European Commission

ISSN 2443-8022 (online)

Trends at the Frontier in Corporate R&D in the Digital Era: Facts, Prospects and Policies

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FELLOWSHIP INITIATIVE

The Productivity Challenge:
Jobs & Incomes in the Dawning Era of Intelligence Robots

DISCUSSION PAPER 120 | OCTOBER 2019

EUROPEAN ECONOMY

Economic and Financial Affairs

2019 Fellowship Initiative Papers are written by external experts commissioned to write research papers, retaining complete academic independence, contributing to the discussion on economic policy and stimulating debate.

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Authorised for publication by Mary Veronica Tovšak Pleterski, Director for Investment, Growth and Structural Reforms.

DG ECFIN's Fellowship Initiative 2018-2019 "The Productivity Challenge: Jobs and Incomes in the Dawning Era of Intelligent Robots" has solicited contributions examining current and possible future productivity developments in Europe. In view of possible hysteresis effects after the crisis and in the general context of ageing populations and globalisation, the aim has been to re-examine the ongoing trends and drivers and to identify policies to tap fully the potential for inclusive productivity growth. The fellowships have been awarded to prominent scholars in the field to interact with staff in ECFIN and other Commission colleagues, and to prepare final reports on specific research questions within this general topic.

This paper exists in English only and can be downloaded from
https://ec.europa.eu/info/publications/economic-and-financial-affairs-publications_en.

Luxembourg: Publications Office of the European Union, 2019

PDF ISBN 978-92-76-11188-7 ISSN 2443-8022 doi:10.2765/477463 KC-BD-19-007-EN-N

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Abstract

Both technological change, especially the digital revolution, and globalisation are predicted to lead to "winner takes most" industries, dominated by a happy few superstar firms. As the importance of large fixed investments driving scale and scope advantages increase, and as network effects become more prominent, sectors will be increasingly concentrated in a small number of firms, leaving an increasingly unequal corporate landscape. This may have important implications for aggregate productivity trends, particularly if the "winners" are the biggest firms with highest productivity growth and innovative performance and the laggards increasingly less likely to produce productivity growth.

This contribution examines how concentrated R&D spending is in few "winners". It finds a high degree of concentration in R&D, much more than sales and employment. The analysis finds no evidence for increasing concentration in the global R&D landscape, only more recently in the digital services sectors, with in particular the top 1 percent of R&D spending firms in these sectors forging ahead. Incumbent R&D leaders slowly lose their positions to new R&D-leading firms. But overall, R&D leadership is persistent and turbulence is relatively modest. Digital services is the most turbulent high-tech sector. The US and China are more likely to produce new R&D leaders taking over top positions from incumbent R&D leaders. This poses difficult questions for Europe, which is at risk of losing out in terms of R&D leadership in more technologically advanced sectors.

JEL Classification: O33.

Keywords: Corporate R&D, concentration, persistence digital era, digital services sector, winner-take-all, Veugelers.

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1. INTRODUCTION

The EU's productivity growth has been suffering since long from weak performance. The long-term weakness was exacerbated during the 2008 crisis, but continues to persist in the current post-crisis juncture. Recent productivity growth in the EU is lacklustre, not only at the aggregate, but also the convergence among EU MS has stalled, with some of the weaker MS no longer catching up (eg ECFIN 2019). This lacklustre productivity growth contrasts with the potential of new technologies, particularly digital technologies, to lift productivity growth. In fact, the EU's lacklustre productivity growth is often related to its weaker performance in digital producing and digital using sectors (eg Van Ark (2015)).

At the same time, we are experiencing an increasing productivity dispersion across firms. Some 'superstar' firms are pushing forward the frontier of technological evolution and exhibit a star performance in productivity growth. Using a harmonised cross-country firm-level database for 24 countries, Andrews, Criscuolo & Gal (2017) show an increasing productivity gap between the global frontier and laggard firms.[1] These superstar firms are typically bigger, more innovative and have higher rates of digital technology adoption (Bessen 2007).

With big, superstar firms increasingly dominating the scene, many industries are experiencing an increasing concentration. Autor et al (2016) find a remarkably consistent upward trend in concentration in each sector for the US for the period 1982-2012. [2]They also find that employment concentration grew, but notably more slowly than sales concentration in finance, services, and especially in manufacturing. The pattern suggests that firms may attain large market shares with a relatively small workforce.

Linked to the evidence on rising concentration, is the evidence on rising mark-ups (De Loecker & Eeckhoudt (2017). Mark-ups are particularly rising by firms in the highest decile of distribution of mark-ups within their industry, consistent with winner-take-all patterns.

This increasing divergence, forging ahead of leading firms and rising concentration and mark-ups holds particularly in the sectors where technology change is higher. This holds particularly for sectors where digital technologies, especially digital services, are developed or intensely adopted. In these sectors, the leading firms are typically US or Chinese, cf "Big Tech" firms like Amazon, Apple, Google, Facebook, Microsoft, Alibaba, Huawei. Autor et al (2016), for example, find for the US that the industries that became more concentrated over time were also the industries in which productivity—measured by either output per worker, value-added per worker, TFP, or patents per worker—increased the most. Also the OECD finds that firms belonging to top digitalised sectors have on average higher mark-ups and that the difference in

[1] Andrews, Criscuolo & Gal (2017) define global frontier firms as the top 5% of firms in terms of labour productivity levels, within each two-digit sector, in each year, across all countries since the early 2000s. All other firms are defined as laggards.

[2] In manufacturing, the sales-concentration ratio increased from 38% to 43%; in finance from 24% to 35%; in services from 11% to 15%; in retail trade from 15% to 30%.

mark-ups between intensive and non-intensive digital sectors has increased over time (Calligaris et al (2018)).

As far as the EU is concerned, there is evidence that the EU is experiencing a somewhat smaller concentration of market power in superstar firms compared for example to the US. Gutierrez & Philippon (2018) found that unlike in the US, concentration has been stable or even declining in Europe, which they attribute to deregulation of product markets and a more vigorous anti-trust enforcement in Europe. Another part of the story, however, might be related to the fact that the EU is largely missing frontier firms, especially in digital technologies.

Finally, the EU is also experiencing business dynamics that are stalling, with less entry, and in general stagnating start-up dynamics, a trend which again seems to be more outspoken in digital sectors (Calvino et al (2015)).

2. INCREASING CONCENTRATION IN CORPORATE R&D

As the increasing concentration of the corporate landscape in superstars seems to be at least partly technology-driven and associated with divergences in productivity & TFP, it is important to look directly at the corporate R&D landscape: how unequal is the corporate landscape, would we see similar increasing concentration trends?

The speed, depth and breadth of technology change, the large sunk investments for building R&D capacity, the need to access networks and alliance partners are all characteristics that lead to R&D races increasingly characterised as "winner take most", where large, incumbent firms, riding on their stock of knowledge and networks of customers and partners, are the most likely winners (Schumpeter Mark II). This is even more so for R&D than for sales & employment, as the R&D capacities are often more "unique", proprietary and difficult to imitate than those in product market space.

Within digital markets, the advantages of size become even more outspoken as these platform based markets[3] are characterised by network effects, where a large user base and/or a large base of applications and equipment will characterise the best performing platforms. These network effects are even more prevailing in multi-sided networks (Belleflamme & Peitz (2018)). Although platforms can operate offline, Internet and digital technologies greatly reduce transaction costs on these platforms, which is why most platforms are on-line. In addition, the availability of bigger data will allow for better applications of AI algorithms.

