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Contents

Abstract

This is the 20th edition of 'The EU Industrial Research & Development (R&D) Investment Scoreboard'. The European Commission issued the first edition of the Scoreboard in 2004 to monitor and analyse industrial R&D investment trends in the context of the EU's 3% of GDP R&D investment policy target, which remains a key performance indicator of the EU's long-term competitiveness.

This report is structured in two parts. Part I provides an overview of the world's top 2 500 R&D investors, responsible for 80% of R&D performed by the business sector globally, based on the financial information in the firms' latest published audited accounts. It analyses the main trends and benchmarks the EU's top R&D investing companies against global competitors, and gives details on the EU's top 1 000 R&D investing firms. For the first time, a panel of Scoreboard firms allows insights into structural R&D trends over the past 10 and 20 years. This sheds light on the strategic role played by R&D through the global financial crisis and the COVID-19 pandemic.

Part II combines the Scoreboard data with other datasets to gain novel insights into the technological advancement of the companies. For example, as Scoreboard firms own two-thirds of the patents filed in the five largest patent offices. Characterising the patent portfolios of Scoreboard firms in automotive, advanced materials and artificial intelligence provides additional insights into the technological positioning of EU firms.

Foreword by Iliana Ivanova, European Commissioner for Innovation, Research, Culture, Education and Youth

This year marks the 20th edition of the European Industrial R&D Investment Scoreboard. It is heartening to witness Europe's industry demonstrating remarkable capacity, with research and development (R&D) investments reaching over EUR 219 billion in 2022 – a growth rate double that of the previous year!

Why does this matter? Europe's prosperity, sustainability and resilience rely heavily on a vibrant and innovative industrial landscape. Our industries are not just developing and producing competitive products and services for Europe and the world, they are also setting the pace for the global green and digital transitions.

In the European Union (EU), the diversity of companies reflected in our Scoreboard spans a broader range of sectors than those in the United States and China. EU companies hold their ground among global competitors, with the automobile sector continuing its reign as a leader in R&D investments worldwide. Dynamic Small and Medium-Sized Enterprises (SMEs) make up 18% of the EU's top 1000 R&D investors, showing high growth potential. A key takeaway from the analysis of 20 years of data is that R&D investments are confirmed as strategic and as supporting industrial resilience and recovery.

EU companies are also at the forefront of embracing sustainability, particularly in clean tech development and ESG (Environmental, Social and Governance) criteria. This commitment places the EU in a strong position for sustainability and accelerating climate action.

The high R&D intensity of the information and communication technologies (ICT) and health industries, paired with high annual growth rates, has made the ICT producer and services sectors a game changer in the global tech race over the past two decades. However, these industries, with fewer large players in the EU compared to the United States (for ICT and health) and China (for ICT), continue to present challenges for the EU in trying to match the United States in global R&D investments while keeping pace with China's recent advancements.

Industrial investment is complemented by EU funding offering investment incentives and risk-sharing through programmes such as Horizon Europe (including the European Innovation Council), regional and cohesion programmes, the Recovery and Resilience facility as well as InvestEU and the Innovation Fund. At the policy level, the Net Zero Industry Act, the Critical Raw Materials Act, and the European Chips Act aim at mobilising investments to reduce dependencies and strengthen the EU's position in dynamic global value chains. The EU Industrial Strategy, the New European Innovation Agenda (including regional innovation valleys), and the European Economic Security Strategy further promote innovation, boost resilience and address global challenges in collaboration with our international partners.

But more can be done. In 2021, the EU would have needed to invest an additional EUR 106 billion to reach the 3% target of investments in R&D, more than the budget of the current seven-year EU research and innovation programme Horizon Europe. The gap in investments in R&D between the EU and its main competitors is mostly due to a gap in private R&D investments. Europe's industry needs to continue to invest in R&D, developing breakthrough technologies for a resilient future and supporting European Green Deal growth strategy.

This Scoreboard report provides a wealth of data and indicators on industrial investments in R&D. I am confident it will provide valuable insights for policymakers, managers, economists, journalists and other interested parties to enrich their knowledge, inform decision-making and nudge future investments.

Acknowledgements

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The GLORIA project 2022-2024 is coordinated by Evgeni Evgeniev (Policy Officer, DG RTD.E1 'Industrial Research, Innovation and Investment Agendas') and Alexander Tübke (Team leader, JRC.B6 'Industrial Strategy, Skills & Technology Transfer') under the leadership of Doris Schröcker and Dominik Sobczak (respectively, Head and Deputy Head of Unit E1 'Industrial Research, Innovation & Investment Agendas', Directorate E, DG RTD) and Asunción Fernández-Carretero and Fernando Hervás (respectively, Head and Deputy Head of Unit B6 'Industrial Strategy, Skills & Technology Transfer').

This edition of the Scoreboard was produced by Elisabeth Nindl, Hugo Confraria, Francesco Rentocchini, Lorenzo Napolitano, Aliki Georgakaki, Ela Ince, Péter Fako, Héctor Hernández Guevara, James Gavigan, and Alexander Tübke (JRC.B6 'Industrial Strategy, Skills & Technology Transfer', JRC.C7 'Knowledge for the Energy Union') as the main authors. Pablo Pinero-Mira, José Manuel Rueda-Cantuche and Santacruz Banacloche-Sánchez (JRC.B7 'Innovation Policies and Economic Impact') drafted Chapter 7 on automotive global value chains, Giuditta de Prato and Elisa Calza (JRC.T1 'Digital Economy') Chapter 9 on the Artificial Intelligence ecosystem. Doris Schröcker, Dominik Sobczak, Evgeni Evgeniev, Constantin Belu, Alex Talacchi, and Florence Roger (all from DG RTD.E1 'Industrial Research, Innovation and Investment Agendas') provided substantial comments, inputs and suggestions for improvement on earlier drafts of the report and offered strategic advice related to the structure and policy orientation of the report.

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Executive summary

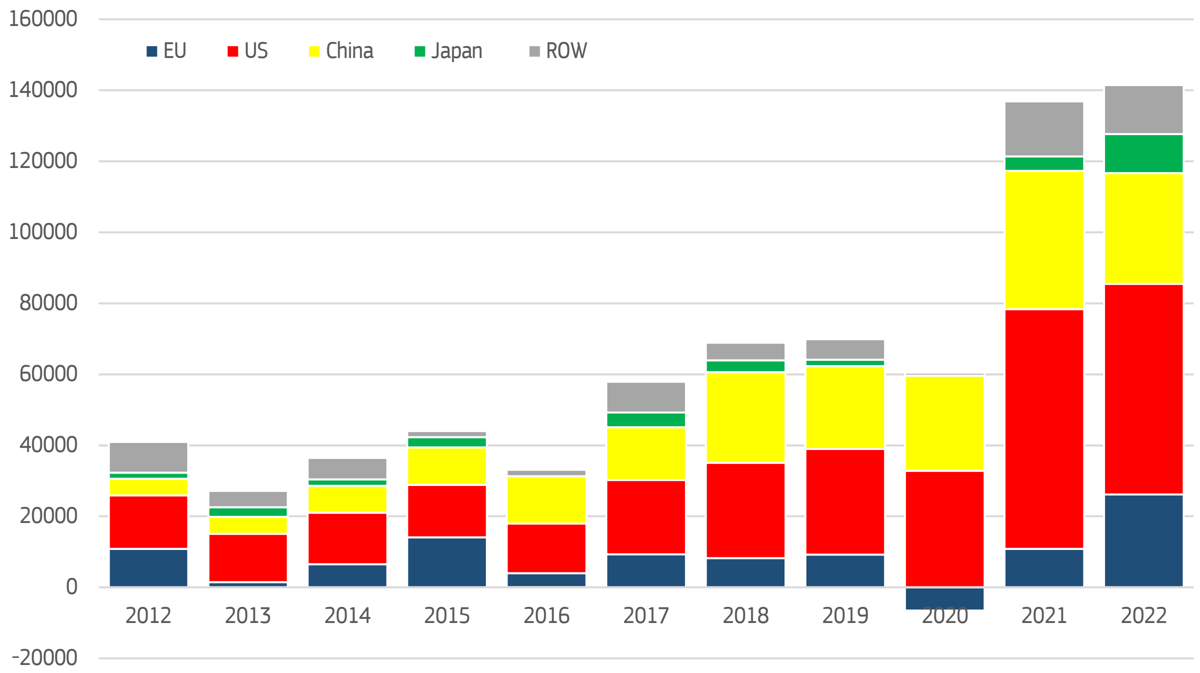
This is the 20th edition of the EU Industrial R&D Investment Scoreboard, which the European Commission has published annually since 2004. The objective of the Scoreboard is to benchmark R&D investment of EU companies against their global competitors and understand global industrial R&D dynamics in order to inform EU policies. The Scoreboard monitors the most recent R&D investment data and financial information based on the latest published audited accounts of the top 2 500 R&D investors worldwide and of the top 1 000 EU R&D investors[1]. This edition also looks at the developments over the past 10 and 20 years.

Global outlook of R&D investment in 2022 and dynamics over the past 10 years

The Scoreboard reports a **record high world R&D investment in 2022** at EUR 1 249.7 billion (EUR 141 billion more than in 2021)[2]. Alphabet from the US tops the ranking with EUR 37 billion, the top EU company is again Volkswagen – the only EU company in the top 10 ranked 6th with EUR 18.9 billion of R&D investments. The threshold for entering this year's Scoreboard at rank 2 500 is EUR 53 million (in 2012, it was EUR 22.6 million).

The R&D nominal investment growth rate in 2022 by the 367 EU Scoreboard companies in the top 2 500 **doubled** (13.6%) compared to 2021, surpassing that of the 827 US Scoreboard companies (12.7%) for the first time since 2015, but remaining lower than that of the 679 Chinese Scoreboard companies (16.5%)[3].

Figure 1 Break-down of annual R&D investment growth of top 2 500 companies across regions



Note: The vertical axis displays the change in absolute R&D investment by the 2500 companies each year (in million euros).
Source: The 2023 EU Industrial R&D Investment Scoreboard, European Commission, JRC/DG R&I.

The top 50 Scoreboard companies (23 US, 10 EU, 5 Chinese, and 5 Japanese) invested EUR 488 billion in 2022, which accounts for 39.1% of total R&D investment, whereas the top 10 account for 17.7% of the total. This shows a **very high concentration of R&D investment in a relatively small number of companies**, which has persisted over the past two decades.

Ten years earlier, the Scoreboard companies invested EUR 538.8 billion and Volkswagen became the first EU company to top the ranking with EUR 9.5 billion invested in R&D. Overall, over the past 10 years, R&D

1 Following open data practices, the underlying Scoreboard database is made publicly available on-line: https://iri.jrc.ec.europa.eu/data

2 The top 2 500 Scoreboard companies have their headquarters in 42 countries and more than one million subsidiaries worldwide (of which 365 000 classified as corporate subsidiaries) in over 200 countries and territories (74 % located in 20 countries).

3 EU Scoreboard firms' real investment growth is also higher than US when inflation is taken into account.

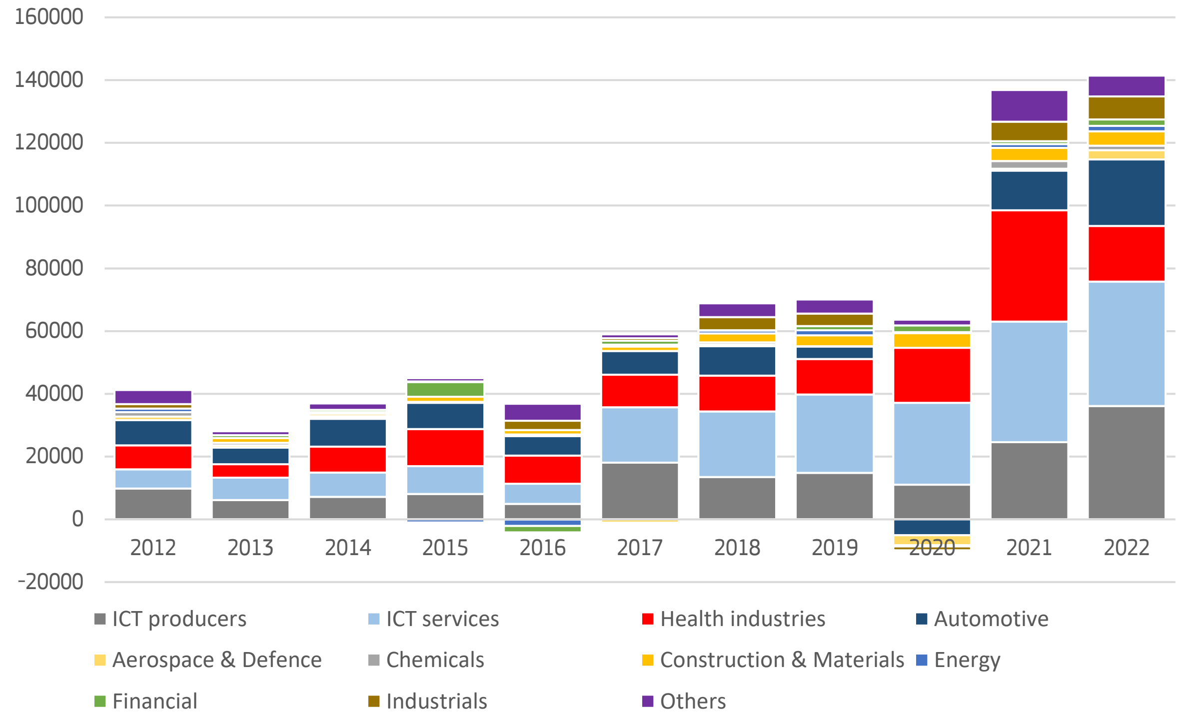
investments by EU Scoreboard companies have been growing at a slower pace than the R&D investments of US and Chinese Scoreboard companies.

R&D investment by sectors

Throughout the past two decades, four sectors **- ICT producers, ICT services, health and automotive –** have been responsible for more than three quarters of Scoreboard R&D investment. The **EU has maintained a lead position in automotive R&D investment as well as in more traditional sectors**, while the US has invested heavily in ICT-related sectors and health. China had a substantial number of newcomers with fast growing R&D investments in the ICT and health sectors, reaching the second rank in the Scoreboard in terms of number of companies and – slightly ahead of the EU – in total R&D investment. Differences in industrial structure between the EU and elsewhere coupled with intersectoral differences in R&D investment contributed to decreasing the number of EU companies in the Scoreboard ranking. Health industries (12.9%), ICT services (10.9%) and ICT producers (7.4%) have higher R&D intensities in 2022 than automotive (4.8%), chemicals (2.2%), industrials (2.3%), energy (0.4%), where EU's R&D investment position is better than US and China.

While EU R&D investment over the past ten years reveals a **high diversity across many sectors**, the **ICT-related sectors have been the main game changer** as far as the sectoral composition of the Scoreboard is concerned. US and Chinese Scoreboard company investment has been substantial and surpassed that of EU. Some of the top Scoreboard companies in ICT services have increased R&D by more than 30%, annually. Median R&D growth has been even higher in younger ICT services companies that entered the Scoreboard more recently, showing dynamism in the sector and the rapid propagation of the digital transformation.

Figure 2 Annual nominal increase in R&D investment by sector in EUR million



Source: The 2023 EU Industrial R&D Investment Scoreboard. European Commission, JRC/DG R&I.

EU top 1 000 companies

The headquarters of the top 1 000 EU companies investing in R&D are located in 17 Member States and the R&D investment of the 1 000th company in this year's Scoreboard is about EUR 3.1 million. Half of the companies, accounting for 73% of the R&D investments are in Germany, France and the Netherlands. Brexit (January 2020) caused a reshuffle in the EU 1 000 sample - the exclusion of UK R&D companies from the EU list led mostly to additional companies from Germany, Sweden, and France joining the ranking. The number of companies from EU Members in Central Europe (Czechia, Hungary, Poland or Slovenia) remained stable. The majority of the EU 1 000 companies are from sectors different to the four top R&D sectors, showing the diversity of EU based R&D investing companies.

The largest contributor to **EU R&D investment is the automotive sector** with a share of 32 %, followed by the health industry and ICT-related sectors, together comprising 76% of EU R&D investment in 2022. The industrials sector represents 6.5%, while the energy sector has a 2.7 % share of overall EU R&D investment.

Of the 1 000 EU companies, 180 are small and medium sized enterprises (SMEs) with less than 250 employees. This is more than in the pre-Brexit times for the EU28 at that time. UK traditionally had the largest number of SMEs in the sample – in the years between 2012 and 2019, the UK accounted for on average 45% of the SMEs in the sample. There is large concentration also of SMEs in the top 1 000 EU sample as 31.7% come from Sweden, followed by France (23.3%) and Germany (13.3%). Czechia, Greece, Hungary, Malta, Portugal and Slovenia do not have any SME in the EU 1 000. Overall, during the period 2012-2019, the Scoreboard analysis reveals that UK companies have been growing at a slower pace compared to non-UK EU 1000 companies – R&D investments increased on average by 3.8% per year for UK companies, compared to 5.5% for non-UK companies.

Corporate R&D investment trends over 20 years and resilience amid crises

An analysis of the effects of economic crises on Scoreboard companies over two decades shows that **R&D investments by top companies were more resilient during crises compared to capital expenditure**. This resilience reveals that R&D is part of the corporate strategic toolkit and is crucial for maintaining global competitiveness. Also, R&D investment by top Scoreboard companies appears to be correlated with increasing sales and productivity growth, and also with environmental sustainability measures. In terms of regional differences, it has to be noted that capital expenditure and R&D investment of US companies recovered more quickly after the financial and the COVID-19 crises, as did those of Chinese companies in the post-COVID-19 period, when compared to their European counterparts. This is in part explained by the fact that the **recovery was led by the ICT software, ICT hardware, and health sectors**, where the US and China fare better than the EU. The COVID-19 pandemic created an R&D push especially for ICT and health sectors, which were instrumental in providing solutions to the pandemic and deepening the digital transformation. In contrast, **automotive and other transport-related industries were hit harder by the two crises**, and recovered slower. Thus, the EU sector composition resulted in a delayed R&D investment recovery compared to the US and China.

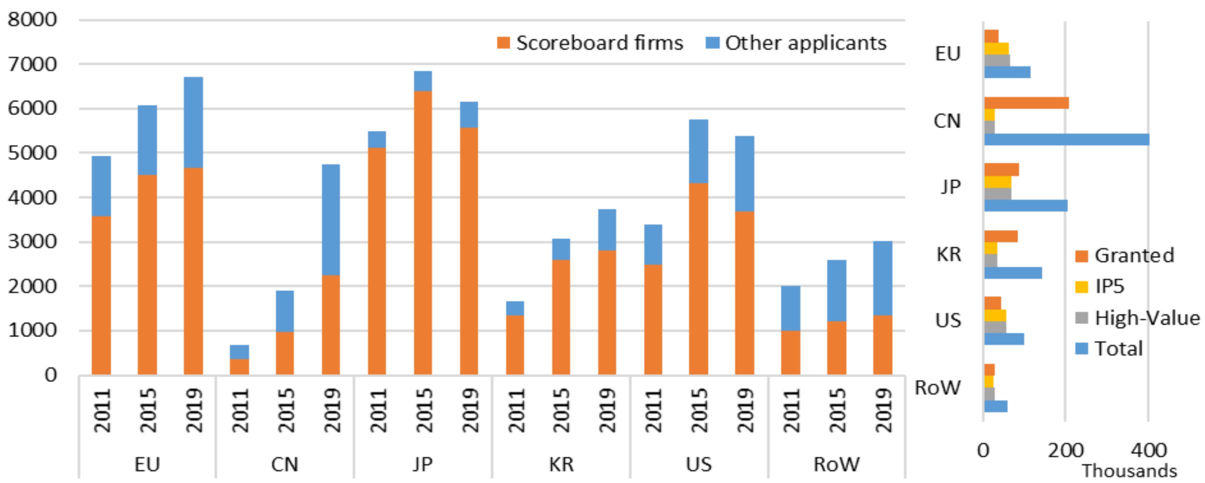
In the periods following the 2008 financial crisis and the 2019 COVID-19 pandemic, data from the Scoreboard suggests an emphasis on using R&D investment to help reduce overall carbon intensity. This is encouraging as it points to a synergistic relationship between R&D and the green transition. Also, Scoreboard companies improved across key social and governance indicators (job safety, gender bias, and corporate governance), showing how corporate strategies adapt to societal needs in response to the crises.

Although the EU still has several global tech companies, and remains relatively strong in the top 50, **the share of EU companies in the top 2 500 R&D investors has fallen over time**. Interestingly, when comparing a panel set of 801 companies over the period 2012-2022 with the Scoreboard top 2 500 dataset, shows that only 82 new EU companies entered the Scoreboard. In comparison, China has 657 new companies in the 2022 Scoreboard that are not in the panel, the US 634 new companies, Rest of the World (RoW) 276, and Japan only 52. This shows **EU is less well placed to host new companies capable of becoming global leaders in R&D investment.** The **emerging gap in R&D investment in the EU** vs US and China is a wake-up call to consider how EU can compete in the future in the context of interdependencies and the EU policy on open strategic autonomy, technological sovereignty and economic security.

Patenting trends in green and clean transport technologies

EU patent applicants continued in their leadership position in green patenting by filing the highest number of high-value inventions when considering all applicants (Scoreboard and non-Scoreboard companies). Japanese Scoreboard companies filed the highest number of high-value patents in climate change mitigation technologies (CCMTs), and China continued to have the highest absolute number of CCMT filings (including domestic applications). Chinese high value patenting, however, picked up in 2019, especially when considering non-Scoreboard companies, and it already surpassed the South Korea.

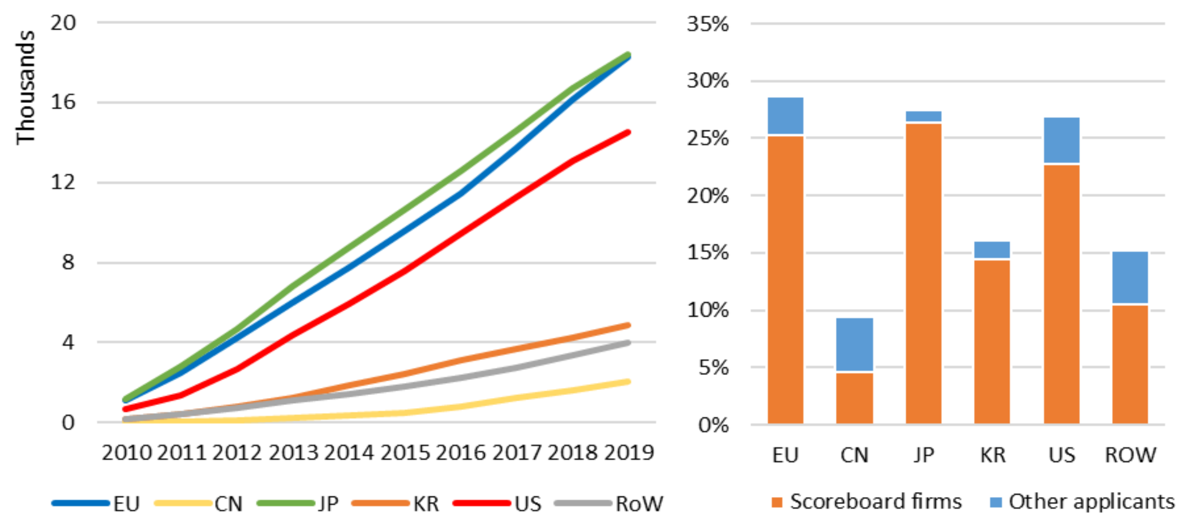
Figure 3 Trends in high-value green inventions. All applicants (Scoreboard companies and other applicants)



Source: The 2023 EU Industrial R&D Investment Scoreboard, European Commission, JRC/DG R&I.

Globally, patenting activity in **clean transport technologies (CTT)** accounted for about 23% of total green high-value inventions between 2010-2019. CTT inventions are actually concentrated in internal combustion engines (29%), electromobility (27%), aeronautics and air transport (15%) and hybrid vehicles (12%). The private sector is the main actor in patenting activity, while the public sector and universities are together responsible for only ca. 2% of global high-value CTT inventions. In fact, **EU** and **Japan** led in CTT inventions in the period 2010-2019. High-value CTT inventions for internal combustion engine improvement accounted for the largest category in the EU's CTT patent portfolio, aeronautics and air transport in the US, and electromobility in the major Asian economies.

Figure 4 High-value inventions in CTTs in major economies. All applicants.



Source: The 2023 EU Industrial R&D Investment Scoreboard, European Commission, JRC/DG R&I.

Patent portfolio distributions reveal the focus of China on the **electric vehicle industry** with the country giving the highest shares to all of the EV-related categories among major economies. Among the EU Member States, Germany had the highest number of high-value CTT inventions, followed by France and Sweden, both in absolute terms and as a share of overall high-value green inventions. Together, these three Member States held around the 87% of the EU inventions in CTTs.

Value added analysis for the automotive industry

In 2019, the total EU value added in the global final demand for motor vehicles amounted to EUR 511.2 billion. This is more than twice the sector's value added and represents 4.3% of the total EU value added for that year. Germany alone accounts for almost half of the EU value added (both total and indirect) in the global final demand. Other significant contributors included Spain, France, Italy, Sweden and Czechia, which accounted for 80% of the value added in the vehicle supply chain. Member States from Central Europe have increased substantially the relative importance of the motor vehicle value chain for their economies over the past two decades. For example, Germany, which is the largest R&D investor in the EU, has 5% of national gross value added in the motor vehicle value chain compared to Slovakia (10%), Czechia (9%), Hungary (6%), Slovakia and Romania (5% each).

Advanced materials

An additional patent analysis addresses trends in advanced materials (AM) over time and their relevance across geographical location and sector. AMs are one of the EU industrial policy's priority advanced tech areas. Between 2001 and 2019, the proportion of AM patents remained stable at around 7% of all patent families filed by Scoreboard companies at the five largest patent offices – the number of AM patents rose from 8 000 to nearly 14 000 (75% increase). Japanese Scoreboard companies are frontrunners in the number of AM patents with a share exceeding 40% of the total every year and growing in recent years; on the contrary, the EU and the US hold similar but declining shares. China is by far the region with the lowest number of AM patents, though its share has grown noticeably in the last decade. Within the EU, most AM patents come from German and French Scoreboard companies.

Artificial intelligence through an ecosystem perspective

In an ecosystems approach, which provides insight into domains, players and activities, the Artificial Intelligence (AI) Techno-Economic ecoSystem (TES) is described and the role of Scoreboard companies analysed. The US, China and the EU are the main geographic areas and together host about 70% of worldwide players and 76% of activities in AI. However, the EU is overall less specialised in AI than other advanced economies. China is the leader in terms of the absolute number of AI players (38% of all AI players), followed by the US (20%) and the EU (11%). Interestingly, the EU (11%) displays a higher share of research institutions engaging in AI activities than China (9.5%) and the US (4%). Patent activities are highly concentrated in China, with the US and South Korea following at a distance. The US host the largest number of companies involved in AI-related industrial activities (34%), followed by the EU (19%).

More synergies at EU and national levels for more efficiency gains

Regarding the EU's ambition to globally lead the digital and green transformations and stay competitive in the global tech race, the 20-year analysis in this 2023 EU Industrial R&D Investment Scoreboard provides key insights revealing vulnerabilities and opportunities. The weak global economic outlook has serious near-term socio-economic consequences and longer-term implications for welfare and competitiveness. In policy terms, overcoming these challenges means achieving Open Strategic Autonomy helped by the new European Economic Security Strategy adopted in June 2023. Such security is intertwined with the ability to make oneself resilient and reduce risks arising from heretofore benign economic linkages.

To increase global competitiveness and address the question of resilience, the EU has undertaken key policy initiatives in the past few months, such as the Green Deal Industrial Plan, launched in February 2023 that is focusing on net-zero industry and critical raw materials, to contribute to climate neutrality. In March 2023 a new Temporary Crisis and Transition Framework for State aid was adopted to offer Member States more flexibility for measures in support of the transition to climate neutrality. Member States have been recently amending their national recovery and resilience plans to include REPowerEU Chapters to address the twin transition. Furthermore, the EU Chips Act and the European Tech Champions Initiative respond to the global tech race, resulting from the Inflation Reduction Act of the US and the Made in China 2025 initiative. Yet, efforts for mobilising more public and private R&D investments need to continue at the EU and national levels, where policies need to be synergised for more efficiency gains.

Quick guide

This report is structured in two parts. Part I provides an overview of the world's top 2 500 R&D investors. It analyses the main trends of the EU's innovation-driven industries against global competitors, with additional detail on the 1 000 biggest R&D investors from the EU. For the first time, a panel of Scoreboard companies allows insights into structural trends of private R&D over the past 10 and 20 years. The strategic role of R&D in two major crises, financial and COVID-19, is addressed. Part II illustrates how the Scoreboard's financial indicators can be combined with other datasets to gain insights into the technological advancement of the companies. A global value chain analysis details on automotive value added in the EU in a multiregional input-output model. By characterising their patent portfolios in automotive, advanced materials and artificial intelligence, the report provides additional insight into the technological positioning of EU companies.

PART I

1 Introduction

A central tenet of EU policy initiatives is the importance of monitoring and analysing the state of overall innovation activity in Europe. The 3% of GDP R&D investment target and industrial research and innovation as one of the key drivers remain central to the EU's long term competitiveness agenda[4]. There is a new generation of industrial policies, which have given rise to initiatives at the EU and national levels, calling for new approaches in public policymaking. Hence, EU and national research and innovation policies need to further align to contribute to the EU green and digital transition in Europe's key industrial ecosystems. All this comes in a context of accelerated global tech race the world has experienced in the past two decades and increased global uncertainties.

The 2023 EU Industrial R&D Investment Scoreboard provides economic and financial information based on the most recent audited balance sheets of the world's top 2 500 R&D investors, which are responsible for about 80% of R&D performed by the business sector. It benchmarks EU against US, China, Japan and the rest of the world through 2022 data and follows industrial R&D dynamics over the past 20 years. The Scoreboard offers also a special focus on data and analysis of the top 1 000 EU-based R&D investing companies. The Scoreboard therefore is a source of data and insight to governments, businesses and academia who aim at fostering public policies in research and innovation, while endorsing the sustainability agenda. In line with the open data practice, the Scoreboard dataset is made publicly available to foster its use by the scientific community and other interested parties[5].

1.1 Setting the Scene: the global context

Recent increases in geopolitical tensions, hostile economic actions and the COVID-19 pandemic have exposed industrial and technological vulnerabilities in the EU, primarily linked to global value chains and other external dependencies. These weigh heavily on EU industrial competitiveness and its resilience to crises, notably in the context of high inflation, skills shortages, demographic change, rising interest rates, energy and other inputs prices.

At the time of writing this report, the global economy proved more resilient than expected in the first half of 2023, but the OECD growth outlook per September 2023 remains weak[6]. With monetary policy becoming increasingly visible and a weaker-than-expected recovery in China, global GDP growth is projected to be lower in 2024 than in 2023 (2.7% vs. 3.0%, respectively). The latest projections of the World Economic Outlook in October 2023 are similar. It means that the global GDP growth is well below the historical average. Furthermore, the report mentions few risks which could further exacerbate the economic outlook for the years ahead. First, the real estate crisis in China could deepen further, impacting the global economy. Second, commodity prices could become more volatile under renewed geopolitical tensions and disruptions linked to climate change (since June 2023, oil prices have increased by about 25%). Third, both, underlying and headline inflation have decreased, but they remain uncomfortably high. Fourth, fiscal buffers have eroded in many countries, with elevated debt levels, rising funding costs, slowing growth, and an increasing mismatch between the growing demands on the state and available fiscal resources. Finally, despite the tightening of monetary policy, financial conditions have eased in many countries[7]. The danger is of a sharp repricing of risk, especially for emerging markets, that would appreciate further the US dollar, trigger capital outflows, and increase borrowing costs and debt distress.

The Commission's very recent Autumn Forecast[8] per November 2023 revises GDP growth in the EU economy down to 0.6% in both the EU and the euro area. This is 0.2 percentage points lower than projected in the summer and an even larger downward revision compared to the Spring Forecast, by 0.4 percentage points. Going forward, growth is expected to rebound mildly as consumption recovers with rising real wages, investment remains supportive and external demand picks up. In the euro area, GDP growth is forecast to be slightly lower, at 1.2% in 2024 and 1.6% in 2025. Inflation is estimated to have reached a two-year low in

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[4] Long-term competitiveness of the EU: Looking beyond 2030, COM(2023) 168 final.
[5] See, https://iri.jrc.ec.europa.eu/data
[6] See https://www.oecd.org/economic-outlook/september-2023/
[7] See, October 2023 Global Financial Stability Report, https://imf.org/en
[8] See https://economy-finance.ec.europa.eu/economic-forecast-and-surveys/economic-forecasts/autumn-2023-economic-forecast-modest-recovery-ahead-after-challenging-year_en

the euro area in October and is projected to continue declining over the forecast horizon. In the EU, headline inflation is set to decrease from 6.5% in 2023 to 3.5% in 2024 and 2.4% in 2025. The loss of growth momentum so far this year has been underpinned by the lack of a solid growth driver, with weakness especially in consumption but also on the external side. Private consumption broadly stagnated on aggregate, as nominal wage growth continued to lag behind inflation. The volume of retail sales was still declining on a year-on-year basis up to summer, notably in automotive fuels and food, where prices remain elevated. At the same time, spending on services held up, partly related to the further recovery in tourist arrivals to the EU. However, exports declined, and net trade contributed positively to growth only because the decline in imports outpaced that in exports. Investment - both public and private - also increased only marginally in the first half of the year, though its dynamics were very volatile across Member States. On the output side, gross value added in industry was held back by weak demand and high energy costs. Similarly, high input and financing costs, as well as labour shortages, dragged on construction activity, particularly in housing. With purchasing power constrained by inflation, business activity in contact-intensive services stagnated, following its fast recovery last year. By contrast, IT and business services, which account for almost one fifth of EU gross value added, enjoyed continued expansion.

The weak global outlook and Europe's vulnerabilities have serious near-term socio-economic consequences and longer-term implications for welfare and the EU's goal to lead globally the digital and green transition. In policy terms, overcoming the above challenges means achieving Open Strategic Autonomy helped by the new European Economic Security Strategy adopted in June 2023. Such security is intertwined with the ability to make oneself resilient and reduce risks arising from heretofore benign economic linkages. Acknowledging that technological shifts are making economic and security challenges ever more complex, one of the key actions of the economic security strategy is to set up a Strategic Technologies for Europe Platform and eventually a Sovereignty Funds. Outside the EU, other advanced economies are already implementing dedicated strategies – e.g., the Chips and Science Act or the Inflation Reduction Act in the US, or the Made in China 2025 Policy in China. Developing economies are also acting, diversifying their economic ties to reduce harmful dependencies and increasing local production.

The EU can and should build its efforts going forward on its cumulated strengths and assets while not taking them for granted. The Single Market – currently emphasizing strategic sectors, cross-border investment, reduced external dependency and the twin transition – is based on openness, fair competition, a business-friendly environment and predictability for investors, and has delivered significant economic benefits over 30 years, including a GDP that is 9% higher than would have been the case without the Single Market[9]. Building on this, the economic security strategy calls for support to safeguard and strengthen value chains linked to deep and digital technologies, clean technologies and biotechnologies, as well as addressing relevant labour and skills shortages. Other recent EU initiatives to support industry:

- The Green Deal Industrial Plan[10], focusing on net-zero industry, critical raw materials and the transition to climate neutrality, provides four pillars (regulatory environment, access to finance, enhancing skills, and open trade for resilient supply chains) to support the scaling up of EU's clean-tech manufacturing capacity.
- The New European Innovation Agenda[11], seeks to position Europe at the forefront of deep tech innovation and startups and scale-ups, improving access to finance by, for example, mobilising untapped sources of private capital.
- A new Temporary Crisis and Transition Framework for State aid[12] adopted in March 2023, Member States have more flexibility for measures in support of the transition to climate neutrality.
- Member States are also currently amending their national recovery and resilience plans to include REPowerEU Chapters[13].
- EU Chips Act and the European Tech Champions Initiative (ETCI).
- The Materials Initiative 2030 Manifesto, which sets out a vision to develop a strong European Materials ecosystem driving the green and digital transitions as well as a sustainable and inclusive European society.

