, 2010), and some have argued that we are witnessing a decline in corporate science (Arora et al., 2018) coupled with a stronger emphasis on technological developments, driven by market considerations (Tijssen, 2004). Nevertheless, companies continue to engage in both, and carry out scientific research while at the same time protecting their technological assets (Archambault and Lariviere, 2011), often by using patents. However, the knowledge and capabilities required to be active in both may at times only partially overlap (Simeth and Lhuillery, 2015), suggesting the existence of possible trade-off when deciding to focusing more on one or the other.

In this section, the portfolios of patents and publications of the world's top R&D investors are jointly analysed to examine the science and technology debate, and provide evidence for the complementarity of basic and applied research.

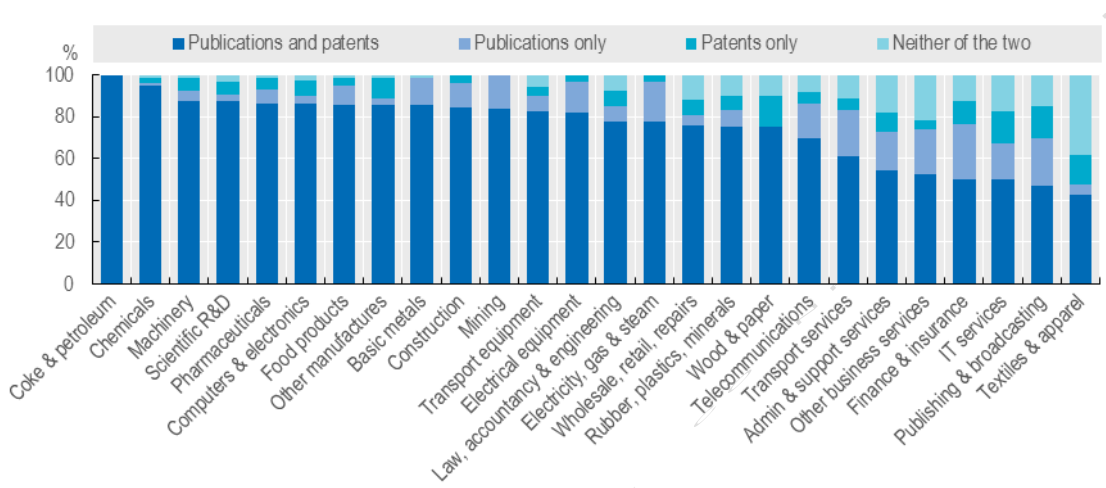
Figure 6.3 provides some initial descriptive evidence about the different strategies pursued by the companies in the top corporate R&D sample. It looks at whether sectors focus on patenting and publishing, only patenting, only publishing, or neither of the two.

Almost 80 % of the top R&D investors worldwide contributed to advancing both science and technology, as proxied by scientific publications and patents

Nevertheless, marked differences emerge across sectors to the extent to which they focus on scientific or technological developments or both. Patenting and publishing are a common practice in the three most represented sectors of the sample in terms of number of firms. In 'Computers and electronics', 86 % of companies generated both patents and scientific publications while this share amounted to more than 86 % in the case of 'Pharmaceuticals' companies and to 82 % in the case of 'Transport equipment' during the period considered.

Figure 6.3. The world's top R&D investors producing patents and publications by sector, ISIC rev. 4, 2014-16

Share in total number of companies by sector



Note: Data relate to sectors with at least 10 companies in the top 2 000 corporate R&D sample.

Source: JRC-OECD, COR&DIP© database v.2., 2019.

Less than 50 % of companies in sectors like 'Finance & Insurance', 'IT services', 'Publishing and broadcasting', and 'Textiles & apparel' both patent and publish scientific papers, and 12 % to 38 % of these do neither of these two.

Of all sectors, 'Finance and Insurance' is the one with the highest share of companies that only focus on publishing scientific papers (27 %) while 'IT services' features the highest share of firms that only file patents (15 %). 40 % of companies in the 'Publishing and broadcasting' sector either only publish or only patent (23 % and 15 %, respectively). It is also worth noting that 38 % of 'Textiles & apparel' firms did not publish scientific papers or file patents during the period.

Overall, the data suggests that sectoral specificities are significant in the way firms engage in science and technology developments

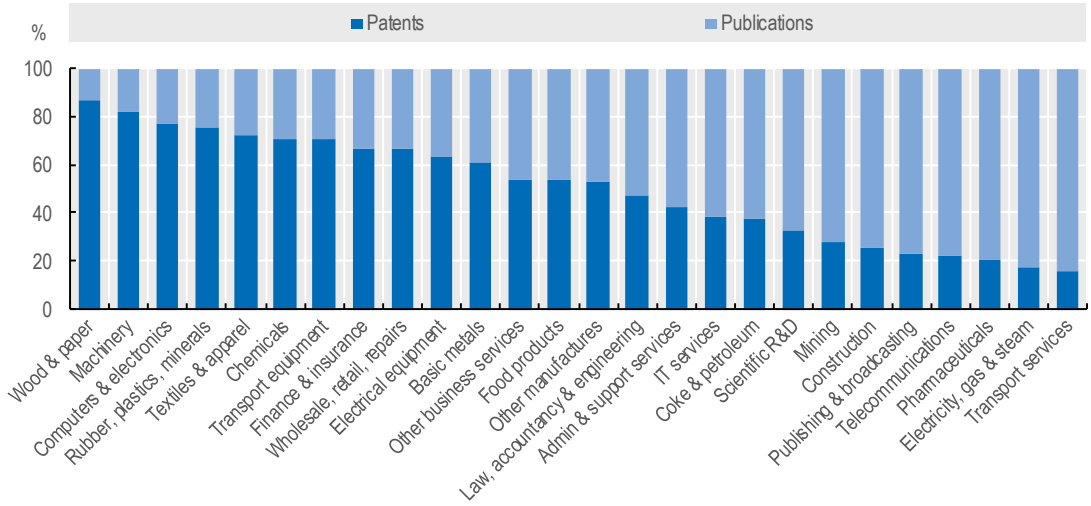
Figure 6.4 further details the way in which patents and publications are bundled together by companies in different sectors by showing the distribution of patents and publications in the portfolio of companies featuring both.

A marked heterogeneity also emerges across sectors in this case. Some sectors appear more technologically oriented because they display larger shares of patents in their overall patent and publication portfolios. This is the case for 'Wood and paper' (86 % of patents), 'Machinery' (82 %), and 'Computers and electronics' (77 %). Others sectors appear to be more oriented towards scientific developments. Among these sectors featuring larger shares of publications in their patent and publication portfolios there are 'Transport services' (84 % of scientific

papers), 'Electricity, gas and steam' (82 %), and 'Pharmaceuticals' (80 %).

Among the top five sectors represented in the sample in terms of number of firms, four are more patents than publications oriented: 'Computers and electronics' (77 % vs 23 %), 'Transport equipment' (70 % vs 30 %), 'Machinery' (82 % vs 18 %), and 'Chemicals' (71 % vs 29 %). The 'Pharmaceuticals' sector is conversely much more intensive in terms of publications than in terms of patents (80 % vs 20 %).

Figure 6.4. Bundling publications and patents by sector, 2014-16
Share in total publications and patents of the world's top R&D investors



Note: Data relate to sectors with at least 10 companies in the top 2 000 corporate R&D sample.

Source: JRC-OECD, COR&DIP© database v.2., 2019.

Figure 6.5 tries to provide additional elements in relation to the patent-publication bundle. For this end, it considers the patented technologies developed by a company and the top three scientific fields in which the same company publish. Data are then aggregated at technology and scientific field level, with the links representing the number of times both a specific technology and a specific scientific field are in the innovative portfolio of top corporate R&D investors.

Of the 27 scientific fields in which Scopus classifies journals, only eight appear in the top three fields that are more often associated with the 33 technologies shown in the figure.

Engineering is among the top three scientific fields for all technologies considered, with the exception of *Pharmaceuticals* technologies. *Engineering* is the first field of publications in 30 technology domains to which patents are bundled in firms.