Not only size is more important, but also incumbency. When two-sided network effects meet high switching costs, new firms will face an important entry barrier, creating an advantage for established firms. In

[3] Platform based Markets are markets where the interaction between at least some participants is facilitated and managed by a platform (Belleflamme & Peitz (2018)

addition, new digital business models rely on the intensive use of knowledge assets, which can be re-used at low marginal cost and/or newly recombined, generating increasing returns to scale to innovating. This will create even more difficult entry and persistency in innovation advantages for incumbents. Particularly this incumbency advantage will be problematic for the EU, as it lacks digital incumbents.

At the same time, technological innovations get diffused voluntarily or involuntarily. This will lead to catching up and dissipating of previous leadership positions. If the diffusion process happens sufficiently fast, differences between leaders and laggards should shrink fast. The evidence on increasing gaps between leaders and followers (cf supra) would however suggest that this diffusion process has stalled more recently. This is also consistent with evidence of a slow take up of digital technologies by SMEs in Europe (EIB 2018).

But also the fluidity of the R&D environment needs to be recognised: competences, network positions and technology leaderships of incumbents can be quickly overturned by radically new technology avenues. These will disrupt the incumbent leaders, creating room for new winners (Schumpeter Mark I). Even if the landscape may still be concentrated in few firms, new tenants can inhabit the top.

But also this creative destruction force may have stalled more recently, as the evidence on stalling business dynamics suggests (cf supra). And even when entrants are successful, if their growth strategy is through take-over by incumbents, the danger of "killer" acquisitions looms (Cunningham et al 2017), when the incumbents would "shelve" any acquired innovations that would radically distort their existing positions.

The evidence on the concentration of the R&D landscape and trends therein is very thin. Rammer & Schubert (2016) examine this for Germany. They provide several interesting findings. The share of German firms that are innovation active has dropped over time. Particularly, many small and medium-sized firms have discontinued their investments in innovation. Consequently, the inequality of innovation activities has become larger over time in Germany. Since the mid-1990s, the Gini coefficient for the distribution of German business sector innovation expenditures has been exhibiting an increasing trend. At the same time, they find a high stability in the group of firms with the largest R&D budgets in Germany. In the 12 years between 2003 and 2015, nine out of ten companies remained in the top 10 of the largest R&D spenders. Even changes in ranks were only marginal within the top 10. All this evidence is very supportive of an incremental technology change environment with increasing concentration on large incumbents.

3. METHODOLOGY AND SOURCES OF INFORMATION

In this contribution, we will look at the concentration of the R&D landscape worldwide. We will particularly zoom in on the digital sector and on the position of Europe. We use various editions of the EC-JRC Scoreboard of largest R&D spenders worldwide. This allows to look at trends in R&D profiles across all sectors and all world regions. We will examine the inequality of the R&D landscape, its concentration in few firms and the trends therein and examine incumbency among the top R&D spenders. Who are these R&D superstars? Are they incumbent firms, persistently leading in their sector in R&D and sales? Are European firms present among these R&D superstars or is this mostly US and more recently Chinese territory?

The study uses various years, with the main trends analysis covering 2005 to 2015 of the EC-JRC-IPTS R&D scoreboard of largest R&D spenders in the world and for current state analysis using the most recently available data, which is from 2018. For the trend analysis, the various year-editions were made compatible and firms linked across the various year-editions (see also Veugelers (2017)).

The R&D scoreboard has the advantage that it covers for individual firms their R&D expenditures, sales and employment and this for several years and for firms from all sectors and all countries. The scoreboard only covers the largest R&D spenders, which means that we will only be characterising the R&D distribution in the top parts of the R&D size distribution. These largest spenders in the Scoreboard represent typically more than 80% of total corporate R&D.[4]

When discussing how unequal the distribution is and how concentrated in top spenders, it matters to keep in mind that we are missing the lower tails of the distribution, where the majority of firms are located, all with smaller R&D budgets. Slicing only the Scoreboard firms in the total distribution of R&D active firms, is therefore likely to generate higher concentration than the total set of R&D active firms and will give a downward bias in levels of concentration.

Also, if the group of leading firms is forging ahead and laggards are falling behind, the concentration on top spenders only may give a downward bias in increasing concentration.

For the analysis per country or region, it is important to note that the Scoreboard allocates all R&D of companies to the country of ownership, rather than on where the expenditures take place.

4. TRENDS IN THE GLOBAL CORPORATE R&D LANDSCAPE

Before we describe the concentration of the global corporate R&D landscape in few firms and the trends therein, we first describe the recent trends in the global corporate R&D landscape and the position of the EU. While for the concentration analysis and trends therein, described in sections 5-9, we will use the 2005-2015 Scoreboard data, the analysis in this section 4, will use the most recent Scoreboard data available (2018).

4.1. RISE OF CHINA

US companies take up most of the 2500 slots in the R&D scoreboard, almost one third. Europe, with a quarter of the slots, comes second. But the rising country is China, which has in the last 4 years more than doubled its slots in the scoreboard. Chinese firms represent in 2018 17,5% of the slots, being already

[4] Comparing the country Scoreboard totals with the OECD statistics on business R&D allows to assess the representativeness of the samples used . While the EU Scoreboard R&D is about 100% of corporate EU R&D, for the US, this is 83% and for Japan 98%. For China however this is only 31%. Within the EU, only Germany, France and UK has a good coverage. For Germany this is 116%, for France 91%, for the UK 104%. All other EU countries either have too small numbers and/or the coverage is biased.

substantially more numerous than Japanese firms. However when looking at the top 250 slots (i.c. the top decile of 250 largest R&D spenders), China still represents only 10% of these top slots, yet this was only 4% four year ago. The US dominates even more in these top slots, where it holds a steady 36% of the top slots. The EU is also well represented in these top slots, but its share is slightly decreasing.

Table 1: **The largest R&D spending firms in the world: 2014-2018**

	China	EUR	US	Japan
% firms among all 2500 Scoreboard firms 2018	17,5%	23%	31%	13,5%
% firms among all 2500 Scoreboard firms 2014	8%	25%	32%	15,5%
% firms among largest 250 Scoreboard firms 2018	10%	27%	36%	17,5%
% firms among largest 250 Scoreboard firms 2014	4%	29%	36%	18%
Share in World R&D 2018	10%	28%	39%	14%
Share in World R&D 2014	7%	30%	36%	16%
R&D to Sales Ratio 2018	2.8	3.4	6.3	3.4

Source: Own calculations based on EC-JRC-IPTS R&D, various editions.

4.2. RISE OF DIGITAL

The three major sectors in the global corporate R&D landscape are ICT, Biotech&Pharma and Vehicles&Parts. While ICT and Biotech&Pharma are high-tech sectors, vehicles & Parts is a medium-high-tech sector. In 2018, vehicles&Parts accounts for 16,5% of total Scoreboard R&D, BioPharma for 20%. But by far the biggest sector in the Scoreboard is ICT, representing 39% of total Scoreboard R&D .

It is typical to characterise the digital sector in different layers:

> Layer I: Network element providers (eg Cisco, Samsung, Apple, Huawei, ZTE, Alcatel, Ericson, Nokia…)
>
> Layer II: Network operations (fixed and mobile) (eg AT&T, BT, DT, Vodafone…)
>
> Layer III: Software & digital service providers; Platform providers, application providers (eg Google, Facebook, Alibaba, SAP…)

Layer I is the hardware layer, while Layers II and III is the services layer. In order not to miss some important players in Layer I, like Samsung, we will include in this layer both the “electronic equipment” and the “technology hardware” Scoreboard sectors. For this reason, we will use in the Scoreboard analysis as label “ICT” rather than “Digital”.