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9 COM(2023)162.
10 Communication on A Green Deal Industrial Plan for the Net-Zero Age, COM(2023) 62 final.
11 Communication on A New European Innovation Agenda, COM(2022) 332 final.
12 Communication on a Temporary Crisis and Transition Framework for State Aid measures (OJ C 101, 17.3.2023).
13 Regulation (EU) 2023/435 as regards REPowerEU (OJ L 63, 28.2.2023, p. 1).

2 Global outlook of R&D investment in 2022 and dynamics over the past 10 years

This section provides an overview of the development of the top 2 500 R&D investing companies worldwide. First, the regional overview of R&D investment in 2022 is presented (section 2.1), followed by the most important developments on the firm level (including their subsidiaries) in sections 2.2 and 2.3. Section 2.4 describes financial key performance indicators of the top R&D investors in 2022. Section 2.5 analyses the developments of the regional R&D distribution which takes into consideration differences in price levels across countries. Furthermore, a regional breakdown of R&D flows based on patent data provides additional information on the actual location of companies' R&D activities. In subsection 2.6, the development of R&D investment since 2012 is presented – this analysis takes account of the recent surge in inflation. The section also contains a specific contribution (2.7) on the role of the R&D content of global value chains in light of technological dependencies, and concludes with key points in 2.8.

2.1 2022 R&D investment across countries/regions

The top 2 500 global companies invested a total of EUR 1249.9 billion on R&D in 2022[14], EUR 141 billion more than in 2021 (+12.8%)[15];. Compared with 2021, the increase in total nominal R&D investment achieved by EU Scoreboard firms amounts to 13.6%, above the US (12.7%), but below China (16.4%). This is the first time since 2015 that EU R&D investment grew more than that of US companies. The minimum R&D investment to enter the Scoreboard for the international ranking this year – in other words, the amount invested in R&D by the company ranked 2 500th – is EUR 53 million, about 11% higher than last year (EUR 47.4 million).

Table 1. Countries: 2022 R&D investment and number of firms

EU countries	Companies in 2022	R&D (EUR bn)	Non-EU countries	Companies in 2022	R&D (EUR bn)
Germany	113 (114)	103.6	**US**	827 (821)	526.5
France	54 (57)	31.6	**China**	679 (678)	222.0
Netherlands	40 (38)	26.9	**Japan**	229 (233)	116.2
Sweden	29 (26)	13.3	**Switzerland**	52 (55)	37.3
Ireland	26 (24)	9.1	**South Korea**	47 (53)	37.0
Denmark	25 (25)	8.6	**UK**	95 (95)	35.8
Finland	13 (12)	5.8	**Taiwan**	77 (83)	26.2
Italy	19 (20)	6.8	**India**	22 (24)	4.7
Spain	12 (12)	5.1	**Canada**	29 (28)	7.45
Belgium	13 (12)	3.3	**Israel**	29 (21)	4.4
Austria	13 (13)	2.1	**Australia**	10 (10)	3.9
Luxembourg	4 (3)	1.8	**Singapore**	7 (7)	2.3
Poland	1 (0)	0.1	**Norway**	8 (8)	1.2
Portugal	2 (2)	0.2	**Türkiye**	5 (3)	0.7
Hungary	1 (1)	0.2	**Brazil**	5 (4)	0.6
Slovenia	1 (1)	0.1	**New Zealand**	3 (3)	0.4
Malta	1 (1)	0.1	**9 other countries**	9 (9)	2.9
Total EU	**367 (363)**	**219.2**	**Non-EU Total**	**2 133 (2139)**	**1 030.4**

Note: Figures in brackets show the number of companies in the 2022 edition of the Scoreboard.
Source: The 2023 EU Industrial R&D Investment Scoreboard, European Commission, JRC/DG R&I.

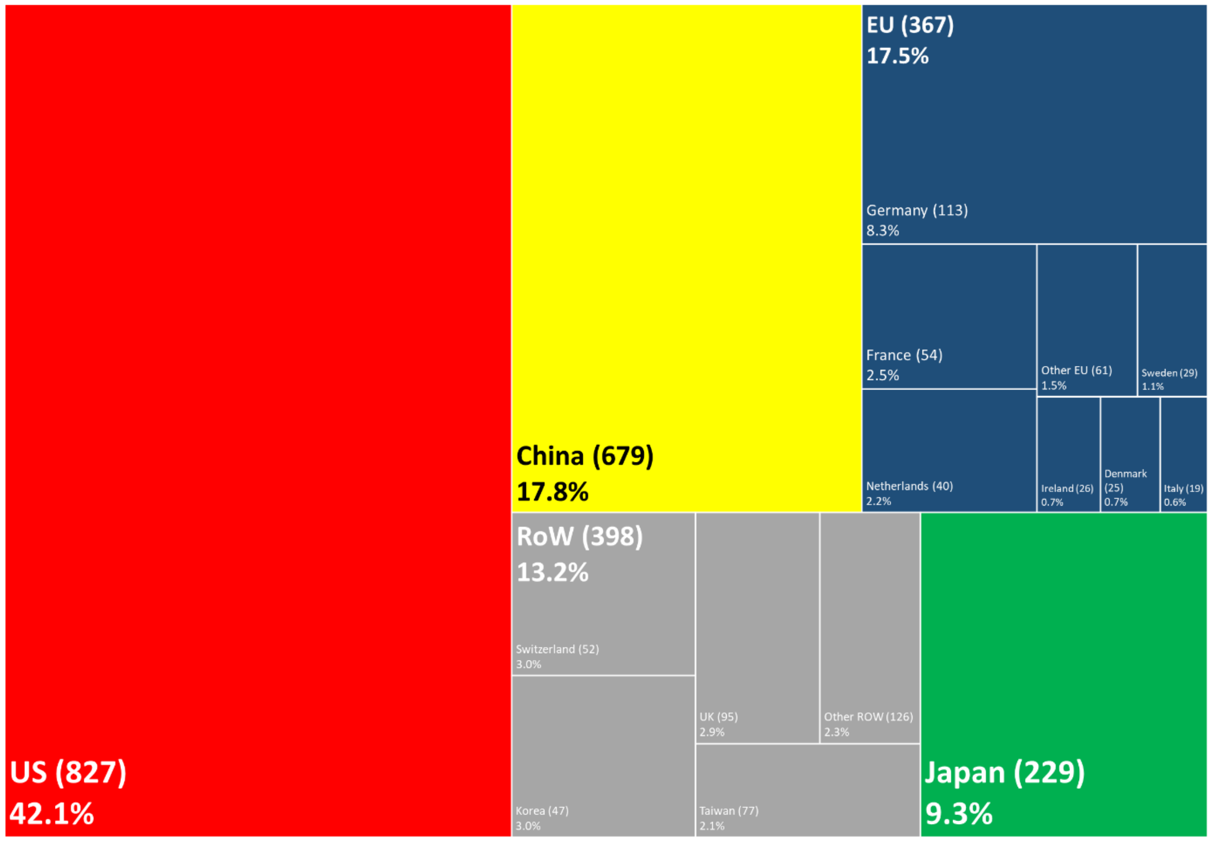
In terms of numbers of firms, most Scoreboard companies are headquartered in the US, followed by China and the EU. Compared with the previous year, the number of EU firms increased by 4 companies, the US

14 The Scoreboard is based on information from the companies' latest published accounts. For most companies, these correspond to the calendar year 2022. However a significant number of companies' financial years ended on 31 March 2023. This is the case for many Japanese and UK firms. Few companies have financial years that ended as late as the end of June 2023. A small number had accounts available only up to the end of 2021. Therefore, we refer to the data of the last available year as 2022/23 and to the previous year as 2021/22, etc. However, for most companies the last available year corresponds to the calendar years 2022. For reasons of clarity, we refer to the last year as 2022, the previous year as 2021, etc.

15 The Scoreboard expresses all monetary values at one common exchange rate – in this case the 2022 end-of-year exchange rates to euro. With this transformation, the 2021 R&D investment is EUR 1,108.4 billion and not EUR 1,093.9 billion as reported in the past Scoreboard and measured at 2021 exchange rates.

gained 6, China 1, while Japan lost 4 and Taiwan lost 7 firms. Figure 5 displays the number of firms per region/country and the corresponding share in total R&D investment in 2022.

Figure 5. Distribution of firms and R&D investment across regions, 2022



Note: Figures in brackets show the number of companies per region/country; the percentage share refers to the regions'/country's share in total Scoreboard R&D.

Source: The 2023 EU Industrial R&D Investment Scoreboard, European Commission, JRC/DG R&I.

2.2 Top R&D investors – firm level analysis

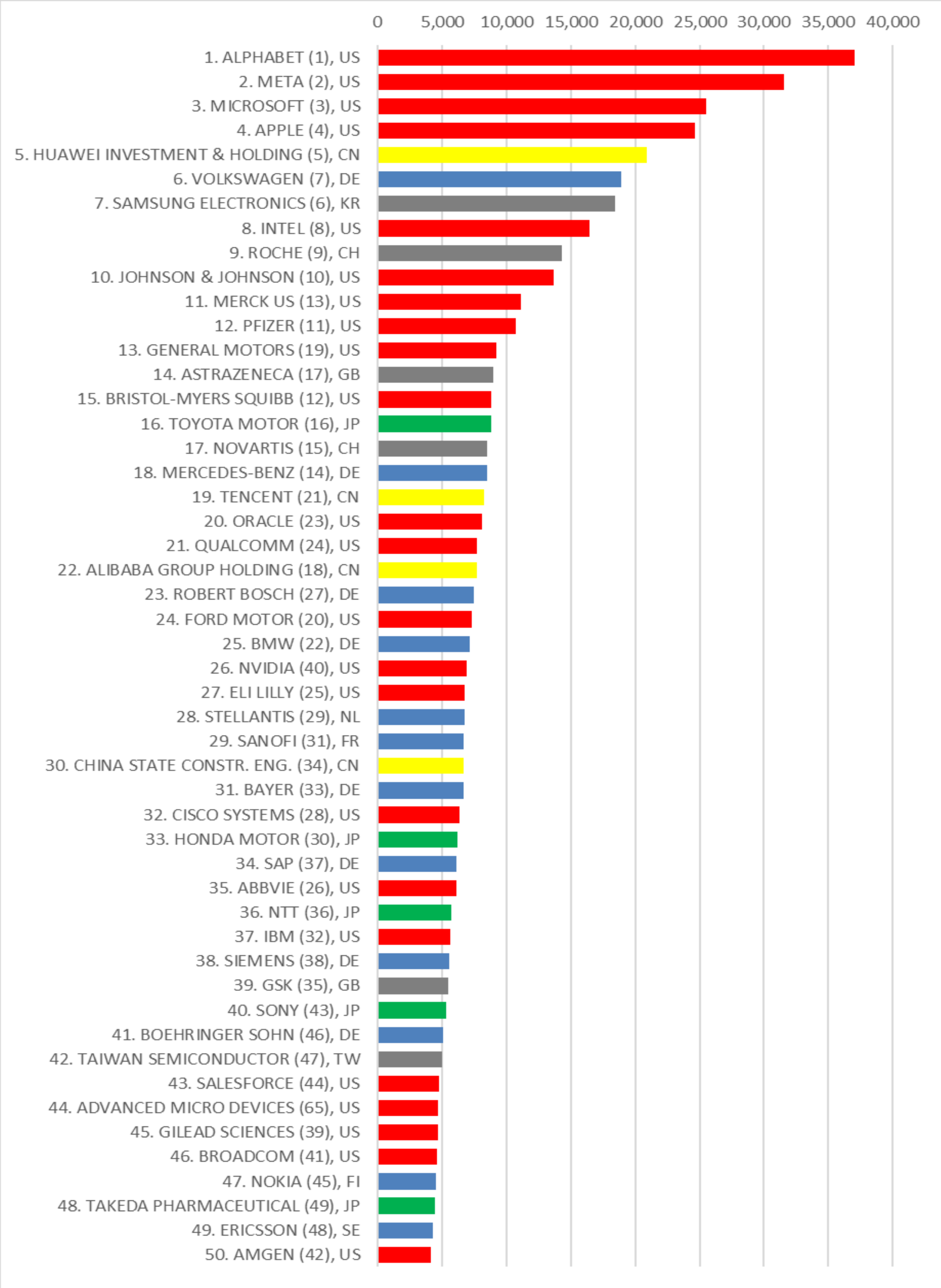
This section presents the changes in the number of companies and amount of R&D investment in 2022. It has a geographical and sectoral focus, and concentrates on the main R&D-investing world regions, namely the US, the EU, China and Japan, as well as on the main R&D-investing sectors, namely ICT producers, health, ICT services, and automotive. Is also describes the dynamics in the ranking by assessing the changes in the common set of companies in the 2022 and 2023 Scoreboard, as well as entries to and exits[16] from the ranking.

2.2.1 The top 50 companies

The top 50 companies invested EUR 488.6 bn in 2022, which accounts for 39.1% of total Scoreboard R&D investment (the top 10 companies for 17.7%); this share has not changed since last year. US companies continue to be the most numerous: 6 of the top 10 and 23 of the top 50 companies have their headquarters in the US. They are active mainly in the two ICT sectors (13 companies) and health (8 companies). They are followed by EU companies, however, mainly in lower positions, with Volkswagen being the only EU company in the top 10. Japanese and Chinese representation in the top 50 is lower with 5 and 4 companies, respectively. While Japan has no company in the top 10, China is represented by Huawei in the group of the 10 largest R&D investors in the world (Figure 6).

[16] An entry refers to a company that is present in the ranking in a certain year (e.g., 2023), but absent in the reference year (e.g., 2022). An exit means a company that is present in the reference year but no longer in the other year (e.g., 2023). At the Scoreboard level, the number of entries corresponds to the number of exits. However, at the quintiles level the two are not necessarily equal, as exiting means disappearing from the full list of 2 500 companies.

Figure 6. Top 50 R&D investors in the 2023 Scoreboard



Note: 2022 Scoreboard ranking in brackets, R&D in EUR billion (colours: US, China, EU, Japan, RoW)
Source: The 2023 EU Industrial R&D Investment Scoreboard, European Commission, JRC/DG R&I

The year-on-year growth of R&D investment was 16.9% in the top 10, and 13% in the top 50 (Table 2), outpacing net sales growth, thus somewhat increasing the R&D intensity to 12.7% for the top 10 and to 10.3% for the top 50.

Table 2. R&D and financial data of the top 10 and top 50 companies, 2022

	R&D	Net sales	Operating profit	Capex	R&D intensity
Top 10					
2023 Scoreboard	221 323	1 744 316	400 794	183 103	12.7%
2022 Scoreboard	189 405	1 649 281	432 937	151 638	11.5%
Growth	16.9%	5.8%	-7.4%	20.8%	
Top 50					
2023 Scoreboard	488 586	4 743 502	855 086	366 131	10.3%
2022 Scoreboard	432 196	4 315 386	842 302	316 225	10.0%
Growth	13.0%	9.9%	1.5%	15.8%	

Note: R&D, net sales, profit and capital expenditures (capex) in EUR million. R&D intensity is R&D investment divided by net sales
Source: The 2023 EU Industrial R&D Investment Scoreboard, European Commission, JRC/DG R&I

Top 50 companies significantly raised their R&D investments, with Meta, Nvidia, Advanced Micro Devices, and Taiwan Semiconductor showing the most impressive changes (Table A4 1 in Annex 4). The top 50 and mainly the top 10 (7 out of 10) are also the top contributors to R&D growth in the global top 2 500. Of the total worldwide Scoreboard R&D growth, 25% is coming from these companies (Table 3).

Table 3. Top 10 contributors to R&D growth, 2022

	2023 Rank	2022 R&D	2021 R&D	Difference	Growth	Region	ICB3 sector
Meta	2	31 520	23 116	8 404	36%	US	ICT services
Alphabet	1	37 034	29 591	7 442	25%	US	ICT services
Apple	4	24 612	20 546	4 066	20%	US	ICT producers
Volkswagen	6	18 908	15 583	3 325	21%	EU	Automotive
Microsoft	3	25 497	22 981	2 515	11%	US	ICT services
Intel	8	16 434	14 242	2 192	15%	US	ICT producers
Advanced Micro Devices	44	4 692	2 667	2 025	76%	US	ICT producers
Huawei Investment & Holding	5	20 925	18 915	2 010	11%	CN	ICT producers
Nvidia	26	6 881	4 939	1 942	39%	US	ICT producers
General Motors	13	9 188	7 407	1 781	24%	US	Automotive
Total		195 690	159 986	35 704	22%		
Total 2 500		1 248 734	1 107 833	141 900	13%		
Share in total		16%	14%	25%			

Note*:* R&D in EUR million.
Source: The 2023 EU Industrial R&D Investment Scoreboard, European Commission, JRC/DG R&I

The largest contributor to Scoreboard R&D growth was Meta, with its increase in R&D of EUR 8.4 billion (+36%). The huge increase in the company's R&D investment relates to its strong belief in the metaverse, which is seen as a 'new immersive version of the internet'[17], involving new technologies such as neural interfaces using electromyography, innovations in AI and new hardware.

The second-largest contributor was Alphabet with an increase of EUR 7.4 billion (+25%) in their R&D investment. According to their 10-K[18] report, 'R&D expenses increased USD 7.9 billion from 2021 to 2022 primarily driven by an increase in compensation expenses of USD 5.4 billion, largely resulting from a 21% increase in average headcount, and an increase in third-party service fees of USD 704 million'. Alphabet acquired several companies in 2022 for at least USD 7 billion dollars[19]. However, these companies are rather small in terms of employment, with the largest being Mandiant with 2 235 employees, other acquired companies had around 50-200 employees. Therefore, the increase of around 33 700 employees appears largely organic and it is likely that the R&D growth of Alphabet is mainly linked to new R&D developments.

Apple Inc comes third in the row of largest contributor to the Scoreboard R&D growth with its EUR 4 billion increase in R&D investment (20% up, y-o-y). According to its annual report (10-K), 'the year-over-year growth in R&D expense in 2022 was driven primarily by increases in headcount-related expenses and engineering

[17] https://www.fdiintelligence.com/content/feature/global-innovation-leaders-2022-edition-82527
[18] https://www.sec.gov/Archives/edgar/data/1652044/000165204423000016/goog-20221231.htm
[19] https://www.statista.com/statistics/192300/price-of-selected-acquisitions-by-google/

program costs.'[20] During 2022, Apple has made only a few acquisitions[21] of rather small companies (Mira Labs, Credit Kudos, and AI Music) each hiring between 11 and 50 employees, according to the data provider Crunchbase[22]. Therefore, M&A activity has played a minor role in the increase of Apple's R&D investment in 2022, but instead resulted most probably from the mobilisation of internal resources.

2.2.1 Top 50 entry and exit: geographical and sectoral developments

In the present Scoreboard, the list of top 50 companies has proven rather stable. Denso (automotive, Japan) is the only company that has left the group. It fell to 53rd position, due to a more moderate increase in R&D spending that was not enough to keep it in the top 50. In exchange, Advanced Micro Devices, a US-based ICT producer (semiconductors) has entered the top 50 at rank 44, after a 76% increase in its R&D investment to EUR 4.7 billion. According to their 2022 annual report (10-K) this huge increase has been driven by strategic investments across all of their business segments. It encompasses a strong increase in employment (from 15 500 in 2021[23] to 25 000 in 2022)[24] as a mix of organic growth and increase by acquisitions.

More details on the geographical and sectoral composition of the most notable developments are presented in Table 4 below and Table A4 2 in Annex 4. The disaggregation of the change in top 50 shares across countries and sectors results in the following main insights:

- Japan's R&D share in the automotive sector fell by 4 percentage points due to the exit of Denso;
- the 3 percentage points increase in the US share in the ICT producers' sector due to the entry of Advanced Micro Devices, among other things;
- a significant increase of EUR 15 billion in US ICT producers' R&D, equivalent to 25% year-on-year growth; almost one third of this was due to the entry of Advanced Micro Devices;
- a significant increase of EUR 20.3 billion in US ICT services' R&D, corresponding to 22% growth year-on-year; this growth comes almost entirely (97%) from the four companies Microsoft, Meta, Alphabet and Oracle;
- a EUR 1 billion reduction in US health sector R&D, resulting in a 3 percentage points smaller share; and
- a significant increase in EU health R&D of EUR 3 billion, resulting in 20% growth year-on-year.

Table 4. Top 50 – Regional shares and growth rates of R&D investment in the main sectors, 2022

	EU	US	China	Japan	ROW	Total
ICT producers	11% (12%)	55% (52%)	16% (17%)	0% (0%)	18% (19%)	100%
Health industries	15% (13%)	52% (55%)	0% (0%)	4% (3%)	30% (29%)	100%
ICT services	4 % (4%)	80% (79%)	11% (12%)	4% (4%)	0% (0%)	100%
Automotive	61% (58%)	21% (19%)	0% (0%)	19% (23%)	0% (0%)	100%
Growth y-o-y						
ICT producers	10%	25%	11%		14%	19%
Health industries	20%	-1%		20%	6%	4%
ICT services	19%	22%	11%	9%		20%
Automotive	12%	14%		-13%		22%
Total	14%	15%	13%	-1%	9%	

Note: Values are shares of R&D investment of the top 50 in 2022 (2021 in parenthesis). Summing up the regional figures might differ from the totals by 1% due to rounding.
Source: The 2023 EU Industrial R&D Investment Scoreboard, European Commission, JRC/DG R&I

The distribution of the 2 500 companies that were in both editions of the Scoreboard 2022 and 2023 across regions and main sectors in the ranking is displayed in Table 5. The table shows that 25% of the EU and Japanese Scoreboard companies are in the top 500, and the shares are 21% for the US, 19% for RoW and 13% for China. In absolute terms, the EU still has a small lead over China in the number of companies in the top 500 ranks of the Scoreboard.

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[20] https://s2.q4cdn.com/470004039/files/doc_financials/2022/q4/_10-K-2022-(As-Filed).pdf
[21] https://en.wikipedia.org/wiki/List_of_mergers_and_acquisitions_by_Apple#cite_note-178
[22] Accessed on the 10th of October, 2023
[23] Company's 10-K, 2021: https://ir.amd.com/sec-filings/filter/annual-filings/content/0000002488-22-000016/0000002488-22-000016.pdf
[24] Company's 10-K, 2022: https://ir.amd.com/sec-filings/content/0001193125-23-088137/0001193125-23-088137.pdf

Table 5. Number of companies per region and main sector in the ranking

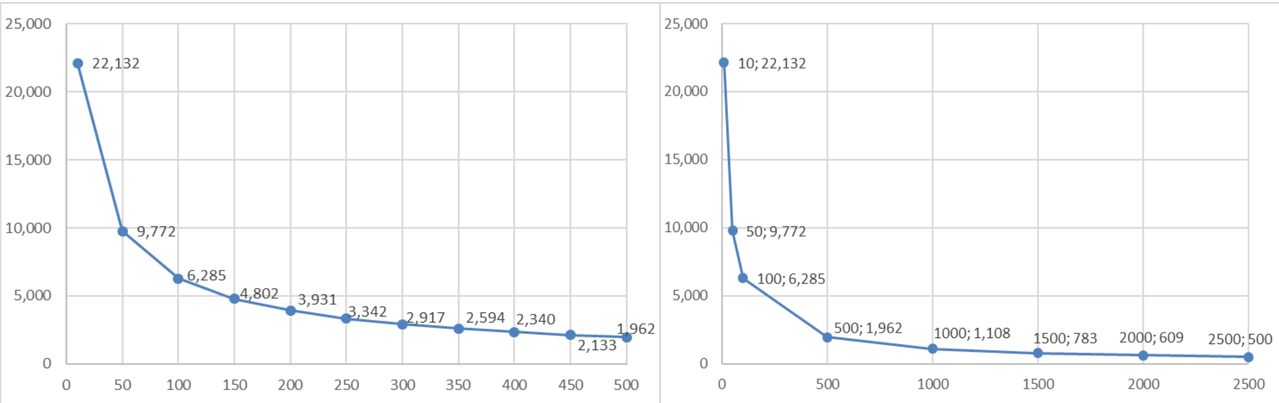
	EU		US		China		Japan		RoW	
Ranks 1-500	SB23	SB22	SB23	SB22	SB23	SB22	SB23	SB22	SB23	SB22
Automotive	18	18	12	11	15	16	14	14	7	7
Health industries	21	22	40	43	5	5	9	9	10	11
ICT producers	12	12	41	41	19	17	15	14	20	21
ICT services	10	10	48	46	14	14	4	4	9	8
Others	33	33	36	34	38	41	17	18	28	23
Total	**94**	**95**	**177**	**175**	**91**	**93**	**59**	**59**	**74**	**70**
Ranks 501-2 500	SB23	SB22	SB23	SB22	SB23	SB22	SB23	SB22	SB23	SB22
Automotive	16	16	23	24	32	31	12	12	18	18
Health industries	42	41	221	218	80	80	21	21	48	47
ICT producers	27	27	66	66	117	119	29	30	77	76
ICT services	17	17	129	131	60	60	2	2	24	25
Others	149	149	116	118	221	218	99	98	121	126
Total	**251**	**250**	**555**	**557**	**510**	**508**	**163**	**163**	**288**	**292**

Source: The 2023 EU Industrial R&D Investment Scoreboard. European Commission, JRC/DG R&I.

2.2.2 Concentration of R&D in the top 2 500

The development of R&D investment by the first k (k=1...2 500) Scoreboard companies shows that, on average, the top 10 companies in the ranking invest more than double the amount invested per firm in the top 50 (including the top 10), the top 50 invest 55% more than the top 100, and the top 100 invests 3.2 times more than the top 500. The differences between the investments of the first quintile (top 500) and the lower quintiles are significantly smaller (Figure 7, left panel). Between the investments of the top 100 and those of the top 150 or the top 200 companies the differences are significantly smaller than the differences between the investments pf top 100 and top 50 companies (Figure 7, right panel). This suggests that it is useful to focus the analysis on the following groups of companies: top 10, top 50, top 500 and the remaining 2 000 companies.

Figure 7. Average R&D investment per company and group



Note: Left panel – top 500 R&D investors; right panel – top 2 500. In the right panel, the number before the semicolon indicates the group, i.e. the top 10 in the ranking, the top 50, etc.

Source: The 2023 EU Industrial R&D Investment Scoreboard, European Commission, JRC/DG R&I.

The companies ranked in the top 10, 50, and 500 differ from the remaining companies also in terms of average time spent in the ranking, as well as company size measured by market capitalization (Table 6)[25]. In this respect there are two further sharp differences between companies in the top quintile and the lower ones.

— While the average time spent in the top quintile (Q1) varies in a narrow band of 9.5-10.2 years, the remaining 2 000 ranks are much more volatile, shown by the significantly shorter time that a

[25] We us the Investopedia definition for the size of the company measures by its market capitalisation. According to this, large-cap firms are companies with a market capitalisation value of more than USD 10 billion. Mid-caps have a market capitalisation of USD 2 billion to USD 10 billion, small-caps between USD 300 million and USD 2 billion. The last category considered are micro-caps with a market capitalisation value of less than USD 300 million. Unlike Investopedia, we did not categorise the companies into mega-caps (market capitalisation greater than USD 200 billion) and nano-caps (less than USD 50 million). See https://www.investopedia.com/terms/l/large-cap.asp

company manages to remain in the Scoreboard. Volatility increases towards the very bottom (Q5) of the ranking.

— The top 500 R&D investors are also the companies with the highest valuation. This quintile is dominated mainly by large companies, and to a smaller extent, by mid-cap companies. Mid-caps appear mainly after the 50th position. In the other four quintiles there is a gradual transition to lower value companies. Half of the bottom quintile is populated by small-cap firms, and about 100 companies are micro-cap companies. There are some large-cap companies present, too, mainly in less R&D-intensive sectors.

Table 6. Average time spent in a percentile and company valuation across groups

	Top 10	Top 50	Q1	Q2	Q3	Q4	Q5
Average time in a percentile, year*	9.9	10.2	9.5	6.4	4.8	4.1	3.5
Share of: large-caps**	93%	91%	60%	19%	9%	5%	4%
...mid-caps	0%	3%	28%	46%	34%	26%	18%
...small-caps	0%	0%	6%	25%	42%	46%	46%
...micro-caps	0%	0%	0%	1%	6%	13%	19%

Note: *12 years under scrutiny spanning between 2011 and 2022, ** large-cap: company valuation >=USD 10 billion, mid cap: USD 2 billion-10 billion, small-cap: USD 300 million-2 billion, micro-cap: USD 50 million-300 million (Source: Investopedia).

Source: The 2023 EU Industrial R&D Investment Scoreboard, European Commission, JRC/DG R&I

2.2.3 Firm dynamics: entry and exit

A total of 2 262 companies are present in both the 2023 Scoreboard and that of last year. They invested EUR 1 226.6 billion in R&D in 2022, a 13.2% increase compared with the previous year (EUR 1 083.6 billion). These companies' share in total Scoreboard R&D was around 98% in both years, showing that the general entry/exit dynamics did not have a significant impact on total R&D, despite the 9.5% turnover in companies (238). Out of this common set of companies of the two consecutive Scoreboards, in the top 500 (investing almost 80% of total Scoreboard) there were 495 companies in 2023 (i.e. 3 companies more than in the top 500 of 2022), and 1 767 companies in the bottom 2 000 (1 770 in Scoreboard 2022). Further to this, the remarkable stability of the common set is also found at the sectoral and regional level - the changes in the compositions are minor (Table A1 – Annex 4).

It is interesting to note position changes within quintile groups as well as between them. As expected, the lower the rank, the more changes there are – and the larger these changes. However, companies changing ranking positions typically pass from one quintile to a neighbouring one. The number of companies changing two quintiles is low and it takes place mainly between Q5 and Q3 with 15 companies improving their rankings and 7 worsening, and between Q2 and Q4 with 3 companies improving and 5 worsening. Finally, the tail (Q5) is the most volatile, with only a little more than half of the companies that were in this group in both the 2022 and the 2023 Scoreboards (Table 7).

Table 7. Internal and entry/exit dynamics in 2023 vs 2022

	Q1 2023	Q2 2023	Q3 2023	Q4 2023	Q5 2023	Total 2022	Exits
Q1 2022	466	26	0	0	0	492	8
Q2 2022	28	393	48	5	3	477	23
Q3 2022	1	66	343	58	7	475	25
Q4 2022	0	3	81	281	96	61	39
Q5 2022	0	0	15	105	237	357	143
Total 2023	495	488	487	449	343	2 262	
Entries	5	12	13	51	157		238

Note: Blue shade indicates that companies stayed in the same quintile, green a move up and red a move down between quintiles. Total 2023/2022 refers to the number of companies that have been in both editions of the Scoreboard.

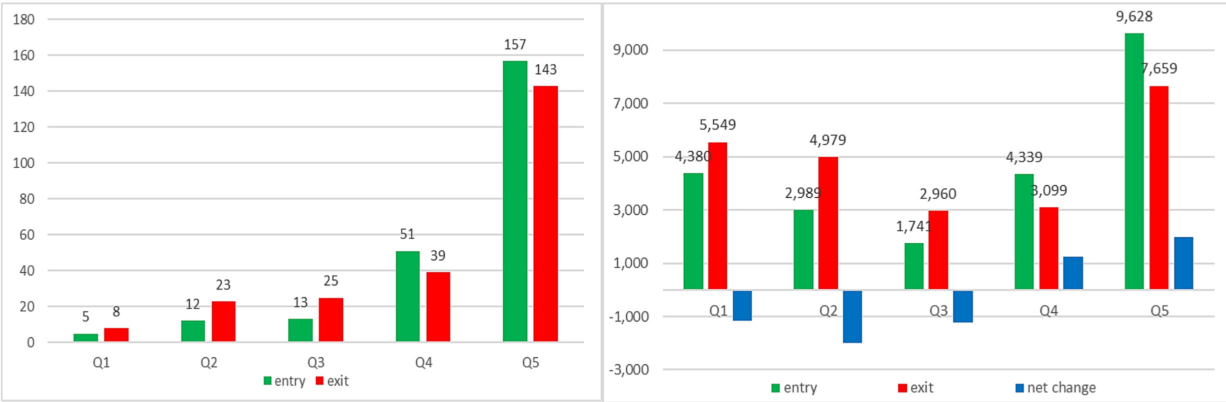
Source: The 2023 EU Industrial R&D Investment Scoreboard, European Commission, JRC/DG R&I

A total of 238 companies entered/exited the ranking between the 2022 and 2023 Scoreboards (Table 7 and Figure 8). As mentioned above, their R&D share in the total Scoreboard was very low, at around 2%. Similar to previous years' Scoreboards, the turnover in companies was the highest in Q5 and somewhat significant in Q4. In the top 3 quintiles, the entry and exit was negligible in terms of number of companies. Contrary to this, the 'new' R&D investments brought to the Scoreboard by the entrants, as well as the 'lost' R&D were disproportionately high in the first quintile (21% of total R&D by companies that entered/exited), given that these changes are related to larger R&D investors. Indeed, among the main entrants we find Daimler Truck (EU, automotive, R&D EUR 1.7 billion), GE Healthcare (US, health, R&D EUR 962 billion) and Mobileye (US, automotive, R&D EUR 740 million). The three main exiting companies are: Twitter (US, ICT services, R&D 2021

EUR 1.4 billion, ranked 142 in Scoreboard 2022), Cerner (US, ICT services, R&D 2021 EUR 777 million, ranked 262 in Scoreboard 2022), and Evergrande (CN, financials, R&D 2021 EUR 742 million ranked 252 in Scoreboard 2022).

Typical reasons for exiting the Scoreboard are M&A (which does not necessarily mean a de facto exit, e.g. above-mentioned Cerner has merged with Oracle Corp), too low R&D investment, and unpublished data until the cut-off date (e.g. Twitter, Evergrande[26]). While in the first two quintiles M&A and unpublished figures are equally important reasons, in Q3 M&A dominates. In Q4 and Q5, a low level of R&D investment explains the exits in about two thirds of the cases.

Figure 8. Number of entering/exiting companies and volume of R&D investment



Note: Left panel– Number of companies entering/exiting each quintile between the 2022 and the 2023 Scoreboard; right panel- amount of R&D gained/lost per quintile (vertical axis: R&D in EUR million).
Source: The 2023 EU Industrial R&D Investment Scoreboard, European Commission, JRC/DG R&I.

On geographical aspects of net new entries, the main recent development is a decrease in the number of US companies in the top three quintiles. The companies exited mainly from health industries (somewhat more than half of them) and to a lesser extent from the two ICT sectors. The turnover in Chinese companies is higher than that in companies from other regions, but mainly in Q4 and Q5, this year with a slightly positive net effect in Q4 (8 more companies) and a slightly negative one in Q5 (9 fewer companies). Other changes in the number of companies by regions throughout the 2023 Scoreboard were minor (Table A4 2 – Annex 4).

Individual rank changes

The volatility of rank changes is increasing towards the lower quintiles, suggesting that the lower the R&D investment, the greater the rank change induced by a certain change in R&D investment, and vice versa.

We analysed outliers in ranking position changes by quintiles, as well as by sectors and world region (Table 8). We used the interquartile range (IQR) rule[27] and the median absolute deviation (MAD) rule[28] to identify outliers. Based on the IQR rule, there are 280 companies in total that experienced an unusually large change – or in some cases an extreme change. – in rank. These companies can be found mainly in the fourth quintile (111 companies, 40% of the total), but their shares are relatively higher also in the third and fifth quintiles (almost 25% each). In the top 500, only 2 companies show unusually large changes (Ionis Pharmaceuticals, US, and Sinovac Biotech, CN). In the second quintile, there were 32.

The relative increase in R&D investment by companies in the positive outlier category was slightly higher than the decrease on the negative side: an increase in the range of 1.3x-3.5x their previous year's investment versus a decrease of 1.1x to 3.2x in the same period.