Engineering is the scientific field underpinning the development of all type of technologies

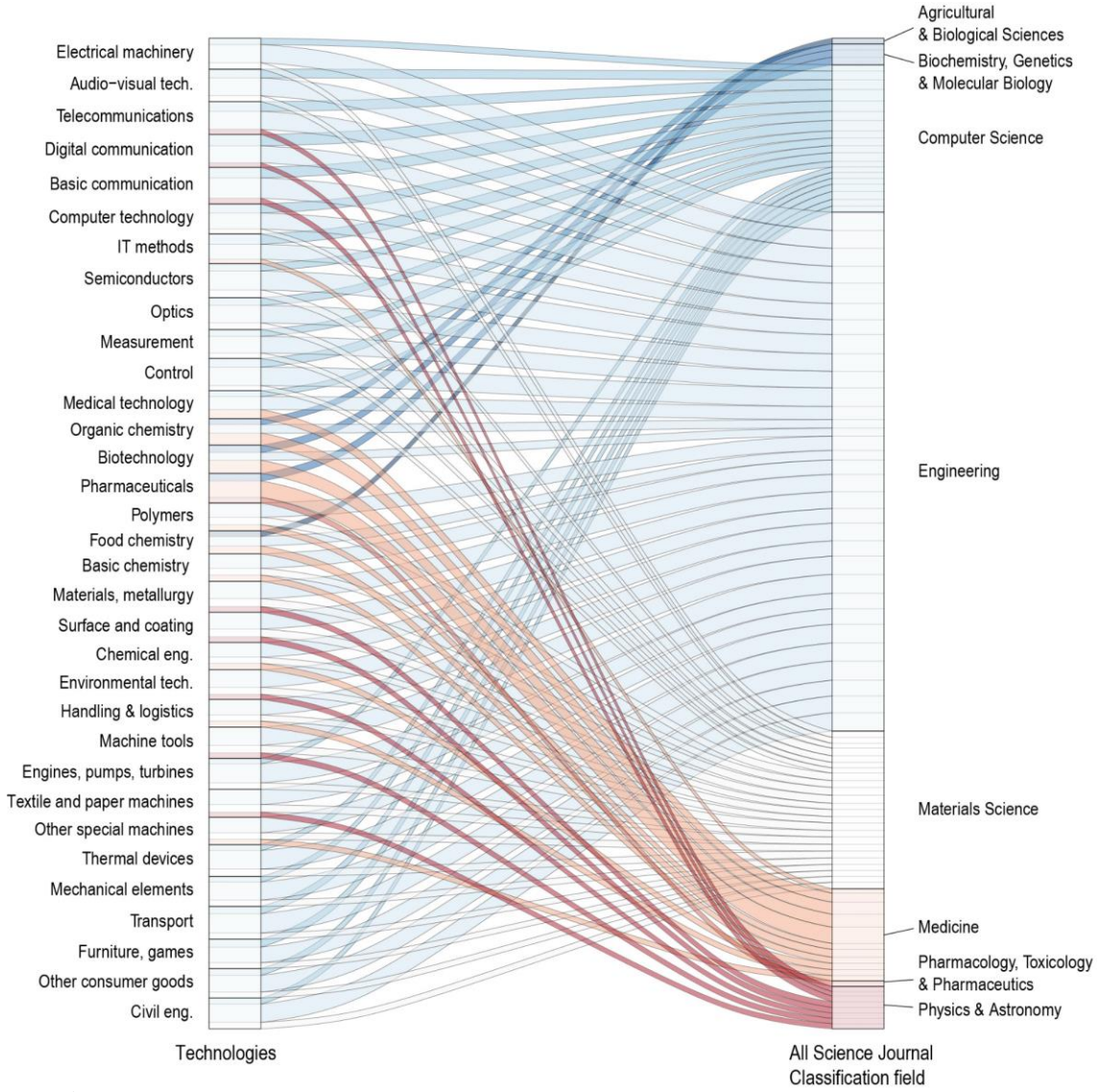
Other scientific fields frequently associated with a large number of patented technologies are *Material Science* and to a lesser extent *Computer Science.*

Overall, patterns emerged when mapping technologies and scientific fields in the portfolio of companies align with expectations. For example, there is a direct relationship between health-related technologies (e.g. *Pharmaceuticals*, *Biotechnology*, *and Medical technology*) and *Medicine.* In addition, selected ICT related technologies (such as *Audio-visual tech.*, *Digital communication*, and *Electrical machinery*) are frequently associated with publications in *Computer Science*.

All in all, the data shows the extent to which science and technologies are inherently related. Furthermore, the fact that *Computer Science* is associated with a substantial part of technological development may be an indication of the digital penetration of sectors.

Figure 6.5. Insights from the patent and publication bundle of the world's top R&D investors, 2014-16

Top three scientific fields combined with patented technologies



Note: Data relate to technologies featuring more than 1 000 patents during the period considered.

Source: JRC-OECD, COR&DIP© database v.2., 2019.

6.3 The AI at work

General purpose technologies (GPTs) are new ideas or techniques having a potentially relevant impact on many sectors in the economy (Bresnahan and Trajtenberg, 1995). They are characterised by pervasiveness (that is, they represent inputs in many sectors); technological dynamism (i.e., possessing potential for technical improvements); and innovation complementarities (with other technologies or advancing the knowledge base).

In contrast, characteristics of the so-called emerging technologies (ETs) are the following: radical novelty (using a new

principle to realise a certain function); relatively fast growth (compared to other technologies); coherence (in the discourse around them); prominent impact (on the broad socio economic system); and uncertainty and ambiguity (in their possible use and outcomes) (Rotolo et al, 2015).

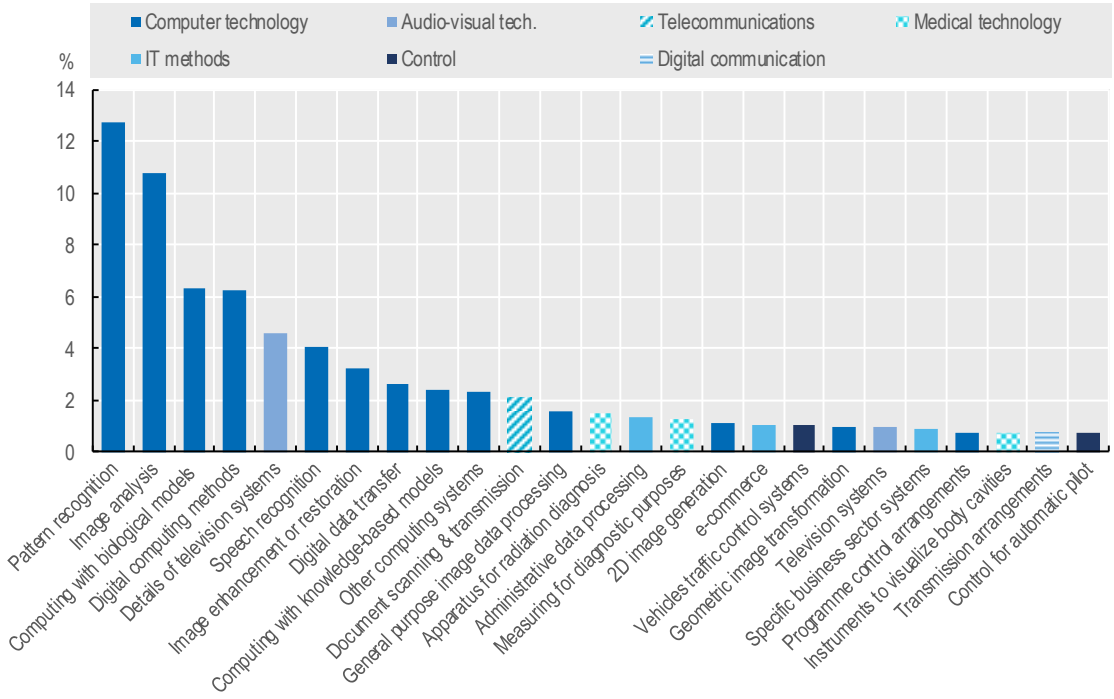
As AI seemingly shares some features of both GPTs and ETs, this section analyses the pervasiveness of AI (trait of a GPTs) and its prominent impact (characteristics of a ETs).

Figure 6.6 provides insights of the pervasiveness and prominent impact of AI, by looking at the specific technologies that appear in AI related patents. To do so, the most frequent combinations of IPC codes within AI patents documents are displayed.