Layer I (ICT hardware & electronic equipment) represents 25% of Scoreboard R&D in 2018, Layer II is small, representing only 1% of total ICT Scoreboard R&D. The major part of ICT services is Layer III, representing 13% of Scoreboard R&D in 2018.

Table 2: **R&D Scoreboard by Region and by Sector (2018)**

Vehicles & Parts			BioPharma			ICT		
CN	**EUR**	**US**	**CN**	**EUR**	**US**	**CN**	**EUR**	**US**
Share of Country's Scoreboard firms in Sector								
8%	6%	3%	7%	15%	26%	37%	21%	39%
Country Share in Sector global Scoreboard R&D								
4.9%	49.1%	14.3%	1.7%	28.6%	46.7%	12.5%	14.4%	50.7%
Country's Specialisation in Sector R&D (RS) *(Share of country's Scoreboard R&D in sector relative to Share of country in All Scoreboard R&D)*								
0.48	1.74	0.37	0.16	1.01	1.21	1.24	0.51	1.31

Source: Own calculations based on EC-JRC-IPTS R&D, latest edition (2018)

When looking at the position of the different regions in the sectors, US strong position in ICT is clear: 39% of its Scoreboard firms are in this sector, US firms represent about half of total global R&D in this sector and its share of global R&D is much higher in this sector than across all sectors, leaving a RS score well above 1 (1.31).

Also China is specialising its R&D in this sector (RS=1.24), 37% of its Scoreboard firms are in ICT. They are nevertheless still small in R&D compared to the US, representing 12,5% of sectoral R&D.

The numbers clearly illustrate Europe's missed ICT story. Although it has 21% of its Scoreboard firms in this sector, this is still substantially smaller than in the US and China. These firms are also much smaller R&D players than the US, as Europe only holds 14% of all ICT Scoreboard R&D, only marginally higher than rising China. Its RS score (0.51) clearly reflects its lack of specialisation in ICT.

Europe's corporate R&D is strongly focused on Vehicles&Parts. Although only 6% of European Scoreboard firms are in this sector, its Vehicles&Parts Scoreboard firms represent almost half of the global R&D in this sector. Its RS score for this sector (1.74) clearly shows how strongly specialised the European corporate R&D landscape is on Vehicles&Parts. China has more of its Scoreboard firms in this sector (8%), but they are (still) all very small in R&D, representing less than 5% of sectoral R&D.

BioPharma is still a stronghold for the US and Europe. China's rise in R&D has not yet materialised in this sector, representing less than 2% of global R&D in this sector. Europe's BioPharma firms represent almost 30% of global sectoral R&D. But US firms command close to half of global sectoral R&D.

4.3. RISE OF DIGITAL SERVICES

Table 3: **R&D Scoreboard by Region and by ICT subsectors (2018)**

ICT-I			ICT-II			ICT-III		
CN	**EUR**	**US**	**CN**	**EUR**	**US**	**CN**	**EUR**	**US**
Share of Country's Scoreboard firms in Sector								
26%	11%	19%	1%	2%	1%	9%	8%	19%
Country Share in Sector global Scoreboard R&D								
13.6%	14.9%	40.7%	5.3%	50.3%	18.0%	11.1%	9.8%	72.6%
Country's Specialisation in Sector R&D (Share of country's Scoreboard R&D in sector relative to Share of country in All Scoreboard R&D)								
1.36	0.53	1.05	0.53	1.78	0.46	1.10	0.35	1.88

Source: Own calculations based on EC-JRC-IPTS R&D, latest edition (2018)

When splitting up the ICT sector in its different layers, it shows that the US strength in ICT holds in Layer I, where it represents 40% of global sectoral R&D, with one out of 5 US Scoreboard firms from Layer I. Europe has retrenched in this sector. Its RS score in this sector is only 0.53, only one out of 10 European Scoreboard firms are in this sector, and these firms represent only 15% of global sectoral R&D. China is most strongly specialising in this sector, with an RS score of 1.36. One out of every 4 Chinese Scoreboard firm is in this Layer I. But again these firms are still relatively small, representing only 13.6% of global sectoral R&D.

The ICT layer where US strength is most outspoken is Layer III. Its RS score for Layer III is 1.88. Almost one out of every 5 US Scoreboard firm is in this Layer, and together they represent about 73% of all global R&D in this sector. Alphabet (Google) and Microsoft are in the Top 10 largest Scoreboard firms, Facebook, Oracle and IBM are among the Top 100 largest Scoreboard firms. Also China is specialising in this sector, with an RS >1. 9% of its Scoreboard firms are in this sector, but together they still represent only 11% of sectoral R&D. Yet, they have already big players here with Alibaba, Tencent and Baidu among the 100 largest Scoreboard firms. In stark contrast, Europe is virtually absent in this layer. It has 8% of its Scoreboard firms in this sector, but these firms have less than 10% of sectoral R&D and its RS score is significantly below 1. It has only 1 firm (SAP) among the 100 largest Scoreboard firms. In Layer II, Europe does hold a strong position, representing about half of global sectoral R&D, but to be remembered is that this is only a tiny segment in the overall ICT corporate R&D landscape (representing 3.5% of all ICT Scoreboard R&D in 2018).

5. CONCENTRATION IN CORPORATE R&D

5.1. OVERALL CONCENTRATION

R&D expenditure are highly unequally distributed and concentrated in few firms (Table 2): the Top 10% largest spenders (ie top 250 companies) account for 71% of all Scoreboard R&D spending, the Top 1% (ie top 25) for more than a quarter. The 100 largest spenders, representing 4% of all Scoreboard firms, account for more than half of all Scoreboard R&D spending, the 10 largest firms account for 15%. Overall, this concentration of R&D spending in a few firms, leaves a very unequal distribution of Scoreboard R&D spending, as the Gini and the Theil coefficients confirm.

Table 4: **Inequality and Concentration Measures for the Top 2500 Global R&D Firms, 2015**

	THEIL	GINI	SHARE OF TOP 1%	SHARE OF TOP 10%
R&D	1.47	0.76	27%	71%
SALES	1.33	0.77	22%	66%
EMPL	1.15	0.74	18%	61%

Source: Bruegel calculations on the basis of EC-JRC-IPTS R&D scoreboard data

Sales and employment of Scoreboard firms are also highly concentrated: the Top 10% largest Scoreboard firms with respect to sales account for 66% of overall Scoreboard sales. The Top 10% largest employers in the Scoreboard account for 61% of Scoreboard employment. Nevertheless, the inequality and concentration of sales and particularly employment of Scoreboard firms is less outspoken than their R&D expenditures.

Are the R&D superstars more or less dominant in sales or employment? Table 5 shows that while the Top 10% R&D spenders account for 71% of all Scoreboard R&D spending, they only account for half of all Scoreboard sales and 42% of all Scoreboard employment. The Top 1% represents 27% of all Scoreboard R&D spending, but only 12% of Scoreboard sales and 7% of Scoreboard employment. The largest R&D spenders are therefore not the largest in terms of sales and are much leaner in terms of employment. The top R&D spenders realise their R&D dominance with a smaller sales and employment profile.