Table 8. Outliers in positive and negative rank change compared to Scoreboard 2022 by sector and region

	EU		**US**		**China**		**Japan**		**ROW**	
	+	**-**	**+**	**-**	**+**	**-**	**+**	**-**	**+**	**-**
Automotive	0	1	4	2	6	2	0	0	1	1

[26] Evergrande filed for protection from creditors with the US bankruptcy court in Manhattan, one month after announcing its huge losses for 2022. Evergrande's disappearance from the Scoreboard may be closely linked to this. Source: https://www.reuters.com/legal/china-evergrande-files-chapter-15-bankruptcy-us-court-filing-2023-08-17/

[27] https://study.com/academy/lesson/interquartile-range-definition-formula-example.html

[28] https://www.sciencedirect.com/science/article/pii/S0022103113000668

Health industries	1	6	36	30	10	6	1	1	5	1
ICT producers	0	0	7	1	16	7	0	1	5	4
ICT services	1	0	13	1	3	3	0	0	2	1
Others	10	7	10	6	22	22	0	4	9	11
Total	12	14	70	40	57	40	1	6	22	18

Note: outliers were identified using the IQR rule

Source: The 2023 EU Industrial R&D Investment Scoreboard, European Commission, JRC/DG R&I

On geographical and sectoral aspects, the below observations can be made.

- There are more outliers on the positive side (162 companies) than on the negative side (118).
- Companies experiencing extreme ranking position changes are mainly headquartered in the US and mainly operate in health industries. Companies in this category (i.e. US, health) that are improving ranking outnumber those worsening their positions.
- Chinese companies that can be considered outliers in their ranking position changes are mainly ICT producers, and to a smaller extent those operating in health industry. They tend to substantially improve their ranking. Similar to their US counterparts, they tend to be more on the positive rather than on the negative side.
- The number of EU and Japanese companies with large changes in their ranking position is small, almost negligible in the four key sectors, with health being the only sector where 6 EU companies have experienced a large ranking drop.
- In the RoW group, the number of outliers is relatively limited, both up- and downwards.

As a robustness check of the above-mentioned conclusions, we performed an outlier analysis applying the MAD rule. This rule proved to be slightly more ‘tolerant’ with larger changes, which resulted in a smaller sample (242 companies) compared with the one obtained by applying the IQR rule. In every other respect, the results are similar, confirming our results presented above.

We assess the most notable rank improvements and deteriorations on the level of individual companies. The lower the R&D, the higher the impact on the change in the ranking of even a moderate level of growth. Such position changes are more common at the tail (typically Q5, and to some extent also Q4) of the Scoreboard. As we have seen, even an extreme change in the ranking position of a company in Q5 brings it up only to Q3 and it took place in 15 cases only. These changes are not central for our analysis. Our focus is on Q1 and Q2 and is guided by the following two conditions: (i) more than twofold R&D investment change. This is the case of large R&D investors, typically in Q1; and (ii) the increase in R&D induced a significant change in the numbers of positions[29]. Company rankings corresponding to these two conditions above vary between drop of 1 474 places and jump of 656 positions.

Based on these criteria, the following three companies had the most notable **rank improvements**[30]:

- *Nio* is a Chinese automobile manufacturer specializing in designing and developing electric vehicles. It also develops battery-swapping stations for its vehicles as an alternative to actual charging stations. In 2021 it invested EUR 587.5 million in R&D (world rank 316). One year later, its investments increased by 2.4 times to EUR 1.4 billion (world rank 161 in the 2023 Scoreboard). This massive increase in R&D spending was due primarily to increased costs for R&D personnel and to a lesser extent to the incremental design and development costs for new products and technologies. The R&D investment is mainly driven by the number of R&D staff, and the stage and scale of vehicle technology development[31].
- *Sinovac Biotech* is a Chinese pharmaceutical and biotech company, ranked 1 066th with a total R&D investment of EUR 145.4 million in the 2022 Scoreboard. In the 2023 Scoreboard, it improved its ranking by 584 places (world rank 482) with an almost threefold increase in R&D to

29 In case of Q2 and Q3 a change of 500 places can be considered as such. Positions changes in Q3 is interesting mainly if it means an improvement of the ranking.

30 The largest improvement in Q1 was Leonardo Spa’s jump by 204 positions to rank 115. This company registered an R&D investment of EUR 2 billion in 2022, which is a 3.38-fold increase compared to the 2022 *Scoreboard*. The last year amount of EUR 584 million was net of third party contracted R&D, being explicitly reported as ‘self-funded’ R&D, while the total R&D amounted to EUR 1.8 billion. This year company reporting does not allow breaking down of the total R&D investment in contract and self-funded parts. See: https://www.leonardo.com/documents/15646808/16736384/Integrated+annual+report+2021.pdf?t=1649761893131 and https://www.leonardo.com/documents/15646808/0/Integrated+Annual+Report+2022+per+sito+%281%29.pdf?t=1681232395120

31 https://ir.nio.com/static-files/a5408c40-1840-488c-9658-dcf5e21c9665

EUR 414.5 million. This massive increase is in line with the company's strategy of expanding the regular business into international market. The firm is developing various vaccines to prevent life-threatening diseases. The number of countries granting licenses to their vaccines increased by 10 in 2022[32].

- *Gotion High-Tech Co, Ltd* is a Chinese ICT producer, ranked 1 113th with a total R&D investment of EUR 136.8 million in the 2022 Scoreboard. In the 2023 Scoreboard, it improved its ranking position by 503 places to world rank 610 with a 2.2-fold increase in R&D investment to EUR 306.6 million. The company focuses on power batteries and related disciplines, such as material science, battery structure, product design, manufacturing engineering, and testing. With its intensive cooperation with Volkswagen and other automobile companies, the company's global R&D expenditures and its market share of lithium-iron-phosphate technology in the passenger vehicle field increased. The major changes in their R&D investment mainly relates to the development of a 300Ah winding cell and a 150Ah battery cell projects[33].

The three companies that experienced the largest **positions drops** based on the above-mentioned criteria are as listed below.

- *Novavax* is a US-based biotech company developing vaccines against serious infectious diseases. It develops vaccines for influenza, respiratory syncytial virus, as well as Ebola. In the 2022 Scoreboard it ranked 129th with EUR 1.5 billion of R&D investment. Due to a massive decrease in R&D to EUR 799 million, it currently ranks at position 269. This drop is mainly due to a reduction in development activities relating to a coronavirus vaccine, an Omicron vaccine candidate, bivalent formulations, and a COVID-19 influenza combination vaccine candidate[34].
- *REE Automotive* is an Israeli automotive company developing and manufacturing commercial electric vehicles. In the 2022 Scoreboard, it invested EUR 266.3 million, and ranked 630th. In the 2023 Scoreboard, its ranking dropped drastically by 898 places to position 1 528 after a reduction in its R&D investment to EUR 73.3 million. This decrease was mainly due to decreased share-based compensation expense as a result of a decrease in the number and value of options granted to the founders before the merger of Merger Sub with 10X Capital[35] and vested at the time of closing.
- *Theravance Biopharma* is a US biopharmaceutical company focusing on the discovery, development and commercialisation of organ-selective medicines. In the 2022 Scoreboard, the company invested in R&D EUR 181.6 million and was ranked 872nd. One year later, its R&D expenditure dropped to EUR 59.4 million and so did its ranking, dropping by 1 474 positions to rank 2 346 in 2023 Scoreboard. The main reason for the decrease was the near-completion of expenses linked to several external-related programmes. The decreases across the other R&D categories were primarily due to a strategic update and corporate restructuring, during which 75% of the headcount was reduced.

2.3 Subsidiary structure of the Scoreboard firms

The top 2 500 companies investing in R&D control just over 1 million subsidiaries, of which 365 000 are classified as corporate subsidiaries[36]. The headquarters of the companies included in this year's ranking are distributed across 42 countries, and the corporate subsidiaries are located in over 200 countries and territories.

[32] http://www.sinovac.com/news/1664-en.html

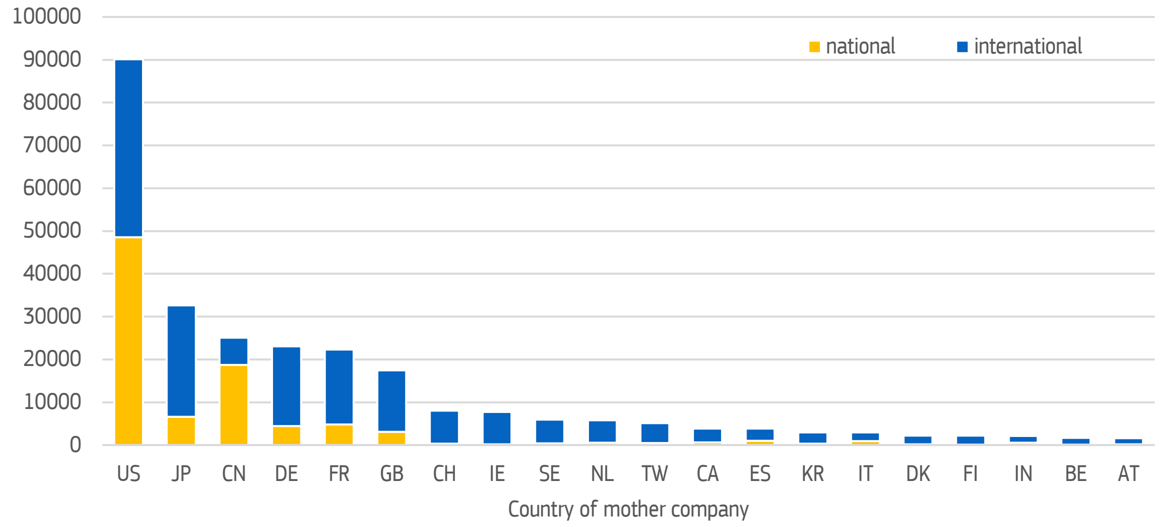
[33] Idem

[34] https://www.annualreports.com/HostedData/AnnualReports/PDF/NASDAQ_NVAX_2022.pdf

[35] According to the annual report 2022 (https://s3.amazonaws.com/sec.irpass.cc/2861/0001843588-23-000010.pdf) "on February 3, 2021, REE entered into a merger agreement with 10X Capital Venture Acquisition Corp, a Delaware corporation and special purpose acquisition company, and Spark Merger Sub, Inc. ,a wholly-owned subsidiary of the REE, pursuant to which Merger Sub merged with and into 10X Capital. The Merger was consummated on July 22, 2021 with 10X Capital becoming a wholly-owned subsidiary of the Company, and the security holders of 10XCapital becoming security holders of REE."

[36] As in previous editions of the Scoreboard, the analysis of the corporate structure focusses on corporate subsidiaries only.

Figure 9. Subsidiaries of the top 2 500 companies by location – top 20 host countries, 2022



Note: Corporate subsidiaries are labelled as national if they are located in the same country as their parent company, otherwise they are international.

Source: The 2023 EU Industrial R&D Investment Scoreboard, European Commission, JRC/DG R&I.

Figure 9 shows that, similar to headquarters, corporate subsidiaries are rather concentrated geographically despite the large number of locations hosting at least one entity. In fact, 74% of subsidiaries are located in 20 countries, which represents a slight increase compared with the last year. In line with the distribution of headquarters, the country where most subsidiaries are located is the US, which accounts for 33.7% of the total, followed by Japan (12.2%), China (9.4%), Germany (8.6%), and France (8.4%).

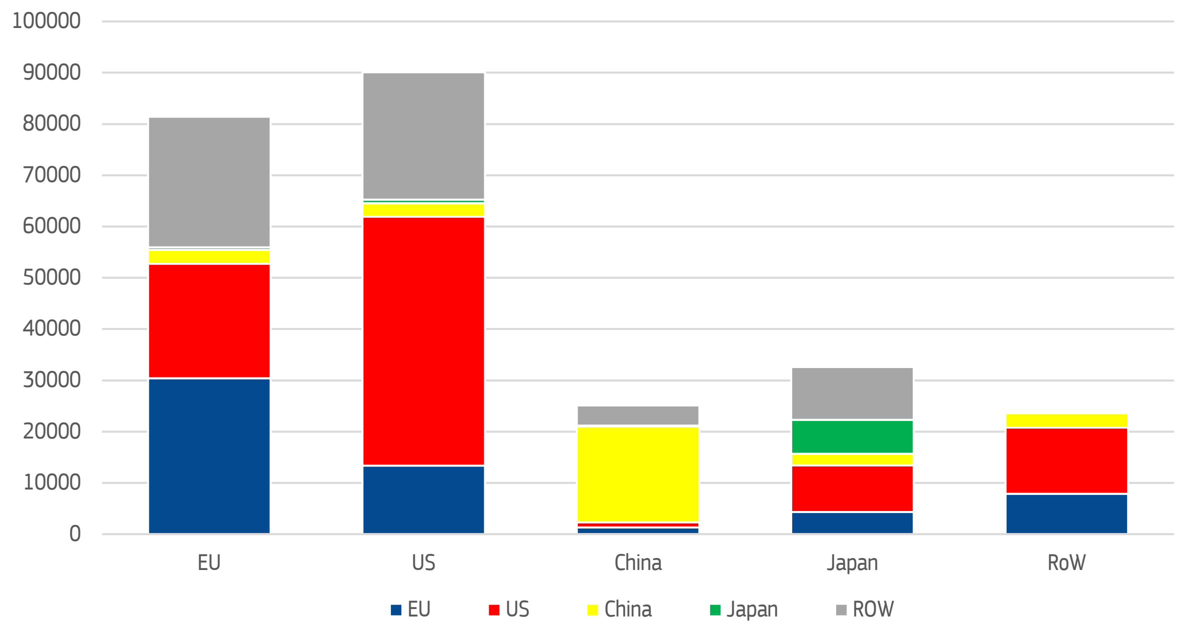
The top 5 countries in terms of hosted subsidiaries are largely unchanged compared to 2021. The only notable exception is Japan (formerly sixth in this ranking), which replaces the UK. The figure also distinguishes between subsidiaries located in a different country than the one where the corporate headquarters are located (i.e. international subsidiaries, represented by the orange bars in the chart) and subsidiaries located in the same country as the parent company (i.e. national subsidiaries; blue bars). It is interesting to notice that, with the exception of the US and China, where the ratio of national to international subsidiaries is around 1.2:1 and 3:1, respectively, the countries represented in the figure host at least twice as many international as national subsidiaries.

Figure 10 focuses on the regional distribution of the subsidiaries of Scoreboard companies. Contrary to the 2022 edition of the Scoreboard, in which most subsidiaries belonged to EU-headquartered parent companies, in this edition US-based companies own the relative majority of subsidiaries (32.9%) spread across 176 countries. EU companies follow closely with 29.7% of subsidiaries located in 188 countries. Japanese companies own 11.9% of subsidiaries across 147 countries, a slightly lower share than in the past edition, while China falls from last year's 11% to 9.1% of total subsidiaries across 127 countries.

Most subsidiaries of companies headquartered in the EU are located in the EU (37.3%), followed by the RoW (31.2%) and the US (27.5%). As in the past, over half of the subsidiaries of companies headquartered in the US are located in the US (53.5%), followed by the RoW (27.6%), and the EU (14.8%). Close to three out of four subsidiaries owned by Chinese companies are located in China (74.5%). On the contrary, Japanese companies remain the most internationalised ones, with only 20.3% of their subsidiaries being located in Japan.

Overall, the number of corporate subsidiaries covered in this year's Scoreboard is noticeably larger than last year (360 000 vs 300 000, a 21.7% increase). However, their geographical distribution has remained qualitatively similar. This means that the industrial structure of the top R&D investors has followed a balanced expansion path throughout the post-COVID-19 recovery.

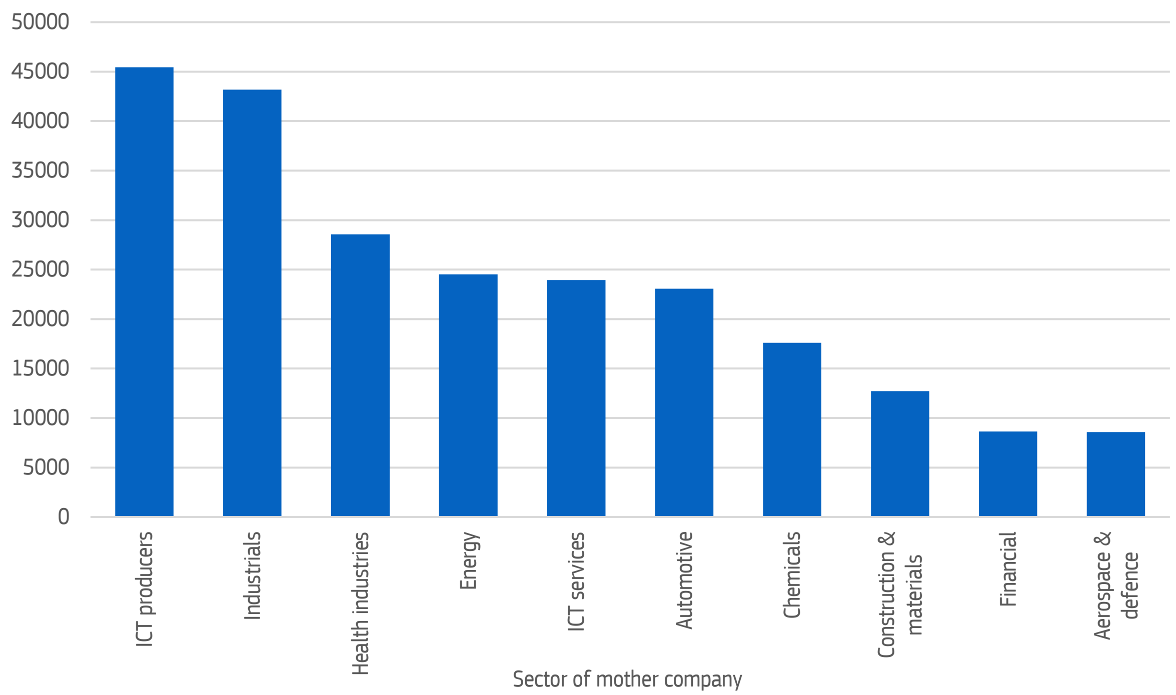
Figure 10. Distribution of the number of subsidiaries by country/region of the mother company, 2022



Note: Data refers to the 2 037 companies (accounting for 84% of R&D investment in 2022), for which data on subsidiaries are available.
Source: The 2023 EU Industrial R&D Investment Scoreboard, European Commission, JRC/DG R&I.

Figure 11 looks at the composition of the Scoreboard from a sectoral viewpoint. In line with last year's edition, companies operating in the ICT producers' and industrials' sectors record the highest number of subsidiaries (both over 40 000) followed at a distance by companies in the health sector. Energy, ICT services, and automotive companies are close in terms of the number of corporate subsidiaries. However, automotive falls from fourth to sixth place in this particular ranking compared with 2021.

Figure 11. Number of subsidiaries of the top 2 500 companies by sector of the mother company, 2022



Note: Data refers to the 2 037 companies (accounting for 84% of R&D investment in 2022), for which data on subsidiaries are available.
Source: The 2023 EU Industrial R&D Investment Scoreboard, European Commission, JRC/DG R&I.

2.4 Business key performance indicators

In addition to information on firms' the R&D investments, we also have information on key performance indicators (KPI) such as net sales, profit, capital expenditure (capex), market capitalisation, as well as on employment.[37] Table 9 displays these KPIs across the five major regions and adds R&D-specific performance indicators such as R&D intensity (measured as R&D investment as a share of net sales), R&D investment per employee (in EUR), profitability (profits divided by net sales) and capital intensity (capital expenditures divided by net sales) for 2022. Regional development is compared with the figures for the entire sample.

Net sales developed favourably with particular high growth in the EU, RoW and Japan. Sales of traditional **energy companies** developed particularly positive in all regions due to the large increases in oil- and gas prices related to Russia's full-scale invasion of Ukraine. US (and RoW) energy companies benefited from the shift in demand away from Russian gas to other sources, causing sales and especially profits to increase strongly. In contrast, energy companies in the EU, Japan and China all increased sales but saw negative profit growth in 2022.

Automotive companies recorded large sales growth in all regions apart from China, with growth rates between 15% (EU) to 22% (US). However, profits were weaker than sales with negative growth for China (-40%) and close-to-zero growth for the EU and Japan, but with strong profit growth for automotive companies located in the RoW (30%) and the US (14%).

Table 9. Business key performance indicators, 2022

	EU	US	China	Japan	RoW	Total
Firms	367	827	679	229	398	2 500
R&D, EUR bn	219.2	526.5	222.1	116.2	165.4	1 249.4
One-year change	13.6%	12.7%	16.4%	10.4%	9.1%	12.8%
Net sales, EUR bn	5 753.5	6 496.4	5 796.4	3 040.9	5 218.4	26 305.8
One-year change	16.8%	11.3%	10.7%	15.2%	17.9%	14.1%
R&D intensity	3.8%	7.9%	3.8%	3.8%	3.2%	4.7%
Operating profits, EUR bn	559.2	984.9	422.9	214.8	946.2	3 128.2
One-year change	-2.2%	0.7%	0.9%	8.7%	21.9%	6.3%
Profitability, %	9.7%	15.4%	7.3%	7.1%	18.1%	11.9%
Capex, EUR bn	312.6	381.3	414.3	174.2	367.0	1 649.7
One-year change	9.3%	19.2%	12.3%	5.1%	18.2%	13.7%
Capital intensity	5.4%	5.9%	7.1%	5.7%	7.0%	6.3%
Employment, million	15.1	11.2	16.6	8.2	6.7	57.1
One-year change	1%	3.9%	4.3%	-2.0%	-2.1%	1.6%
R&D per employee, EUR	14 423	46 091	14 073	14 160	24 524	21 702
Market capitalisation, EUR bn	4 775.2	19 902.4	2 615.1	2 693.0	7 806.3	39 504.9
One-year change	-20.2%	-17.8%	-21.9%	-1.2%	-6.3%	-15.6%

Note: Capex stands for capital expenditures. R&D intensity is defined as R&D as a share of net sales, profitability is defined as profits as a share of net sales. Measured in nominal values.

Source: The 2023 EU Industrial R&D Investment Scoreboard, European Commission, JRC/DG R&I.

Aggregate profits increased by 6.4%, driven by the massive profits earned by oil- and gas-producers in the RoW group, while in all other sectors profits declined compared with the previous year (or increased only slightly, such as in automotive and aerospace and defence). As an illustration, the total RoW energy sector profit in 2022 was EUR 494 billion – almost twice as much as the entire US ICT producers' sector profit, and around 1.5 times the US ICT services sector profit. The main company behind this is Saudi Arabian Oil, which earned a profit of EUR 286 billion only in 2022. This constitutes the highest profit ever recorded by a Scoreboard firm. The high energy prices that caused record profits for some constituted skyrocketing input prices for others: energy-intensive companies, in particular in the chemicals sector, saw their profits decline

[37] Unfortunately, data are systematically missing across regions and years, with more data missing in more recent years. However, aggregating the indicators per region/country and year and comparing the share of R&D of firms with data on the financial indicators to total R&D shows that firms with non-missing KPI data represent more than 95% of total R&D, except for employment for RoW (only around 63%), and market capitalisation for the EU and China (around 85%). Still, in light of the skewness of the R&D data distribution, the missing data disproportionally affects smaller R&D investors (that can be numerous but do not have much weight in aggregate R&D investment).

(while sales grew strongly); only RoW chemicals companies located in oil- and gas-producing countries were less affected by supply shortages and rising prices and saw their profits increase strongly.

In contrast, profits developed sluggishly for the EU, the US and China. For EU companies, the decrease in aggregate profit follows a year with record profits related to the recovery from COVID-19 and the large profits earned by health and automotive companies. The relative decrease relates mainly to a stagnation of profits in the health sector, and only modest growth of automotive profits, while the energy sector, the sectors grouped under 'others' and industrials saw reductions in profits. US companies' profits declined compared with the previous year in the important sectors of health and ICT services, as well as in industrials, but the energy sector benefited enormously from the energy price hike following Russia's full-scale invasion of Ukraine – the US energy sector profit increased by 139% to EUR 129 billion. However, this is still only half of the profit of the best-earning oil- and gas-company in the sample. US automotive companies' profits increased strongly too, but the sector has only little weight in the US aggregate.

The **profitability** of EU companies decreased compared with the previous year because sales grew faster than profits, but it remains the second highest since 2012 (after 2021). Profitability is highest in the RoW countries, again, driven by the energy companies (with a profitability of 15.8%) and the financial sector. The financial sector is traditionally the sector with the highest profitability (22.2% in 2022, 16.8% on average since 2012). Profitability in the US remains high but decreased somewhat compared with the past year. The three most R&D-intensive sectors ICT producers, ICT services and health are characterised by high profitability ranging from 12% for ICT producers, over 14.5% for health to 16% for ICT services on average over the past decade. The sectoral structure thus also determines the high profitability of US companies in the aggregate. Japanese and Chinese companies have a similar profitability, and in both countries, it declined slightly compared with 2021.

Capex continued to increase, in particular in the US and RoW, but also in the EU. In 2020, capex growth was negative in all regions except for China. In 2021, US and RoW companies, next to Chinese, already increased their capex, and only EU and Japanese companies continued to reduce their capex. Only in 2022, all regions reported a positive development again. EU capex increased in particular in automotive, the ICT sectors, and health. Also in the energy sector, EU capex increased but to a lower extent than in the US, China or the RoW. However, with 25%, the share of the EU energy sector in total EU capex is much higher than in the US (9%) due to the comparably small role of other capex-intensive sectors in the EU (in particular ICT producers).

In 2022, the energy sector and ICT producers were responsible for the highest shares of total capex by all Scoreboard companies with, ca. 19.5% for each of the two sectors. The difference, however, lies in the development over time: while the share of the energy sector in total capex has halved since 2012, that of ICT producers has doubled.

Employment increased in aggregate, in particular in China, the US, and also the EU, but decreased in Japan and the RoW countries. It is interesting to observe that US companies' aggregate employment is 4 million below EU companies' employment, even though the US has more than twice as many companies in the sample. The situation is similar for China, with employment only 1 million above EU companies' employment. However, the EU sample contains 40 companies with more than 100 000 employees, while China has only 29 (and the US 23). This implies that EU Scoreboard companies are mostly large companies with (in aggregate) high R&D investment, while in the US and also in China, there are more smaller companies with relatively higher R&D investment. This insight also relates to the lower (equal) R&D intensity of EU firms compared with the US (China). For the RoW, around 35% of firms do not have employment data, which impedes a sound analysis and comparison of these companies' development.

R&D per employee is EUR 20 708 on average, but this aggregate figure is driven by the US with the highest R&D investment per employee. EU companies, in contrast, invest the same amount in R&D per employee as their Chinese or Japanese counterparts: slightly above EUR 14 000 (an increase of around EUR 2 000 for all three regions/countries). The RoW has a higher R&D investment per employee, mainly driven by UK and Swiss companies, but also by ICT producers in South Korea or Taiwan.

Market capitalisation declined strongly in all regions after the large increase in 2021. Overall, the decrease in market capitalisation in the Scoreboard sample is broadly in line with the reduction in global aggregate market capitalisation in 2022 by ca. 20%[38]. In the Scoreboard, the market capitalisation of EU companies

[38] https://www.statista.com/statistics/274490/global-value-of-share-holdings-since-2000/

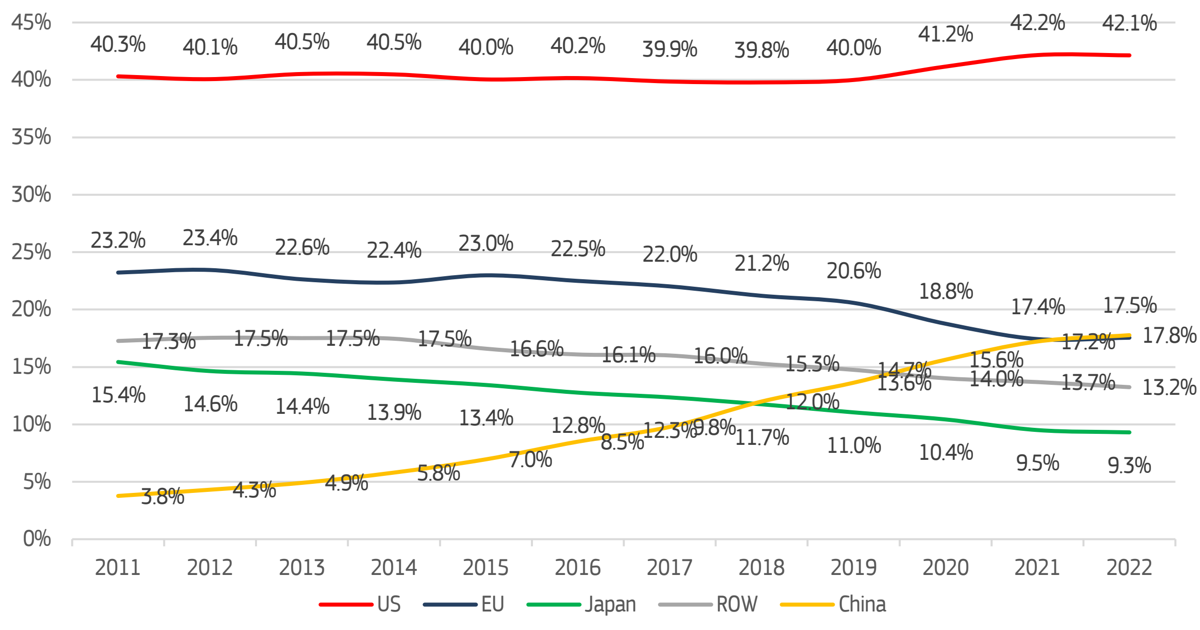
decreased across all sectors. The same holds for the US except for energy (plus 62%) and automotive (0.18%). In the RoW, only energy and financials increased their market capitalisation. In Japan, automotive, energy health and ICT services increased (but at lower rates than in other regions), and in China, only the energy sector could maintain its market capitalisation, while all other sectors witnessed a reduction. Market capitalisation is highly concentrated: US companies' market capitalisation is higher than that of all other regions in the Scoreboard together.

2.5 Regional distribution of R&D investment

In the past year, the number of EU firms in the Scoreboard increased slightly from 363 to 367. The increase in Chinese firms (and to a smaller extent in US firms) over the past decade has been at the expense of companies headquartered in the EU, Japan and the rest of the world (RoW). The number of Chinese firms in the Scoreboard has increased by a factor of 3.1 since 2012 from 216 to 679; the number of US firms rose until 2015, declined then, before the trend reversed – in 2022 the US held the highest number of firms in the Scoreboard. Since 2012, the share of Chinese firms has increased to 27% and the US share has remained around 32%. In contrast, Japan has experienced a drastic decline and now has only half the number of firms it had in 2012 (9.2% of Scoreboard companies). The EU and RoW countries lost around one quarter of the number of firms compared with 2012 (2022: EU 14.7% of companies, RoW 15.9%). In terms of companies, China overtook Japan in 2016, and the EU and the RoW in 2018. The rise of Chinese firms is related to sharp and continuous increases in R&D investment, on the one hand, and improved data coverage thanks to the adoption of international accounting standards, which make it possible to include these companies in the Scoreboard, on the other hand.

The nominal R&D investment in euro for each year is distributed across the five major countries/regions as displayed in Figure 12. The US consistently maintains over 39% of total R&D investment, and since the COVID-19 crisis, US firms have even been able to increase their share of the total to over 42% (this is due to the sector composition of the US, as will be discussed in Section 3). The US share of R&D thus exceeds its share of firms by almost 10 percentage points. EU-headquartered companies account for 17.5% of total R&D investment in 2022, down from 23.4% in 2012 (the decline in R&D share corresponds to the reduction in companies). In line with the decreasing share of companies from Japan (down from 17.6% to 9.2%) and the RoW (from 21.5% to 15.9%), also their share in total R&D investment declined. In contrast, the percentage of Chinese firms in the Scoreboard increased from 7% to close to 27%. However, in terms of R&D investment the Chinese share is lower – 4.3% in 2012 and 17.8% in 2022.

Figure 12. R&D investment shares by region/country, 2012-2022



Note: Figures show the share of total nominal R&D investment per year and region, calculated at 2022 exchange rates to the euro.
Source: The 2023 EU Industrial R&D Investment Scoreboard, European Commission, JRC/DG R&I.

This raises several interrelated questions: why is the share of US R&D so much higher than its share of firms, why is the share of the US so much larger than that of the EU, and why is China's share of R&D so much lower than its share of firms? Box 1 zooms in on this question, finding that after making a purchasing power adjustment the shares of R&D investment by world region are closely related to the share of firms in the Scoreboard. This adjustment leads to fewer differences for EU and Japanese firms, smaller leadership of US Scoreboard firms, and an improvement in the share of Chinese Scoreboard firms.

Box 1. R&D Investment in purchasing power parities – Regional Distribution

The analysis as displayed in Figure 12 makes the simplifying assumption that one euro can purchase the same "amount" of R&D across the regions/countries under considerations, i.e. that the costs for labour and capital are the same across all countries. As a consequence, high-cost countries automatically account for a larger share of aggregate investment.

More realistically, R&D investment can be significantly impacted by the cost of labour, capital and infrastructure and other factors unique to each country. Whereas nominal R&D (in current prices) provides a good indication of the amount of R&D activity of a firm, it is less informative about the real resources devoted to R&D in comparison to firms in other countries because it does not take account of differences in the relative prices of R&D inputs across countries. Furthermore, when analysing R&D investment over time, inflation can distort the apparent growth or decline in investment. To adjust for cross-country differences and inflation, R&D specific purchasing power parity (PPP)[39] can give a better measure of the differences in actual resources devoted to R&D between countries, since PPP measures how much needs to be spent in a country to acquire (for example) EUR 1 of R&D inputs.

As argued by Hall et al. (2010)[40], the ideal for constructing a deflator for R&D expenditures would be a division of prices by sector and the various components of R&D (e.g. labour, capital, etc.). Preferably, R&D across countries should be estimated based on prices for a basket of 'standard' R&D inputs at the economy-wide level (Dougherty et al., 2007[41]; OECD, 2002[42]). Already in 1965, Freeman and Young[43] estimated a PPP for R&D by breaking up total R&D expenditure into labour costs, material costs, and other current and capital expenditures. For labour costs, Freeman and Young calculate the wage cost per worker in R&D and assume this is also appropriate for other current expenditures. However, this type of fine-grained PPP data is not available for all countries in the sample, and the best approximations found are from the International Comparison Program, which only has PPP values from 2011-2017, classified into five broad sectors[44]. Neither of these sectors is R&D-specific, and there is no updated version for more recent years.

Due to these limitations we follow the alternative approach suggested by the OECD or Bravo-Ortega & García Marín (2011)[45], and use the implicit GDP deflator and GDP-PPP (PPP for GDP), which provides an approximate measure of the average real 'opportunity cost' of carrying out R&D. For each firm, we convert the nominal R&D investment for each year (in local currency) to constant prices (2015) using the World Bank GDP deflator (the ratio of GDP in current local currency to GDP in constant local currency).[46] This indicator makes it possible to check for changes in the general price level of goods and services in the economy (inflation). Then, we convert all firm/year R&D investments in constant prices (2015) to US dollars using the appropriate exchange rate in 2015. Finally, we convert the constant R&D investment in US dollars to PPP by dividing the inflation-adjusted value by each country's 2015 PPP conversion factor.

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[39] PPP is a metric used by macroeconomic analysts that compares different countries' currencies through a 'basket of goods' approach. PPP can be used to convert national accounts data, like GDP and its expenditure components, into a common currency, while also eliminating the effect of price level differences between countries. Typically, higher income countries have higher price levels, while lower income countries have lower price levels (Balassa-Samuelson effect).

[40] Hall, B. H., Mairesse, J., & Mohnen, P. (2010). Measuring the Returns to R&D. *Handbook of the Economics of Innovation*, *2*, 1033–1082. Retrieved 10 April 2015, from http://www.sciencedirect.com/science/article/pii/S0169721810020083

[41] Dougherty, S. M., & et al. (2007). *International Comparisons of R & D Expenditure : Does an R & D PPP Make a Difference ? International Comparisons of R & D Expendit* (No. WORKING PAPER 12829). NBER.

[42] OECD. (2002). R&D Deflators and Currency Converters. *Frascati Manual: Proposed Standard Practice for Surveys on Research and Experimental Development* (pp. 1–8). Paris: OECD Publishing.