Among the top 25 technologies combined in AI-related patents, the majority relates to *Computer technologies* (13). *Medical technology* and *IT methods* appears three times each, followed by *Audio-visual tech.* and *Control* (2 times each) and by *Telecommunications* and *Digital communication* (1 time each).

Figure 6.6. Top 25 technologies combined in AI-related patents of the world's top R&D investors, 2014-16

Share of IPC groups in AI-related patents by technology field



Note: Data refer to the most frequent IPC codes listed in AI-related patent documents.

Source: JRC-OECD, COR&DIP© database v.2., 2019.

Although mostly associated with computer technologies, AI features in technologies in multiple domains, signalling its pervasiveness and potential impact

Pattern recognition is the IPC class that is most frequently associated with AI-related patents (about 13 %), closely followed by *Image analysis* (11 %), and by *Computing with biological models* (6.3 %). It is worth noting that the three medical technologies associated with AI (*Instruments to visualize body cavities*, *Measuring for diagnostic purposes*, *Apparatus for radiation diagnosis*) are all

related to developments aiming to improve medical diagnosis.

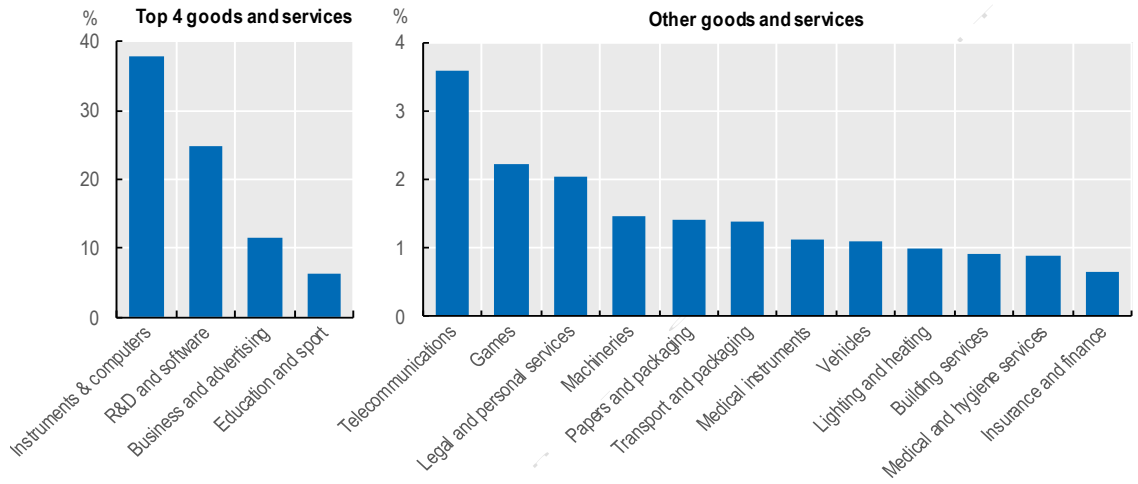
In turn Figure 6.7 uses Nice classes to list the types of goods and services that are frequently associated with AI-related trademarks.

More than one third of AI-related registered trademarks fall into the *Instruments & computers* (37.7%), followed by *R&D and software* (24.7 %), and *Business and advertising* (11.5 %).

The predominance of AI-related trademarks in the aforementioned classes of goods and services meets expectations. However, AI-related trademarks are also present in other 13 classes of goods and services, which is again a sign of its pervasive nature.

Figure 6.7. Top goods and services classes of AI-related trademarks of the world's top R&D investors, 2014-16

Share of NICE classes in AI-related trademarks, EUIPO, JPO, and USPTO



Note: Class titles correspond to short labels based on the International Classification of Goods and Services for the Purposes of the Registration of Marks (Nice Classification). For an exact description of the classes, see https://www.wipo.int/classifications/nice/nclpub/en/fr/

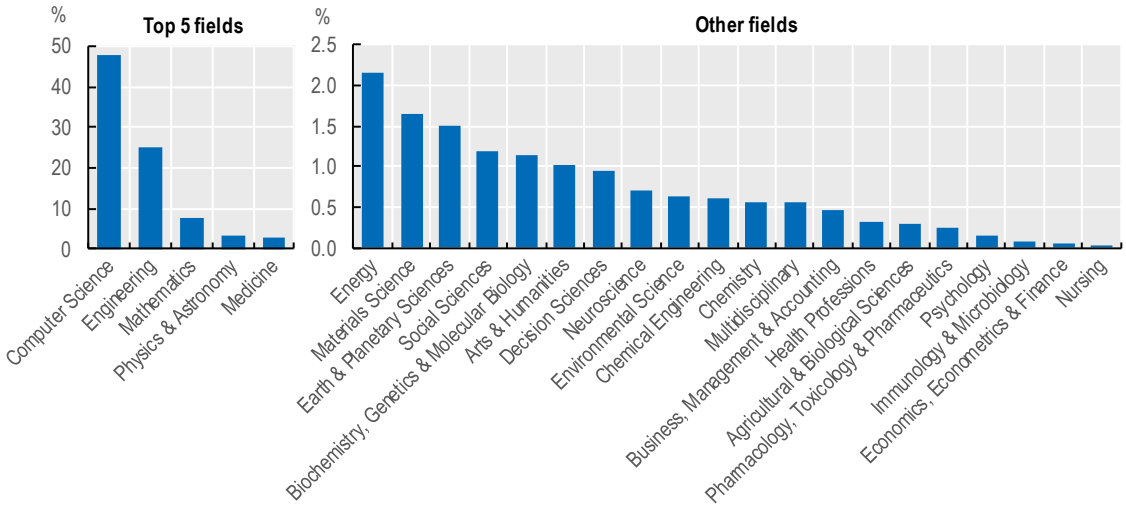
Source: JRC-OECD, COR&DIP© database v.2., 2019

In addition, Figure 6.8 presents the scientific fields in which AI publications appear most frequently. In line with the findings for patents and trademarks, the largest share of AI-related publications refers to computers: almost half of AI-related publications are classified as *Computer Science* (48 %).

Engineering is another field in which AI-related articles are published to a large extent, i.e., 25 % of the total publications. Other scientific fields are also associated with AI in publications but to a lesser extent.

In the case of scientific publications, the pervasive nature of AI is less evident compared to technological development

Figure 6.8. Top scientific fields in AI publications of the world's top R&D investors, 2014-16
Share of ASJC fields in AI publications



Source: JRC-OECD, COR&DIP© database v.2., 2019.

6.4 Organising the innovation network

Companies in the sample are present in more than 170 economies around the world (see chapter 2). It is therefore logical to expect that their geographical dispersion may also be reflected in their knowledge production to some extent.

Internationalisation of science (Zitt and Bassecoulard) and technology (Patel and Vega, 1999) is a well-documented phenomenon in the economic and management innovation literature. Publications (Katz and Martin, 1997) and patents (Guellec and de la Potterie, 2001) are often used to study the patterns of internationalisation in science and technology alongside collaboration between firms and between firms and universities (Veugelers and Cassiman, 2005; Bruneel et al., 2010).

This is why this section presents evidence about the patterns of international collaboration between the world's top R&D investors in the development of both science and technology.

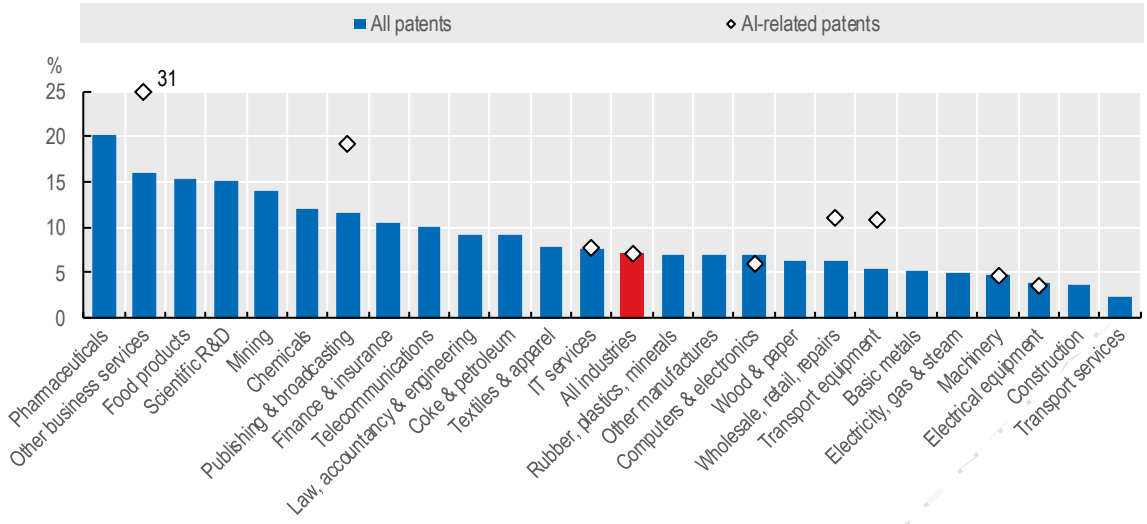
Figure 6.9 displays the shares of international co-inventions observed in the entire patent portfolio of top R&D investors worldwide (bars), and highlights the patterns in AI- patents (diamonds).