Table 5: **Sales and Employment by Top R&D Spenders**

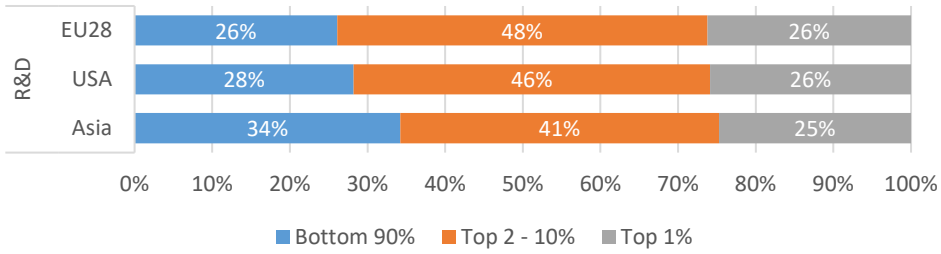
	SHARE IN TOTAL SCOREBOARD		
	R&D	**Sales**	**Employment**
TOP 1% R&D SPENDERS	27%	12%	7%
TOP 10% R&D SPENDERS	71%	50%	42%

Source: Bruegel calculations on the basis of EC-JRC-IPTS R&D scoreboard data (2015)

5.2. R&D CONCENTRATION BY REGION

A comparison of European with non-European firms in the Scoreboard allows to see whether the R&D concentration in few superstar firms is a bigger phenomenon in the EU than in other parts of the world. The 2015 Scoreboard includes 837 firms from the US and 933 from Asia[5]. The US Scoreboard firms are on average much smaller in employment (14 973 employees) than their European counterparts (23.793) and with much smaller sales (5 724 mio compared to 6 458 mio), but they have on average a larger R&D budget (320 mio compared to 193 mio for EU28). This is partly due to the selection bias in favour of European firms in the Scoreboard. However, this also correlates with a different sectoral composition, with more US Scoreboard firms in ICT (cf infra). To reduce this bias, we will use for the comparison between EU28, USA and Asia, the same number of firms, which is the 800 largest Scoreboard firms in each region. Figures 1 and 2 compare some key concentration statistics for the EU28, USA and Asia.

Figure 1: **Concentration of R&D by Scoreboard Firm: by Region**

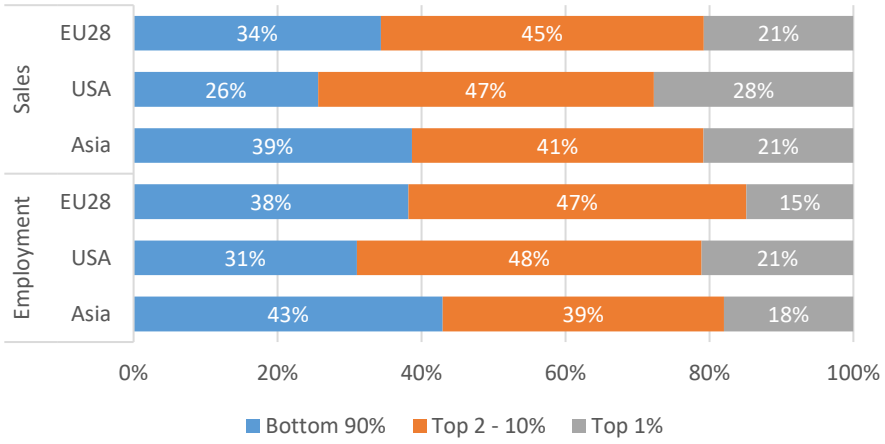


Source: Bruegel calculations on the basis of EC-JRC-IPTS R&D scoreboard data (2015)

The concentration of the US Scoreboard landscape looks similarly concentrated as the EU28 landscape in a few R&D spending firms: the top 10% accounts for 72% of all US Scoreboard R&D expenditures, a number slightly smaller than for the EU28 (74%); and the top 1% of firms for 26%, equal to that for the EU28.

[5] 356 Japan, 327 China, 111 Taiwan, 74 South Korea), representing 82.3% and 59.3% of total BERD respectively.

Figure 2: **Concentration of Employment and Sales by Scoreboard Firms: by Region**



Source: Bruegel calculations on the basis of EC-JRC-IPTS R&D scoreboard data (2015)

In contrast to the R&D distribution, the distribution of Scoreboard sales and employment is more concentrated in the US than in the EU, especially the sales distribution, as shown by the higher share which the US Top 10% decile can secure, but especially the US Top 1%.

5.3. R&D CONCENTRATION BY SECTOR

In 2015, there are 852 Scoreboard firms active in ICT, accounting for 37% of all Scoreboard R&D. ICT services represents 12% of all Scoreboard R&D. Pharma & Biotech has 369 Scoreboard firms, accounting for 19% of all Scoreboard R&D. Vehicles&Parts is the third biggest sector accounting for 15.5% [6].

R&D expenditures in **Pharma & Biotech** are highly concentrated. This holds most notably for R&D expenditures, but also sales and employment are heavily concentrated in the top firms. The top decile of the R&D distribution represents 83% of total Scoreboard R&D spending in this sector; the largest 10 spenders represent 43% of all sector spending. The BIG 4 (Novartis, Roche, J&J, Pfizer) hold 22% of all sectoral R&D spending. The biggest, Novartis represents 6%. The R&D landscape in Pharma & Biotech, with its high economics of scale in R&D is therefore a very skewed one. R&D dominance is important in this sector, as the top 10% of R&D spenders, also secure a much higher share of sales and employment compared to other sectors.

[6] Other sectors are too small to look at individually, because there are not enough Scoreboard firms (eg Aerospace and Defense N=53; Chemicals (N=126). A scoreboard based analysis of these sectors would therefore give a too biased analysis of the sector, certainly with respect to sales and employment.

The digital sectors are often portrayed as being "winner take all". The distribution of R&D spending among **ICT** firms is indeed more concentrated than on average, but less than Pharma & Biotech. The Top 10% represent 70% of total sector spending. This concentration is high, but not higher than average, and certainly not when compared to Pharma/Biotech. The largest 10 spenders account for 32% of all R&D spending. The BIG 6 (Samsung, Intel, Alphabet, Microsoft, Huawei, Apple) account for 24%. The concentration of sales in the top 10% is however higher than average, although again less so than in Pharma/Biotech. What is also distinctive for this sector, is the higher concentration in a few "winners". This is most outspoken for ICT Services/Software. The share that the top 1% R&D spenders in ICT hold in sales is much higher than in other sectors, reflecting the importance of R&D power for market power, although again less outspoken than in Pharma/Bio. Their share in employment is much smaller compared with Pharma/Biotech, reflecting their leaner employment profile.