[43] https://books.google.es/books/about/The_Research_and_Development_Effort_in_W.html?id=FLOJAAAAMAAJ&redir_esc=y

[44] Households' final consumption expenditure, actual individual consumption, general government final consumption, gross fixed capital formation and domestic absorption (see: https://databank.worldbank.org/embed/ICP-Annual-PPPs/id/8b9dca71?inf=n).

[45] Bravo-Ortega, C., & García Marín, A. (2011). R&D and Productivity: A Two Way Avenue? *World Development.* 39-7. https://doi.org/10.1016/j.worlddev.2010.11.006.

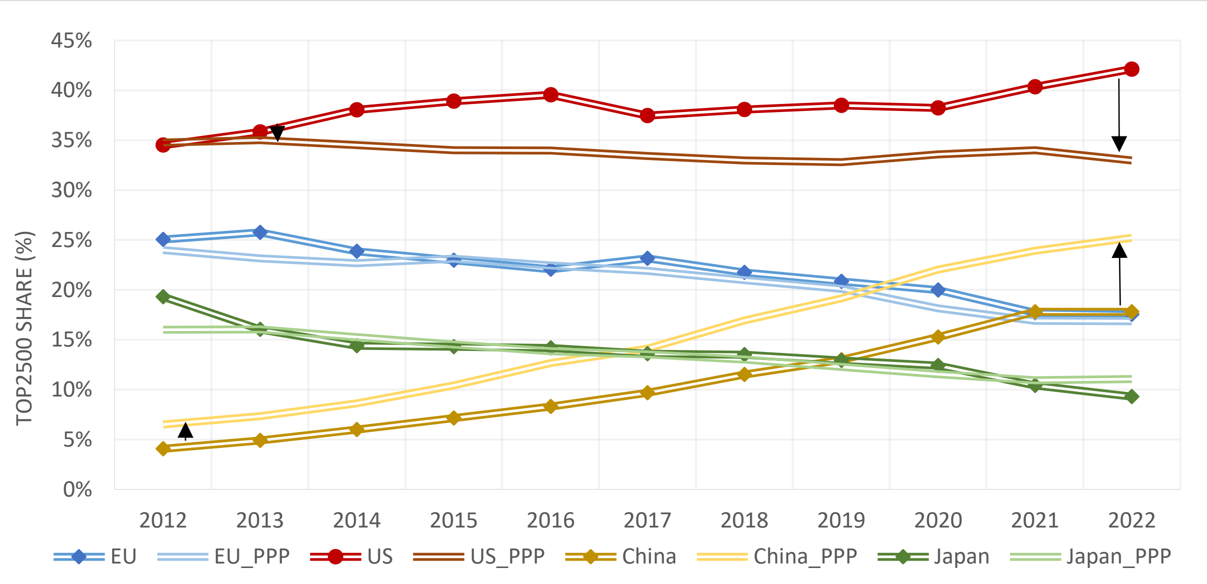
[46] Some adjustments had to be made: Taiwan has no PPP values available (we used the GDP deflator and the PPP of China); Liechtenstein has no PPP values available (we used the GDP deflator and the PPP values of Switzerland).

By definition, the PPP-adjustment factor for the US is 1, and all other countries compare to this benchmark. For most countries the PPP-adjustment is smaller than 1, implying that USD 1 one can buy 'more' R&D in this country compared with the US. Consequently, the real PPP-adjusted R&D investment of firms in e.g. China or EU countries is higher than indicated by their nominal values.[47]

In Figure B1 1 we combine all data from the top 2 500 firms by year to show differences across countries using these two approaches: R&D in current USD vs R&D in deflated PPP USD (2015).

The main insight from this analysis is that the US loses up to 9 percentage points in the distribution of R&D, while the share of Chinese firms increases between 2 and 7 percentage points; the share of EU R&D remains largely unchanged compared with the nominal values. With around 33% in 2022, the US still holds the largest share of corporate R&D in the Scoreboard, China follows second with a share of 25%, and the EU third with 17%. For the countries summarised as the RoW and Japan, the transformation to PPP does not affect the results much (14% and 10.7%). Overall, the shares of R&D investment across regions are now much closer to the respective shares of firms.

Figure B1 1. Share of R&D by region, 2012-2022 - R&D in current USD vs. R&D in deflated PPP USD (2015)



Note: The base year for inflation adjustment is 2015 (GDP deflator in 2015 = 100). For the adjustment to PPP, the US is set to 1 and the exchange rate is fixed to US dollars in 2015. The transformed series is cleaned of effects of inflation, exchange rate appreciations/depreciations and differences in purchasing power.
Source: The 2023 EU Industrial R&D Investment Scoreboard, European Commission, JRC/DG R&I.

One word of caution: the same qualifications as for inflation adjustment apply to the analysis in terms of PPP. First, for such large firms as those in the Scoreboard, the firm's headquarter usually does not fully correspond to the country where it performs its R&D and other activities. Second, we do not have information on the number of countries firms distribute their R&D investments across, and what these countries are. However, our previous R&D investment surveys indicated a strong home-bias of R&D, with EU-based Scoreboard firms performing on average 80% of their R&D inside the EU[48]. Naturally, firms operating in countries with higher price levels will effectively purchase less, while firms in lower-cost countries will see the value of their investment increase.

Overall, this analysis cannot reveal the 'true' R&D investments of firms, but instead gives an indication of the effect of cost differences. In the end, the true R&D investments of a firm will be located somewhere between the nominal and the PPP-adjusted values.

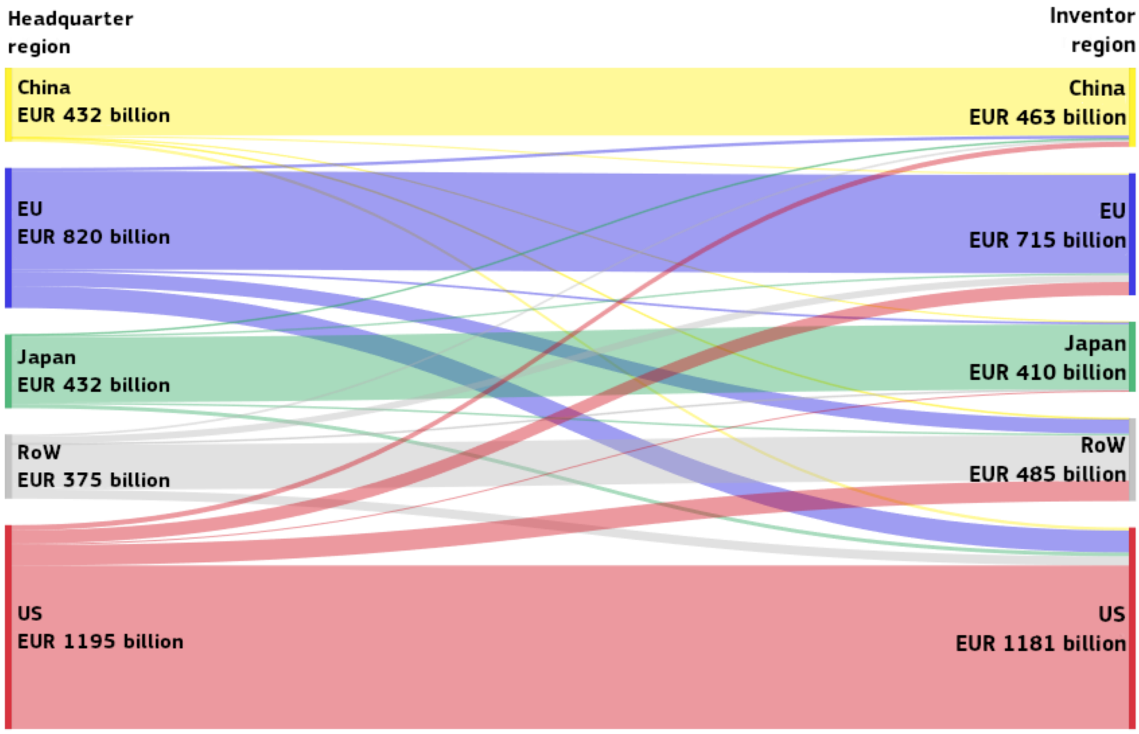
[47] Examples of 2015 PPP values: Switzerland (1.21), Norway (1.13), Japan (0.91), Germany (0.88), Italy (0.77), China (0.65), Taiwan (0.65).

[48] Nindl, E., The 2022 EU Survey on Industrial R&D Investment Trends, Publications Office of the European Union, Luxembourg, 2022, doi:10.2760/579174, JRC131984.

As mentioned in Box 1, assigning a company's activities exclusively to the country where it has its headquarters does not necessarily give an accurate picture of the actual location where R&D or other industrial activity is actually performed. This is especially true in the case of multinational companies such as the companies included in the Scoreboard; an illustration of this is in Section 8, (Figure 89 and Figure 90).

In order to approximate the regional distribution of a company's R&D activities we use the location of the inventors of the patents owned by Scoreboard companies as a proxy for the actual location in which they perform their R&D activities (as done also in previous editions of the Scoreboard)[49]. To this aim, we rely on the data contained in the 2023 COR&DIP[50] database reporting the patents filed by Scoreboard companies at one of the five main intellectual property (IP) offices between 2017 and 2020[51]. We use this information to reallocate R&D investment of the Scoreboard parent companies from the headquarters to the location of the inventors responsible for the patents for which the companies applied. This way, we obtain an estimate of the actual geographic distribution of worldwide industrial R&D. The computation relies on several strong assumptions, namely that: i) the amount of R&D invested to generate one patent is uniform across technologies; ii) the propensity to patent does not vary between technologies and companies; and iii) the success rate of R&D is comparable across companies. Nevertheless, what we obtain is the best approximation given the available data.

Figure 13. R&D flows from headquarter to inventors' locations, 2017-2020



Note: Figures show the sum of R&D flows from headquarters to locations of the respective mother companies in different countries/regions; values represent aggregate R&D flows in 2017-2020, measured at 2020 exchange rates to the euro.
Source: Own elaboration based on COR&DIP 2023.

Knowing the 'R&D flows' from the locations of patent owners to the locations of patent inventors makes it possible to calculate the total R&D flows across borders. For a given country or region, the inward flow is defined as the R&D performed in the country and funded by companies with headquarters located in another country, while the outward flow is defined as the R&D funded by local companies (with headquarter in the

[49] https://iri.jrc.ec.europa.eu/scoreboard/2020-eu-industrial-rd-investment-scoreboard; https://iri.jrc.ec.europa.eu/scoreboard/2021-eu-industrial-rd-investment-scoreboard

[50] https://www.oecd.org/sti/EC-JRC-OECD-CORDIP-Database-Flyer-2023.pdf

[51] The 2023 COR&DIP database contains the patents of the top 2 000 R&D investing firms as ranked in the 2021 Scoreboard. The R&D values are converted to euro using exchange rates computed on 31.12.2020, which can lead to some discrepancy with the nominal R&D reported in the current report for the same period. As in previous editions of the Scoreboard, R&D investment of Scoreboard companies not contained in the COR&DIP database is allocated to the country where the company has its headquarter.

country) but performed abroad. Figure 13 shows the flow of R&D between regions according to our breakdown and makes clear that the Scoreboard companies perform the vast majority of their R&D in their respective headquarter region/country. For instance, over the examined period, 70% of R&D investment by EU-based companies flowed within the EU. Similarly, 80% of the R&D of US-based Scoreboard companies remained within the country, 88% of R&D was performed domestically in Japan, and 91% of R&D performed by companies with headquarters in China was domestic. This means EU companies have the highest share of R&D performed across borders; most of this cross-border R&D investment (15% of total R&D) flows to the US. Japan (5%) and China (4%) also perform the majority of their international R&D in the US. This confirms the relative attractiveness of US R&D ecosystems and markets. For the US-based Scoreboard companies, the EU is the region attracting most of the R&D performed outside the US (10%).

2.6 Development of R&D investment since 2012

Since its inceptions, the Scoreboard ranking is built on the nominal R&D investments as reported in the consolidated company accounts and adjusted for externally funded R&D (see Annex 2 for methodological details). Since the expansion of the Scoreboard to its current coverage of 2 500 companies in 2012[52], inflation rates have been moderate, at around 1.5% per year. However, this has significantly changed in the past 2 years. To take account of the worldwide rise of inflation rates in 2021 and the particular sharp increase in 2022, in the 2023 Scoreboard we – for the first time also – also look at inflation-adjusted R&D investment (real or deflated R&D investment) to see by what magnitude companies' investments exceeded the increase in prices and thus are real additions to R&D investment. Comparing nominal and real values thus makes it possible to differentiate between increases in R&D investments into two types: real additional R&D investment and increases that only reflect the general increase in prices.

It should be noted that the transformation to inflation-adjusted values has certain technical specifics. The Scoreboard firm-level data reported in original currency values are transformed using the country-specific GDP deflator[53] of the country of headquarter and then converted to euro values (using the 2022 end-of-year exchange rates to euro). All R&D investment of a company is allocated to its country of headquarter as there is no information available on the actual location of a company's R&D investments. Thus the country specific inflation rate does not always accurately capture the true increase in prices a company faced as the country of headquarters is not necessarily the country where a firm performs (all) its R&D activities. Moreover, many firms have R&D locations in various countries and are thus exposed to a set of different inflation rates. Depending on the firm, the deflated series might thus over- or underestimate the inflation-adjusted R&D investment. Still, even though there are shortcomings, this analysis is timely and enables important insights.

Given these restrictions, because the ranking is based on nominal values, and in order to maintain consistency with previous Scoreboard editions, the main analysis in the present Scoreboard thus continues to be based on nominal R&D investments, but adds inflation-adjusted values if deemed informative.

Figure 14 displays the growth rate of worldwide R&D investment by the top 2 500 R&D investors in nominal and inflation-adjusted (real) values[54]. In the low-inflation period from 2012 to 2020, the difference between both series is on average only 1.5%. However, the inflation rate rises to 3.6% in 2021 and 5.6% in 2022, reducing the real increase in R&D investment to 10.5% in 2021 and 7.2% in 2022. Still, even in this difficult economic environment, companies continued to push their R&D investment to previously unseen levels.

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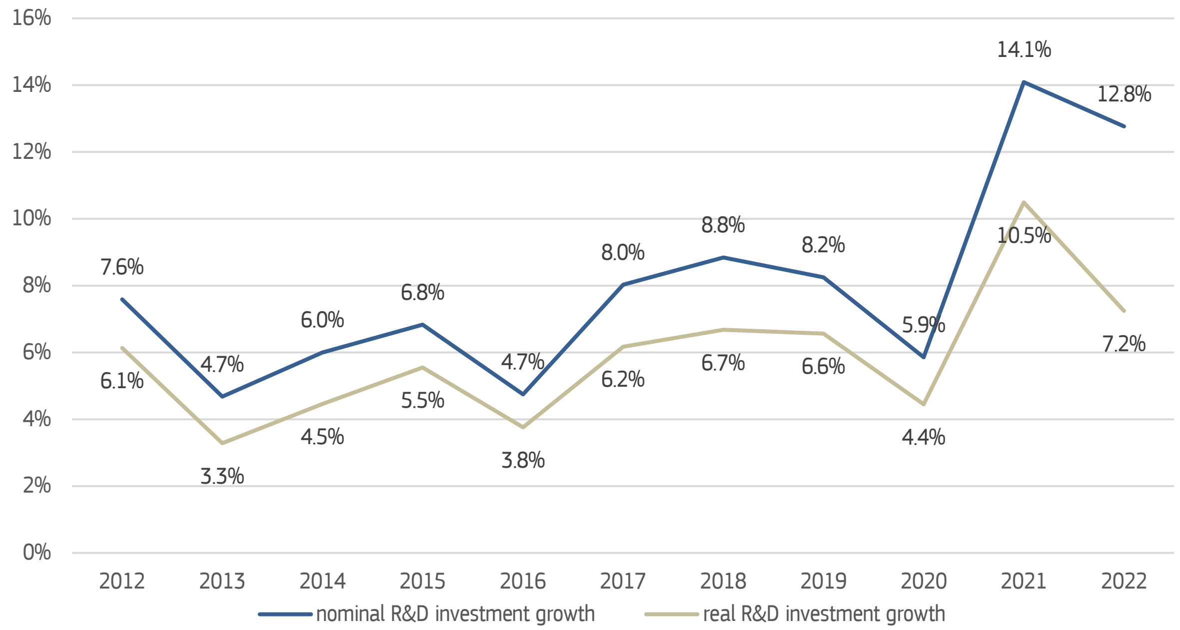
[52] The Scoreboard started in 2004 with 500 EU companies plus 500 non-EU companies; coverage was expanded continuously since then, and reached 2 500 global plus the EU 1 000 companies in 2012 (however, in 2012 and 2013 the report covered only the top 1 500 companies, but data was collected on the larger sample).

[53] The GDP deflator is defined as the ratio of GDP in current local currency to GDP in constant local currency in linked series; data is taken from the World Bank with the base year set to 2015.

[54] In contrast to previous editions of the Scoreboard we calculate growth rates using the Scoreboard Panel (see Annex 3 for details) comparing, e.g. all EU companies in 2022 to all EU companies in 2021, while in the past this was calculated using the companies that were present only in the current cross-section. Applying this methodology results in following nominal R&D growth rates for 2022 (real values in brackets): EU 14.1% (8.3%), US 14.1% (6.1%), China 17.1% (14.3%), Japan 10.2% (9.2%). RoW 11.5% (6.8%).

Figure 14. Nominal vs real top 2 500 companies' R&D investment growth, 2012-2022



Note: The base year for the inflation adjustment is 2015 (GDP deflator in 2015 = 100).
Source: The 2023 EU Industrial R&D Investment Scoreboard, European Commission, JRC/DG R&I.

As the recent increase in prices did not hit all countries equally, Table 10 displays the growth rates of R&D investment for the main countries/regions in the analysis and compares the nominal to the inflation-adjusted development since 2012.

In 2022, the inflation adjusted R&D investment growth of EU Scoreboard firms (7.8%) exceeded the US growth rate (4.9%) for the first time since 2015. This is a strong improvement compared with most of the period since 2012 (see also Figure 15). For the 17 EU countries with companies among the top 2 500 R&D investors, the inflation-adjusted reduction in R&D investment due to the COVID-19 crisis in 2020 was -5.2%, and the 3.4% growth in 2021 was not enough to reach pre-COVID-19 levels. Only in 2022, inflation-adjusted R&D investment by EU companies exceeded the 2019 level (by 5%).

Table 10. Regional R&D investment growth 2012-2022, nominal and inflation adjusted series, top 2 500 companies

	EU		**US**		**China**		**Japan**		**RoW**	
	nominal	**real**	**nominal**	**real**	**nominal**	**real**	**nominal**	**real**	**nominal**	**real**
2022	13.6%	**7.8%**	12.7%	**4.9%**	16.4%	13.6%	10.4%	9.3%	9.1%	4.6%
2021	6.0%	3.4%	16.9%	12.2%	25.7%	20.4%	4.0%	5.0%	11.4%	8.5%
2020	**-3.5%**	**-5.2%**	9.0%	7.7%	21.4%	20.9%	**-0.1%**	**-1.0%**	0.6%	**-0.9%**
2019	5.1%	3.0%	8.8%	6.9%	23.0%	21.5%	1.8%	1.1%	4.5%	3.8%
2018	4.8%	3.0%	8.7%	6.1%	33.6%	29.1%	3.5%	3.5%	3.9%	2.3%
2017	5.7%	4.4%	7.2%	5.2%	24.4%	19.5%	4.5%	4.6%	7.4%	5.4%
2016	2.5%	1.6%	5.1%	4.0%	27.9%	26.5%	**-0.5%**	**-0.9%**	1.6%	0.6%
2015	9.8%	**7.9%**	5.7%	**4.6%**	28.1%	28.3%	3.2%	1.1%	1.5%	0.8%
2014	4.7%	3.5%	5.9%	4.0%	25.3%	23.8%	2.1%	0.5%	5.7%	4.8%
2013	1.1%	**-0.3%**	5.9%	4.0%	19.2%	16.7%	3.2%	3.5%	4.5%	2.9%
2012	8.6%	7.0%	6.9%	5.0%	23.0%	20.1%	2.1%	2.9%	9.3%	7.5%

Note: The base year for the inflation adjustment is 2015 (GDP deflator in 2015 = 100).
Source: The 2023 EU Industrial R&D Investment Scoreboard, European Commission, JRC/DG R&I.

In contrast, the EU's main competitors, the US and China, achieved a massive increase in R&D investment during the years 2020 and 2021 as well. US firms increased their real R&D investment by 7.7% and 12.2%, driven by the booming health and ICT services sectors. However, in 2022, this growth slowed down somewhat in nominal terms, and in real terms, US companies recorded the lowest real growth since 2016. However, given the massive expansion in the two preceding years this appears like a cyclical development.

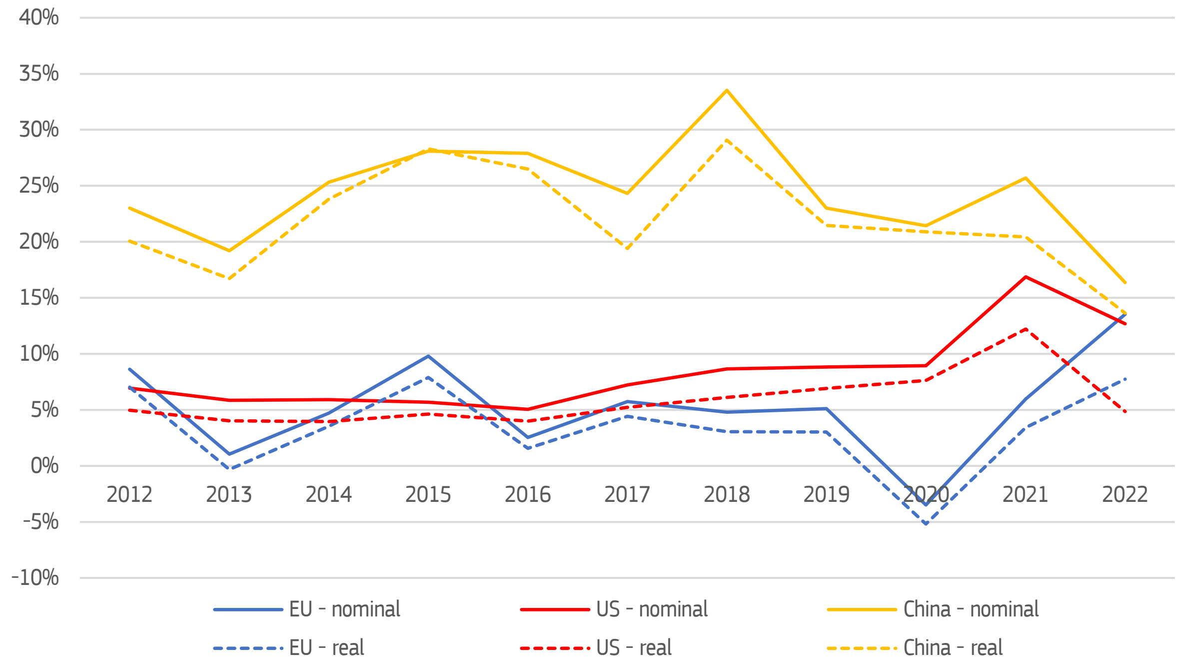
For China, in contrast, inflation-adjusted R&D investment growth slowed down for the fifth consecutive year. Yet, with 13.6%, China's real R&D increase is still by far the highest in comparison with the other countries/regions. R&D investment growth in China appears to lose pace –, in nominal terms, but in particular in real terms.

A highly positive development in terms of R&D performance is observed for Japanese firms: after moderate economic dynamics in the country over many years, Japanese Scoreboard firms significantly stepped up R&D investment after COVID-19. In 2022 they achieved the highest R&D growth (both in nominal and in real terms) since 2012. Their inflation-adjusted growth rate (9.3%) exceeds that of the EU companies and is even twice as high as the real growth of US-headquartered companies. In the 2023 Scoreboard, Japan ranks second after China in terms of real R&D investment growth.

Finally, the RoW group in the Scoreboard comprises companies headquartered in 22 other countries. They increased their real R&D investment by 4.6%. As can be seen from Table 10, real R&D investment growth for these countries turned negative in 2020, while in 2021, the companies in this group increased their R&D by 8.5%.

Figure 15 displays the nominal and real R&D investment growth rates since 2012 for the EU, the US and China. While for the EU and China, the growth in R&D investment is rather cyclical, it follows a steadier trend in the US. The figure also shows that while until 2017, EU and US growth rates were rather similar on average, since 2018, US firms have increased their R&D considerably more than their EU counterparts. Only in 2022, EU firms were able to match the growth rate of the US companies again.

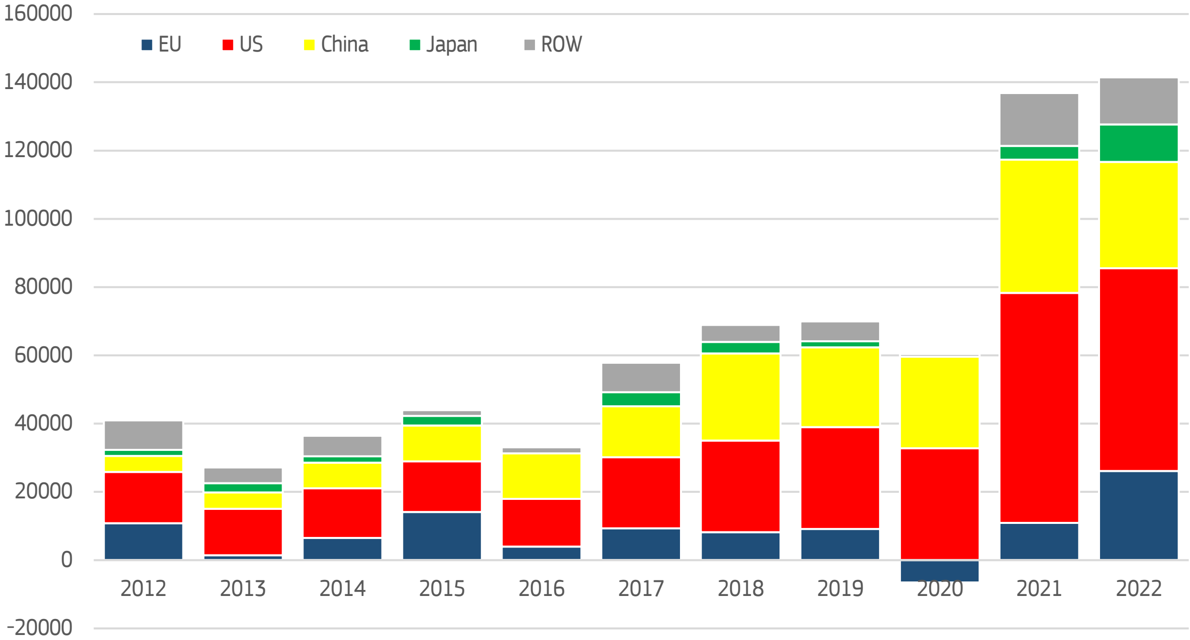
Figure 15. Nominal vs real R&D growth for the EU, the US and China, top 2 500 companies, 2012-2022



Note: The base year for the inflation adjustment is 2015 (GDP deflator in 2015 = 100).
Source: The 2023 EU Industrial R&D Investment Scoreboard, European Commission, JRC/DG R&I.

Figure 16 breaks the absolute nominal R&D growth in the Scoreboard since 2012 down by the main regions/countries. US companies drive the overall growth in R&D investment throughout the observed time period, followed by China. The contribution of companies headquartered in the EU was relatively smaller, and in 2020 even negative. In 2022, EU companies more than doubled their additional R&D investment compared with 2021, from plus EUR 10.8 billion to plus EUR 26.1 billion. However, in 2022 US R&D increased by EUR 59.3 billion, and Chinese R&D by EUR 31.2 billion. Companies originating in the RoW increased their R&D investment by EUR 13.8 billion in 2022, and Japanese companies by EUR 10.9 billion.

Figure 16. R&D investment growth decomposition by regions, top 2 500 companies, 2012-2022



Note: The vertical axis displays the change in absolute R&D investment by the 2 500 companies for each year (in EUR million).
Source: The 2023 EU Industrial R&D Investment Scoreboard, European Commission, JRC/DG R&I.

Overall, 80.3% of companies report an increase in R&D investment in 2022 compared with the previous year, the second highest share after 2021 (83.9%). In 2012-2020, on average, only 71% of companies showed positive changes. Absolute contributions to R&D increased strongly too, while R&D reduction (sum of negative changes) is low: loss of R&D measured as a share of gain stands at 10%, the lowest value observed since 2012. This means that in 2022 and 2021, only 10% of the R&D that was added to the Scoreboard was lost by other firms in the sample. In 2012-2020 this share was 30% on average. While this is also an effect of sampling – if a firm loses too much R&D it will drop out of the ranking – it nevertheless gives further evidence for the broad and sustained increase in R&D investment in the past 2 years.

2.7 R&D in global value chains

One of the most significant overall findings emerging from the Scoreboard is a persistent gap in R&D investment in the EU versus the US and its top competitors, especially China. Global value chains (GVCs) have become a critical concept to understand the links between the organisation of production and services and the role for economic development and prosperity[55]. China has become a key global supplier of intermediate products to companies in the EU and the US[56]. Scoreboard firms have shown a high degree of R&D internationalisation, mostly in the EU, followed by the US and China[57]. Case studies on these firms revealed innovation networks with a high degree of organisational and functional decomposition, where the performance of R&D by suppliers and contract research organisations is specific to each firm and highly dynamic[58]. However, the COVID-19 in 2020 crisis has highlighted supply chain bottlenecks not only in production but also in R&D, raising awareness of the links between vulnerabilities in production as well as innovation.

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[55] Stefano Ponte, Gary Gereffi and Gale Raj-Reichert (2019). *Handbook on Global Value Chains*. Edward Elgar, ISBN 9781788113762

[56] Dachs, B. and Zahradnik, G., *From Few to Many: main trends in the internationalization of business R&D*, Transnational Corporations, Vol. 29, Nr. 1, 2022, pp. 107-135

[57] Nindl, E., *The 2022 EU Survey on Industrial R&D Investment Trends*, Publications Office of the European Union, Luxembourg, 2022, doi:10.2760/579174, JRC131984

[58] Dosso, M., Ramirez, P. (2020). *Organization and geography of global R&D and innovation activities: insights from qualitative research on leading corporate R&D investors*, JRC Working Papers on Corporate R&D and Innovation No 03/2020, JRC119966, Joint Research Centre, Seville, Spain..

Against this background, Box 2 provides a novel approach to estimate the R&D content of GVCs over 2010-2019 using the Scoreboard dataset[59]. It shows how the R&D content of GVCs has developed over time, what countries provide the greatest R&D input, and the role of Chinese R&D in GVCs.

Box 2. R&D in Global Value Chains

Data from the EU Industrial R&D Investment Scoreboard can be used to model the dependency on foreign R&D transferred in GVCs According to Antràs[60], a GVC includes 'a series of stages involved in producing products and services that are sold to consumers, with each stage adding value'. The basic idea is that each stage of a value chain creates inputs that become part of the final product. At the same time, production activities at each stage require R&D that enters downstream stages of production embedded in the output of this stage.

The empirical analysis of potential dependencies uses data from the EU Industrial R&D Scoreboard panel dataset (see Annex 3) and input-output-tables from FIGARO provided by Eurostat. Input-output tables trace the flows of goods for intermediate or final use throughout the economy. The 2022 edition of FIGARO covers the years 2010 to 2020 and includes data for EU Member States, the UK, the US, China, and the EU's other main trading partners. The linkage of countries via imports and exports of intermediate and final goods makes it possible to analyse inputs and outputs GVCs across countries. Both, FIGARO and Scoreboard R&D investment data are aggregated at the NACE 2-digit industry level as well as at country level.

Method and data

The total R&D use in an industry of a country consists of its own R&D activities, R&D by domestic upstream sectors, and R&D imported via GVCs. The R&D content of each stage of a value chain is proxied by weighting the intermediate goods supplied to downstream stages by the R&D activities of this stage. Thus, the R&D content of a certain good can be considered as the sum of the R&D activities in upstream sectors and R&D activities of the producing sector.

Breaking down a value chain into its domestic and foreign upstream components weighted by their R&D content allows to measure the direct and indirect R&D content of GVCs at country and industry level. The difference between the domestic and the global share corresponds to imported R&D.

Results

Dachs et al. (2023)[61] calculate an indicator of dependence by relating imported to total (domestic and imported) R&D use. Dependence is lowest in Japan, the US, and **Germany**, where this share is below 20%. Overall, the results demonstrated EU has a slightly higher dependence than the US and Japan. China is also among the countries with a comparatively lower dependence. On the other end of the distribution are several countries where the indicator is larger than 50%, revealing that most R&D originates from abroad (such as Russia, Hungary, Poland or Czechia).

The results suggest a negative relationship between the share of imported R&D in total R&D and the size of the country. The highest levels of dependence are found in small countries; this can be explained by the higher trade openness in smaller countries. Moreover, not all relevant knowledge may be available in smaller countries, which may also lead to more imported R&D. In contrast, domestic R&D capabilities (domestic R&D as a share of gross output) are negatively related to the share of imported R&D. Thus, domestic capacities are a substitute for imported R&D and dependence from sources abroad. The idea of reducing dependence by improving domestic capacities is also found in some recent EU industrial policy documents (European Commission, 2021b[62], 2022b[63]).

[59] Dachs, Bernhard, Wolfmayr, Anna, Stehrer, Robert, *Europe's Technology Sovereignty and the Role of Knowledge Diffusion in Global Value Chains*, European Commission, Joint Research Centre, Seville, Spain, 2023, forthcoming November 2023

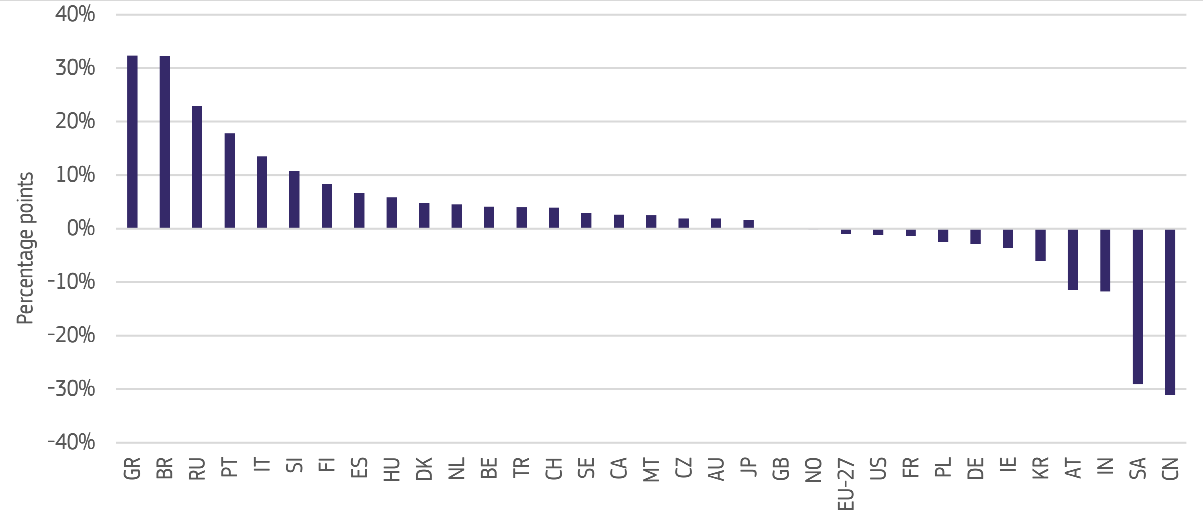
[60] Antràs, P., *Conceptual Aspects of Global Value Chains*, World Bank Economic Review 34, 2020, 551-574.