'Pharmaceuticals' (20 %), 'Other business services' (16 %), and 'Food products' (15 %) are the sectors with the highest shares of patents developed by international teams of inventors.

The share of AI-related patents developed by international teams of inventors is highest in 'Other business services' (31 %)

Figure 6.9. International co-inventions of the world's top R&D investors by sector, ISIC rev.4, 2014-16

Share of patents with international co-inventions, all technologies and AI-patents



Note: Data relate to sectors with at least 10 companies in the top 2 000 corporate R&D sample that filed patents in 2014-16.Only sectors with more than 50 AI-related patents for AI-related technologies are displayed.

Source: JRC-OECD, COR&DIP© database v.2., 2019.

While sectors like 'Construction' and 'Transport services' stand towards the end of the distribution with low rates of international collaborations, 'Computer and electronics' or 'Electrical equipment' exhibit levels of international co-inventions below the average for the sample. These technologies are widely diffused and developed in many economic areas, but feature a relatively low level of international collaboration.

As technological applications related to AI are a relatively new phenomenon, a relatively low number of patents are still observed. This makes it difficult to provide reliable statistics on the levels of international collaborations in AI for a number of sectors. The threshold of sectors exhibiting at least 50 AI-related patents means the ratios of international collaboration for only eight sectors are displayed.

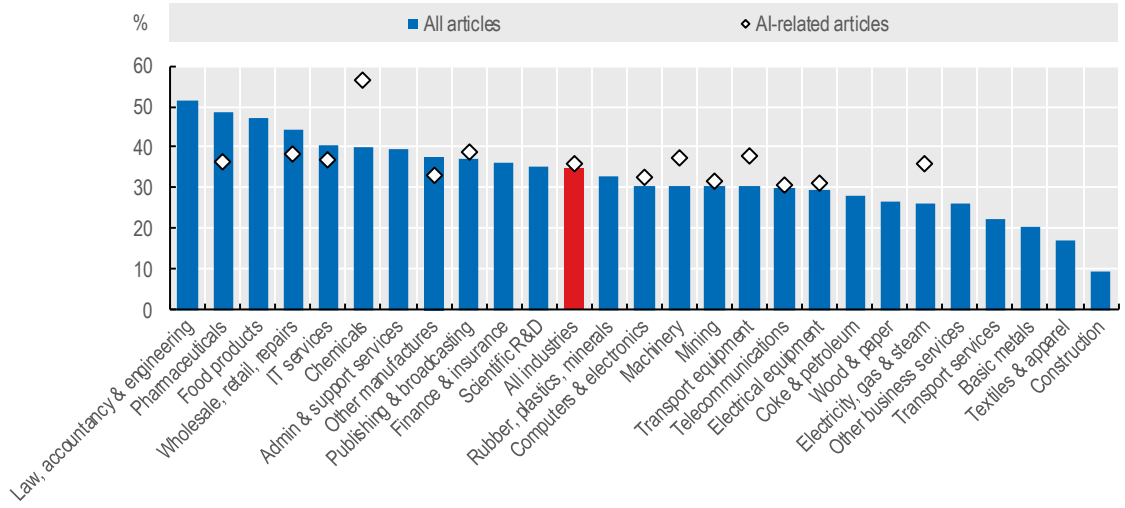
Whatever the technology considered, the share of international co-invention for AI-related patents is much higher than that observed for all patents in four of these sectors – 'Other business services', 'Publishing and broadcasting', 'Wholesale, retail, repairs', and 'Transport equipment',. This may signal that the development of AI-related technologies in these sectors may require greater engagement in international networks of inventors than in the case of other technologies.

'Computer & electronics' is the only sector where international collaborations in AI-related technologies are less frequent than for other technologies

Figure 6.10 shows the share of internationally co-authored publications by sector (bars) compared to the share for AI-related publications (diamonds). Similarly to patents, no international collaborations in AI are reported for sectors featuring 50 or less AI-related publications.

Figure 6.10. International co-authorship of the world's top R&D investors by sector, ISIC rev.4, 2014-16

Share of scientific publications with international co-authorship, all articles and AI-related articles



Note: Data relate to sectors with at least 10 company headquarters in the top 2 000 corporate R&D sample with publications in 2014-16. Only sectors with more than 50 AI-related articles are displayed for articles.

Source: JRC-OECD, COR&DIP© database v.2., 2019

On average, the ratio of international co-authored publications (35 %) is much higher than the share of international co-inventions (7 %).

International collaborations in AI appear to be more common in scientific papers than is the case for patents

However, some similarities emerge in the two rankings: the same sectors feature towards the top and the bottom part of the two distributions: 'Pharmaceuticals' (49 %) and 'Food products' (47 %) are ranked among the top three sectors in terms of international co-authorship, which is similar to co-inventorship (albeit to a lesser extent). In contrast, 'Construction' (9 %) and 'Transport services' (22 %) appear towards the end of the distribution.

When looking at the international co-authorship of AI-related publications, their share is generally higher than for all articles in ten out of the fourteen sectors shown in the figure. This result is in line with what was observed for international co-invented AI patents.

Similar to patents, AI publications tend to rely more on (international) networks of authors than publications in other fields

However, a different pattern emerges in some sectors: in 'Pharmaceuticals', 'Wholesale, retail, repairs', 'IT services', and 'Other manufactures' scientific AI research is less internationalised than in other scientific fields.

What's next?

This third report on the innovative activity of the world top 2 000 R&D investors is accompanied by the database on the "IP bundle of top corporate R&D investors" (*JRC-OECD, COR&DIP© database, v.2, 2019*).

The database (as well as its previous versions) is made available for free, upon request, to allow for further analysis in support of evidence-based policy making.

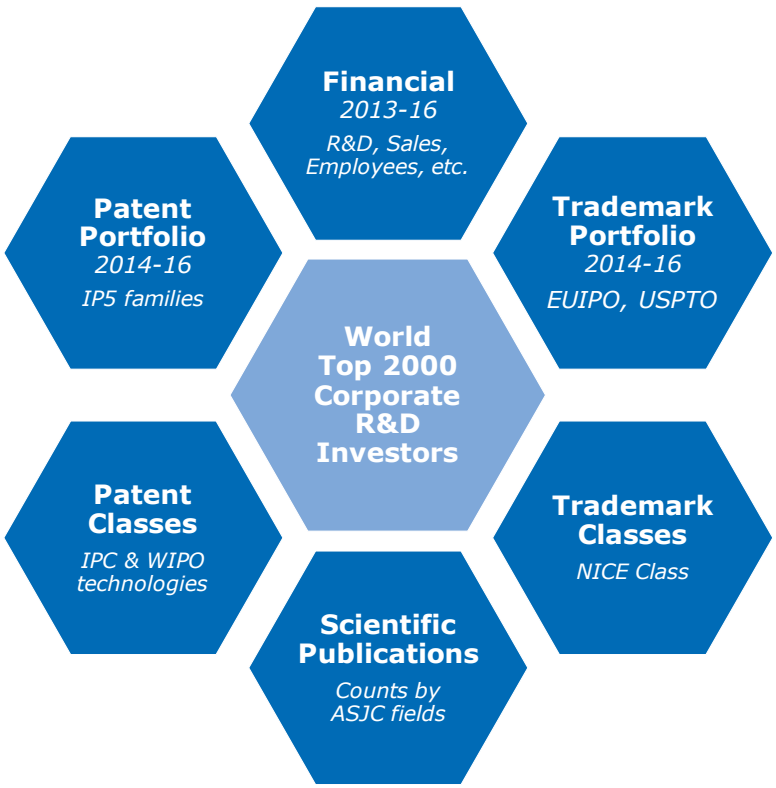
The JRC-OECD COR&DIP© v.2 database contains information about the R&D activity and IP assets (i.e. patents and trademarks) of the top 2 000 corporate R&D investors worldwide. Information about the R&D investors is taken from the 2017 EU Industrial R&D Investment Scoreboard (Hernández et al., 2017). Industrial property (IP) records are extracted from EPO's Worldwide Patent Statistical Database (PATSTAT, Spring 2019) in the case of patents, and, from the EU IPO and the USPTO in the case of trademarks (raw data on JPO trademarks are not included in the dataset). Scientific publication data have been consolidated at the headquarters' level, with counts provided by AJSC.