Table 6: **Inequality and Concentration in Selected Major Sectors**

		ALL	BIOPHARMA	ICT	ICT SERVICES	VEHICLES
TOP 1% R&D	Share R&D	27%	25%	31%	34%	20%
TOP 10%R&D	Share R&D	71%	83%	70%	71%	73%
	Share Empl	42%	64%	51%	37%	48%
	Share Sales	50%	75%	60%	51%	64%
TOP 10%SALES	Share Sales	66%	81%	73%	73%	67%
TOP 10%EMPL	Share Empl	61%	74%	69%	71%	50%

Source: Bruegel calculations on the basis of EC-JRC-IPTS R&D scoreboard data, latest version

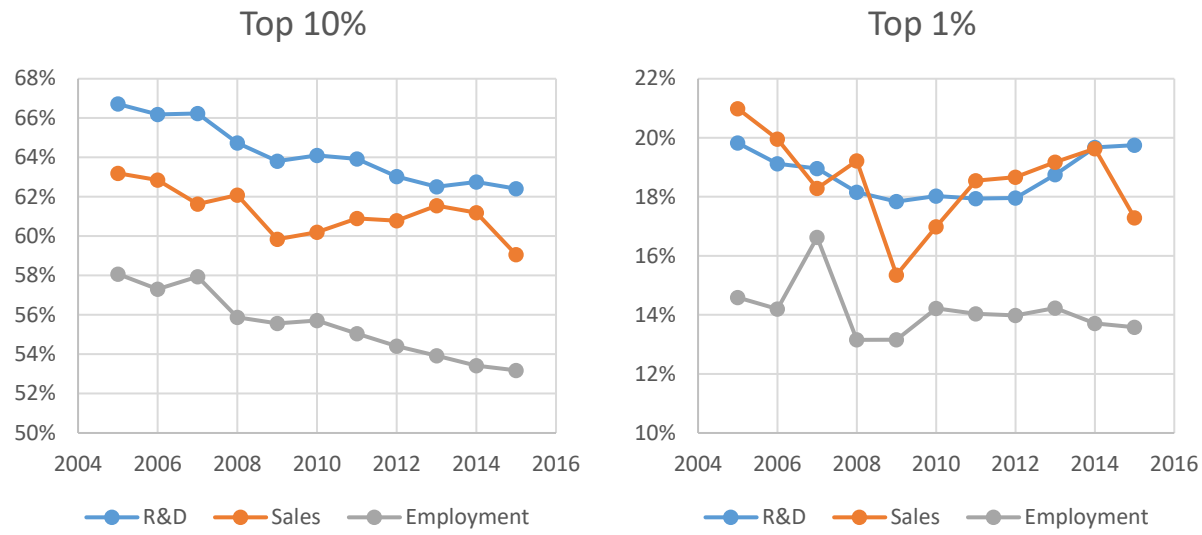
6. TRENDS IN R&D CONCENTRATION

Has the distribution of corporate R&D become more unequal over time? More concentrated in fewer superstar firms? The Scoreboard data allow a comparison over time from 2005 till 2015. As the number of firms included in the Scoreboard changed over time, we will work for this part of the analysis with the same number of firms for each year. In 2005 the Scoreboard included 1337 firms globally, which will serve as a cut-off for the trend analysis. In this time-comparable sample, we are slicing off smaller R&D firms. The concentration in the top decile is lower in the time comparable sample, but it is nevertheless still very substantial.

The concentration of R&D expenditures in the top decile of firms (Figure 3, left panel) has gone done over time, although only slowly, remaining at high levels. Also for employment the concentration in the top decile has declined over time. In contrast, the concentration of sales by Scoreboard firms in the top decile, while trending down before the crisis, has increased since, consistent with increasing sales concentration trends observed in the literature (cf supra).

While the share of the top 10% for R&D expenditures continued to go down, the share of the top 1% has started since 2012 to trend up slightly (Figure 3, right panel): while the top 1% represented 18% of total R&D spending in 2010, they held 20% in 2014-2015. The top percentile of Scoreboard firms in terms of sales increased its share from 17% in 2010 to 20% in 2014.

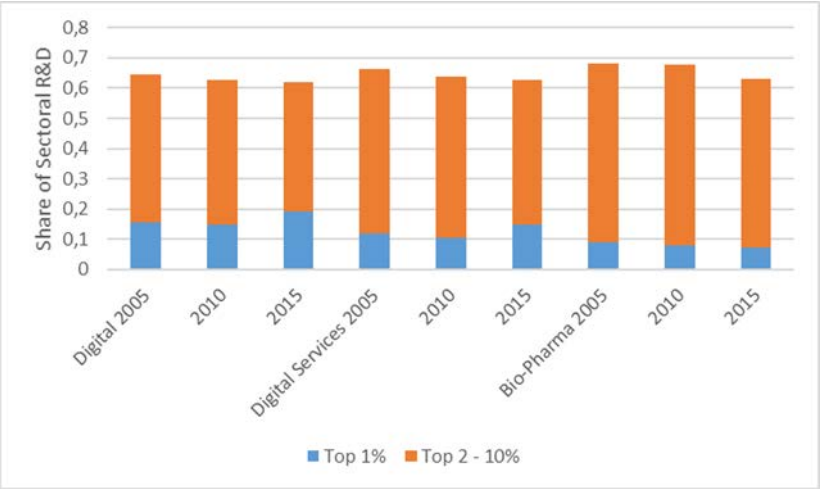
Figure 3: **Share of Scoreboard Employment, Sales and R&D Expenditure of the Top 1% and Top 10% of Firms: Trends over time**



Source: Bruegel calculations on the basis of EC-JRC-IPTS R&D scoreboard data, various years, time comparable sample

Figure 4 zooms in on the two major sectors in the Scoreboard: Bio-Pharma and ICT. For **Biotech & Pharma**, the time comparable sample contains 145 Scoreboard firms. For this set, the concentration, as measured by P10% (as well as P1%) has gone down slightly, more recently, but nevertheless remains at high levels. For **ICT**, the time comparable sample contains 466 Scoreboard firms. For this set, the concentration, as measured by top 10% share, remained fairly stable at a high level, going down slightly. However, the share of the Top 1% went up from 15% to 19%. This increasing share of R&D expenditures for the top 1% R&D spenders is realised without increasing shares in sales and employment. It does reflect an increasing focus of these companies on R&D. The recent increasing concentration in the top 1% in ICT is most outspoken in the **ICT services**, where the top 1% increased its share in R&D expenditures from 10% in 2010 to 15% in 2015.

Figure 4: **Trends in R&D Concentration: by Sector**



Source: Bruegel calculations on the basis of EC-JRC-IPTS R&D scoreboard data, various years, time comparable sample

7. PERSISTENCY IN R&D LEADERSHIP

An important issue to examine is whether the "superstar R&D firms" are incumbent R&D leaders or new R&D leading firms. In this section we look at which of the current R&D leading firms were already leading R&D firms before in their sector. Identifying the incumbency status of Top firms in the Scoreboard is a cumbersome exercise, requiring to trace the history of firms and their entry in the Scoreboard across time, from 2005 (or from their first entry in Scoreboard) to 2015.

Among the Scoreboard companies that can be traced over time, most of them are "old" (ie born before 1975). Only 19% were born after 1990. When looking for incumbency among leading R&D firms, 83 are persistent leaders (i.e. belonged to the top 10% in their sector almost the entire time from 2005 till 2015, ie 10 or 11 times). These are 6% of the annual sample of Scoreboard companies. Among the persistent leaders, the age distribution is ever more skewed towards "old age", as 88% of them were born before 1975, only 3% (or 5) of persistent leaders were born after 1990. Only 9 firms are "new leaders", ie companies entering the Scoreboard in the top 10% and stay among the group of leaders in all years until 2015 (one lapse allowed). Of these 9 firms, 5 were born after 1990.

This small group of persistent leaders (about 6%) nevertheless accounts for about half of total sample R&D expenditures in every year, supportive of a strong incumbency advantage for leading innovators. The incumbency advantage is much less outspoken for sales and employment in the Scoreboard sample, as both for sales and employment, the share which persistent leaders can secure never exceeds one third of the total sample. All this evidence is supportive of an important incumbency advantage for innovators, as suggested by Schumpeter Mark II.