[61] Dachs, Bernhard, Wolfmayr, Anna, Stehrer, Robert, *Europe's Technology Sovereignty and the Role of Knowledge Diffusion in Global Value Chains*, European Commission, Joint Research Centre, Seville, Spain, 2023, forthcoming November 2023

[62] European Commission, Strategic dependencies and capacities. Staff Working Document accompanying the Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions Updating the 2020 New Industrial Strategy: Building a stronger Single Market for Europe's recovery., SWD(2021) 351 final, Brussels, https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:52021SC0352&from=EN

Figure B2 1 presents the change in the share of imported R&D in total R&D investments over time. In around half of the countries, imported R&D had a higher share in total R&D in 2020 compared with 2010, which indicates that dependence on foreign R&D had increased (e.g. Greece, Portugal, Italy, Slovenia and Finland) between 8 and 32 percentage points. In large countries such as Germany and the US, dependence remained almost unchanged. This also holds for the EU, where dependence decreased by 1.1 percentage points. China, Saudi Arabia and India reduced their dependence on imported R&D considerably between 11 and 30 percentage points between 2010 and 2020.

Figure B2 1. Change in dependence on imported R&D, 2020 vs 2010



Source: Dachs et al., 2023

Overall, there is no clear trend towards higher dependence across the group of countries covered in this study. Dependence on foreign R&D changed only little for large countries and the EU as a whole. In some countries technological capacities in terms of domestic R&D increased faster than imported R&D despite increasing imports, reducing dependence.

Sectoral differences are important drivers of technological dependence at country level. **Countries with a high share of industries that are dependent on imported technology exhibit higher overall dependence.** The sectors are grouped into high- and low-technology sectors, and (less) knowledge-intensive services (Eurostat classification 2014[64], 2016[65]). Intra-EU trade was excluded to make the data for the EU as a whole comparable with other countries.

The EU has high dependence levels of 30% or more for four sectors, three of them are low-tech sectors (see Figure B2 2: high-technology sectors - first group left, low-technology sectors - second group, knowledge-intensive services - third group, less knowledge-intensive services - last group to the right). High-tech sectors and knowledge-intensive services in general have lower levels of dependence than low-tech sectors. Thus, the degree of dependence is correlated with the R&D intensity of sectors. This may be related to the fact that low-tech, supplier-oriented industries receive technology not through own R&D but embodied in products from upstream sectors.

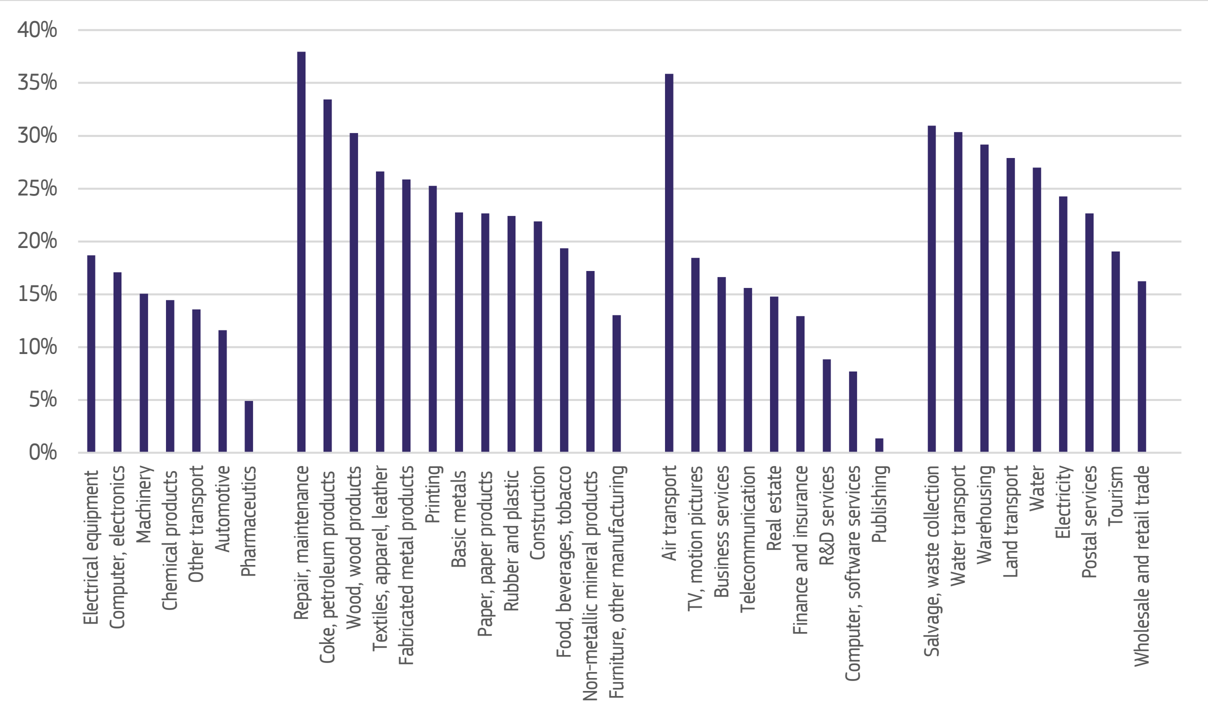
63 European Commission, A Chips Act for Europe. Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions., COM(2022) 45 final, Brussels, https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:52022DC0045&from=EN

64 Eurostat, *Glossary: Knowledge-intensive services (KIS)*, 2014.

65 Eurostat, Glossary: High-tech classification of manufacturing industries, http://ec.europa.eu/eurostat/statistics-explained/index.php/Glossary:High-tech_classification_of_manufacturing_industries, 2016.

Some high-tech sectors such as pharmaceuticals or automotive rank in the lower half of the distribution with dependence levels of 15% or less. Low dependence in automotive and other transport equipment indicates EU's global technological leadership in these sectors. In pharmaceuticals, there is a considerable and widening gap in R&D investment between the EU and the US and a vivid discussion on the EU's dependence on Asia. However, the results of the GVC analysis indicate only a low dependence. At aggregate level, the EU's pharmaceuticals production is highly autonomous in terms of the knowledge it needs to create new products. The result also indicates that imports of pharmaceuticals into the EU are much less R&D-intensive than goods produced in the EU. However, dependence may also emerge at the level of individual substances and products, which this analysis is not able to catch.

Figure B2 2. EU dependence on imported R&D, sectoral level, 2020



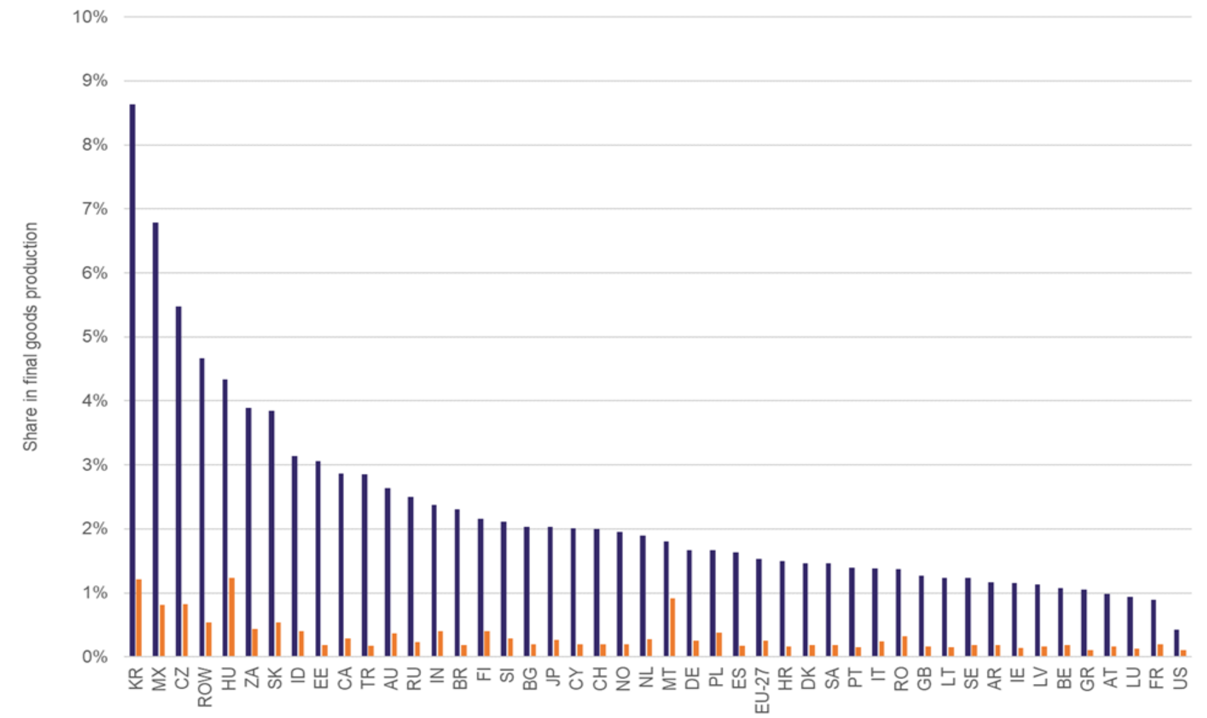
Note: high-technology sectors - first group left, low-technology sectors - second group, knowledge-intensive services - third group, less knowledge-intensive services - last group to the right
Source: Dachs et al., 2023

Figure B2 3 below depicts R&D imported from China as a share of the value of total final goods production in 2010 and 2020. A high share indicates strong technological dependence of these economies on China. We find such high values in South Korea, Mexico, but also in some Central and Eastern European countries (Czechia, Hungary and Slovakia are among the top 7 most dependent countries on imported R&D from China). The figure also shows an increased regional integration between China and Asian-Pacific countries such as South Korea, Indonesia, or Australia.

The share of imported R&D from China increased and at least doubled in all countries between 2010 (orange bars in Figure B2 3) and 2020 (dark blue bars in Figure B2 3), and small countries on average faced a bigger change than large countries. However, imported R&D from China was still only a small fraction of total imported R&D. Overall, the patterns for 2010 and 2020 appear quite similar, and there are only a few countries with little or no dependence in 2010 and high dependence in 2020. Thus, dependence on imported R&D from China grew roughly at comparable speed in all countries.

The Member States of the EU together are slightly more dependent on technology from China than the US or Japan. This can be explained mainly by the share of China in imported value-added content of final demand, which is lower in the US than in the EU. Overall, the US shows the lowest dependence, both in 2010 and 2020, compared to all other countries in the study.

Figure B2 3. Share of imported R&D from China in total final goods production, 2010 and 2020



Note: orange bars refer to 2010, dark blue bars to 2020

Source: Dachs et al., 2023

Conclusions

The current debate on technological dependence and strategic autonomy may reflect changing perceptions of dependence and an increased importance of autonomy rather than changes in the economic fundamentals. However, dependencies certainly exist at the level of single intermediate products or raw materials. The Critical Raw Materials Act, proposed by the European Commission on 16 March 2023, as well as the risk assessment of critical technologies advanced by the EU recently will open new discussions in the context of the European Economic Security Strategy in a situation of weak global economy outlook and increased global uncertainties

The analysis confirms that the dependence on China in terms of imported R&D has at least doubled in most countries over the last decade. China, in contrast, has reduced its dependence due to fast-growing domestic R&D investments. In addition, regional integration in terms of technology flows between Asian countries increased significantly between 2010 and 2020.

2.8 Key points

— The top 2 500 global companies invested a total of EUR 1249.7 billion on R&D in 2022, EUR 141 billion more than 2021. This corresponds to an increase of 12.8% compared to the previous year.

— Compared with 2021, private R&D investment growth by EU Scoreboard firms doubled to 13.6%, which is higher than that of US firms (12.7%) for the first time since 2015, and below that of Chinese Scoreboard firms (16.4%).

— Adjusting for inflation, global R&D investment grew by 7.2%. The inflation-adjusted R&D investment growth of EU Scoreboard firms amounted to 7.8%, the highest growth rate since 2015, exceeding the US inflation adjusted growth rate of 4.9%.

— After a decade of moderate R&D growth, Japanese Scoreboard firms have strongly recovered (10.4% in nominal and 9.3% in inflation-adjusted terms).

— Alphabet, Meta, Microsoft and Apple lead the global Scoreboard ranking, followed by Huawei from China and Volkswagen from the EU. There are 12 other EU-based firms in the top 50 of the global ranking, 23 US-based ones, 5 each from Japan and China, and 5 from the RoW (mainly Switzerland and the UK).

- US companies are responsible for over 40% of total R&D investment, while the R&D shares of EU firms and Chinese firms are now head-to-head (17.5% and 17.8%, respectively). After a continuous increase the share of Chinese firms seems to have stabilised over the past 2 years.
- Purchasing power parity is used to take account of differences in R&D input prices and inflation. Using this approach, the US lost up to 9%, China gained 2-7%, and the EU maintained its share in 2012-2022. In 2022, the US leads with 33%, China followed with 25%, and the EU had 17%.
- Using a patent analysis to investigate the R&D flows within companies but across regions and countries shows that around 80% of a company's R&D investment remains within the same country/region. The US remained the most popular foreign R&D location for non-US-based companies.
- Augmenting input-output tables with the R&D investment data from past Scoreboards in a global value chain analysis allows to investigate potential dependence on imported R&D content. This novel approach does not find a general trend for rising dependence by countries worldwide on foreign technology in the past decade. The share of imported R&D increased in around half of the countries in the analysis and decreased in the other half. Dependence in the US and the EU is overall low and has changed only very little.
- The EU has high dependence on foreign R&D of 30% or more for 4 sectors, 3 of which are low-tech sectors (repair and maintenance, coke and petroleum products, wood and wood products). This may be related to the fact that low-tech, supplier-oriented industries receive technology not through their own efforts in R&D but embodied in products from upstream sectors.

3 R&D investment by sectors

Large and multinational companies often operate in multiple domains, rendering it difficult to assign such companies to one single industrial sector. Therefore, since its first edition, the Scoreboard has assigned companies to their main sector according to the taxonomies provided by the Industry Classification Benchmark (ICB) and its predecessors. The main sector is usually the one indicated by the companies in their annual reports. The 38 ICB 3-digit classifications are grouped into 10 broader categories and the remaining, mostly small sectors are moved into the category 'others'. Section 3.1 describes the characteristics of these 11 sector groups, section 3.2 makes a deep-dive into the four sectors that cover the largest share of R&D in the Scoreboard – health, ICT services, ICT producers, and automobiles and other transport ('automotive'), 3.3 analyses the remaining sectors along the same lines. The section concludes with key points in 3.4.

3.1 Overview of sectors

Table 11 shows the breakdown of the 2022 companies by ICB 3-digit classification and provides the number of firms and the sector's share of the 2 500 companies, the sector's R&D investment and its share in total Scoreboard R&D, the R&D intensity, and the average R&D investment per firm.

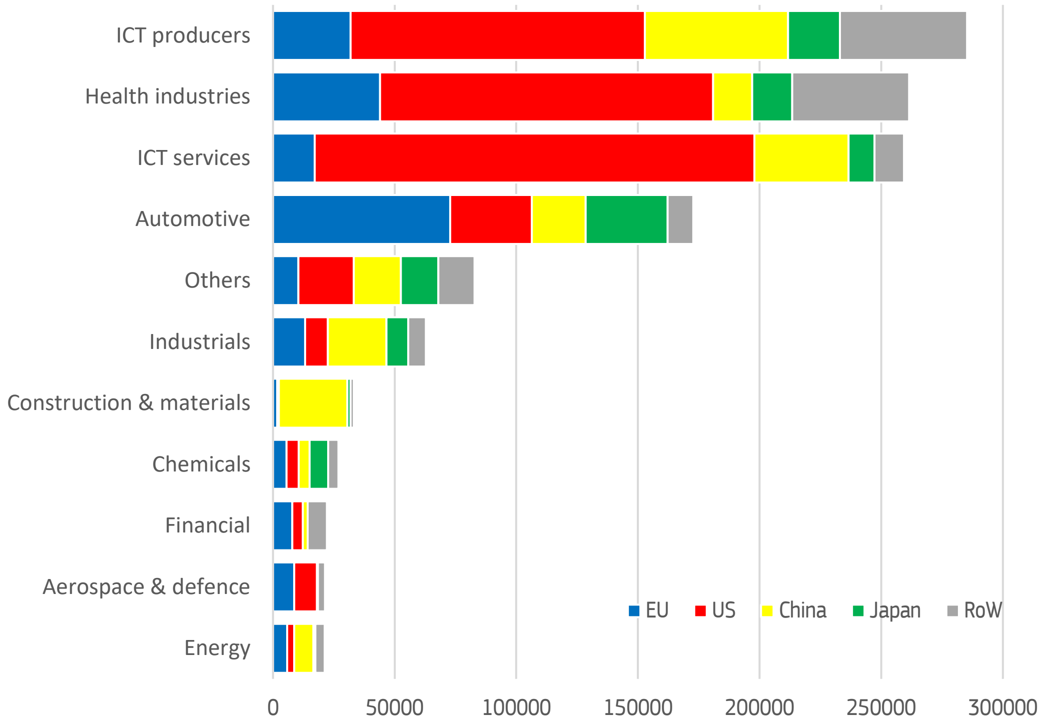
Table 11. R&D by ICB3 sector classification

ICB3 sector	Sector classification (ICB4)	Firms, share	2022 R&D (EUR bn), share	R&D intensity	R&D per firm (EUR million)
Aerospace & defence	Aerospace; Defence	41 (46) 1.6%	21.3 1.7%	4.5%	520.9
Automotive	Automobiles & parts; Tyres; Commercial vehicles & trucks	172 (176) 6.9%	172.7 13.8%	4.8%	1 004.1
Chemicals	Chemicals; Specialty chemicals; Specialty retailers	113 (116) 4.5%	26.9 2.2%	2.2%	238.3
Construction	Heavy construction; Construction & materials; Building materials & fixtures	66 (64) 2.6%	33.2 2.7%	2.3%	503.5
Energy	Exploration & production; Renewable energy equipment; Oil & gas producers; Electricity; Oil equipment, services & distribution; Alternative energy; Alternative fuels; Conventional electricity; gas, water & multiutilities; Gas distribution	72 (80) 2.9%	21.2 1.7%	0.4%	295.3
Financial	Banks; Specialty finance; Financial services; Real estate investment & services; Investment services; Real estate holding & development; Consumer finance; Full line insurance; Reinsurance; Life insurance	59 (64) 2.4%	22.1 1.8%	3.5%	375.2
Health industries	Pharmaceuticals; Biotechnology; Medical equipment; Healthcare equipment & services; Healthcare providers; Medical supplies	584 (566) 23.4%	261.4 20.9%	12.9%	447.6
ICT producers	Computer hardware; Telecommunications equipment; Electronic equipment, Semiconductors; Electrical component & equipment; Electronic office equipment	470 (456) 18.8%	285.3 22.9%	7.4%	607.1
ICT services	Computer Services; Software; Telecommunication services	356 (357) 14.2%	259.3 20.8%	10.9%	728.4
Industrials	General industrials; Iron & steel; Diversified industrials; Industrial machinery; Transportation services; Coal; Industrial metals & mining; Containers & packaging; Nonferrous metals; Industrial transportation; General mining; Aluminium; Gold mining; Platinum & precious Metals; Industrial suppliers;	281 (276) 11.2%	62.8 5.0%	2.3%	223.6
Others*	General retailers; Food producers; Household goods & home construction; Media; Travel & leisure; Personal goods; Support services; Beverages; Tobacco; Food & drug retailers; Forestry & paper	286 (299) 11.4%	82.8 6.6%	2.7%	289.8
Total		**2 500**	**1 249.4**	**4.7%**	**499.9**

Note: *Sectors listed under 'Others' are presented at ICB3 digit level. Figures in brackets represent the number of companies in the 2022 Scoreboard. R&D intensity is defined as R&D investment divided by net sales per sector, R&D per firm is the average per sector.
Source: The 2023 EU Industrial R&D Investment Scoreboard. European Commission, JRC/DG R&I.

Figure 17 shows the distribution of the R&D investment of the 2 500 companies in 2022 by sector and region. Corporates headquartered in the US contribute most to the top three R&D investing sectors, namely ICT producers, health industries and ICT services, with a particularly high degree of dominance in ICT services. The second largest R&D investment in the two ICT sectors originates from Chinese firms, while EU companies are responsible for the third largest. In the health sector, US-based firms dominate as well, but here EU companies are second and invest more than Chinese firms. The fourth largest sector, automotive, is the EU stronghold with 42.2% of the sector's total investment, and EU firms invest more than twice as much in R&D than their competitors from Japan or the US, and over three times more than Chinese automotive companies.

Figure 17. R&D investment by sector and country/region, 2022



Notes: R&D investment in EUR million.
Source: The 2023 EU Industrial R&D Investment Scoreboard. European Commission, JRC/DG R&I.

Table 12 shows the share of firms per sector across the five countries/regions; each cell contains the number of firms and the share of firms in the respective regional total in 2022. The column 'Total' contains each sector's share of companies in top 2 500, and the row 'Total' each region's number and share of Scoreboard companies. Comparing the shares (number) of companies for each region with the regional total (row total) shows in which sector a region has a larger share than its overall share of firms (marked in bold).

Table 12. Distribution of firms across sectors and regions, number and share per region (in brackets), 2022

	EU	US	China	Japan	RoW	Total
Aerospace & defence	**12 (29.3%)**	**15 (36.6%)**	3 (7.3%)	0	**11 (26.8%)**	41 (1.6%)
Automotive	**35 (20.3%)**	37 (21.5%)	**48 (27.9%)**	**26 (15.1%)**	26 (15.1%)	172 (6.9%)
Chemicals	15 (13.3%)	20 (17.7%)	**34 (30.1%)**	**28 (24.8%)**	16 (14.2%)	113 (4.5%)
Construction & materials	**9 (13.6%)**	4 (6.1%)	**36 (54.5%)**	**20 (15.2%)**	7 (10.6%)	66 (2.6%)
Energy	**24 (33.3%)**	10 (13.9%)	19 (26.4%)	**8 (10.6%)**	**11 (15.3%)**	72 (2.9%)
Financial	**23 (39.0%)**	9 (15.3%)	12 (20.3%)	0	**15 (25.4%)**	59 (2.4%)
Health industries	69 (11.8%)	**319 (54.6%)**	99 (17%)	30 (5.1%)	67 (11.5%)	584 (23.4%)
ICT producers	42 (8.9%)	117 (24.9%)	**161 (34.3%)**	**47 (10.0%)**	**103 (21.9%)**	470 (18.8%)
ICT services	30 (8.4%)	**193 (54.2%)**	81 (22.8%)	7 (2.0%)	45 (12.6%)	356 (14.2%)
Industrials	**60 (21.4%)**	34 (12.1%)	**110 (39.1%)**	**37 (13.2%)**	40 (14.2%)	282 (11.2%)
Others	**48 (16.8%)**	69 (24.1%)	76 (26.6%)	**36 (12.6%)**	**57 (19.9%)**	286 (11.4%)
Total	367 (14.7%)	827 (33.1%)	679 (27.2%)	229 (9.2%)	398 (15.9%)	2 500 (100%)

Note: % refer to the row total. Bold figures indicate that the sector has a higher share than the region's overall share of firms in 2022.
Source: The 2023 EU Industrial R&D Investment Scoreboard. European Commission, JRC/DG R&I.

In bold, we indicate for each region those sectors for which the share (number) of companies is larger than its overall share in the Scoreboard. In this relative specialisation pattern we observe that the EU is over-represented in 7 of the 11 sectors. However, these seven sectors are of low R&D intensity (see Table 11), and in fact EU firms are significantly under-represented in the top three R&D sectors.

The distribution of EU firms can be interpreted as the EU having a good representation of R&D investors in a broad range of sectors, indicating a high degree of diversity of major R&D investors from the EU. In the health sector, the share of EU companies has been decreasing since 2012, but the EU companies are nevertheless responsible for a substantial share of R&D, and, as will be discussed in Section 4, has a large and growing number of small but innovative firms in this sector. Still, the low and declining share of EU firms in ICT services is a reason for concern regarding the future development and growth of such firms in the EU.

The US shows a distinct specialisation picture: US firms are overrepresented only in three sectors, but two of them, ICT services and health, are among the top four sectors by R&D investment. These two sectors are basically dominated by US firms that account for more than half of all companies. As will be shown in this section below, US companies also dominate the R&D investments in the ICT producers sector, albeit the largest number of firms is headquartered in China. Moreover, the US is leading in aerospace and defence, both in terms of number of companies and R&D investment, but with a smaller lead compared with ICT services and health.

China and Japan exhibit a very similar pattern in terms of sectoral representation in 2022; both countries have an over-proportional number of firms in sectors with low R&D intensity such as construction or chemicals. However, a large share of firms does not automatically correspond to a high share in R&D investment, as can be seen when connecting the insights from Table 12 and Figure 17. While China has a larger number of companies in the automotive sector than the EU and Japan, China's aggregate R&D investment is considerably lower (see Section 3.2.4). Moreover, both countries have an overproportioned share of ICT producer firms, but also here, their share of R&D is well below their share of companies.

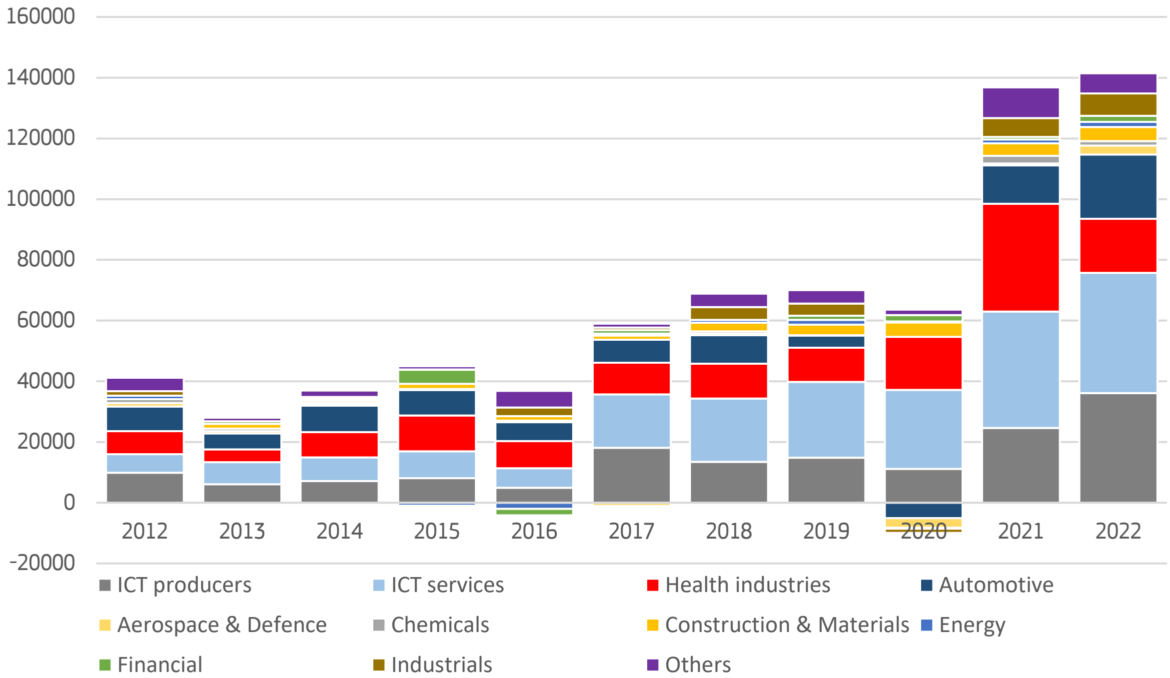
The countries grouped under RoW include major R&D locations such as the UK, Switzerland, South Korea and Taiwan, and more emergent innovation locations such as Vietnam or Türkiye. This diverse group of countries has an over-proportional share in ICT producers due to the semiconductor manufacturers, electric and electronic equipment producers and other prominent firms notably in Taiwan and South Korea. Likewise, the energy sector is well represented with large oil and gas producers from Saudi Arabia or the UK.

The more than threefold increase in the number of Chinese companies in the Scoreboard since 2012 led to changes in the regional composition. The rise of Chinese firms was mostly at the expense of companies headquartered in the EU and Japan. As a consequence of the EU's decline in the company share among the top 2 500 from 20.5% in 2012 to 14.5% in 2022, the EU leads in terms of firms in only relatively small sectors such as energy and financials; both sectors are small also in terms of R&D share (1.7% and 1.8%, see Table 11). However, while the EU share in financials (and other sectors) declined from over 51% in 2012, the share of firms in the energy sector increased slightly to 33.3% in 2022, mostly due to traditional energy suppliers.

In industrials, the EU held the largest number of firms in 2012 (28.5%), but in 2022 the share decreased to 21.4%, and China now leads in terms of companies. The share of EU firms in aerospace and defence increased to 29.3%, while in chemicals it decreased from 15% to 13.3%. In the ICT producers sector, the EU share decreased from 10.7% to 8.9%, and in ICT services it dropped significantly from 17.2% to only 8.4% in 2022. The same development was to be observed in health where the EU firm share fell from 21% in 2012 to 11.8%. In automotive the share decreased from 22.9% to 20.3%.

Figure 18 shows the contribution of each sector to the annual nominal increase in total R&D investment in absolute terms. This visualisation clearly displays how significant the increase in the ICT sectors has been over time – particularly in 2022, the additional R&D investment by the two broad ICT sectors was nominally higher than every year's total increase in R&D investment between 2012 and 2020. In other words, even though the ICT sectors were largest in terms of R&D already, they have expanded their R&D activities even more. The third-largest contributor to overall growth is the health sector, which particularly strongly increased its R&D investment during the COVID-19 pandemic (2020 and 2021), and continued to grow at a faster speed than before the pandemic in 2022. In 2021 and 2022, also the automotive sector constituted an important driver of overall R&D growth in the Scoreboard.

Figure 18. Annual nominal increase in R&D investment by sector in EUR million - Sectoral decomposition, 2012-2022



Source: The 2023 EU Industrial R&D Investment Scoreboard. European Commission, JRC/DG R&I.

Table 13 shows R&D investment growth (in %) compared with the previous year since 2012 for each of the 11 sectors, both in nominal values and in inflation-adjusted growth rates (in brackets). In 2022, the highest increments occurred in the ICT services sector, followed by aerospace and defence, construction and materials, ICT producers, and automotive.

Table 13. Nominal and inflation adjusted growth rates of R&D investment per ICB3 sector in %, 2012-2022

	2012	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**	**2021**	**2022**
Aerospace & defence	6.2 (4.2)	3.6 (2.1)	2.6 (1.2)	0.3 (-0.7)	2.3 (1.2)	-4.9 (-6.5)	2.7 (0.7)	-0.6 (-2.3)	-15.3 (-17.1)	3.1 (-0.3)	16.2 (10.1)
Automotive	9.4 (8.2)	5.6 (4.3)	8.8 (7.1)	7.7 (6.1)	7.8 (4.3)	5.3 (4.3)	6.1 (4.7)	2.8 (1.3)	-3.5 (-4.8)	9.2 (6.3)	13.9 (8.9)
Chemicals	6.8 (5.7)	4.0 (2.9)	1.8 (0.4)	1.1 (0.3)	-0.2 (-0.9)	-0.1 (-1.3)	3.1 (1.5)	0.6 (-0.6)	-1.4 (-2.3)	10.8 (8.4)	6.2 (2.3)
Construction & materials	-0.5 (-1.9)	23.5 (21.6)	9.2 (8.1)	18.7 (17.9)	13.9 (12.6)	12.0 (8.5)	20.8 (17.3)	21.5 (19.7)	23.7 (22.6)	16.9 (12.3)	16.1 (12.9)
Energy*	6.9 (3.9)	-3.1 (-4.8)	2.8 (1.5)	-5.5 (-7.1)	-12.0 (-12.6)	4.3 (1.5)	6.4 (4.7)	9.7 (8.4)	1.7 (0.5)	6.8 (2.9)	8.9 (3.7)
Financial	-1.8 (-3.2)	8.5 (6.9)	6.0 (4.7)	39.1 (38.0)	-12.6 (-13.5)	7.9 (6.1)	0.4 (-1.6)	8.6 (6.6)	12.5 (10.3)	4.7 (2.2)	10.5 (4.6)
Health industries	6.5 (5.1)	3.4 (2.1)	6.5 (5.1)	8.6 (7.6)	6.1 (5.2)	6.6 (5.1)	6.8 (4.8)	6.3 (4.6)	9.2 (7.7)	17.0 (13.6)	7.3 (1.5)
ICT producers	7.5 (6.0)	4.4 (2.9)	4.9 (3.3)	5.2 (3.9)	3.0 (1.9)	10.8 (8.5)	7.3 (5.0)	7.5 (5.9)	5.2 (3.9)	11.0 (7.3)	14.6 (9.4)
ICT services	11.0 (9.3)	11.6 (9.9)	11.2 (9.3)	11.6 (10.5)	7.5 (6.4)	19.2 (16.9)	19.1 (16.3)	19.2 (17.2)	16.8 (15.5)	21.1 (16.6)	18.0 (11.1)
Industrials*	3.7 (2.0)	-0.8 (-2.3)	-1.3 (-2.8)	0.4 (-1.0)	7.4 (6.4)	2.1 (0.4)	9.9 (7.6)	8.5 (6.9)	-2.6 (-3.9)	12.6 (8.9)	13.2 (8.9)
Others	11.2 (10.3)	2.6 (1.7)	4.7 (3.1)	2.1 (0.7)	11.1 (10.0)	2.3 (0.7)	7.9 (5.9)	7.5 (5.9)	2.7 (1.4)	15.4 (12.4)	8.7 (4.1)
Total	**7.6 (6.1)**	**4.7 (3.3)**	**6.0 (4.5)**	**6.8 (5.5)**	**4.7 (3.8)**	**8.0 (6.2)**	**8.9 (6.7)**	**8.3 (6.6)**	**5.9 (4.5)**	**14.1 (10.5)**	**12.8 (7.2)**

Note: Due to low number of firms in some sectors growth rates can change considerably due, e.g., to firm entry/exit. Inflation adjusted values in brackets. * Sector affected by strong decline in number of firms in 2014 and 2015
Source: The 2023 EU Industrial R&D Investment Scoreboard. European Commission, JRC/DG R&I.

Since 2012, ICT services has been the sector with the highest growth rates, and regardless of if the sector's already very high levels of R&D, growth has still accelerated over time. Similarly, producers of ICT hardware continue to expand their R&D investment at even higher rates, achieving the highest addition of R&D investment in 2022. In 2022, aerospace and defence achieved the highest increase in R&D investment ever, driven by the simultaneous events of easing COVID-19 restrictions and the Russian war against Ukraine, which caused a strong increase in military spending. The automotive sector also stepped up its R&D activities and, just like the ICT producers sector, in 2022, it achieved its highest nominal and real growth rates of R&D investment ever recorded in the Scoreboard.

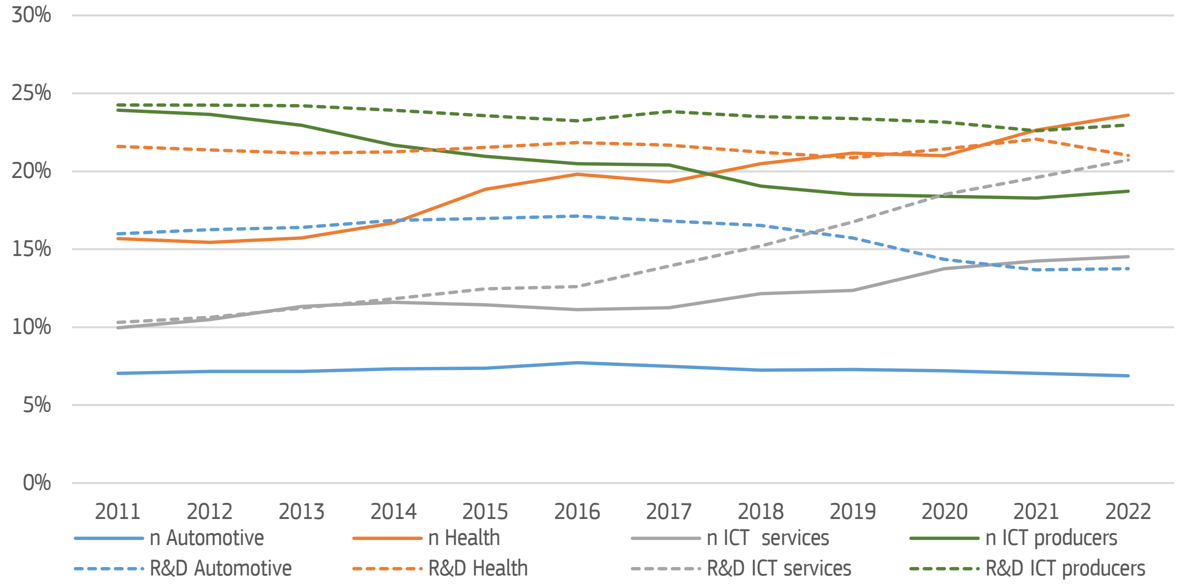
The fast-growing construction sector is small in terms of number of firms and R&D investment and dominated by Chinese firms with government ownership (to varying degrees). It thus follows a different entrepreneurial logic that can hardly be compared to other sectors.