Raw data are made available through the OECD website at http://oe.cd/ipstats, and are accompanied by a short technical document.

The structure of the JRC-OECD COR&DIP© v.2, 2019 database is detailed below.

JRC-OECD COR&DIP© v.2, 2019

Database structure



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References

Acs, J.Z., & Audretsch, D.B. (1989). Patents as a measure of innovative activity. *Kyklos*, 42(2), 171-180.

Aghion, P., & Howitt, P. (1990). A model of growth through creative destruction (No. w3223). National Bureau of Economic Research.

Archambault, É., & Larivière, V. (2011). Scientific publications and patenting by companies: a study of the whole population of Canadian firms over 25 years. *Science and Public Policy*, 38(4), 269-278.

Archibugi, D., & Iammarino, S. (2002). The globalization of technological innovation: definition and evidence. *Review of International Political Economy*, *9*(1), 98-122.

Arora, A., Belenzon, S., & Patacconi, A. (2018). The decline of science in corporate R&D. *Strategic Management Journal*, 39(1), 3-32.

Baruffaldi, S., B. van Beuzekom, H. Dernis, D. Harhoff, N. Rao, D. Rosenfeld and M. Squicciarini (2019). Identifying and Measuring Developments in Artificial Intelligence. *OECD Science, Technology and Industry Working Papers.*

Belderbos, R., Van Roy, V., Leten, B., & Thijs, B. (2014). Academic Research Strengths and Multinational Firms' Foreign R&D Location Decisions: Evidence from R&D Investments in European Regions. *Environment and Planning A: Economy and Space*, 46(4), 920–942. https://doi.org/10.1068/a45536

Breschi, S., Malerba, F., & Orsenigo, L. (2000). Technological regimes and Schumpeterian patterns of innovation. *The Economic Journal*, 110(463), 388-410.

Bruneel, J., d'Este, P., & Salter, A. (2010). Investigating the factors that diminish the barriers to university–industry collaboration. *Research Policy*, 39(7), 858-868.

Camerani, R., Rotolo, D., & Grassano, N., (2018). Do firms publish? A multi-sectoral analysis. *JRC Working Papers on Corporate R&D and Innovation* No 5/2018, Joint Research Centre.

Castellani, D., Montresor, S., Schubert, T., & Vezzani, A. (2017). Multinationality, R&D and productivity: Evidence from the top R&D investors worldwide. *International Business Review*, 26(3), 405-416.

Craglia M. (Ed.), Annoni A., Benczur P., Bertoldi P., Delipetrev P., De Prato G., Feijoo C., Fernandez Macias E., Gomez E., Iglesis M., Junklewitz H., Lòpez Cobo M., Martens B., Nascimento S., Nativi S., Polvora A., Sanchez I., Tolan S.. Tuomi I.. Vesnic Alujevic L.,(2018). Artificial Intelligence – A European Perspective, EUR 29425 EN, Luxemburg Publication Office

Chung, W., & Alcácer, J. (2002). Knowledge seeking and location choice of foreign direct investment in the United States. *Management Science*, 48(12), 1534-1554.

Ciriaci, D., Grassano, N., & Vezzani, A. (2019). Regulations and location choices of top R&D investors worldwide. *Structural Change and Economic Dynamics*, 49, 29-42.

Cohen. W.M. & Klepper, S. (1992). The anatomy of industry R&D intensity distributions. *The American Economic Review*, 82(4):773-799.

Contractor, F. J., Kumar, V., Kundu, S. K., & Pedersen, T. (2010). Reconceptualizing the firm in a world of outsourcing and offshoring: The organizational and geographical relocation of high‐value company functions. *Journal of management studies*, 47(8), 1417-1433.

Daiko, T., Dernis, H., Dosso, M., Gkotsis, P., Squicciarini, M., Tuebke, A., & Vezzani, A. (2017). World top R&D investors: Industrial property strategies in the digital economy (No. JRC107015). Joint Research Centre (Seville site).

Dasgupta, P., & David, P.A. (1994). Toward a new economics of science. *Research Policy*, 23(5), 487-521.

DeCarolis, D.M., & Deeds, D.L. (1999). The impact of stocks and flows of organizational knowledge on firm performance: An empirical investigation of the biotechnology industry. *Strategic Management Journal*, 20(10), 953-968.

Dernis, H., Dosso, M., Hervás, F., Millot, V., Squicciarini, M., & Vezzani, A. (2015). World corporate top R&D investors: Innovation and IP bundles (No. JRC94932). Joint Research Centre (Seville site).

Dosi, G. (1982). Technological paradigms and technological trajectories: a suggested interpretation of the determinants and directions of technical change. *Research policy*, 11(3), 147-162.

Dosi, G., Grazzi, M., & Moschella, D. (2017). What do firms know? What do they produce? A new look at the relationship between patenting profiles and patterns of product diversification. *Small Business Economics*, 48(2), 413-429.

EC Communication from the Commission to the European Parliament, the European Council, the Council, the European Economic and Social Committee and the Committee of the Regions. Artificial Intelligence for Europe. COM(2018) 237 final {SWD(2018) 137 final}.

Faria, L.G.D. & Andersen, M.M. (2017). Sectoral patterns versus firm-level heterogeneity-The dynamics of eco-innovation strategies in the automotive sector. *Technological Forecasting and Social Change*, 117:266-281.

Gomez, E. (ed) (2018). Assessing the impact of machine intelligence on human behavior: an interdisciplinary endeavor. 1st HUMAINT workshop, Barcelona.

Gkotsis, P., Pugliese, E., & Vezzani, A. (2018). A Technology-Based Classification of Firms: Can We Learn Something Looking Beyond Industry Classifications?. *Entropy*, 20(11), 887

Gotsch, M., & Hipp, C. (2012). Measurement of innovation activities in the knowledge-intensive services industry: a trademark approach. *The Service Industries Journal*, 32(13), 2167-2184.

Grant, R. M. (1996). Toward a knowledge‐based theory of the firm. *Strategic Management Journal*, 17(S2), 109-122.

Guellec, D., & de la Potterie, B.V.P. (2001). The internationalisation of technology analysed with patent data. *Research Policy*, 30(8), 1253-1266.

Hall, B., Helmers, C., Rogers, M., & Sena, V. (2014). The choice between formal and informal intellectual property: a review. *Journal of Economic Literature*, 52(2), 375-423.

Hernández, H., Grassano, N., Tübke, A., Potters, L., Amoroso, S., Doss, M., Gkotsis, P., & Vezzani, A., (2017). The 2017 EU Industrial R&D Investment Scoreboard; EUR 28870 EN; Publications Office of the European Union, Luxembourg, 2017, ISBN 978-92-79-76298-7, doi:10.2760/912318, JRC108520.

Hertog, P. D. (2000). Knowledge-intensive business services as co-producers of innovation. *International journal of innovation management*, 4(04), 491-528.

Hicks, D. (1995). Published papers, tacit competencies and corporate management of the public/private character of knowledge. *Industrial and Corporate Change*, 4(2), 401-424.

IPO (2019). Artificial Intelligence: A Worldwide Overview of AI Patents and Patenting by the UK AI Sector.

Katz, J.S., & Martin, B.R. (1997). What is research collaboration? *Research Policy*, 26(1), 1–18.