The share of R&D expenditures of persistent leaders has not increased over time, even eroded somewhat, especially more recently: In 2015, "persistent leaders" managed to secure 47%, compared to 50% in 2005. It nevertheless remains substantial. Persistent leaders are losing their share mostly to the "new leaders". The 9 new leading firms managed to secure 4% of total Scoreboard R&D in 2015 All this suggests that there are important incumbent's innovative advantages, but that these nevertheless slowly dissipate, being displaced by new leading firms: ie although the overall concentration in few firms may not go down drastically over time, there is nevertheless some turbulence in who these few firms are, but this turbulence is albeit relatively modest: breaking into the top R&D positions is not easy.

The next table further illustrates the persistency in top innovation leadership: the top 10% R&D leaders from 2005, while holding 62% of overall R&D expenditures in 2005, were still able to hold 56% of R&D expenditures in 2010 and ten years later in 2015, 50%. The top 10% R&D leaders from 2015, while holding 59% of overall R&D expenditures in 2015, already held 56% of all R&D expenditures in 2010, 54% in 2005. Ie the top R&D leaders of 2015 where already very likely to be top R&D leaders before.

Table 7: **R&D Shares of Early Leaders and Recent Leaders over Time**

	Share in Scoreboard R&D		
	2005	**2010**	**2015**
TOP 10% in 2005	62%	56%	50%
TOP 10% in 2015	54%	56%	59%

Source: Bruegel calculations on the basis of EC-JRC-IPTS R&D scoreboard data, various years

A final perspective on the persistency in top R&D leadership is provided by transition probabilities. For top 10% R&D leaders in 2005, the probability that they will still be in the top decile the year after is 90%, ten years after in 2015 is 65%. Top 10% R&D leaders in 2010 have a 93% chance to be in the top decile the year after and 72% five years after in 2015.

We further zoom in on persistency in top R&D leadership by sector. The next table looks at the transition probabilities by sector. **Vehicles&Parts** is the sector with the highest persistency, as the leaders in 2005 are still leaders in 2015 with a probability of 89%. Also in **BioPharma**, the likelihood to be continue R&D leadership is high.

Somewhat in contrast to these two sectors, **ICT** displays a lower persistency: firms belonging to the Top10% in 2005 were likely to still be Top 10% in 2015 with a probability of 52%, those that were leaders in 2010, with a probability of 72% . For **ICT services**, these transition probabilities are even smaller, with leaders in 2005 have a probability of 31% to be still leaders in 2015, those with leadership in 2010 have a probability of 46% to be still leaders in 2015.

Table 8: **Persistency in R&D Leadership: By Sector**

	Probability to be TOP 10% in 2015				
	All Sectors	**ICT (All)**	**ICT Services**	**BioPharma**	**Vehicles&Parts**
TOP 10% in 2005	65%	52%	31%	86%	89%
TOP 10% in 2010	72%	72%	46%	79%	89%

	Share of sector R&D 2015				
	All sectors	**ICT**	**ICT Services**	**BioPharma**	**Vehicles&Parts**
Top 10% in 2015	**59%**	**62%**	**59%**	**63%**	**58%**
Top 10% in 2005	**50%**	**48%**	**29%**	**63%**	**56%**
Persistent Top 10%	**47% (6% of Cies)**	**43% (5% of Cies)**	**48% (4% of Cies)**	**54% (7% of Cies)**	**54% (8% of Cies)**

Source: Bruegel calculations on the basis of EC-JRC-IPTS R&D scoreboard data, time-comparable sample (N=1337 for all; N=466 for ICT, 137 for ICT services, 145 for BioPharma, 99 for Vehicles&Parts)

In the **ICT** sector, 5% of sample firms are persistent leaders (25) (These include Samsung, Intel, Alphabet, Microsoft, Cisco, Oracle, Qualcomm, Siemens, IBM). In general, ICT has a younger age structure, with "only" 40% of its Scoreboard companies born before 1975. It has 28% born after 1990. Although the 40% "old" companies in this sector still commanded 62% of total R&D in 2005, while the 28% youngest "only" 9%, the share of "old" companies has been eroding, representing only 40% of total R&D in 2015. Especially the youngest cohort has made serious inroads, representing 19% of total sector R&D in 2015. The biggest young persistent leader is Alphabet, who started in 1998, and is in 3th position in 2015 (2nd position in 2018). Next to Alphabet, Microsoft, Cisco, Oracle and Qualcomm as young persistent leaders, there are also new leaders in 2015: Huawei in 5th position, Apple in 6th, Facebook in 12th position. None of these young new leaders are EU.

Persistency in leading positions in ICT is shown by the share that the 2005 top 10% leaders can still command in 2015: 48%. Compared to the 64% share they held in 2005, this is still considerable, but nevertheless significantly less. This 48% they can still command in 2015 is also only 77% of the share held by the Top10% of 2015.

Persistency in leading positions is much less outspoken in **ICT services**: leaders in 2005 were able to command only 29% of sector R&D in 2015, which is only half of share of the Top 10% for 2015. There are also only 6 persistent R&D leaders in this sector (4% of companies) (Alphabet, Microsoft, Oracle, IBM, SAP, Fujitsu). Nevertheless, even though there are few persistent R&D leaders, they command 48% of sector R&D, and represents 81% of the share of the Leaders in 2015.

In **Bio/Pharma**, the high concentration of R&D expenditures is characterised by a very strong incumbency effect. Bio/Pharma has 11 persistent leaders (Novartis, Roche, J&J, Pfizer, Merck, BristalMyersSquibb, Sanofi, AstraZeneca, Bayer, GSK, EliLilly), all of which are "old". Although most of the firms in this sector are "young" (52% is born after 1975), most of them entering in the wave of the biotech revolution in the sector (30% born after 1990), young firms only represented 15% of sector R&D in 2005 (youngest firms 3%). In 2015 the position of "old" firms has eroded somewhat, with young firms holding about one quarter

of Scoreboard R&D, with the "youngest" firms, born after 1990, holding 6%. Although a wave of new firms entered in the Scoreboard, they failed to establish themselves at the top of the R&D distribution. In the 2015 ranking, the first 10 places are for the persistent leaders. A few young (biotech) firms made it close to this group of 10: Abbvie is the first non-persistent leader in 11th position[7]; Amgen, born in 1983, holds the 13th position in 2015 (12th in 2005), Celgene, born in 1986 in 14th position (52th in 2005) and Gilead Sciences, born in 1987, holding the 16th position in 2015 (40th in 2005). All of these companies are US.