As mentioned in Section 2.6, until the year 2020 inflation was low, with an average value of 1.5%, but in 2021 and 2022, prices increased considerably in the EU and the US, and to a lesser extent also in China and Japan. Price increases affect sector aggregates to a different degree depending on the regional distribution of the companies' R&D activities and markets. Consequently, the largest effect of inflation appears in sectors, like ICT services or health services, which are dominated by a high number of firms headquartered in the US. In ICT services, inflation-adjusted R&D growth was 6.9% lower than nominal R&D growth in 2022.

3.2 The top four R&D investing sectors

As shown in Table 11, the distribution of firms and R&D across the 11 sectors is highly concentrated: 78.4% of all R&D investment in 2022 (EUR 934 billion) was realised by 63.2% of the firms (1 592 firms) in four key sectors, namely ICT producers, health industries, ICT services, and automotive. The concentration in these four sectors in terms of firms increased in the period of analysis from 72.5% of R&D and 56.7% of all companies in the ranking. These top sectors cover technologies that are considered critical technology areas for the EU's economic security[66] such as advanced semiconductors, artificial intelligence technologies, quantum technologies, and biotechnologies. The following subsections will thus elaborate on how EU companies compare with their competitors in these critical sectors.

Figure 19. R&D top sectors – share of firms and share of R&D



Source: The 2023 EU Industrial R&D Investment Scoreboard. European Commission, JRC/DG R&I.

Figure 19 shows the evolution of the share of firms and R&D investment of these sectors between 2012 and 2022. Several trends, which will be analysed in more detail in the following four subsections, are visible.

- The largest share of R&D is (still) realised by the companies in the ICT producers sector. Since 2012, its share of R&D investment remained rather stable around 23%, while the share of firms decreased from 23.6% to 18.8% (see section 3.2.1);

[66] C(2023) 6689 final

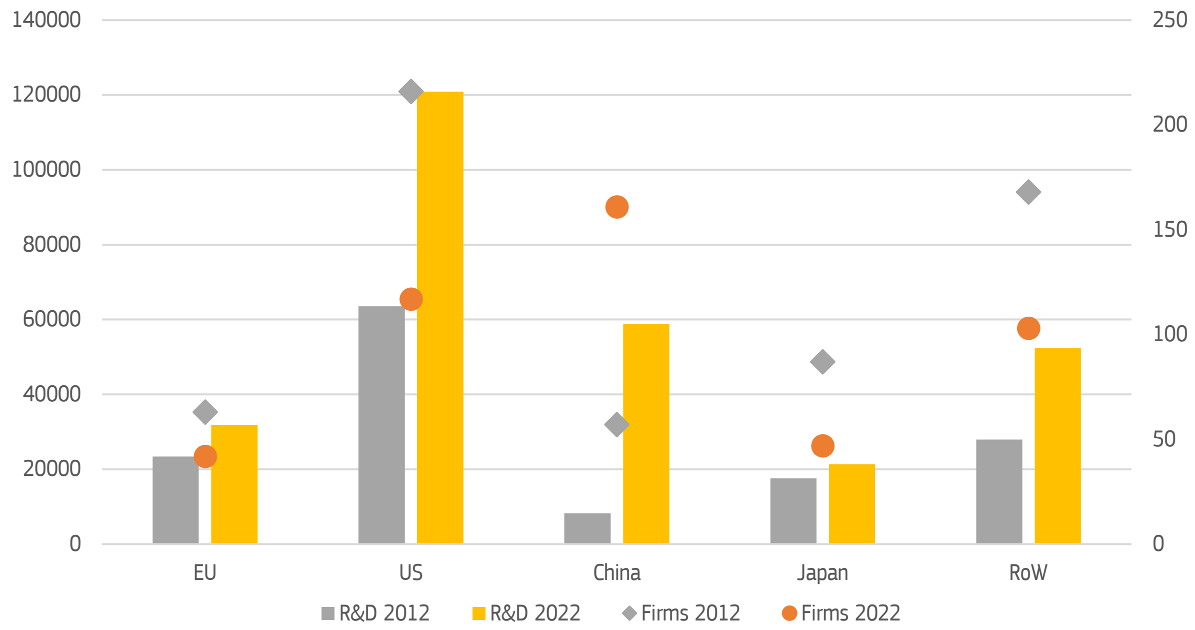
- The number of firms in the health sector increased strongly from 15.4% to 23.4%, the share of R&D investment amounted to around 21% - this shows that in the recent years, many firms – mostly younger and smaller but R&D intensive-firms – from the biotech (biopharma as it is often called in the US) sector entered the Scoreboard (see section 3.2.2).
- While the ICT software and services sector accounted for around 10.5% of firms and R&D in 2012, the sector's R&D investment share doubled over the years and reached almost 21% in 2022, while the number of firms increased by 5 percentage points. It has been the fastest growing sector in terms of R&D in the past decade (see section 3.2.3).
- The automotive sector is responsible for only around 7% of the companies, but for 16% (2012) and 13.8% (2022) of the R&D investment. Since 2016, the automotive sector R&D share has been declining slightly, while the number of companies remains stable (see section 3.2.4).

Overall, the two ICT sectors cover 43% of the total R&D investment of the 2 500 Scoreboard companies, and 33% of the firms. Taking into account that the world's largest ICT company – Amazon – is missing in the Scoreboard due to its accounting practice[67], the actual share of the ICT sector would be even higher. This makes it clear that the ICT technologies/infrastructure/equipment, software and related services connected to the aspects of digitalisation of life and businesses have been – since more than 10 years – the world's drivers of corporate R&D. While the role of tech hardware and equipment remains as central as it was a decade ago, it is the ICT software and service sector that has both shaped and reaped the benefits of the internet and smartphone age.

3.2.1 ICT producers

The ICT producers sector comprises firms producing computer hardware, electronic and electric equipment (including electronic office equipment), semiconductors, and telecommunications equipment. It constitutes the largest sector in terms of R&D in the Scoreboard. In the general context, the number of ICT producers in the Scoreboard decreased from 591 (23.6%) in 2012 to 470 (18.8%) in 2022. At the same time the R&D investment remained rather stable, declining only slightly from 24.2% in 2012 to 22.9% in 2022. Overall, the sector increased its R&D investment on average by 6.6% per year (5.3% adjusted for inflation).

Figure 20. Firms & R&D in ICT producers, 2012 and 2022, across regions/countries



Notes: R&D investment in EUR million on the left axis, number of firms on the right axis.
Source: The 2023 EU Industrial R&D Investment Scoreboard. European Commission, JRC/DG R&I.

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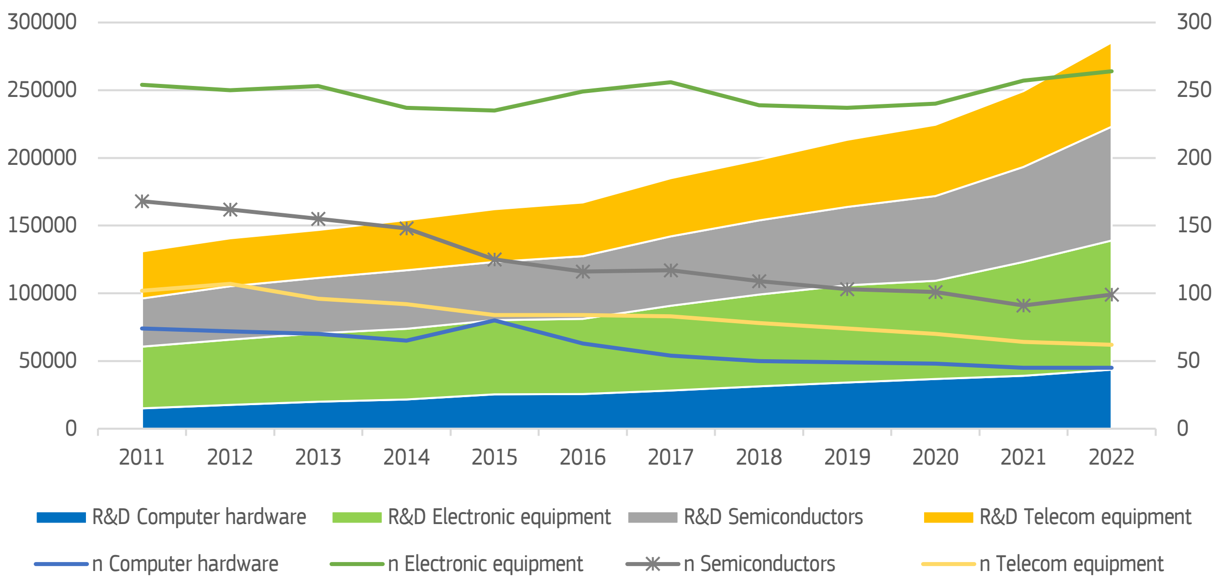
67 Amazon does not report R&D investment, but only a combined figure for 'Technology and Content' investment in its accounts. Since no information is given on how to extract the R&D component, it is not possible to include Amazon in the Scoreboard. However, using statements in Amazon's accounts it is estimated that Amazon's R&D could be larger than Alphabet's so Amazon should probably have been #1 in the 2023 Scoreboard R&D ranking.

Figure 20 compares the number of firms and their R&D investments in 2012 and 2022. The first observation is that the US was the dominant player in 2012 and is still the largest R&D investor worldwide. In the same period, China made a huge improvement, jumping to the second-largest investor (in 2012 only fifth) and coming on top with regard to the number of Scoreboard firms. EU and Japanese R&D investment in this sector increased only moderately over this decade.

With regard to the number of companies, there has been a concentration effect resulting from a reduction of Scoreboard companies in all regions except China, but this increase does not compensate for the losses in other regions. From a technology point, this decrease has been more pronounced in the number of firms producing computer hardware, semiconductors and telecommunications equipment, while there has been a modest increase in electronic and electrical equipment companies (see Figure 21).

Figure 21. ICT producers, number of firms and R&D investment, ICB4 classification, 2012-2022



Note: R&D investment in EUR million on the left axis, number of firms on the right axis.
Source: The 2023 EU Industrial R&D Investment Scoreboard. European Commission, JRC/DG R&I.

In 2022, the ICT producers together invested EUR 285.6 billion in R&D (in nominal terms, adjusted for inflation it was EUR 243.1 billion). Since 2012, the sector's nominal R&D investment grew on average by 6.1% (compound annual growth rate, CAGR), and by 4.8% if accounting for inflation. The strongest growth was realised in the computer hardware subsector with 8.7% on average per year, followed by semiconductors with 7.1%, electronic and electrical equipment with 6.4%, and telecommunications equipment with 5.3%.

The ICT producers sector is characterised by a strong regional concentration, as seen in Figure 20, and summarised in Table 14 below. In 2022, 25% of ICT producers were headquartered in the US (see column 'total'), and they spend EUR 120.9 billion or 42.3% of the sector's total R&D. While the US share of firms decreased from 36.6% in 2012, its share in R&D declined only moderately over the period (45.2% in 2012). The share of Chinese ICT producers increased considerably from 9.6% in 2012 to 34.6% in 2022, and their share of R&D went up from 5.9% to 20.3%, thereby exceeding the R&D share of RoW.[68] Companies grouped in RoW constitute traditional major players in the global ICT producers sector, and the countries account for 18.3% (19.9% in 2012) of the sector's R&D and 21.4% (28.4% in 2012) of the companies. The country with most ICT producers in RoW is Taiwan with 66 companies in 2022 (down from 97 in 2012), followed by UK with 9, Switzerland with 8 and South Korea with 7. The EU and Japan headquarter the lowest number of firms and R&D, but while the EU has fewer firms than Japan, their R&D investment of EUR 31.9 billion in 2022 is almost 50% higher than that of the Japanese ICT producers. The share of Japanese firms decreased from 14.7% in 2012 to 10% in 2022, while the EU's share declined only slightly from an already low level (from 10.6% to 8.9%). In terms of R&D, Japan's share decreased from 12.5% to 7.5%, and the EU's share from 16.6% to 11.2%. Consequently, the EU ranks only fourth in this sector in terms of R&D investment.

[68] Note that in PPP adjusted terms the US share would be around 10 %-points lower, and the Chinese share correspondingly higher.

Table 14. ICT producers 2022: Firms and R&D across regions, ICB4 classification

		Computer hardware	Electronic & electric equipment	Semiconductors	Telecommunication equipment	Total
EU	Firms	3	26	10	3	42
	Share	6.7%	9.8%	10.1%	4.8%	8.9%
	R&D	1 158	11 841	9 891	9 006	31 988
	Share	2.6%	12.4%	11.7%	14.5%	11.2%
US	Firms	12	48	37	20	117
	Share	26.7%	18.2%	37.4%	32.3%	24.9%
	R&D	34 733	13 725	50 824	21 628	120 911
	Share	79.6%	12.5%	62.6%	34.5%	42.3%
China	Firms	11	105	18	27	161
	Share	24.4%	39.8%	18.2%	43.5%	34.3%
	R&D	3 673	23 307	2 862	30 004	59 847
	Share	8.3%	23.5%	3.5%	47.9%	20.9%
Japan	Firms	0	35	10	2	47
	Share	0.0%	13.3%	10.1%	3.2%	10.0%
	R&D	0.0	18 021	2 562	258.9	20 843
	Share	0.0%	18.9%	3.7%	0.4%	7.3%
RoW	Firms	19	50	24	10	103
	Share	42.2%	18.9%	24.2%	16.1%	21.9%
	R&D	4 145	30 828	15 616	1 400	51 990
	Share	9.4%	32.6%	18.3%	2.6%	18.2%
Total	Firms	45	264	99	62	470
	Share	9.6%	56.2%	21.1%	13.2%	19%
	R&D	43 648	95 344	84 092	62 251	285 337
	Share	15.3%	33.5%	29.4%	21.8%	100%

Note: R&D expressed in EUR million.
Source: The 2023 EU Industrial R&D Investment Scoreboard. European Commission, JRC/DG R&I.

The regional concentration of ICT producers is most visible in its smallest subsector, **computer hardware**. In 2022, 45 companies with a total R&D investment of EUR 43.6 billion constituted this sector. Out of this, 79.5% was invested by the 12 companies headquartered in the US, including big players such as Apple (world rank 4, R&D EUR 24.6 billion), Dell (world rank 81, R&D EUR 2.5 billion), or Western Digital (world rank 103, R&D EUR 2.1 billion). The first non-US company in this subsector is Lenovo from China (world rank 126, R&D EUR 1.7 billion), and the first EU company is Seagate (world rank 249, R&D EUR 866 million), an US based company with headquarters in Ireland. Also Logitech International (world rank 691, R&D EUR 263 million), registered in Switzerland, has its operative headquarters in the US. The largest number of firms comes from RoW, but they only account for 9.5% of the R&D; the prinicipal R&D investors from this region are located in Taiwan, such as Wistron (world rank 282, R&D EUR 763 million) or Quanta Computer (world rank 409, R&D EUR 499 million).

The **electronic and electrical equipment subsector** is the largest in terms of companies (264, or 56.2% of the companies) and in R&D (EUR 95.6 billion or 33.5% of ICT producers R&D). The sector is composed of a set of quite heterogeneous companies, the three largest in the 2022 ranking are Samsung Electronic from South Korea (world rank 7, R&D EUR 18.4 billion), Siemens from Germany (world rank 38, EU rank 9, R&D EUR 5.5 billion) and Hon Hai (Taiwan, world rank 22; R&D EUR 3.5 billion, the mother company of large component manufacturers and assemblers such as Foxconn). Even if the EU has some significant companies in this sector, the EU accounts the lowest share of firms and R&D relative to the other regions. China is the region with most companies – almost 41% of the companies in the subsector have their headquarters there – but the R&D share is only 23.9% (the highest-ranked Chinese company is Contemporary Amperex Technology, world rank 114, R&D EUR 1.9 billion). The largest share of R&D investment originates from companies in RoW, they are responsible for EUR 30.8 billion (18.9% of the companies, 32.5% of electronic and electrical equipment R&D). Japanese companies account for 18.8% of R&D with the largest companies being Hitachi (world rank 89, R&D EUR 2.5 billion) and Canon (world rank 104, R&D EUR 2.2 billion).

Semiconductors constitute central components of many products. As a consequence of the shortage of semiconductors during the COVID-19 pandemic, the companies earned much political attention, in the US and Europe, and also in China. All regions/countries aim at strengthening their position in the semiconductor sector. Data from the Scoreboard shows that the sector is highly concentrated in terms of R&D – the US companies account for 62.2% of the total R&D investment of EUR 84.1 billion and for 40% of the companies. The largest US players are Intel (world rank 8, R&D EUR 16.4 billion), Nvidia (world rank 26, R&D

EUR 6.9 billion) and Advanced Micro Devices (world rank 44, R&D EUR 4.7 billion). RoW with Taiwan and South Korea account for 25.5% of the companies and 19.1% of R&D. The most dominant companies are Taiwan Semiconductor TSMC (world rank 42, R&D EUR 4.9 billion) and SK Hynix (world rank 54, R&D EUR 3.3 billion) in South Korea. In terms of R&D the EU ranks third with 12.1% of the investment, and 11% of the companies, with the most important EU companies being the two Dutch companies ASML Holding (world rank 64, EU rank 14, R&D EUR 3.1 billion) and NXP Semiconductors (world ranks 111, EU rank 24, R&D EUR 2.0 billion) and Infineon Technologies from Germany (world rank 113, EU rank 25, R&D EUR 1.9 billion). In contrast, China has a larger share of companies (14.4%) but with EUR 2.8 billion only 3.5% of the subsector's R&D investment. The largest Chinese semiconductor company in the Scoreboard is TCL Zhonghuan Renewable Energy Technology Co (world rank 508, R&D EUR 348 million).

In **telecommunications equipment,** the number of firms declined between 2012 and 2022 from 18.1% to 14.1% of the ICT producers companies, and the R&D share also decreased from 25% to 21.9%. China is specialised in R&D in telecommunications equipment, but the relative importance of this subsector decreased also in China as from 2012 from 73.9% to 50.1% of total Chinese ICT producers R&D (even if total telecom equipment R&D investment grew). Overall, Chinese companies account for 44% of telecommunication equipment firms, and for 48% of the R&D; the US is second with 31.8% of the companies and 34.6% of R&D investment. The largest company is China's Huawei Investment & Holding on world rank 5 (R&D EUR 20.9 billion), followed by Qualcomm (world rank 21, R&D EUR 7.7 billion) and Cisco Systems (world rank 32, R&D EUR 6.2 billion) from the US. The EU comes third in terms of R&D (14.6% in 2022), but has only 6% of the companies. The largest R&D investors from the EU are Nokia from Finland (world rank 47, EU rank 11, R&D EUR 4.5 billion) and Ericsson from Sweden (world rank 49, EU rank 12, R&D EUR 4.2 billion).

Table 15. R&D ICT producers, ICB4 classification, EU vs other countries, 2012 and 2022

	US		**China**		**Japan**		**RoW**	
	2012	2022	2012	2022	2012	2022	2012	2022
ICT producers - Total	**0.37**	**0.26**	**2.82**	**0.54**	**1.33**	**1.49**	**0.84**	**0.61**
Computer hardware	0.09	0.03	1.42	0.32	8.88	NA	0.47	0.28
Electronic and electrical equipment	1.13	0.99	8.12	0.53	0.52	0.66	0.50	0.38
Semiconductors	0.15	0.19	12.55	3.33	2.99	3.16	0.80	0.64
Telecommunications	0.64	0.42	1.59	0.30	23.49	35.42	2.51	5.48

Note: Factors represent ratios of R&D investment in EUR million per region, year and (sub)sector. Values greater than 1 indicate the EU's relative strength and values lower than 1 relative weakness.

Source: The 2023 EU Industrial R&D Investment Scoreboard. European Commission, JRC/DG R&D.

Table 15 provides an overview of the position of the EU vis-à-vis other regions for ICT producers and their subsectors in 2012 and 2022. The relative strength is their respective ratios (e.g. EU R&D investment vs US R&D investment) whereby a ratio larger than one implies that the EU has more R&D in this (sub)sector than the other country/region and vice versa. The comparative change over time is an indicator for the development in the two respective regions. The table shows that the EU is losing grounds with respect to all regions except Japan, and that the gap widened considerably after 2012. Beyond this unfavourable general trend, the analysis reveals the following insights:

- **EU-US:** The EU invested only 37% of the US R&D in 2012, and this ratio declined to 26% in 2022. This increase for the US can be attributed to strong US computer hardware companies that invested 30 times more in R&D in 2022 than the EU. In electronic and electrical equipment, the EU companies invested more than the US in 2012, but this lead decreased and companies in both regions are now on a par. On the positive side, for semiconductors the ratio of EU to US investment increased from 15% to 19%.
- **EU-China**: In 2012 the EU was ahead of China in every subsector. Now China leads in every subsector apart from semiconductors, where EU companies invest over 3.33 times more in R&D than the Chinese companies (down, however, from a factor of 12.55 in 2012).
- **EU-Japan:** In 2012, the EU ICT producers invested 33% more than Japanese companies, and by 2022 the gap increased to almost 50%. The EU lead is a result of the higher investments in semiconductors and telecommunications equipment, while Japanese companies invest more in electronic and electrical equipment; here the Japanese lead decreased somewhat over time.
- **EU-RoW:** The gap between the EU and RoW increased between 2012 and 2022, and the EU companies now only invest 61% of the total of their RoW counterparts. The RoW companies, notably in Taiwan and South Korea, increased their R&D investment more than the EU companies in all subsectors apart from telecommunications equipment, and the growth was particularly strong in

computer hardware and electronic and electrical equipment. In these two sectors, the EU companies invest only 28% and 38% of the ROW companies in 2022.

Table 16 lists the top 10 firms contributing most to the R&D growth of the ICT producers sector in absolute terms in 2022. These 10 companies invested EUR 109.7 billion in R&D in 2022 (38% of the sector total), an increase of EUR 17.7 billion compared with the previous year (48% of the total change in the sector's R&D investment).

Table 16. Top 10 growth contributors in the ICT producers sector, 2022

	Region	World rank	R&D	Absolute change, y-o-y	%-change, y-o-y
Apple	US	4	24 612	4 066	20%
Huawei Investment & Holding	CN	5	20 925	2 010	11%
Samsung Electronics	RoW	7	18 435	1 719	10%
Intel	US	8	16 434	2 192	15%
Qualcomm	US	21	7 682	954	14%
Nvidia	US	26	6 881	1 942	39%
Taiwan Semiconductors	RoW	42	4 985	1 176	31%
Advanced Micro Devices	US	44	4 692	2 025	76%
ASML Holding	EU	64	3 072	641	26%
Contemporary Amperex Technology	CN	114	1 977	1 034	110%

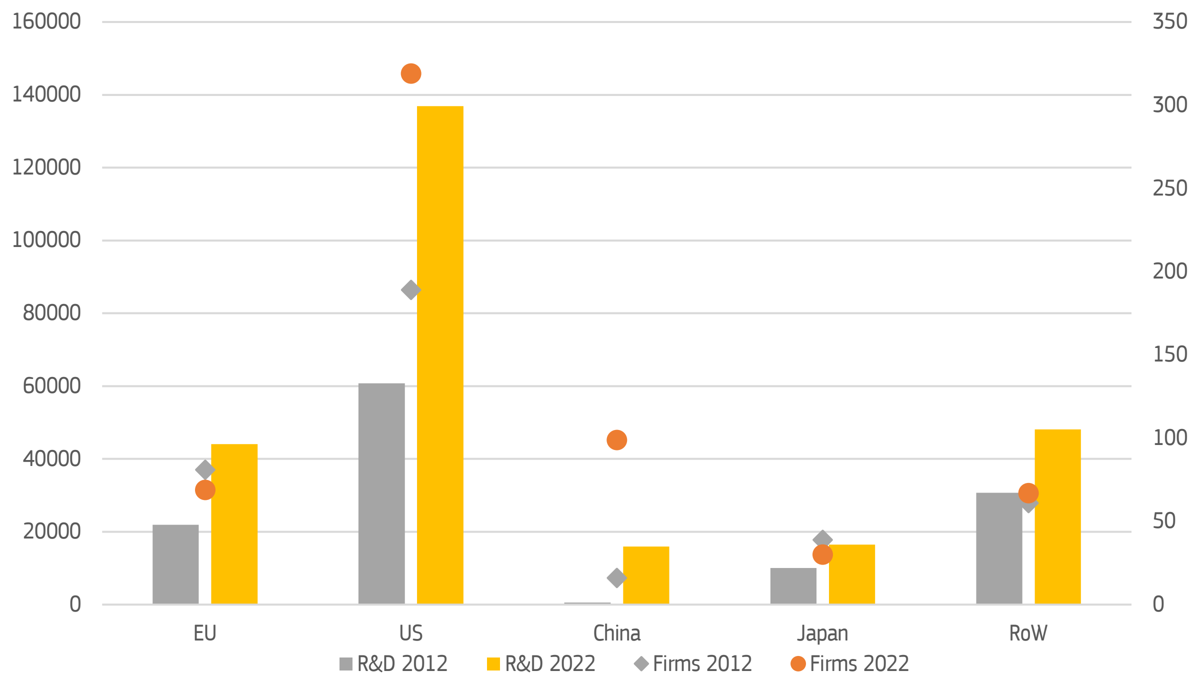
Note: R&D expressed in EUR million.

Source: The 2023 EU Industrial R&D Investment Scoreboard. European Commission, JRC/DG R&I.

3.2.2 Health industries

The health sector constitutes the largest sector in the Scoreboard in terms of number of firms and – by a small margin – the second largest in terms of R&D. This sector developed dynamically over the period of investigation. The share of firms increased from 15.4% to 23.4%, while its R&D share remained largely constant at around 21% of the total. The number of health companies increased by a factor of 1.5 from 386 in 2012 to 584, and R&D investment rose between 2012 and 2022 by a factor 2.1 (1.7 adjusted for inflation).

Figure 22. Firms & R&D in health industries, 2012 and 2022, across regions/countries



Notes: R&D investment in EUR million on the left axis, number of firms on the right axis.

Source: The 2023 EU Industrial R&D Investment Scoreboard. European Commission, JRC/DG R&I.

As shown in Figure 22, since our monitoring in 2012, the US has been leading this sector's R&D efforts by a large margin. While R&D investment increased in all regions, the development in the US was more dynamic and on a larger scale. The EU ranks third, closely behind the RoW companies. The EU and Japan lost a small number of companies after 2012, while the number of companies in RoW increased slightly.

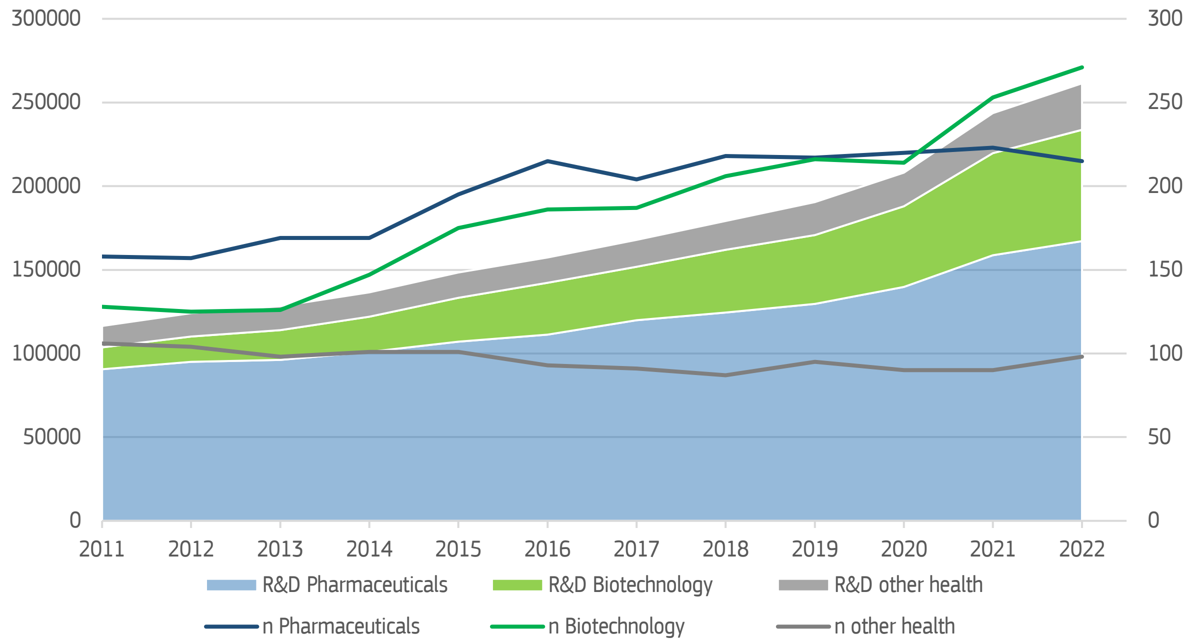
Behind the aggregate figures lie interesting dynamics. Disaggregating the health sector further at the ICB4 classification level in to pharmaceuticals, biotech and other health firms (e.g. medical supplies, health care providers and services) as done in Figure 23, reveals a rapid increase of firms in the biotech sector[69]. The biotech firms are the main driver of the sector's total firm growth, and its number of firms more than doubled since 2012 (from 125 to 271 companies); the number of pharmaceutical companies increased by 36%, while the number of companies in the other health sector declined slightly (-5%).

Between 2012 and 2022, pharmaceutical R&D grew on average by 5.3% a year, biotech R&D by 14.5% and 'other health' R&D by 6.5%, compared with an average value of 7% (CAGR) for the health sector in aggregate. In real terms, the growth rates were 3.9% for pharmaceuticals, 13.3% for biotech, and 5.2% for other health.

The pharmaceutical companies invest 64% of the total sector R&D of EUR 261.4 billion, and biotech 25.4%. While in 2012, the R&D of the biotech sector was only 15% of pharmaceuticals R&D, by 2022 the biotech companies invested already 39.8% of the R&D of the much larger pharma sector. Overall, biotech firms increased their share of the health sector R&D by more than their share of firms, suggesting that the newly entered companies are more R&D intensive than the incumbents (compare subsection 5.1.3).

The increasing share of biotech R&D has been accompanied by a decrease of the pharmaceutical sector share, which is experiencing a structural transformation from more traditional (chemical) medicine towards biotechnologies and molecular medicine[70].

Figure 23. Health sector – number of firms and R&D investment, ICB4 digit level



Note: R&D investment in EUR million on the left axis, number of firms on the right axis. Other health refers to medical supplies, medical equipment, health care providers and services, and health care providers.
Source: The 2023 EU Industrial R&D Investment Scoreboard. European Commission, JRC/DG R&I.

As presented in Table 17 (column 'total'), 54.6% of all health companies are from the US and these 319 companies invested 52.4% of the sectors total R&D of EUR 261.4 bn. Companies headquartered in the EU account for 11.8% of the companies and 16.8% of the sector R&D. Overall, the number of health companies headquartered in the EU decreased since 2012 from 81 to 69 due to a lower number of firms in pharmaceuticals and other health. RoW countries experienced an increase in the number of health firms from 61 to 67 due to a growing number of biotech companies. Leading health companies are headquartered in RoW countries, in particular in Switzerland, the UK and Australia. The RoW countries represent 11.5% of the

69 The companies classified as biotech are not the only ones funding biotech R&D, but also most pharma companies (if not all) fund biotech R&D. However, there is no data available distinguishing the companies' share of pharma and biotech R&D; moreover, the term 'biopharma' is commonly used in particular by firms, rendering this differentiation even more blurred.

70 Vezzani, Antonio, *Top EU R&D investors in the global economy. Benchmarking technological capabilities in the health industry*, European Commission-JRC, Seville, 2022

health sector companies, but they were responsible for 18.4% of R&D. Chinese and Japanese companies each accounted for over 6% of the health R&D in 2012, but while the Chinese representation in the Scoreboard has increased over six fold since 2012, the number of Japanese companies decreased from 39 to 30. Japan has become the country with the lowest number of health companies of the five main countries, basically lacking biotech company representation with only one firm in this sector.

The US dominance is particularly pronounced in **biotech.** 76.4% of the companies come from the US, and they were responsible for 79.1% of the total biotech R&D investment of EUR 66.5 billion in 2022. The growth in this subsector is almost entirely due to the entry of US firms, up from 83 companies in 2012 to 207 in 2022. The 21 EU biotech companies invested EUR 5.5 billion in 2022, which corresponds to 8.3% of the subsector total. Between 2012 and 2022, the total number of EU biotech companies remained unchanged (but the firm composition changed), and R&D share increased slightly from 7.2% to 8.3%. Also RoW and China experienced an increase in biotech companies, and companies from both regions account for a similar share of biotech R&D (6.8% for RoW, 5.7% for China). Out of the top 10 biotech companies, eight are in the US, the largest two being Gilead Sciences (world rank 45, R&D 2022 EUR 4.6 billion) and Amgen (world rank 50, R&D EUR 4.1 billion). The seventh largest and first non-US biotech company in the sample is Chinese-American BeiGene (world rank 153, R&D EUR 1.5 billion), and the ninth largest is the German company BioNtech (world rank 169, EU rank 35, R&D EUR 1.4 billion). With a nominal CAGR of 14.5% in R&D investment since 2012, the biotech sector is the fastest growing subsector in the Scoreboard after ICT software and services (see section 3.2.3).

The US also dominates R&D in the **pharmaceuticals** subsector but to a lower extent than in biotech – 28.4% of the companies and 41.4% of this subsector's R&D. The US representation of pharma companies increased since 2012 by 19, from 26.7% to 28.4% of the companies. Among the top 10 pharma companies, 5 are headquartered in the US with the largest being Johnson & Johnson (world rank 10, R&D EUR 13.7 billion). The EU headquarters 32 pharma companies that together invested over EUR 31 billion (18.8%) in 2022; while the number of EU pharma companies decreased from 38 in 2012, their share of R&D remained almost unchanged. The EU headquarters some of the largest R&D investors of this sector and has two companies among the 10 largest: Sanofi from France (world rank 29, EU rank 6, R&D EUR 6.7 billion) and Bayer from Germany (world rank 31, EU rank 7, R&D EUR 6.6 billion).

Table 17. Health industry 2022: Firms and R&D across regions, ICB4

		Biotechnology	Pharmaceuticals	Other health	Total
EU	Firms	21	32	16	69
	Share	7.8%	14.9%	16.3%	11.8%
	R&D	5 562	31 418	7 068	44 050
	Share	8.3%	18.8%	25.4%	16.8%
US	Firms	217	61	51	319
	Share	76.4%	28.4%	52.0%	54.6%
	R&D	52 565	69 122	15 193	136 882
	Share	79.1%	41.4%	54.6%	52.4%
China	Firms	16	67	16	99
	Share	5.9%	31.2%	16.3%	16.9%
	R&D	3 799	10 202	1 975	15 978
	Share	5.7%	6.1%	7.1%	6.1%
Japan	Firms	1	23	6	30
	Share	0.4%	10.7%	6.1%	5.1%
	R&D	0.072	14 769	1 608	16 451
	Share	0.1%	8.8%	5.8%	6.3%
RoW	Firms	26	32	9	67
	Share	9.6%	14.9%	9.2%	11.5%
	R&D	4 501	41 615	1 960	48 077
	Share	6.8%	24.9%	7.1%	18.4%
Total	Firms	271	215	98	584
	Share	46.4%	36.8%	16.8%	100%
	R&D	66 501	167 129	27 807	261 438
	Share	25.4%	63.9%	10.6%	100%

Note: R&D expressed in EUR million. Other health refers to medical supplies, medical equipment, healthcare providers and services, and health care providers.
Source: The 2023 EU Industrial R&D Investment Scoreboard. European Commission, JRC/DG R&I.