Levenshtein, V. I. (1965). Binary Codes Capable of Correcting Deletions, Insertions and Reversals. *Doklady Akademii Nauk SSSR*, 163(4), 845-848.

Lundvall, B. (2016). Innovation as an Interactive Process: From User– Producer Interaction to the National Systems of Innovation. In B. Lundvall (Author), *The Learning Economy and the Economics of Hope* (pp. 61-84). Anthem Press.

March, J. G. (1991). Exploration and exploitation in organizational learning. *Organization science*, 2(1), 71-87.

McMillan, G.S., & Hamilton III, R.D. (2000). Using bibliometrics to measure firm knowledge: an analysis of the US pharmaceutical industry. *Technology Analysis & Strategic Management*, 12(4), 465-475.

Mendonça, S., Pereira, T. S., & Godinho, M. M. (2004). Trademarks as an indicator of innovation and industrial change. *Research Policy*, 33(9), 1385-1404.

Montresor, S., & Vezzani, A. (2015). On the R&D giants' shoulders: do FDI help to stand on them?. *Economia e Politica Industriale*, 42(1), 33-60.

Narin, F., Noma, E., & Perry, R. (1987). Patents as indicators of corporate technological strength. *Research Policy*, 16(2-4), 143-155.

Nelson, R. R. and Winter, S.G., (1982). *An Evolutionary Theory of Economic Change*. Cambridge MA: Harvard University Press.

OECD (2019). Scoping principles to foster trust in and adoption of AI, Proposal by the Expert Group on Artificial Intelligence at the OECD (AIGO), http://oe.cd/ai

OECD (2009). OECD patent statistics manual. France: OECD Publications.

OECD (2017). OECD Science, Technology and Industry Scoreboard 2017: The digital transformation, OECD Publishing, Paris, doi: 10.1787/9789264268821-en.

OECD and SCImago Research Group (CSIC) (2016), *Compendium of Bibliometric Science Indicators*. OECD, Paris. Accessed from http://oe.cd/scientometrics.

Pakes, A., & Griliches, Z. (1980). Patents and R&D at the firm level: A first report. *Economics letters*, 5(4), 377-381.

Park, G., & Park, Y. (2006). On the measurement of patent stock as knowledge indicators. *Technological Forecasting and Social Change*, 73(7), 793-812.

Patel, P. & Pavitt, K. (1997). The technological competencies of the world's largest firms: complex and path-dependent, but not much variety. *Research Policy*, 26(2):141-156.

Patel, P., & Vega, M. (1999). Patterns of internationalisation of corporate technology: location vs. home country advantages. *Research Policy*, 28(2-3), 145-155.

Ramello, G.B. (2006). What's in a sign? Trademark law and economic theory. *Journal of Economic Surveys*, *20*(4), 547-565.

Reinganum, J. F. (1985). Innovation and industry evolution. *The Quarterly Journal of Economics*, 100(1), 81-99.

Rilla, N., & Squicciarini, M. (2011). R&D (re) location and offshore outsourcing: a management perspective. *International Journal of Management Reviews*, 13(4), 393-413.

Rosenberg, N. (2010). Why do firms do basic research (with their own money)?. *In: Studies On Science And The Innovation Process*: Selected Works of Nathan Rosenberg (pp. 225-234).

Rotolo, D., Hicks, D., & Martin, B.R. (2015). What is an emerging technology?. *Research Policy*, 44(10), 1827-1843.

Sachwald, F. (2008). Location choices within global innovation networks: the case of Europe. *The Journal of Technology Transfer*, *33*(4), 364-378.

Santos-Paulino, A. U., Squicciarini, M. & Fan, P. (2014), Foreign Direct Investment, R&D Mobility and the New Economic Geography: A Survey. *World Economy*, 37: 1692-1715. doi:10.1111/twec.12208

Schubert. A.. & Braun. T. (1986). Relative indicators and relational charts for comparative assessment of publication output and citation impact. *Scientometrics*, *9*(5-6), 281-291.

Teece, D.J., Pisano, G., & Shuen, A. (1997). Dynamic capabilities and strategic management. *Strategic Management Journal*, 18(7), 509-533.

Shane, S. (2001). Technological opportunities and new firm creation. *Management science*, *47*(2), 205-220.

Simeth, M., & Lhuillery, S. (2015). How do firms develop capabilities for scientific disclosure? *Research Policy*, 44(7), 1283–1295.

Soo, C.W., Devinney, T.M., & Midgley, D.F. (2004). The role of knowledge quality in firm performance. *In: Organizations as knowledge systems* (pp. 252-275). Palgrave Macmillan, London.

Squicciarini, M., Dernis, H., & Criscuolo, C. (2013). Measuring Patent Quality: Indicators of Technological and Economic Value, *OECD Science, Technology and Industry Working Papers*, 2013/03, OECD Publishing.

Tijssen, R.J.W. (2004). Is the commercialisation of scientific research affecting the production of public knowledge?: Global trends in the output of corporate research articles. *Research Policy*, 33(5), 709–733.

Trajtenberg, M. (1990). Patents as Indicators of Innovation, *Economic Analysis of Product Innovation*. Cambridge (MA): Harvard University Press.

Turing, A. M. (1950). Mind. *Mind*, 59(236), 433-460.

Veugelers, R., & Cassiman, B. (2005). R&D cooperation between firms and universities. Some empirical evidence from Belgian manufacturing. *International Journal of Industrial Organization*, 23(5-6), 355-379.

Winkler, W. E. (1999). The State of Record Linkage and Current Research Problems. *Statistics of Income Division,* Internal Revenue Service Publication R99/04.

WIPO (2019). WIPO Technology Trends 2019. Artificial Intelligence. Geneva, Switzerland.

Zanfei, A. (2000). Transnational firms and the changing organisation of innovative activities. *Cambridge Journal of Economics*, 24(5), 515–542.

Zitt, M., & Bassecoulard, E. (2004). Internationalisation in science in the prism of bibliometric indicators. *In Handbook of Quantitative Science and Technology Research* (pp. 407-436). Springer, Dordrecht.

Appendix

Annex A - List of sectors, ISIC rev. 4

38 sectors, ISIC rev. 4

01-03	Agriculture
05-09	Mining
10-12	Food products
13-15	Textiles & apparel
16-18	Wood & paper
19	Coke & petroleum
20	Chemicals
21	Pharmaceuticals
22-23	Rubber, plastics, minerals
24-25	Basic metals
26	Computers & electronics
27	Electrical equipment
28	Machinery
29-30	Transport equipment
31-33	Other manufactures
35	Electricity, gas & steam
36-39	Water, sewerage & waste
41-43	Construction
45-47	Wholesale, retail, repairs
49-53	Transport services
55-56	Hotels & food services
58-60	Publishing & broadcasting
61	Telecommunications
62-63	IT services
64-66	Finance & insurance
68	Real estate
69-71	Law, accountancy & engineering
72	Scientific R&D
73-75	Other business services
77-82	Admin & support services
84	Public administration and defence
85	Education
86	Health services
87-88	Care & social work
90-93	Arts & entertainment
94-96	Other services

Source: OECD, STAN Structural Analysis Database, http://oe.cd/stan , May 2019

Annex B - Definition of the ICT sector

ICT economic activities (sectors) are defined according to the general definition that follows:

"The production (goods and services) of a candidate industry must primarily be intended to fulfil or enable the function of information processing and communication by electronic means, including transmission and display".

The list of ICT sectors (ISIC Rev. 4) that meet this condition is provided below:

ICT manufacturing sectors

2610 Manufacture of electronic components and boards
2620 Manufacture of computers and peripheral equipment
2630 Manufacture of communication equipment
2640 Manufacture of consumer electronics
2680 Manufacture of magnetic and optical media

ICT trade sectors

4651 Wholesale of computers, computer peripheral equipment and software
4652 Wholesale of electronic and telecommunications equipment and parts

ICT services sectors

5820 Software publishing

61 Telecommunications

6110 Wired telecommunications activities
6120 Wireless telecommunications activities
6130 Satellite telecommunications activities
6190 Other telecommunications activities

62 Computer programming, consultancy and related activities

6201 Computer programming activities
6202 Computer consultancy and computer facilities management activities
6209 Other information technology and computer service activities

631 Data processing, hosting and related activities; web portals

6311 Data processing, hosting and related activities
6312 Web portals

951 Repair of computers and communication equipment

9511 Repair of computers and peripheral equipment
9512 Repair of communication equipment

Source: OECD (2007).