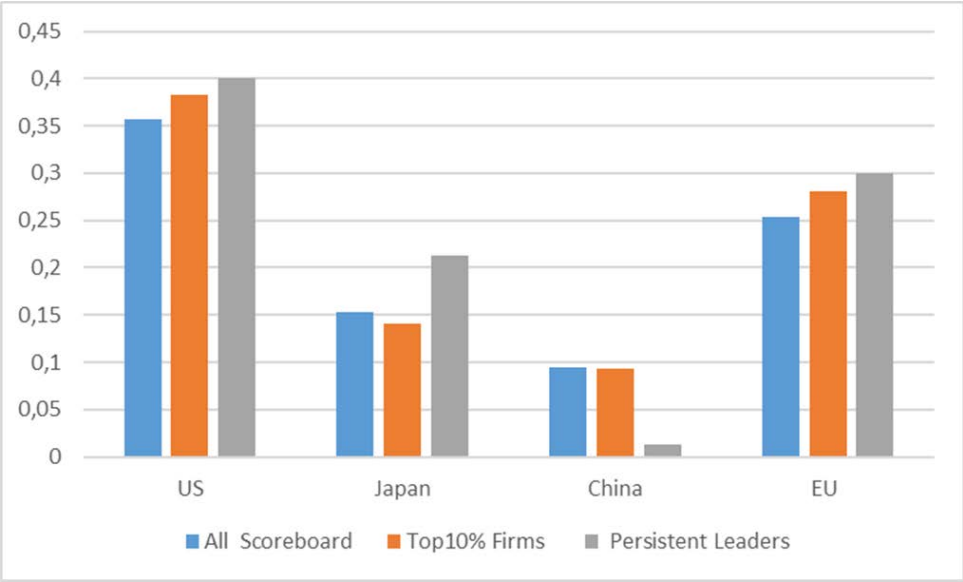
In **Vehicles&Parts,** there are only 99 firms in the time comparable sample. Nevertheless, some specific characteristics can be noted for this sector. Although its concentration in top spenders is less outspoken than in Pharma and ICT, it is nevertheless still substantial and furthermore persistent over time. In addition, the incumbency effect is substantial and stable over time. The sector has 8 persistent leaders (VW, Toyota, GM, Daimler, Ford, Honda, Bosch & BMW). These 8 persistent leaders manage to account for half of sector R&D and this for every year in the sample. Furthermore, all of these persistent leaders are old in a sector that has in general few new firms in the scoreboard. Old firms represent more than 90% of the sector R&D. There are however some signs of change. Tesla Motors has entered the Scoreboard since 2003, it is still not among the Top 10% of R&D spenders, but it is an undisputable disrupter of the dominant ICE (Internal Combustion Engine) model in the sector. It is fast increasing in R&D, claiming in 2015 to a 32nd position in the sector, and in the latest edition, 2018 to 22nd position.

8. EU'S POSITION AT THE CORPORATE R&D FRONTIER

Figure 5 shows the shares that the various countries/regions hold at the corporate R&D frontier, ie of the Top10% Scoreboard firms and among the persistent R&D leaders in the Scoreboard, and all this compared to the share in overall Scoreboard Firms. It shows that the US not only dominates in terms of number of Scoreboard firms, it dominates even more so among Top10% Scoreboard firm, and even more so among Persistent R&D leaders, where it held 40% of these slots in 2015. Europe is also stronger in Top 10% and Persistent Leaders than in general in the Scoreboard, but nevertheless, it only comes in second place after the US, holding only 30% of the Persistent Leaders slots in the Scoreboard in 2015. Japan is the country with the highest "specialisation" in persistent leaders compared to its overall share. China, being the new kid on the block, not surprisingly does not hold many persistent leaders slots. But nevertheless, its share of firms in the Top 10% is similar to its overall share in Scoreboard firms, indicating that China on average is able to take up new positions in the Scoreboard, not only in the bottom part of the distribution, but equally so in the top part of the distribution, among the R&D leaders.

[7] Abbvie operates since 2013 as a split off from Abbott Lab. Although Abbvie could be considered a "young" firm, Abbott Lab was established in 1888.

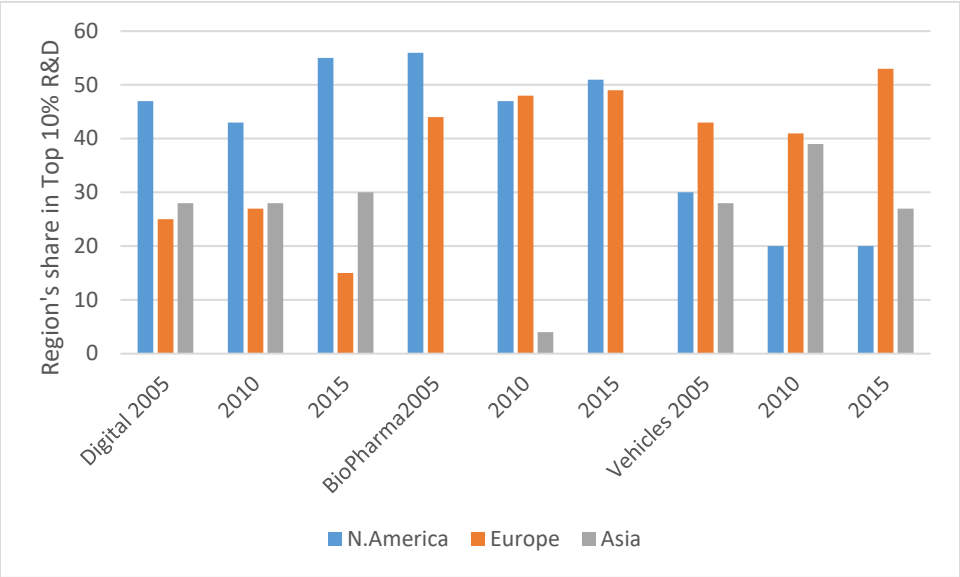
Figure 5: **Regions' share in R&D leaders (2015)**



Source: Bruegel calculations on the basis of EC-JRC-IPTS R&D scoreboard data, 2015

Figure 6 looks at how the share of Europe at the top R&D distribution has changed over time in the three most important sectors: ICT, BioPharma and Vehicles&Parts. In the ICT sectors, the new and young R&D leaders all come from the US and China and have been able to displace some of the incumbents, as noted supra. Consequently, European firms have lost out substantially at the top in digital sectors, having been displaced by US and Asian (primarily Chinese) new leading firms. This is different in BioPharma. In this sector, the top 10 percent of R&D spenders continue to be US and European firms. Even though most of the new leading firms are from the US, they have not made significant inroads into the Top10 percent and the regional balance has therefore not changed much; it has perhaps even evolved to be more favourable to European firms. In Vehicles&Parts, EU's stronghold for corporate R&D, its position at the frontier of corporate R&D in this sector seems secure, even increased over time. Yet, the future may be quite challenging in this sector. The electric mobility value chain disruption and how well our European persistent R&D leaders are able to deal with this will be of critical importance for the EU (eg Fredrikson et al (2018). Volkswagen's recent drop in the Scoreboard from 1st to 3th position in the 2018 Scoreboard ranking, being surpassed by Samsung and Alphabet, is hopefully not the sign of a secular decline.

Figure 6: **Share of country/region in top 10 percent R&D spending, by sector**



Source: Bruegel on the basis of EC-JRC-IPTS R&D scoreboard data. Note: numbers are calculated from the time-comparable subsample, which has 202 biopharma firms, 466 digital firms and 99 vehicles firms.

9. CORPORATE R&D CONCENTRATION BEYOND R&D: PATENTS

Like R&D expenditures, also innovative output in the form of patents are highly concentrated. In 2014, the top 10% of Scoreboard R&D investors accounted for 61% of IP5 patent families (inventions patented in the five top IP offices) . The top 1% of corporate R&D investors accounted for 15% of IP5 patents families (OECD 2017).

Corporate R&D investors from the Scoreboard in the "Computers and electronics" industry are, by far, the most reliant on intellectual property (IP) rights and account for about one-third of total patent filings by all Scoreboard R&D investors (Samsung being the biggest). They account for the ownership of about 75% of all global ICT-related patents (OECD 2017).