RoW has the same number of pharma companies as the EU, and countries such as Switzerland and the UK are home countries of major R&D investors such as Roche (world rank 9, R&D EUR 14.2 billion) or AstraZeneca (world rank 14, R&D EUR 8.9 billion). The number of Chinese companies in the pharmaceuticals subsector increased substantially since 2012 from 12 to 67, driving the overall increase and later stabilisation of the number of pharma companies in the sample. However, R&D investment of Chinese pharma companies remains comparatively low with EUR 10.2 billion (6.1%). The Chinese company with the highest R&D is Fosun International (world rank 251, R&D EUR 856 million). Finally Japan, home to 23 pharmaceutical companies in the Scoreboard, witnessed a comparatively small decrease in the number of firms since 2012 (29), and the share of R&D remained almost stable at close to 9%. The largest Japanese company is Takeda Pharmaceutical (world rank 48, R&D EUR 4.4 billion).

The **other health** subsector is the smallest with 16.8% of the companies and 10.6% of health R&D. As in the other two subsectors, the US dominates with 52% of the companies and almost 55% of R&D. The EU is second with 25% of R&D performed by 16.3% of the companies. The other three regions only play a small role in this subsector and account together for 31.6% of the companies and 20% of R&D. Seven of the 10 largest R&D investors are US-based, the remaining three come from the EU. The largest is Medtronic plc, Ireland, on world rank 85 (EU rank 18) with an R&D investment of EUR 2.5 billion, and the fifth largest is the German company Carl Zeiss (world rank 191, EU rank 39, R&D EUR 1.2 billion). The largest US companies are Thermo Fisher Scientific (world rank 166, R&D EUR 1.4 billion) and Stryker (world rank 178, R&D EUR 1.3 billion). Other major companies in this sector are the Swiss company Alcon (world rank 324, R&D EUR 656 million) and the two Japanese companies Olympus (world rank 379, R&D EUR 553 million) and Terumo (world rank 426, R&D EUR 482 billion).

For a fair comparison of the health sector with other sectors, the analysis is differentiated in before and after the COVID-19 pandemic. Between 2012 and 2019, the nominal R&D investment by health companies grew on average by 6.7%, slightly below the overall top 2 500 R&D growth rate. During the COVID-19 pandemic, health R&D increased by 9.2% in 2020 and 17.1% in 2021, and returned to lower values in 2022 with 7.3%. Inflation was high in 2021 and 2022, particularly in the US where most health firms are located. Adjusting for inflation, the growth rate for R&D investment in 2022 shrank from the nominal 7.3% to barely 1.5%, the lowest value recorded so far. Similarly for the three subsectors: growth in 2022 in the biotech sector decreased from 9.1% (nominal) to 2.1% (inflation-adjusted), from 5.3% to 0.1% for pharmaceuticals and from 16.1% to 9.1% for other health companies

For the US specifically, this means that overall real R&D investment in the health sector decreased by 3%, with an increases of 0.5% in biotech, and of 9.2% in other health, and a reduction of 8.3% in pharmaceuticals For the EU, inflation adjustment results in a real growth of R&D in biotech of 5.1%, 9.4% in pharmaceuticals and a fall of 0.7% in other health (total EU health real growth was 7.1%). In real terms, EU growth leads the US development for the first time since 2015.

Table 18. R&D health industry, ICB4 classification, EU vs. other countries, 2012 and 2022

	US		**China**		**Japan**		**RoW**	
	2012	2022	2012	2022	2012	2022	2012	2022
Overall	**0.36**	**0.32**	**41.04**	**2.76**	**2.19**	**2.68**	**0.71**	**0.92**
Biotech	0.08	0.11	39.64	1.46	37.69	76.53	0.97	1.24
Pharmaceuticals	0.47	0.45	48.30	3.08	2.02	2.13	0.63	0.75
Other health	0.28	0.47	19.16	3.58	2.78	4.39	4.40	3.61

Note: Factors represent ratios of R&D investment in EUR million per region, year and (sub)sector. Values greater than 1 indicate the EU's relative strength and values lower than relative weakness.
Source: The 2023 EU Industrial R&D Investment Scoreboard, European Commission, JRC/DG R&I.

As discussed earlier, the dominance of US firms in the health sector increased over time from 49% to 55% of the firms, and in terms of R&D investment from 49% to 52.4% of the total Scoreboard health R&D. To relate this development to the various subsectors and regions/countries, Table 18 summarises the EU positioning as against the other regions in 2012 and 2022. The numbers represent the ratios with the EU investment in the nominator such that a ratio larger than one implies that EU has more R&D in this (sub)sector than the other country/region and vice versa. The table clearly indicates that the EU lags behind the US and somewhat behind RoW, but outperforms China and Japan. Overall, R&D investment of EU health companies is on an increasing trajectory.

- **EU-US:** The EU invested 36% of US health R&D in 2012, and only 32% 2022. This is mainly due to the US biotech sector where the EU companies invested only 8% of US R&D in 2012. However, EU companies were able to increase their R&D to 11% of the US biotech R&D in 2022. In pharmaceuticals, the EU companies invest less than half of the US companies, and the gap increased slightly between 2012 and 2022. In other health, EU companies reduced the gap with the factor increasing from 28% to 47% of US investment in 2022.

- **EU-China:** While Chinese health companies were hardly present in the Scoreboard in 2012, by 2022, China had reduced the gap to the EU considerably, with EU companies investing 2.76 times more health R&D. Chinese companies caught up in particular in biotech where the EU lead shrank to 46%, and to a lesser extent also in pharmaceuticals and other health where the EU lead is larger. The EU holds its lead over China, but needs to strengthen its performance in order to keep its position.
- **EU-Japan:** In 2012, the EU health companies invested more than twice as much in R&D as the Japanese health companies, and by 2022 this lead increased to 2.68 times more. The EU improved its position against Japan in all subsectors.
- **EU-RoW:** The gap between EU and RoW narrowed between 2012 and 2022. While in 2012 the EU companies spent only 71% of the RoW, the share increased to 92% in 2022. In the biotech sector, the relation shifted to an EU lead, with EU companies investing 24% more. In pharmaceuticals, the EU gap decreased evidenced by a factor increase from 0.63 to 0.75. In other health, the EU companies invest almost 4 times more than RoW companies, but here the EU lead decreased slightly.

Table 19 shows which 10 firms contributed most to the R&D growth of the health sector in absolute terms. These 10 companies invested EUR 53.9 billion in R&D in 2022 (20.6% of the sector total), an increase of EUR 9.7 billion compared with the previous year (54.6% of the total change in R&D investment in the sector).

Table 19. Top 10 growth contributors in the health sector, 2022

	Region	World rank	R&D	Absolute change, y-o-y	%-change, y-o-y
Merck US	US	11	11 080	1 381	14%
Astrazeneca	RoW	14	8 943	1 393	18%
Sanofi	EU	29	6 705	1 016	18%
Bayer	EU	31	6 630	1 115	20%
Boehringer Sohn	EU	41	5 047	920	22%
Takeda Pharmaceutical	JP	48	4 476	760	20%
Regeneron Pharmaceuticals	US	57	3 368	642	24%
Novo Nordisk	EU	65	2 926	735	34%
Daiichi Sankyo	JP	93	2 414	575	31%
Moderna	US	96	2 313	1 191	106%

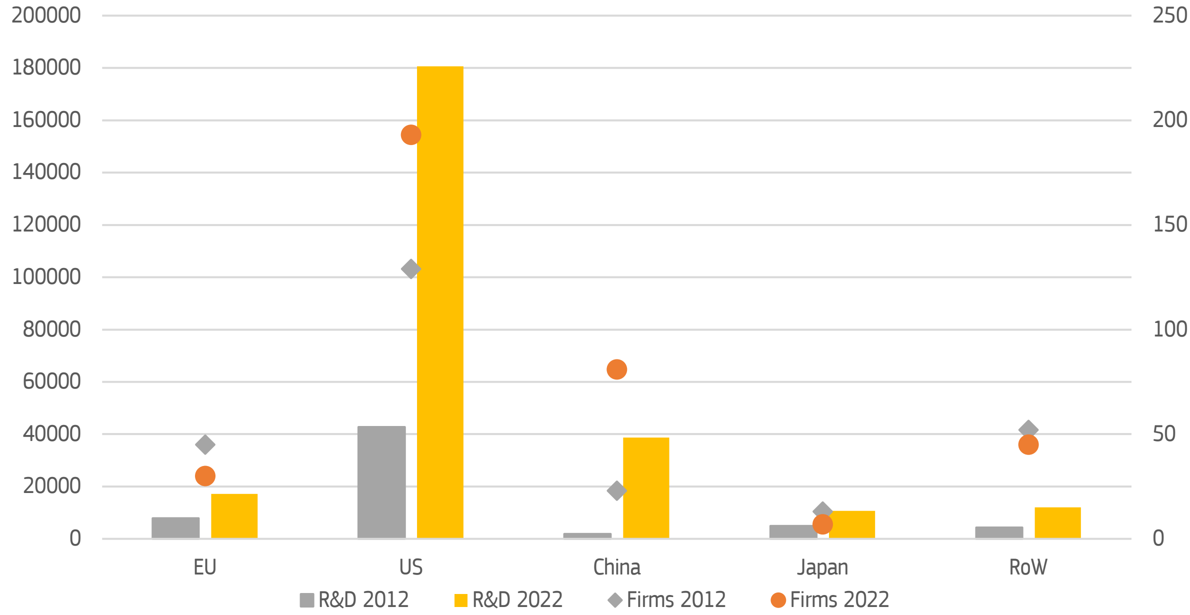
Note: R&D expressed in EUR million.
Source: The 2023 EU Industrial R&D Investment Scoreboard. European Commission, JRC/DG R&I.

3.2.3 ICT software and services

The ICT software and services sector ranks third, only by a small margin behind the health sector, in terms of R&D investment with 20.8% of R&D and 14.2% of companies in 2022. The sector summarises companies that produce software, and provide computer services, and telecommunication services (mostly (mobile) internet providers). In no other sector is the regional concentration more pronounced – and the US continues to lead the global R&D efforts. For comparison, the US companies invested more in R&D in 2012 than the second-ranked (China) in 2022. Over the past decade, only China was able to establish significant own R&D-investing companies, while the R&D investment of the EU, Japanese and RoW companies remains marginal. In total, the R&D investment of all non-US companies in 2022 reached only 43% of the US R&D investment (2012: 44%).

In 2022, the ICT software and service companies invested EUR 259.3 billion in R&D (adjusted for inflation EUR 216.4 billion). This sector is the fastest growing with a CAGR of R&D investment of 13.9% per year since 2012 (11.7% adjusted for inflation), so that R&D in 2022 is higher by a factor 4 than in 2012. The fastest growth rate was realised by computer services companies with 17.2% on average per year, followed by software with 12.7%, and telecommunication services with 7% (adjusted for inflation 14.9% for computer services, 10.3% for software, and 5.6% for telecom services). This rapid growth meant that the sector doubled its share in total Scoreboard R&D from 2012 to 2022. At the same time, the number of ICT software and service companies increased from 262 (10.5%) to 355 (14.2%).

Figure 24. ICT software and services – number of firms and R&D investment, 2012 and 2022, across regions/countries

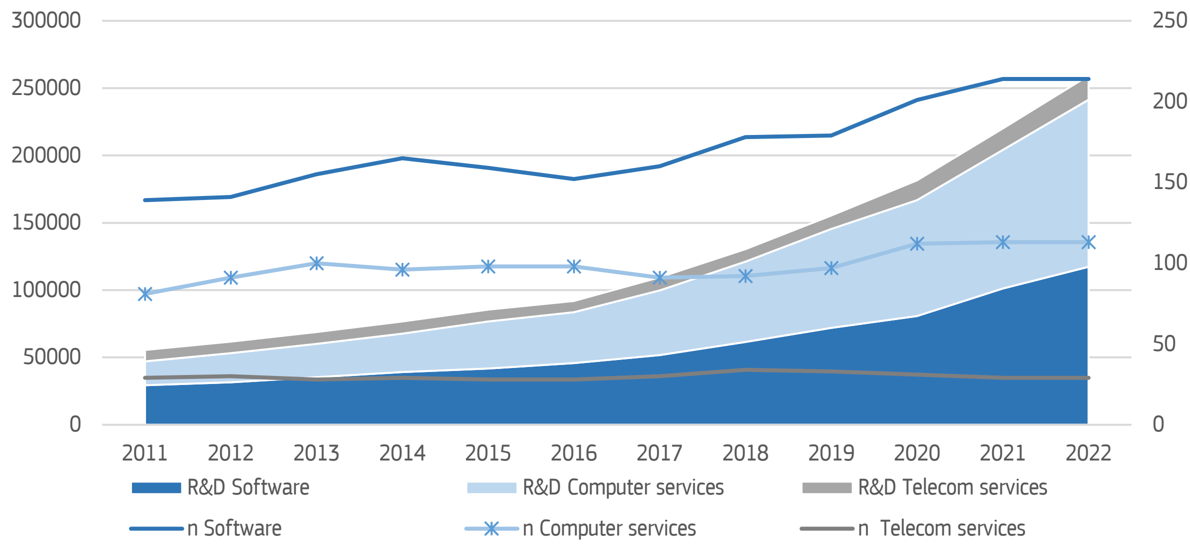


Notes: R&D investment in EUR million on the left axis, number of firms on the right axis.
Source: The 2023 EU Industrial R&D Investment Scoreboard. European Commission, JRC/DG R&I.

As Figure 25 shows, the increase in firms relates mainly to companies developing software: Their number grew by 52% from 141 to 214, compared with a more modest increase of companies in computer services (from 91 to 113) or a reduction of telecommunication service providers from 30 to 28. In terms of R&D investment, the graph displays the particular strong increase related to the COVID-19 pandemic: since 2020 the sector has stepped up its R&D efforts by over EUR 77 billion, of which EUR 58 billion were invested by US companies.

In 2022, the companies in computer services were responsible for 47.8% of the ICT services R&D, software for 45.2% and telecommunication services for 6.9%. Since 2012 the share of computer services has increased from 35%, while the software share has decreased by six percentage points and the telecommunication services R&D share in the sector total has halved.

Figure 25. ICT software and services – number of firms and R&D investment, ICB4 digit level



Notes: R&D investment in EUR million on the left axis, number of firms on the right axis.
Source: The 2023 EU Industrial R&D Investment Scoreboard. European Commission, JRC/DG R&I.

As reported in Table 20 (column 'Total'), 54.2% of all ICT software and service companies have their headquarters in the US and these 193 companies invested 69.7% of the sector's R&D in 2022. The concentration in terms of firms is similar to the health sector, but in terms of R&D it is substantially stronger (in health, the US companies are responsible for 52% of the R&D). Companies with headquarters in the EU account for 8.4% of the companies and 6.6% of the R&D. Also in this sector, the number of EU companies has decreased since 2012 from 45 to 30 due to fewer software companies, while the number of companies in computer services and telecom services remained stable. The number of Chinese companies grew steadily from 23 to 81 in 2022, increasing the share of companies from 8.8% to 22.7%. R&D investment of Chinese companies also grew continuously and amounted to 14.9% of the sector in 2022. Overall, Chinese R&D increased by a factor 20 over the past decade, while EU investment increased by a factor of 2.2 and the US by 4.2. Japan has only 7 ICT software and services companies in the Scoreboard (2012: 13), 5 are in computer services and one each in software and telecommunications services. While the company share amounts to only 2% of the sector, the firms invest 4.8% of the R&D in 2022. The number of firms in RoW fell from 52 to 45 due to fewer firms in computer services and telecom services, while the number of software companies increased (from 32 to 34). The countries represent 12.6% of the sector's companies, but only 4.6% of R&D.

The **computer services** sector is dominated by the US, with 46% of the companies and 70.3% of R&D investment in 2022. However, the concentration in the US already decreased somewhat from 52.8% of the companies and 73.6% of R&D in 2012. The two largest R&D investors are the US companies Alphabet (world rank 1, R&D EUR 37 billion) and Meta (world rank 2, R&D EUR 31.5 billion), well ahead of the third in this sector, China's Tencent (world rank 19, R&D EUR 8.2 billion). Alphabet and Meta together increased their R&D compared to 2021 by EUR 15.8 billion, which corresponds to 75% of the total increase in this sector. The massive R&D growth of these two companies raised their share of total R&D in this sector from 51% to 55% within only 1 year. From the top 10 R&D investors, 4 each come from the US and China, and one each from the EU and Japan. The EU company is Spotify on world rank 175 (EU rank 36) with an R&D investment of EUR 1.3 billion, and the Japanese is Softbank (world rank 97, R&D EUR 2.2 billion). The share of EU R&D in computer services decreased from 5.1% in 2012 to 3.4% in 2022, and Japan's share from 13.7% to 3.9%. Overall, only companies from China were able to climb the Scoreboard ranks and they accounted for 21.6% of the R&D in 2022 (6.2% in 2012).

Table 20. ICT software and services – distribution across regions, 2022, ICB4

		Computer services	Software	Telecom services	Total
EU	Firms	11	12	7	30
	Share	9.7%	5.6%	25.0%	8.4%
	R&D	4 217	9 605	3 374	17 198
	Share	3.4%	8.2%	18.8%	6.6%
US	Firms	52	134	7	193
	Share	46.0%	62.6%	24.1%	54.2%
	R&D	87 207	91 183	2 225	180 617
	Share	70.3%	77.7%	12.4%	69.7%
China	Firms	38	33	10	81
	Share	33.6%	15.4%	34.5%	22.75%
	R&D	26 779	6 344	5 603	38 726
	Share	21.6%	5.4%	31.1%	15.0%
Japan	Firms	5	1	1	7
	Share	4.4%	0.5%	3.5%	2.0%
	R&D	4 776	183	5 721	10 680
	Share	3.9%	0.2%	31.8%	4.2%
RoW	Firms	7	34	4	45
	Share	6.2%	15.9%	14.2%	12.6%
	R&D	1 051	9 974	1 069	12 095
	Share	0.9%	8.5%	6.0%	4.6%
Total	Firms	113	214	29	356
	Share	31.7%	60.1%	8.2%	100%
	R&D	124 032	117 291	17 994	259 318
	Share	47.8%	45.2%	6.9%	100%

Note: R&D expressed in EUR million.
Source: The 2023 EU Industrial R&D Investment Scoreboard. European Commission, JRC/DG R&I.

The **software** sector is characterised by an even higher concentration in the US with 77.7% of the R&D and 62.6% of the companies in the 2022 ranking. In terms of companies, the US share increased in the past decade from 53.9%, while in terms of R&D it decreased from 80.9%. The companies located in RoW were responsible for 8.5% of R&D in 2022, up from 6.3% in 2012. However, their company share declined from

22.7% in 2012 to 15.9% in 2022. The EU is third in terms of R&D with 8.2% of the total in 2022, but has only 5.6% of the companies. Since 2012 the number of EU companies in the software sector fell from 22 to 12 (2012: 15.6% of the companies and 11.9% of R&D). Companies from China account for 15.4%, but only 5.4% of R&D investment in 2022 (2012: 6.4% of companies and 0.8% of R&D). With only one firm, Japan plays virtually no role in this sector (2012: 2 companies). Among the top 10 software companies, 9 are headquartered in the US and one in the EU. The top 3 are Microsoft (world rank 3, R&D EUR 25.5 billion) and Oracle (world rank 20, R&D EUR 8.1 billion) from the US and German SAP is third (world rank 34, EU rank 8, R&D EUR 6.1 billion). The number of Chinese companies increased substantially, and the largest in terms of R&D is Didi (world rank 179, R&D EUR 1.2 billion). Major R&D investors from ROW countries are Shopify form Canada (world rank 164, R&D EUR 1.3 billion) and SEA from Singapore (world rank 180, R&D EUR 1.2 billion).

The smallest subsector in terms of R&D and number of firms is **telecommunication services** and it differs substantially from software and computer services. The largest number of firms with 34.5% comes from China, and Japan, at 31.8%, holds the largest share of R&D. The number of Chinese companies more than tripled from 3 to 10, and their share of R&D increased by a factor of almost 10 from 3.5% to 31.1%. Japan, interestingly, has one single company in this sector, the Nippon Telegraph and Telephone Corporation NTT (world rank 36, R&D EUR 5.7 billion) and its share of R&D increased from 22.6% in 2012 to 31.8% in 2022. The development of NTT thus drives the sector's global R&D investment: in 2020 the company raised its R&D efforts by almost EUR 3 billion with the launch of NTT Ltd., a de facto holding company. The EU companies account for 24.1% of the subsector and 18.8% of R&D investment, while the US also headquarters 24.1% of the companies, but invests only 12.5% of the sector's R&D. While the US gained in terms of company share from 16.7% in 2012, the EU share decreased from 36.7%. In R&D investment, the US share declined moderately from 15.7% in 2012, while the EU share fell considerably from 35% in 2012. RoW countries account for 13.8% of the companies and 5.6% of R&D in 2022, compared with 33% of the companies and 23.1% of R&D in 2012. The 10 largest companies in this subsector consist of the Japanese NTT as the largest, two Chinese companies, 2 US companies, 4 EU companies and one RoW (UK). In each case, they are the largest telecom providers in their respective home countries, such as China Mobile (world rank 78, R&D EUR 2.6 billion), AT&T (world rank 193, R&D EUR 1.1 billion) in the US or Telecom Italia (world rank 231, EU rank 48, R&D EUR 950 million).

- **EU-US:** The EU invested only 18% of the US R&D in 2012, and this share fell to only 10% in 2022. The main reason is computer services, where the US invest over 20 times more than the EU companies. Also in software the gap increased, as shown by the factor falling from 0.15 to 0.11. The EU invests more only in telecommunication services, but also here the EU position deteriorated. The US has over 6 times more companies in this sector and is on growing trend, while the opposite holds for the EU.
- **EU-China:** While in 2012 the ICT service sector companies in the EU invested over 4 times more than the Chinese companies, by 2022 the Chinese companies were leading and investing 2.25 times more in R&D than their EU counterparts. China gained in all three subsectors, but in particular in computer services, where the EU investment was 17% below China in 2012, and only 16% in 2022. In software, the EU still leads but Chinese companies are catching up quickly. In telecom services, the EU lead in 2012 turned into a lag and Chinese companies now invest 40% more than the EU companies.
- **EU-Japan:** The EU companies invest around 60% more in R&D than the Japanese companies and this relationship has remained largely unchanged since 2012. In computer services, Japanese companies were leading significantly in 2012, but EU companies increased their R&D faster than the Japanese companies so reducing the lead to 12%. In software, Japanese companies invest only 1.2% and 1.9% of EU companies. In telecom services, the EU led Japan in 2012, but with the massive investment of NTT, Japanese R&D is now 40% higher than EU R&D investment.
- **EU-RoW:** The EU lead decreased between 2012 and 2022 from 1.84 to 1.42. In computer services, EU companies spend 3.5 (2012) and 4 (2022) times more than the RoW. In the software sector, the EU position deteriorated and both regions invested approximately the same amount in R&D in 2022. In telecom services, the EU lead increased slightly between 2012 and 2022.

Table 21 shows the development of R&D investment between 2012 and 2022 across the subsectors among the five regions/countries from an EU perspective. The numbers represent the ratios with the EU investment in the nominator such that a ratio larger than one implies that the EU has more R&D in this (sub)sector than the other region and vice versa. The table shows how far the EU lags behind the US in the ICT software and service sector, while it still leads over the other regions/countries except for China. In contrast to the health sector, R&D investment of EU ICT service companies is on a declining trend:

- **EU-US:** The EU invested only 18% of the US R&D in 2012, and this share fell to only 10% in 2022. The main reason is computer services, where the US invest over 20 times more than the EU companies. Also in software the gap increased, as shown by the factor falling from 0.15 to 0.11. The EU invests more only in telecommunication services, but also here the EU position deteriorated. The US has over 6 times more companies in this sector and is on growing trend, while the opposite holds for the EU.
- **EU-China:** While in 2012 the ICT service sector companies in the EU invested over 4 times more than the Chinese companies, by 2022 the Chinese companies were leading and investing 2.25 times more in R&D than their EU counterparts. China gained in all three subsectors, but in particular in computer services, where the EU investment was 17% below China in 2012, and only 16% in 2022. In software, the EU still leads but Chinese companies are catching up quickly. In telecom services, the EU lead in 2012 turned into a lag and Chinese companies now invest 40% more than the EU companies.
- **EU-Japan:** The EU companies invest around 60% more in R&D than the Japanese companies and this relationship has remained largely unchanged since 2012. In computer services, Japanese companies were leading significantly in 2012, but EU companies increased their R&D faster than the Japanese companies so reducing the lead to 12%. In software, Japanese companies invest only 1.2% and 1.9% of EU companies. In telecom services, the EU led Japan in 2012, but with the massive investment of NTT, Japanese R&D is now 40% higher than EU R&D investment.
- **EU-RoW:** The EU lead decreased between 2012 and 2022 from 1.84 to 1.42. In computer services, EU companies spend 3.5 (2012) and 4 (2022) times more than the RoW. In the software sector, the EU position deteriorated and both regions invested approximately the same amount in R&D in 2022. In telecom services, the EU lead increased slightly between 2012 and 2022.

Table 21. R&D ICT services, ICB4 classification, EU vs other countries, 2012 and 2022

	US		**China**		**Japan**		**RoW**	
	2012	2022	2012	2022	2012	2022	2012	2022
Overall	**0.18**	**0.10**	**4.17**	**0.44**	**1.59**	**1.61**	**1.84**	**1.42**
Computer services	0.07	0.05	0.83	0.16	0.37	0.88	3.52	4.01
Software	0.15	0.11	14.7	1.51	83.13	52.41	1.89	0.96
Telecommunication services	2.23	1.52	10.17	0.60	1.56	0.59	2.23	3.16

Note: Factors represent ratios of R&D investment in EUR million per region, year and (sub)sector. Values greater than 1 indicate the EU's relative strength and values lower than 1 relative weakness.
Source: The 2023 EU Industrial R&D Investment Scoreboard. European Commission, JRC/DG R&I.

Table 22 shows which 10 firms contributed most to the R&D growth of the ICT software and services sector. These 10 companies invested EUR 126 billion in R&D in 2022 (49% of the sector total), an increase of EUR 25.8 billion compared to the previous year (65% of the total change in R&D investment).

Table 22. Top 10 growth contributors in the ICT software and services sector, 2022

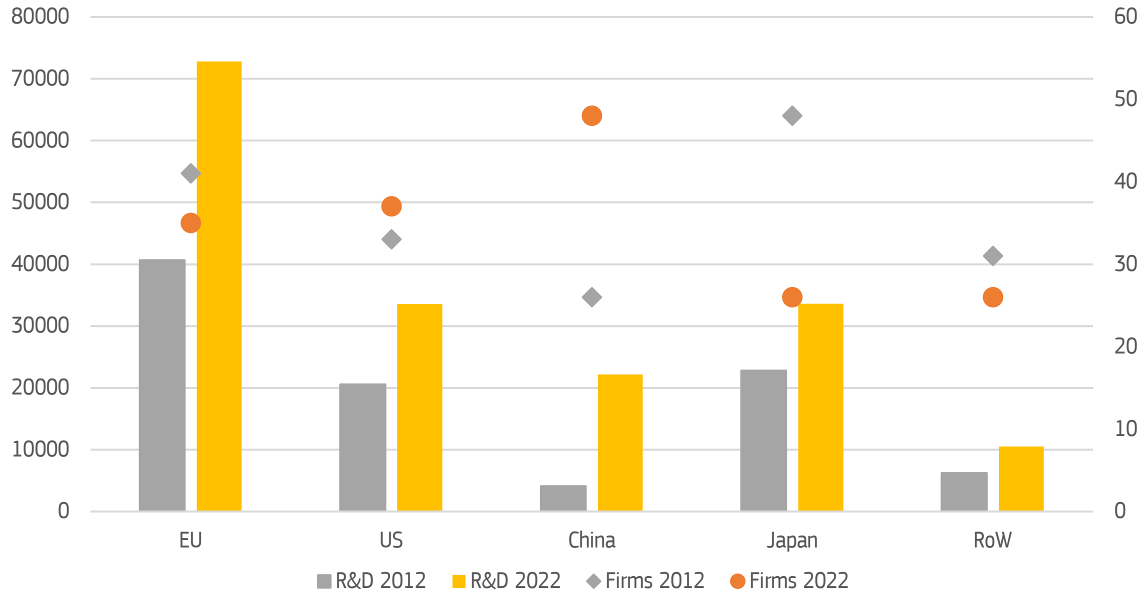
	Region	**World rank**	**R&D**	**Absolute change, y-o-y**	**%-change, y-o-y**
Alphabet	US	1	37 034	7 442	25%
Meta	US	2	31 520	8 404	36%
Microsoft	US	3	25 496	2 515	11%
Tencent	CN	19	8 240	1 278	18%
Oracle	US	20	8 085	1 316	19%
SAP	EU	34	6 139	971	19%
Uber Technologies	US	77	2 623	698	36%
China Mobile	CN	78	2 605	1 709	191%
Softbank	JP	97	2 293	847	59%
Block	US	112	2 002	685	52%

Note: R&D expressed in EUR million.
Source: The 2023 EU Industrial R&D Investment Scoreboard. European Commission, JRC/DG R&I.

3.2.4 Automotive

The automotive sector comprises firms in the automobiles and parts, commercial vehicles and trucks, and tyres subsectors. Accounting for 13.8% of R&D investment and 6.8% of the companies, it constitutes the fourth largest R&D sector in the Scoreboard with a lower R&D intensity than the top three. Since 2012, the number of automotive companies has remained largely stable (179 in 2012, 172 in 2022), but the share of R&D investment has declined from 16.3% to 13.8%. The automotive sector is the only one of the top four in which the EU leads in terms of R&D investment, accounting for 42.2% of the sector total in 2022, compared with 19.5% for each of Japan and the US. However, while Japan has experienced a large drop in the number of companies, the US is – next to China – the only country with an increasing number of companies. R&D investment in RoW is comparatively low and showed the smallest increase since 2012.

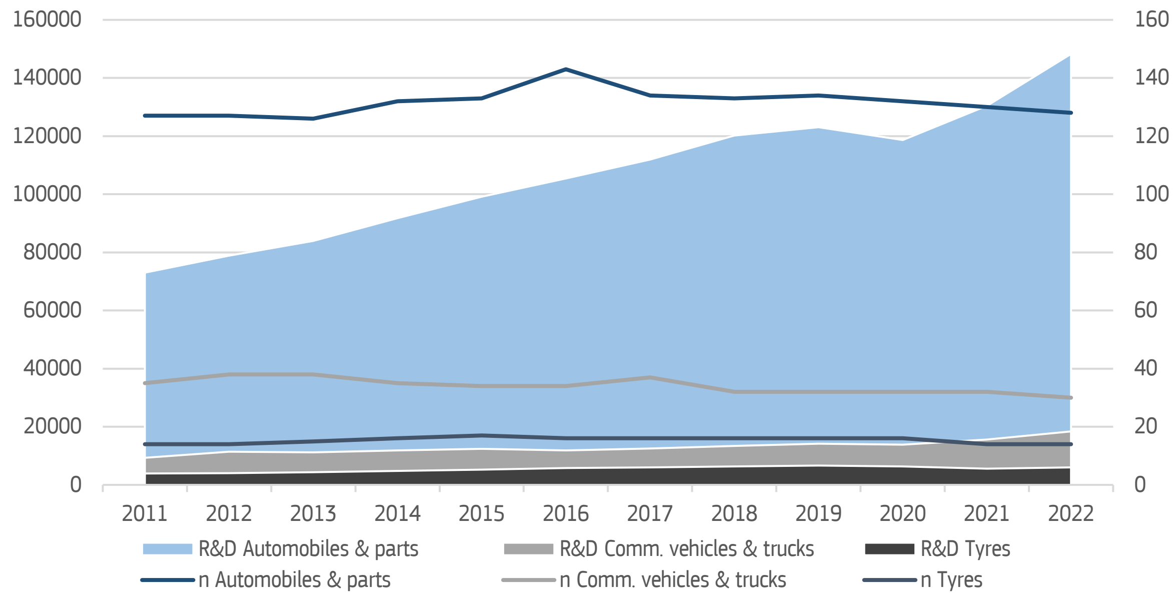
Figure 26. Automotive– number of firms and R&D investment, 2012 and 2022, across regions/countries



Notes: R&D investment in EUR million on the left axis, number of firms on the right axis.
Source: The 2023 EU Industrial R&D Investment Scoreboard. European Commission, JRC/DG R&I

As Figure 27 shows, the sector is dominated by companies in automobiles and parts, both in terms of R&D and number of firms. Total R&D in this sector amounted to EUR 172.7 billion (adjusted for inflation EUR 149.8 billion). In 2022, 85.8% of this was invested by companies in automobiles and parts, 10.6% in commercial vehicles and trucks, and 3.5% in the tyres subsector. These shares have remained largely unchanged over the past 10 years. Since 2012, the sector's nominal R&D investment grew on average by 5.7% (CAGR), or by 3.9% when accounting for inflation. The strongest growth was realised in automobiles and parts at 5.9%, followed by commercial vehicles and trucks at 4.4%, and tyres at 3.6% (respectively 4.1%, 2.6% and 2.1% inflation-adjusted).

Figure 27. Automotive sector – number of firms and R&D investment, ICB4 digit level



Notes: R&D investment in EUR million on the left axis, number of firms on the right axis.
Source: The 2023 EU Industrial R&D Investment Scoreboard. European Commission, JRC/DG R&I.

The automotive sector CAGR was the lowest of the four top sectors, leading to a total R&D investment in 2022 83% higher than in 2012. While the three top sectors benefitted from the COVID-19 pandemic, the automotive sector saw a decrease of R&D investment of 3.5% in 2020 – though growth rebounded in 2021, and in particular in 2022. In only 2 years, automotive R&D investment grew by almost EUR 30 billion.

Overall, 74.4% of the companies are in the subsector automobiles and parts, increasing by 4 percentage points since 2012. The share of companies in commercial vehicles and trucks decreased from 21.2% to 17.4% since 2012 while the share of companies producing tyres remained around 8%.

The automotive sector companies spread more evenly across the world regions relative to the other three large sectors (see Figure 26). In general, there is no strong regional concentration in terms of the number of firms in any of the automotive subsectors. The EU share of companies decreased from 22.9% in 2012 to 20.4% in 2022 due to a lower number of companies in commercial vehicles and trucks. The share of Chinese companies increased from 14.5% to 27.9% due to a doubling of the number of automobile and parts companies. Japan saw its share of companies shrinking from 26.8% in 2012 to 15.1% in 2022 due to a loss of 20 companies in automobiles and parts in the ranking. In contrast, the number of US automotive companies grew over the past 10 years, from 18.4% to 21.5% primarily due to new companies in automobiles and parts. The share of companies headquartered in RoW fell by 2 percentage points to 15.1%.

In terms of R&D, in **automobiles and parts** the largest share of 42.5% of R&D is held by companies headquartered in the, followed by Japan with 20% and the US with 18.1%. China and RoW invested 12.2% and 6.3% of the subsector's R&D in 2022. These shares have changed somewhat over the past decade, with the EU starting at 44.8% in 2012, experiencing an increase until 2020 up to 46.9%, before decreasing to 42.1%. The drop in 2020 is due to the COVID-19 pandemic and the merger of the Italian-American conglomerate Fiat Chrysler Automobiles (FCS) and the French PSA Group into Stellantis which caused a loss of over EUR 3 billion of R&D that was not fully absorbed by the new mother company. The share of Japanese companies has declined steadily from 26.6% in 2012 to 20.9%, while the US share has remained at 18.1% over the past decade. The number of US automobiles and parts companies declined from 2012 to 2020 to 14%, but since then has increased due to newly entering companies (e.g. Rivian Automotive). The share of Chinese R&D increased from 4.3% in 2012 to 12.8% due to new entrants (e.g. BYD), Japan's share decreased from 24.1% to 19.5% and the share of RoW headquartered companies in R&D remained at 6%.