Annex C - Linking company data to IP data: a matching approach

Characterising the portfolio of IP rights and scientific publications of companies requires raw data to be linked with enterprise data. To this end, the names of the top corporate R&D investors and of their subsidiaries were matched to the applicants names provided in published patent and trademark documents, and to the companies to which authors of scientific papers are affiliated. The matching was carried out on a by-country basis using a series of algorithms contained in the Imalinker (Idener Multi Algorithm Linker) system developed by IDENER (http://www.idener.es/).

The matching exercise was implemented over a number of key steps:

- The names of top corporate R&D investors and subsidiaries and of the firms included in the data on IP rights and scientific publications were separately harmonised using country-specific 'dictionaries'. These aimed to dealing with legal entity denomination (e.g. 'Limited' and 'Ltd'), common names and expressions, as well as phonetic and linguistic rules, that might affect how enterprise names are written. Failing to account for such features of the data might mistakenly lead to excluding a company (not considering only because its name had been misspelt or shortened in some places), or double counting a company (because different spellings of its name made it appear to be different entities). The compilation of suitable country- and language-specific dictionaries required country-level and language-related knowledge.
- In a second step, a series of string-matching algorithms – mainly token-based and string-metric-based, such as token frequency matching and Levenshtein (1965) and Jaro-Winkler (Winkler, 1999) distances – were used to compare the harmonised names from the two datasets and provide a matching accuracy score for each pair. The precision of the match, which depended on minimising the number of false positive matches, was ensured through a selection of pairs of company names/ IP rights owners made on the basis of high-score thresholds imposed on the algorithm.
- A post-processing stage was handled manually and involved reviewing the results of the matches; assessing the proportion of non-matched firms (possibly false negatives, that is, firms that the algorithm had failed to recognise as part of the sample) among the top R&D performers and affiliates; and identifying new matches on a case-by-case basis (e.g. allowing for lower thresholds for a given algorithm), by correcting and augmenting dictionaries and through manual searches. More specifically, to cope with the heterogeneity of the affiliations fields recorded in the SCOPUS© database, additional matching was manually performed for the top 10% of companies by sector.

The matching was performed using the names of both the top corporate R&D investors and their subsidiaries. IP portfolios and published articles were aggregated at the level of the headquarters: patents, trademarks owned by a given subsidiary - and authors of articles affiliated in a given subsidiary - were thus fully attributed to the parent company of the group, regardless of the precise structure of the group. In practical terms, this choice meant that the patents, trademarks and publications of a certain subsidiary were attributed to the parent R&D performer under all circumstances, and regardless of the exact share of the affiliate that the parent company owns (whether, for example, 60 % or 70 %).

Overall, 98 % of top R&D-performing companies could be matched to at least one patent applicant in the patent database, either directly or through one or more subsidiary firms. The same overall matching rate was observed for trademark applications (95 %). Because of the higher heterogeneity in the way in which affiliation names are recorded in the database used, the matching rate is a little lower for publications (87 %).

Annex D - List of technological fields for patents

WIPO technology fields	
Electrical engineering	
1	Electrical machinery, apparatus, energy
2	Audio-visual technology
3	Telecommunications
4	Digital communication
5	Basic communication processes
6	Computer technology
7	IT methods for management
8	Semiconductors
Instruments	
9	Optics
10	Measurement
11	Analysis of biological materials
12	Control
13	Medical technology
Chemistry	
14	Organic fine chemistry
15	Biotechnology
16	Pharmaceuticals
17	Macromolecular chemistry, polymers
18	Food chemistry
19	Basic materials chemistry
20	Materials, metallurgy
21	Surface technology, coating
22	Micro-structural and nano-technology
23	Chemical engineering
24	Environmental technology
Mechanical engineering	
25	Handling
26	Machine tools
27	Engines, pumps, turbines
28	Textile and paper machines
29	Other special machines
30	Thermal processes and apparatus
31	Mechanical elements
32	Transport
Other fields	
33	Furniture, games
34	Other consumer goods
35	Civil engineering

Source: WIPO, IPC Concordance Table, http://www.wipo.int/ipstats/en/index.html, January 2018.

Annex E - List of Goods and Services for Trademarks

NICE classes	
1	Chemical goods
2	Paints and colorants
3	Cleaning products
4	Oils and fuels
5	Pharma products
6	Metals
7	Machineries
8	Hand tools
9	Instruments & computers
10	Medical instruments
11	Lightening and heating
12	Vehicles
13	Firearms
14	Precious goods
15	Musical instruments
16	Papers and packaging
17	Rubber and plastics
18	Leather and complements
19	Building material
20	Furniture
21	House utensils
22	Fibrous products
23	Yarns and threads
24	Textiles
25	Clothing and footwear
26	Decorations
27	Carpets and floor covers
28	Games
29	Food
30	Condiments and cereals
31	Animals and grains
32	Low and non alcohol drinks
33	Alcoholic drinks
34	Tobaccos
35	Business and advertising
36	Insurance and finance
37	Building services
38	Telecommunications
39	Transport and packaging
40	Treatment of materials
41	Education and sport
42	R&D and software
43	Food, drink and accommodation
44	Medical and hygiene services
45	Legal and personal services

Source: WIPO, Nice Classification, https://www.wipo.int/classifications/nice, May 2019 .

Annex F - List of All Science Journal Classification (ASJC) fields

ASJC fields	
10	Multidisciplinary
11	Agricultural & Biological Sciences
12	Arts & Humanities
13	Biochemistry, Genetics & Molecular Biology
14	Business, Management & Accounting
15	Chemical Engineering
16	Chemistry
17	Computer Science
18	Decision Sciences
19	Earth & Planetary Sciences
20	Economics, Econometrics & Finance
21	Energy
22	Engineering
23	Environmental Science
24	Immunology & Microbiology
25	Materials Science
26	Mathematics
27	Medicine
28	Neuroscience
29	Nursing
30	Pharmacology, Toxicology & Pharmaceutics
31	Physics & Astronomy
32	Psychology
33	Social Sciences
34	Veterinary
35	Dentistry
36	Health Professions

Source: Elsevier, Scopus Support Center, https://service.elsevier.com/app/overview/scopus, May 2019.

Annex G - Definition of ICT-related patents, designs and trademarks

ICT-related patents

Patents in ICT-related technologies are identified using the classes of the International Patent Classification (IPC) in which patents are classified. ICT technologies are subdivided into 13 areas defined with respect to the specific technical features and functions they are supposed to accomplish (e.g. mobile communication), and the details provided about the ways in which the technologies relate to ICT products.