The development of AI-related technologies, as measured by inventions patented in the five top IP offices (IP5), increased by 6% per year on average between 2010 and 2015, twice the average annual growth rate observed for patents in every domain. The development of AI technologies is concentrated. Top 2000 corporate R&D investors own 75% of the IP5 patent families related to artificial intelligence (AI). Of these, R&D corporations based in Japan, Korea, China & Chinese Taipei (resp 37%, 18%, and 20%) account for about 70% of all AI-related inventions belonging to the world's 2000 top corporate R&D investors and their affiliates, US-based companies for 18%, the EU28 for about 12%. Within the EU28, German firms

hold the most, with 3% of all AI-related inventions. Although the EU28 is not out of the race, it is clear it is not in the driver' seat in this technology, deemed to be pivotal for the next digital waves.

10. SUMMARY OF MAIN FINDINGS

As recent research has shown a trend of increasing concentration of corporate sales and employment in few "superstars", a trend which seems to be at least partly (digital) technology-driven, it is important to look at the corporate R&D landscape and its concentration in "superstars". R&D races in the digital age are expected to become "winner take most", in view of high economies of scale, scope and network economies. This would predict an increasingly concentrated corporate R&D landscape. At the same time, technology leaderships of incumbents can be quickly overturned by radically new technology avenues. This will disrupt the incumbent leaders, creating room for new winners. Even if the R&D landscape may still be concentrated, competition for the top places may be fierce with new tenants challenging incumbent positions.

In this contribution, we examined the concentration of the R&D landscape and trends therein. We use the 2005 till 2015 editions of the EC-JRC Scoreboard of largest R&D spenders worldwide, which allows to analyse for each year the R&D expenditures, sales and employment of max 2500 Scoreboard firms worldwide.

Our main findings can be summarised as follows:

- R&D expenditures by Scoreboard firms are concentrated in few "winning" firms. R&D is more concentrated than Sales and Employment.

- The Scoreboard data do not signal increasing concentration in R&D over time; on the contrary, the trend is one of slow decline. Nevertheless, this downward trend still leaves high levels of concentration and furthermore seems to have stopped since 2011.

- The Scoreboard data show a strong incumbency advantage: Those few "winning" firms that have been able to be a Top 10% leading R&D firms throughout the period covered, represent more than half of the corporate R&D worldwide. Incumbency is also demonstrated by the high share which leaders in 2005 can still command in 2015 and vice versa.

- The EU is relatively well represented as the home base for persistent R&D leaders, particularly in BioPharma and especially in Vehicles & Parts.

Digital sectors are expected to be particularly characterised by winner-take-all features. Our findings for the digital sector can be summarised as follows:

- The distribution of R&D spending among **digital** Scoreboard firms is highly concentrated, but less than in other high-tech sectors: BioPharma and Vehicles&Part.

- The incumbency effect is smaller than in BioPharma; There is more turbulence at the top and more new, young "winners".

- We see no trend of increasing R&D concentration over time.

- But more recently, concentration of R&D spending in the Top 1% of R&D spenders has risen and turbulence at the top has cooled.

- As the new and young leading R&D firms in digital service sectors are all from US and Asia (particularly China), Europe has lost out in terms of top R&D shares and misses scale and incumbency advantage. This holds also for the new digital technology areas, most notably AI.

- These results are particularly worrisome in light of future technological developments. While the EU seems to have lost the race in digital services, currently dominated by US or Chinese tech companies (i.e. the likes of Amazon, Google or Ali Baba), the question is whether the EU will be able to take up leading positions in the new races to come. These are going to be centred on the integration of new technological breakthroughs, most notably advanced digital services/ artificial intelligence (AI), into manufacturing and services platforms. The evidence from AI patenting is not however not favourable for the EU.

11. CONCLUDING TAKE-AWAYS

As markets are predicted to become more winner-take-all, what implications does the rise in concentration and winner-take-all trends have for productivity growth? Would it lead to faster productivity growth overall, or only for those economies with "winners"? Or would it lead to slower productivity growth overall?

The impact of concentration and trends therein for the overall innovative and productivity growth performance of nations will depend on who these R&D superstars are, how they can obtain, maintain and expand their superstardom and how contestable these superstar-positions are.

In a world where the increasing concentration is driven by drastic technological change, such as the digital technology revolution, the "winners" will be the few new superstar firms with higher productivity. In a world of more incremental technological change, incumbents, riding on their stock of accumulated assets and experience, are the more likely "winners". In both scenarios, the industries becoming increasingly concentrated will tend to be more dynamic with higher productivity and technical change, be it that with drastic technology change, the "winners" will involve new leaders, while in case of more incremental technology change, the "winners" will be incumbent leaders.

But when the rising concentration arises from anti-competitive forces, dominant firms can increasingly prevent actual and potential new rivals from introducing new drastic innovations who might cannibalise their leading positions. Dominant firms may for instance lobby for regulatory barriers that complicate market entry for new firms, they may slow down the diffusion of new technologies to competing firms, or they may acquire new successful start-ups to shelve their disruptive innovations, cf "killer acquisitions"

(Cunningham et al (2018)). In contrast with the technology change story, in the anti-competitive explanation, the concentrating industries are likely to be dominated by "winners" that are not necessarily more productive or dynamic, but could even slow the process of potential technology growth.

A very important issue for the policy discussion is therefore to examine whether the superstar R&D firms are incumbent market leaders exploiting their market and technology power or incumbent R&D superstars exploiting their superior innovative capacities and experience, or new superstar firms introducing radically new innovations.

The evidence of declining concentration in R&D found in this analysis, can be interpreted as a positive sign, but its high incumbency characteristic, its slow downward pace and particularly its losing momentum more recently, requires further monitoring and analysis to understand its implications for overall corporate R&D and growth performance, especially in digital technologies and especially in new digital technologies (AI).

With the US, and more recently China, hosting most of the new R&D leaders, especially in digital sectors but also in other sectors, the weaker creative-destruction power of EU corporate R&D system generating less new superstar firms, as well as its missing scale and incumbency advantages in digital could contribute to a shifting regional R&D pattern to Europe's detriment in favor of the US and East Asia (China).

What would also this imply for policy making in the EU?

For **innovation policy**, it is first of all important to recognise that overall corporate R&D performance depends on a handful of firms. Understanding the innovation advantages and barriers incumbent leaders might enjoy, which incentives and barriers new leading firms might face and which incentives and barriers following firms might enjoy will matter for assessing the trends in R&D and innovation performance, and beyond, how innovation powers growth. Further analysis is needed to further our understanding on this.

In any case, for innovation policy in the EU, it is important to keep technology markets and platforms open for new contesters, if we want to improve our performance in hosting new R&D leaders, especially in ICT sectors but also in other sectors, using new ICT technologies. This means that regulation and competition policy will become an increasingly important part of the innovation policy mix. For regulation, especially for digital regulation, the "innovation principle" should figure high with issues like compatibility and data portability high on the radar. But particularly competition policy will be an increasingly important component in the innovation policy mix to keep markets and technologies open and contestable; with all of its instruments: mergers, anti-trust and state-aid.

For **competition policy**, it is important to understand the impact of a highly concentrated R&D landscape and its trends therein. Innovation dynamics should be higher on the radar of competition policy authorities. Are they associated with leading R&D firms enjoying innovative advantages? How contestable are existing leading positions are? Do leading firms use their dominant R&D positions to raise entry barriers against more efficient new innovators? Do R&D leaders can turn their R&D weight into market power?

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