Technology area	Sub area	IPC
1. High speed network	Digital communication technique	H03K, H03L, H03M, H04B1/69-1/719, H04J, H04L (excluding H04L9, H04L12/14) **H04L9, *H04L12/14*
	Exchange, selecting	H04M3-13,19,99, H04Q
	Others	H04B1/00-1/68, H04B1/72-1/76, H04B3-17 (excluding H04B1/59, H04B5, H04B7), H04H **H04B1/59, *H04B5, *H04B7*
2. Mobile communication		H04B7, H04W (excluding H04W4/24, H04W12) **H04W4/24, *H04W12*
3. Security	Cyphering, authentication	G06F12/14, G06F21, G06K19, G09C, G11C8/20, H04K, H04L9, H04M1/66-665, H04M1/667-675, H04M1/68-70, H04M1/727, H04N7/167-7/171, H04W12
	Electronic payment	G06Q20, G07F7/08-12, G07G1/12-1/14, H04L12/14, H04W4/24 **G06Q30/02*
4. Sensor and device network	Sensor network	G08B1/08, G08B3/10, G08B5/22-38, G08B7/06, G08B13/18-13/196, G08B13/22-26, G08B25, G08B26, G08B27, G08C, G08G1/01-065 **G06F17/40, *H04W84/18*
	Electronic tag	H04B1/59, H04B5 **G01S13/74-84, *G01V3, *G01V15*
	Others	**H04W84/10*
5. High speed computing		G06F5, G06F7, G06F9, G06F11, G06F13, G06F15/00, G06F15/16-15/177, G06F15/18, G06F 15/76-15/82
6. Large-capacity and high speed storage		G06F3/06–3/08, G06F12 (exclude G06F12/14), G06K1-7, G06K13, G11B, G11C (exclude G11C8/20), H04N5/78-5/907 **G06F12/14, *G11C8/20*
7. Large-capacity information analysis	Database	G06F17/30, G06F17/40
	Data analysis, simulation, management	G06F17/00, G06F17/10-17/18, G06F17/50, G06F19, G06Q10, G06Q30, G06Q40, G06Q50, G06Q90, G06Q99, G08G (exclude G08G1/01-065, G08G1/0962-0969) **G08G1/01-065, *G08G1/0962-0969*
8. Cognition and meaning understanding		G06F17/20-17/28, G06K9, G06T7, G10L13/027, G10L15, G10L17, G10L25/63,66 **G06F15/18*
9. Human-interface		H04M1 (exclude H04M1/66-665, H04M1/667-675, H04M1/68-70, H04M1/727), G06F3/01-3/0489, G06F3/14-3/153, G06F3/16, G06K11, G06T11/80, G08G1/0962-0969, G09B5, G09B7, G09B9 **H04M1/66-665, *H04M1/667-675, *H04M1/68-70, *H04M1/727, *G06F17/50, *G06K9, *G06T11, *G06T13, *G06T15, *G06T17-19*
10. Imaging and sound technology	Imaging technique	H04N (excluding H04N5/78-5/907, H04N7/167-7/171), G06T1-9 (excluding G06T7), G06T11 (excluding G06T11/80), G06T13, G06T15, G06T17-19, G09G **H04N5/78-5/907, *H04N7/167-7/171, *G06T7, *G06T11/80*
	Sound technique	H04R, H04S, G10L (excluding G10L13/027, G10L15, G10L17, G10L25/63,66) **G10L13/027,* G10L15, *G10L17, *G10L25/63,66*
11. Information communication device	Electronic circuit	H03B, H03C, H03D, H03F, H03G, H03H, H03J
	Cable and conductor	H01B11
	Semiconductor	H01L29-33, H01L21, 25, 27, 43-51
	Optic device	G02B6, G02F, H01S5
	Others	B81B7/02, B82Y10, H01P, H01Q
12. Electronic measurement		G01S, G01V3, G01V8, G01V15
13. Others	Computer input-output	G06F3/00, G06F3/05, G06F3/09, G06F3/12, G06F3/13, G06F3/18
	Other related technique	G06E, G06F1, G06F15/02, G06F15/04, G06F15/08-15/14, G06G7, G06J, G06K15, G06K17, G06N, H04M15, H04M17

Note: An asterisk precedes those IPC codes that are relevant, although of secondary importance, for the technology area considered, and that may conversely be key in other ICT areas.

Source: Inaba and Squicciarini (2017).

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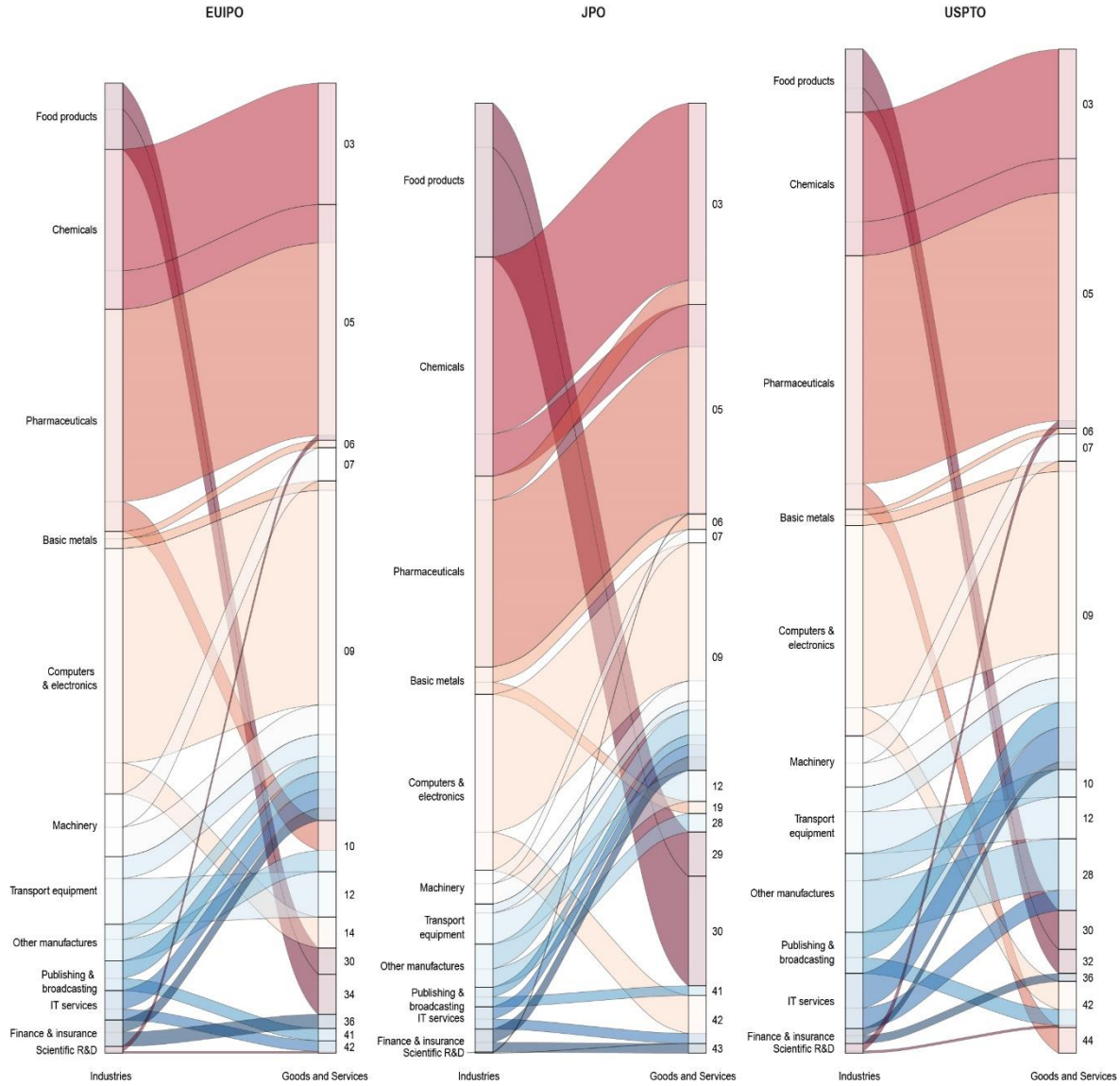
Digital trademarks are identified using combinations of classes of the international classification of goods and services, the Nice Classification, and a list ICT related keywords (or combination of keywords) searched in the description of trademarks.

Nice classes	Description
9	Scientific, nautical, surveying, photographic, cinematographic, optical, weighing, measuring, signalling, checking (supervision), life-saving and teaching apparatus and instruments; apparatus and instruments for conducting, switching, transforming, accumulating, regulating or controlling electricity; apparatus for recording, transmission or reproduction of sound or images; magnetic data carriers, recording discs; compact discs, DVDs and other digital recording media; mechanisms for coin-operated apparatus; cash registers, calculating machines, data processing equipment, computers; computer software; fire-extinguishing apparatus.
28	Games, toys and playthings; video game apparatus; gymnastic and sporting articles; decorations for Christmas trees.
35	Advertising; business management; business administration; office functions.
38	Telecommunications.
41	Education; providing of training; entertainment; sporting and cultural activities.
42	Scientific and technological services and research and design relating thereto; industrial analysis and research services; design and development of computer hardware and software.

Source: WIPO, Nice classification, *http://www.wipo.int/classifications/nice/en/*

Annex H – Top two goods and services registered by sector, ISIC rev.4, 2014-16
Share in total trademarks owned by world's top R&D investors, by IP office



Note: Data relate to sectors tow ith at least 50 company headquarters in the top 2 000 corporate R&D sample having filed trademarks in 2014-16.

Source: JRC-OECD, COR&DIP© database v.2., 2019.

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doi:10.2760/472704

ISBN 978-92-76-09669-6