In 2022, this subsector invested EUR 148.2 billion in R&D (EUR 128.8 billion inflation adjusted). From the top 10 companies in automobiles and parts, 5 are from the EU, 3 are from Japan and 2 from the US; the top 10 companies account for 57.6% of R&D. The largest R&D investor is Volkswagen with EUR 18.9 billion (world rank 6, EU rank 1), which is twice as much as the second largest, General Motors with EUR 9.1 billion (US, world rank 13). Toyota Motors is the third largest with an R&D investment of EUR 8.7 billion in 2022 (Japan, world rank 16). The other EU companies in the top 10 are Mercedes-Benz (world rank 18, EU rank 2, R&D EUR 8.5 billion), Robert Bosch (world rank 23, EU rank 3, R&D EUR 7.4 billion), and BMW (world rank 25, EU rank 4, R&D EUR 7.1 billion) and Netherlands-headquartered Stellantis (world rank 28, EU rank 5, R&D EUR 6.7 billion). The first Chinese company in terms of R&D in 2022 is SAIC Motor with an R&D investment of EUR 2.8 billion (world rank 70), and the first company from RoW is the South Korean company Hyundai Motor (world rank 91, R&D EUR 2.4 billion).

The other automotive subsectors are small in comparison. **Commercial vehicles and trucks** companies invest since 2012 between 12% and 10.7% of the sector's R&D, which, at EUR 18.4 billion in 2022, is less than Volkswagen's R&D investment in the same year. The EU and the US each hold approximately one third of the R&D in this subsector. The subsector experienced a boost in R&D investment in 2022 of 18% mainly due to the spin-off of Daimler Truck from Mercedes-Benz in 2021. Among the 10 largest companies in this subsector, three come from the EU, three from the US, and two each from China and Japan. Overall, six of the 30 companies invested over EUR 1 billion in R&D in 2022, accounting for 56% of the subsector's R&D total. The largest R&D investor in this subsector is Volvo from Sweden (world rank 101, EU rank 22, R&D EUR 2.1 billion), followed by the US tractor producer Deere (world rank 128, R&D EUR 1.7 billion) and Germany's Daimler Truck (world rank 129, EU rank 30, R&D EUR 1.7 billion). The largest Chinese company is CRRC China (world rank 138, R&D EUR 1.6 billion) and the largest Japanese company is Isuzu Motors (world rank 256, R&D EUR 841 million).

The subsector **tyres** had a total R&D investment of EUR 6 bn in 2022, of which EUR 3.8 bn was invested by EU companies (63.9%), and EUR 1.1 bn by Japanese companies. The largest company is Continental from Germany (world rank 67, EU rank 16) which invested EUR 2.8 bn in 2022. The second one is Bridgestone from Japan (world rank 272, R&D EUR 792 million). Other relevant EU companies include Michelin from France and

Pirelli from Italy. The largest US company is Goodyear (world rank 434, R&D EUR 469 m), from RoW the South Korean company Hankook Tire & Technology and from China Shandong Linglong Tire.

Table 23. Automotive – Distribution across regions, 2022, ICB4

		Automobiles & parts	Commercial vehicles & trucks	Tyres	Total
EU	Firms	24	7	3	34
	Share	18.9%	23.3%	21.4%	19.9%
	R&D	61 060	5 977	3 857	70 895
	Share	42.1%	32.6%	63.6%	41.9%
US	Firms	27	9	1	37
	Share	21.3%	30.0%	7.1%	21.6%
	R&D	26 262	6 217	469.7	32 949
	Share	18.1%	33.9%	7.7%	19.5%
China	Firms	37	8	3	48
	Share	29.1%	26.7%	21.43%	28.1%
	R&D	18 125	3 851	220.5	22 198
	Share	12.5%	20.9%	3.63%	13.1%
Japan	Firms	20	2	4	26
	Share	15.8%	6.7%	28.57%	15.2%
	R&D	30 195	1 388	1 179	32 762
	Share	20.8%	7.56%	19.43%	19.4%
RoW	Firms	19	4	3	26
	Share	14.9%	13.3%	21.43%	15.20%
	R&D	9 244	923.9	342.2	10 510
	Share	6.4%	5.0%	5.64%	6.2%
Total	Firms	127	30	14	171
	Share	74.3%	17.5%	8.2%	100.0%
	R&D	144 889	18 358	6 069	169,316
	Share	85.6%	10.8%	3.6%	100%

Note: R&D expressed in EUR million.
Source: The 2023 EU Industrial R&D Investment Scoreboard. European Commission, JRC/DG R&I.

Table 24 summarises the EU positioning versus the other regions in the automotive sector and its subsectors in 2012 and 2022. The numbers represent the ratios of, for example, EU R&D investment over US R&D investment; a ratio larger than one thus implies that the EU has more R&D in this (sub)sector than the other region/country and vice versa. The comparison over time makes it possible to judge the development in the two respective regions. The table shows clearly to what extent the EU leads against all competitors.

- **EU-US:** In 2022, the EU automotive companies invested over twice as much as their US counterparts, a slight increase since 2012. In the automobiles and parts sector the EU has increased its lead, and in commercial vehicles and trucks the EU caught up with US investment and is now almost on a par (in 2012, EU companies invested 18% of the US R&D, in 2022 this share rose to 96%). In tyres, the EU lead was strong and increased over the past decade.
- **EU-China:** While the EU companies invested almost 10 times more in automotive R&D in 2012, it was only 3.28 times more in 2022. China increased its investment relative to the EU in all subsectors, but the EU is still leading.
- **EU-Japan:** While Japan was and is traditionally the second automotive stronghold in the world, the EU companies were always considerably more R&D-intensive than their Japanese counterparts. Relative to Japan, the EU companies increased their R&D investments in all subsectors. In 2022 EU companies invested more than twice as much in R&D than Japanese companies.
- **EU-RoW:** The gap between EU and ROW companies increased slightly between 2012 and 2022; the EU automotive companies invest by a factor of almost 7 more than companies in ROW.

Table 24. R&D automotive sector, ICB4 classification, EU vs. other countries, 2012 and 2022

	US		China		Japan		RoW	
	2012	2022	2012	2022	2012	2022	2012	2022
Overall	**1.97**	**2.17**	**9.89**	**3.28**	**1.78**	**2.17**	**6.52**	**6.93**
Automobiles & parts	1.72	2.34	13.00	3.48	1.68	2.03	6.50	6.74
Commercial vehicles & trucks	0.18	0.96	1.95	1.56	2.81	4.05	4.02	7.00
Tyres	6.70	8.21	58.51	17.50	3.04	3.27	6.70	12.44

Note: Factors represent ratios of R&D investment in EUR million per region, year and (sub)sector. Values greater than 1 indicate the EU's relative strength and values lower than 1 relative weakness.
Source: The 2023 EU Industrial R&D Investment Scoreboard. European Commission, JRC/DG R&I.

Table 25 shows the 10 firms that contributed most to the R&D growth of the automotive sector in absolute terms. These companies invested EUR 66 billion in R&D in 2022 (38% of the sector total), an increase of EUR 11.7 billion compared with the previous year. This corresponds to 55% of the total change in R&D investment in this sector.

Table 25. Top 10 growth contributors in the automotive sector, 2022

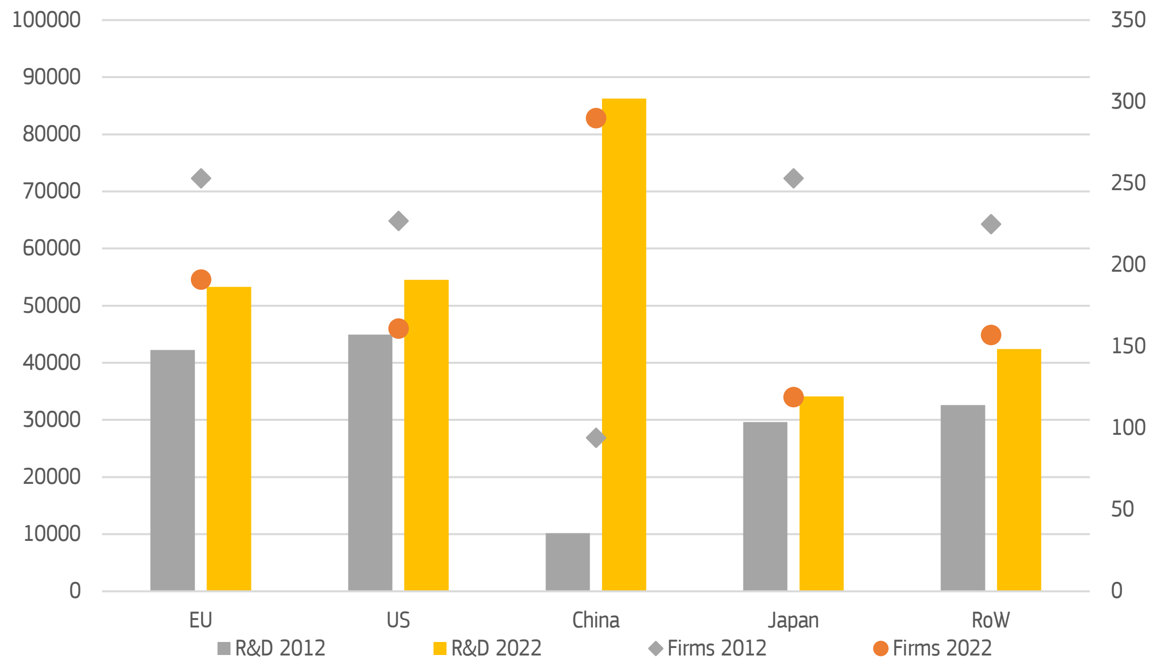
	Region	World rank	R&D	Absolute change, y-o-y	%-change, y-o-y
Volkswagen	EU	6	18 908	3 325	21%
General Motors	US	13	9 188	1 781	24%
Toyota Motor	JP	16	8 776	830	10%
Robert Bosch	EU	23	7 483	1 155	18%
Stellantis	EU	28	6 720	831	14%
Honda Motor	JP	33	6 220	394	7%
BYD	CN	82	2 547	1 134	80%
Forvia	EU	108	2 078	871	72%
Volvo	EU	101	2 199	541	33%
NIO	CN	160	1 410	822	140%

Note: R&D expressed in Euro million.
Source: The 2023 EU Industrial R&D Investment Scoreboard. European Commission, JRC/DG R&I.

3.3 R&D in the sectors beyond the top 4

The remaining six sectors (plus the collection category 'others', see Table 11 in section 3.1 for details) comprised, in 2022, 36.7% of the companies (918) and 21.7% of R&D. Both shares had declined by the same margin of around 6% since 2012 (43.4% of companies and 27.5% of R&D). For improved readability, the development of these sectors is presented only in terms of regional aggregates in Figure 28, while Table 26 and Table 27 present the details on the sectoral level for each region.

Figure 28. R&D investment and firms across regions, 2012 and 2022, remaining sectors



Notes: R&D investment in EUR million on the left axis, number of firms on the right axis.
Source: The 2023 EU Industrial R&D Investment Scoreboard. European Commission, JRC/DG R&I.

All countries lost companies in these sectors except for China, which tripled its company representation from 94 to 290, while the EU has 25% fewer companies in 2022 than in 2012, the US and RoW 30% fewer, and Japan over 50% fewer. The same holds for (nominal) R&D investment – the compound annual growth rate for the EU in 2012-2022 is only 2.1%, for the US 1.8%, Japan 1.3% and RoW 2.4% - around the level of the inflation rate. Only China grew its investment strongly by 21.4% on average per year and now leads in sum the R&D investment across these sectors.

The lowest R&D investment growth was recorded in aerospace and defence with only 0.6% on average per year (CAGR) since 2012, followed by energy with 1.6%, chemicals with 2.3%, industrials with 4.3%, others with 5.8%, financials with 7.1% and with the highest annual growth being in construction with 15.8%.

In terms of number of companies, all sectors lost except for financials, which still has the same number of companies as in 2012. The energy sector lost 28% of the firms it had in 2012, aerospace and defence lost 25%, chemicals and industrials about 20% and the other sectors approximately 10% of the companies. The loss of R&D or slow growth of R&D in the past decade thus contributes to the sectoral changes in the Scoreboard.

Table 26 describes the shares of each sector in terms of companies and R&D across the five countries/ regions in the year 2022. In **aerospace and defence**, the EU is second after the US, followed by RoW, while China and in particular Japan have only little (or no) representation in the Scoreboard in this sector. While RoW countries have almost the same number of companies as the EU, the EU companies invest almost four times more in R&D.

In **chemicals**, the EU had the smallest share of companies in 2022, but the second largest R&D share after Japan, the global leader in R&D in the chemicals sector (compare Section 6 on patents). The US, while having five more companies than the EU, invest slightly less in R&D than their EU counterparts.

The **construction** sector in the Scoreboard is mainly represented by Chinese companies (54.6%) that invested 84.6% of the sector's R&D in 2022. The EU ranks second with 5.4% of R&D, and Japan third with 3.9%. China is also leading in the **energy** sector with 37.1% of the R&D, followed by EU companies that invest 27.3% of the sector's R&D; interestingly, there are five more EU companies in the energy sector than Chinese companies, but the Chinese companies invest more in R&D than their EU counterparts.

Table 26. R&D investment in factors, EU vs other regions/countries, 2012 and 2022, other sectors

		Aerospace & defence	Chemicals	Construction & materials	Energy	Financials	Industrials	Others	Total
EU	Firms	12	15	9	24	23	60	48	191
	Share	29.3%	13.3%	13.6%	33.3%	38.9%	21.3%	16.8%	20.8%
	R&D	8 686	5 540	1 798	5 804	7 873	13 160	10 431	16 026
	Share	40.7%	20.6%	5.4%	27.3%	35.6%	20.9%	12.6%	19.7%
US	Firms	15	20	4	10	9	34	69	161
	Share	36.6%	17.7%	6.1%	13.9%	15.3%	12.1%	24.1%	17.5%
	R&D	9 362	4 997	656	2 873	4 399	9 420	22 833	15 017
	Share	43.8%	18.6%	1.9%	13.5%	19.9%	14.9%	27.6%	20.2%
China	Firms	3	34	36	19	12	110	76	290
	Share	7.3%	30.1%	54.6%	26.4%	20.3%	39.2%	26.6%	31.6%
	R&D	362	4 528	28 119	7 881	2 002	24 113	19 249	86 258
	Share	1.7%	16.8%	84.6%	37.1%	9.1%	38.4%	23.2%	31.9%
Japan	Firms	0	28	10	8	0	37	36	119
	Share		24.8%	15.2%	11.1%		13.2%	12.6%	12.9%
	R&D	0.0	7 591	1 316	852	0.0	8 942	15 390	34 094
	Share		28.2%	3.9%	4.0%		14.2%	18.6%	12.6%
RoW	Firms	11	16	7	11	15	40	57	157
	Share	26.8%	14.2%	10.6%	15.3%	25.4%	14.2%	19.9%	17.1%
	R&D	2 945	4 272	1 343	3 852	7 861	7 201	14 964	42 442
	Share	13.8%	15.9%	4.0%	18.1%	35.5%	11.5%	18.1%	15.7%
Total	Firms	41	113	66	72	59	281	286	918
	Share	4.5%	12.3%	7.2%	7.8%	6.4%	30.6%	31.2%	100.0%
	R&D	21 357	26 930	33 234	21 264	22 137	62 838	82 868	270 632
	Share	7.9%	9.9%	12.3%	7.9%	8.2%	23.2%	30.6%	100%

Note: R&D expressed in Euro million.
Source: The 2023 EU Industrial R&D Investment Scoreboard. European Commission, JRC/DG R&I.

The **financial** sector is characterised by EU companies (38.9%) and their R&D investment (35.6%), and RoW that has fewer companies (25.4%) but almost the same R&D investment as the more numerous EU companies. The third in this sector is the US, followed by China. Japan does not have a company representation in this sector. The number of companies in this sector increased again in the past years due to a rising number of holding companies that invest in innovative firms and thereby enter the Scoreboard ranking.

The **industrial sector** – the largest of the sectors analysed here – is dominated by Chinese companies that account for 39.2% of the companies and 38.4% of R&D investment. The EU is second with 21.3% of the companies and 20.9% of R&D. Japan, RoW and US have a similar number of firms and also the R&D investment is rather evenly distributed. The size of the industrial sector, and the rather equal representation of countries in terms of companies and R&D, suggests that the large industrial companies continue to play an important role in the economies across the board.

Finally, the collection group 'others' (see Table 11 for sectoral details) holds a relatively high number of companies. Similar to the industrial sector, each country/region has a significant number of companies in this sector and also R&D is not exposed to a very strong regional concentration. Japan has the lowest number of companies, followed by the EU, but Japanese companies invest more in R&D than their EU counterparts. Also, the US has a larger share of R&D than companies. This results from the specific composition of this sector in the countries: the two largest R&D investors (sector classification 'Leisure goods', 'Consumer electronics') are Sony and Panasonic from Japan, but the sector also contains companies such as Nestle, Airbnb, or L'Oréal.

Table 27 summarises the EU positioning versus the other regions in the automotive sector and its subsectors in 2012 and 2022. The numbers represent the ratios of, for example, EU R&D investment over US R&D investment; a ratio larger than one thus implies that the EU has more R&D in this (sub)sector than the other region/country and vice versa. The comparison over time makes it possible to judge the development in the two respective regions. The table shows clearly to what extent the EU leads against all competitors.

- **EU-US:** The EU position vis-à-vis the US has improved since 2012, and in 2022 the R&D investment of the EU and the US companies were almost equal. The EU leads over the US in construction, energy and industrial and increased this lead over time. In aerospace and defence, the EU was slightly leading over the US in 2012, until in 2022 the situation reversed, but only by a small margin. In chemicals, the EU invested only 68% of the US total in 2012, but by 2022 the EU companies took the lead. In financial, the EU is still leading, but the gap with the US decreased. For the other sectors, the US lead increased over the past decade.
- **EU-China:** While the EU invested 4.46 times more in this sector in 2012, Chinese companies are leading the EU companies in 2022. This change is driven by all sectors, in particular construction. The EU is still investing more in R&D in chemicals and financial, and aerospace and defence (which is basically not present in the Scoreboard for China).
- **EU-Japan:** The EU lead over Japan increased over time slightly, driven by aerospace and defence as well as financial, as Japan does not have company representation in this sector (any more). In chemicals, the Japanese lead increased slightly, while in all other sectors - except for others - the EU leads and the lead increased over the last decade.
- **EU-RoW:** The lead of EU companies over RoW decreased slightly between 2012 and 2022. On a sectoral level, the EU position improved in aerospace and defence and energy, while it deteriorated in the remaining sectors. Overall, the EU leads in five sectors, is on a par in financial and lags only in the sector 'others' behind the RoW companies.

Table 27. R&D investment in factors, EU vs other regions/countries, 2012 and 2022, other sectors

	US		China		Japan		RoW	
	2012	2022	2012	2022	2012	2022	2012	2022
Overall	**0.89**	**0.98**	**4.46**	**0.62**	**1.34**	**1.56**	**1.33**	**1.26**
Aerospace & defence	1.05	0.93	88.33	23.96	NA	NA	2.11	2.95
Chemicals	0.68	1.11	44.56	1.22	0.79	0.73	1.44	1.30
Construction & materials	1.99	2.74	0.53	0.06	1.36	1.37	2.22	1.34
Energy	1.12	2.02	1.47	0.74	4.07	6.81	0.95	1.51
Financials	2.88	1.79	NA	3.93	34.35	NA	1.06	1.00
Industrials	1.09	1.40	3.97	0.55	1.40	1.47	1.84	1.83
Others	0.55	0.46	5.91	0.54	0.56	0.68	0.78	0.70

Note: Factors represent ratios of R&D investment in EUR million per region, year and (sub)sector. Values greater than 1 indicate the EU's relative strength and values lower than 1 relative weakness.

Source: The 2023 EU Industrial R&D Investment Scoreboard. European Commission, JRC/DG R&I.

3.4 Key points

— The concentration of R&D in the four top sector continues to increase. 78.3% of R&D investment was realised by 1 592 companies (63.2% of the companies) in the sectors ICT producers, health, ICT services, and automotive. (2012: 72.5% of R&D and 56.7% of firms).

- The ICT service sector has been the fastest growing sector in the past decade with an compound annual growth rate of R&D investment of 13.9%, followed by the health sector with 7%, ICT producers with 6.6% and automotive with 5.6%.
- ICT hardware and technology (ICT producers) maintain their share of total R&D investment of around 23% while the number of companies decreased from 23.6% to 18.8%.
    - The ICT producers sector is characterised by a strong regional concentration. In 2022, 25% of ICT producers were headquartered in the US and they spent 42.3% of the sector's total R&D.
    - Companies in RoW constitute traditional major players in the global ICT producers sector, these companies account for 18.3% of the sector's R&D and 21.4% of the companies. The share of Chinese ICT producers increased from 9.6% in 2012 to 34.6% in 2022, and their share of R&D went up from 5.9% to 20.3%.
    - The share of EU firms decreased to 8.9%, and in terms of R&D the EU share is only 11.2%; consequently, the EU ranks only fourth in this sector.
    - The semiconductors subsector R&D is highly concentrated. The US companies account for 62.2% of the total R&D investment and for 40% of the companies. RoW with Taiwan and South Korea account for 25.5% of the companies and 19.1% of R&D. In terms of R&D the EU ranks third with 12.1% of the investment, and 11% of the companies. In contrast, China has a larger share of companies (14.4%) but only 3.5% of the subsector's R&D investment.
- The number of firms in the health sector increased by 50% while the share of R&D investment remains rather stable around 21%, as mostly smaller R&D-intensive biotech firms entered the Scoreboard.
    - 54.6% of all health companies are from the US and they invested 52.4% of the sector's R&D.
    - EU companies account for 11.8% of the companies and 16.8% of the sector R&D. The number of health companies in the EU decreased since 2012 from 81 to 69 due to lower numbers of firms in pharmaceuticals and other health.
    - RoW countries represent 11.5% of the health sector companies, but they were responsible for 18.4% of R&D.
    - The US dominates in biotech with more than three quarters of R&D and 10 times as many firms than the EU or China. The US biotech firms are almost entirely responsible for the R&D growth in this sector. Chinese companies caught up in biotech; the EU invests around three times more in biotech than their Chinese counterparts, but needs to continue to strengthen its performance in order to keep this lead.
- ICT services doubled its share of R&D since 2012 from 10.6% to 20.8%, while the number of firms increased by almost 50% (from 10.4% to 14.2%).
    - R&D in ICT services is highly concentrated: 54.2% of the companies have their headquarters in the US and they invested 69.7% of the sector's R&D in 2022, while EU companies account for only 8.4% of the companies and 6.6% of the R&D. The number of EU companies decreased since 2012 due to fewer software companies, while the number of companies in computer services and telecom services remained stable.
    - The number of Chinese companies grew steadily from 8.8% to 22.7% of the companies, and the R&D investment of the Chinese companies amounted to 14.9% of the sector in 2022.
    - R&D investment of EU ICT services companies is on a declining trend: the US investment exceeded EU R&D in 2012 by a factor of 5.44, and the US lead almost doubled to 10.51 in 2022. The main reason is computer services, where the US companies invest over 20 times more than the EU companies. Also in software the gap between the two increased from a factor 6.8 to 9.49.
- In the automotive sector, the EU traditionally has the lead with 42.2% of the sector's R&D in 2022, compared with 19.5% each for Japan and the US, and 12.8% for China. The number of Chinese Scoreboard firms doubled in the past decade, and there is also a substantial number of newcomers from the US.
    - While Japan was and is traditionally the second automotive R&D stronghold in the world, the EU companies were always considerably more R&D-intensive than their Japanese counterparts. In

2022, Japanese companies only invested 46% of the EU R&D in this sector, while in 2012 they stood at 56%.

   - o Comparing the EU and China, the EU invested 10 times more in automotive R&D than China in 2012, but only 3 times more in 2022.

   - o In 2022, US automotive companies invested 46% of their EU counterparts, down from 51% in 2012. In the automobiles and parts sector, the US investment increased slightly, while in commercial vehicles and trucks the US lost its lead over the EU and is now on a par with the EU.

— Beyond these four sectors determining the technology race, aerospace and defence realised in 2022 the highest increase in R&D investment ever (16.2%), driven by the simultaneous events of easing COVID-19 restrictions and the Russian war in Ukraine that caused a strong increase in military spending.

— The industrials sector is dominated by Chinese companies that account for 39.2% of the companies and 38.4% of R&D investment; the EU is second with 21.3% of the companies and 20.9% of R&D. Japan, RoW and US have a similar number of firms and also the R&D investment is rather evenly distributed.

— The distribution of EU firms can be interpreted as the EU having a good representation of R&D investors in a broad range of sectors, confirming a high degree of diversity of major R&D investors from the EU. US Scoreboard firms are overrepresented only in three sectors, but two of them, ICT services and health, are among the top four sectors by R&D investment.

— China and Japan exhibit a very similar pattern in terms of sectoral representation; both countries have an over-proportional number of firms in sectors with low R&D intensity such as construction or chemicals.

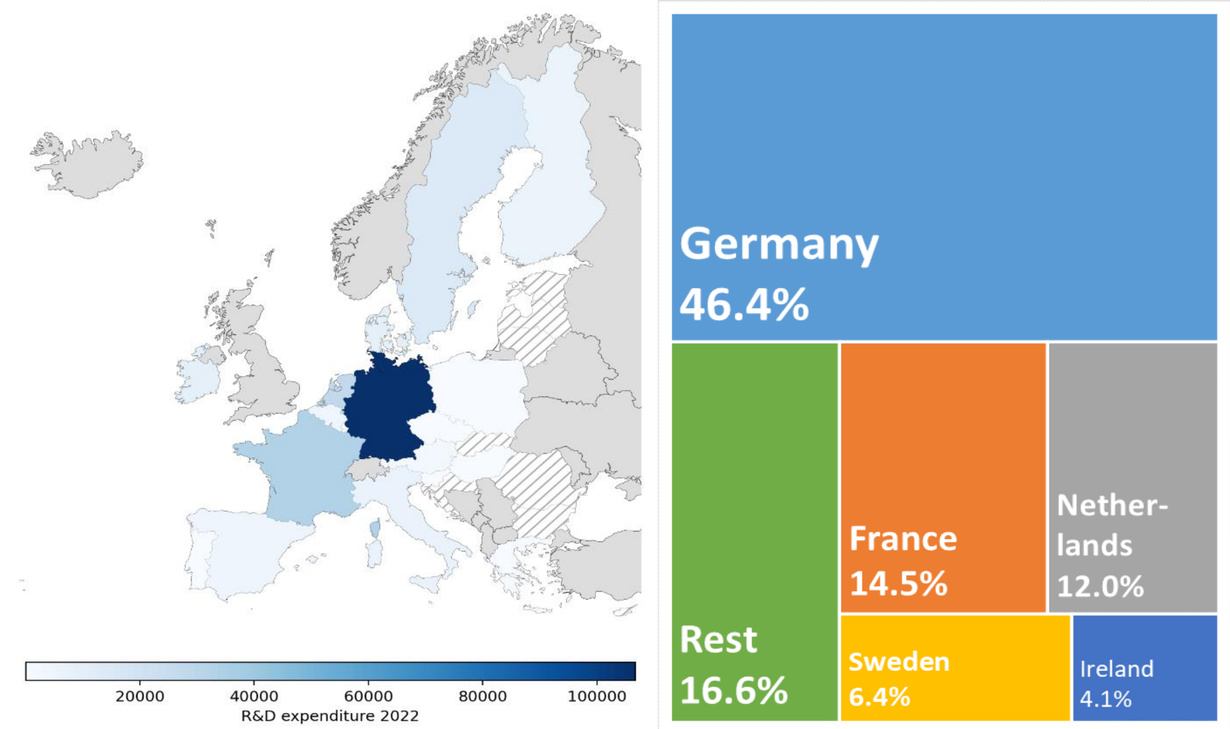
4 A closer look at the EU

This section provides a more detailed analysis of the private R&D investment across EU countries, based on data of the 1 000 companies with the highest R&D investment headquartered in the EU. There are 367 companies headquartered in the EU in the global top 2 500. This core group had R&D investments above EUR 53 million in 2022, with on average EUR 597 million per company. The emerging group of 633 companies headquartered in the EU invested more than EUR 3.1 million in R&D in 2022 (on average EUR 17 million per company). This year's EU 1 000 lower bound is slightly above that of last year (EUR 2.8 million). This section is structured as follows: Section 4.1 gives a country overview, section 4.2 investigates the effect of the Brexit on the EU sample, Section 4.3 presents a sectoral overview for the EU 1 000 with a special focus on the four R&D key sectors in the EU core and EU emerging sample, Section 4.4 zooms in on the SMEs in the EU 1 000, Section 4.5 presents details on the three largest R&D sectors in the extended sample, Section 4.6 makes a closer look at the 5 countries with the headquarters of the largest R&D investing companies in the EU. The section concludes with key points in section 4.7.

4.1 Top 1000 EU R&D investors – overview

Figure 29 presents the geographical distribution of the EU 1 000 companies by headquarter location. The EU 1 000 companies are located in 18 Member States and invested EUR 229.9 billion in R&D in 2022. The 633 companies from the emerging group add EUR 10.8 billion to the EUR 219.2 billion of the core 367 companies (4.7% of the total R&D investment by the EU 1 000). Nominal R&D investment by the EU 1 000 increased by 13.1% compared with the previous year, and by 7.4% adjusted for inflation – by far the largest increase ever recorded for this sample[71]. It has taken 3 years for the total R&D investment by the EU 1 000 to reach the 2019 pre-COVID-19 level when the UK was still an EU member (EUR 229.5 billion, of which EUR 35 billion were contributed by companies headquartered in the UK – see Table 29).

Figure 29. EU 1000 Map, Treemap of top 5 countries



Note: Map - colour darkness proportional to R&D investment in 2022 by companies Headquartered in the country. Treemap – Top 5 countries representing 83.4% of R&D in the EU1000 sample, the remaining 13 countries are responsible for 16.6% of the total.
Source: The 2023 EU Industrial R&D Investment Scoreboard, European Commission, JRC/DG R&I.

[71] This increase closely corresponds to the predicted 8% increase in R&D investment reported in '*The 2022 EU Survey on Industrial R&D Investment Trends*' (Nindl, E., Publications Office of the European Union, Luxembourg, 2022, doi:10.2760/579174, JRC131984)

Table 28 presents the distribution of the EU 1 000 firms headquarter locations and R&D by EU Member State. The top three countries in terms of R&D investment in the EU 1 000 sample, Germany, France, and Netherlands, represent together 50.7% of the companies and 72.9% of R&D investment. The figure for the Netherlands overstates R&D investment in the country as the list of companies includes some whose main operations are in other countries[72]. Moreover, it needs to be mentioned that also Member States without representation of a consolidated headquartered Scoreboard firm in the EU 1 000 do have R&D investing firms but their investment either does not reach the lower bound of EUR 3.1 million, or they are affiliates/subsidiaries, headquartered in other countries or do not provide sufficient information on R&D investment in their company reports.

Table 28. EU Member State in the EU1000 sample, 2022

Country	Companies (core/emerging)	R&D (EUR m)	Share of companies	Share of R&D
Belgium	38 (13/25)	3 804	3.8%	1.6%
Czechia	1 (0/1)	22.8	0.1%	0.01%
Denmark	69 (25/44)	9 225	6.9%	4.0%
Germany	291 (114/177)	106 630	29.1%	46.4%
Ireland	42 (26/16)	9 436	4.2%	4.1%
Greece	8 (0/8)	62.5	0.8%	0.03%
Spain	27 (12/15)	5 308	2.7%	2.3%
France	147 (54/93)	33 343	14.7%	14.5%
Italy	44 (19/25)	7 448	4.4%	3.2%
Luxembourg	23 (4/19)	2 307	2.3%	1.0%
Hungary	1 (1/0)	187.4	0.1%	0.08%
Malta	1 (1/0)	82.3	0.1%	0.04%
Netherlands	69 (40/29)	27 597	6.9%	12.0%
Austria	38 (13/25)	2 804	3.8%	1.6%
Poland	3 (1/2)	141.4	0.3%	0.06%
Portugal	5 (2/3)	337.2	0.5%	0.15%
Slovenia	1 (1/0)	162.6	0.1%	0.07%
Sweden	144 (28/116)	14 804	14.4%	6.4%
Total	1000 (367/633)	229 051	100.0%	100.0%

Note: 'Core' refers to the 367 companies in the global top 2 500, 'emerging' refers to the additional 633 companies that form the EU 1 000.

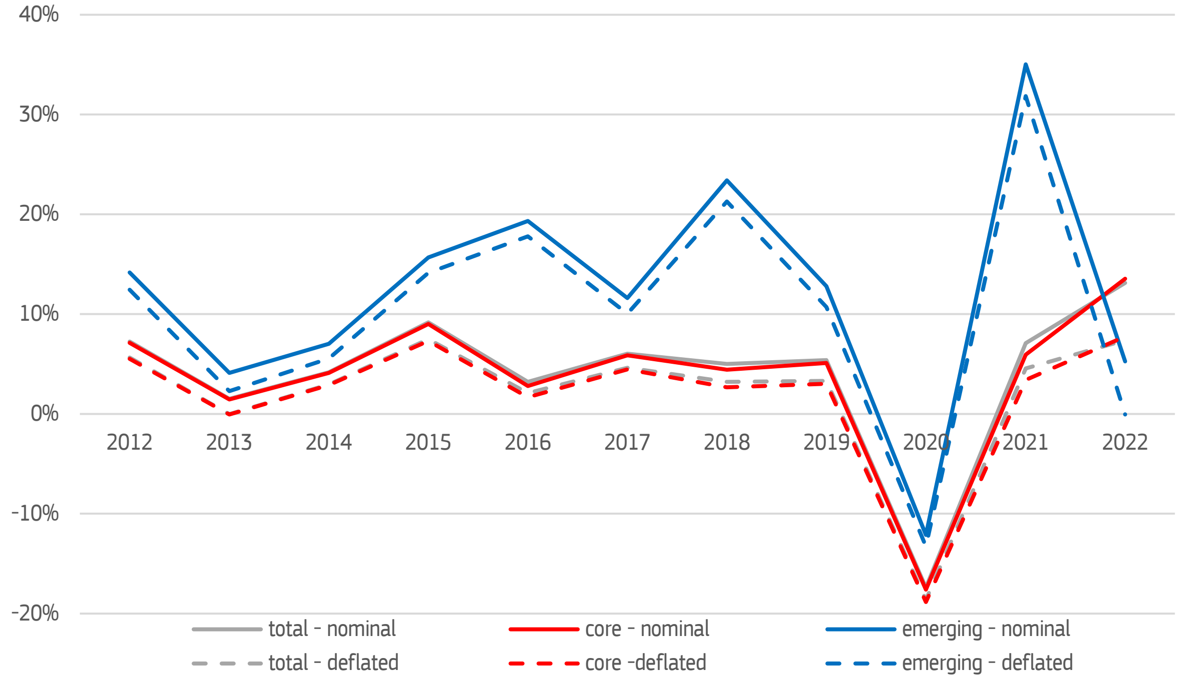
Source: The 2023 EU Industrial R&D Investment Scoreboard, European Commission, JRC/DG R&I.

The annual growth rates of R&D investment for the total EU1000, the core and the emerging EU sample (nominal and deflated) are shown in Figure 30. Given that the companies that also belong to the Top 2 500 global R&D investors account for over 95% of R&D of the EU 1 000, the growth rates of the EU 1 000 and the top companies are broadly similar. The emerging group companies exhibited higher growth rates throughout the observation period, and only in 2022 the core group increased their R&D more than the emerging group. The reduction in R&D during the COVID-19 pandemic in 2020 was smaller for the emerging EU companies.

In 2022, R&D investment of the core companies increased by 13.5% (7.4% adjusted for inflation), substantially higher than for the emerging group (5.3%, and -0.04% adjusted for inflation). The core group invested EUR 26.5 billion more in R&D in 2022 than in the previous year, the highest absolute increase ever recorded for this sample (plus EUR 13.5 billion adjusted for inflation). The remaining 633 companies nominally increased their R&D by EUR 538.2 million, which was not enough to increase R&D beyond the increase in prices.

72 Several top R&D investors, e.g. Airbus, Stellantis, STMicroelectronics and CureVac, are headquartered in the Netherlands but have most of their operations in other countries.

Figure 30. EU total/core/emerging R&D growth rates, 2012-20222, nominal and deflated series

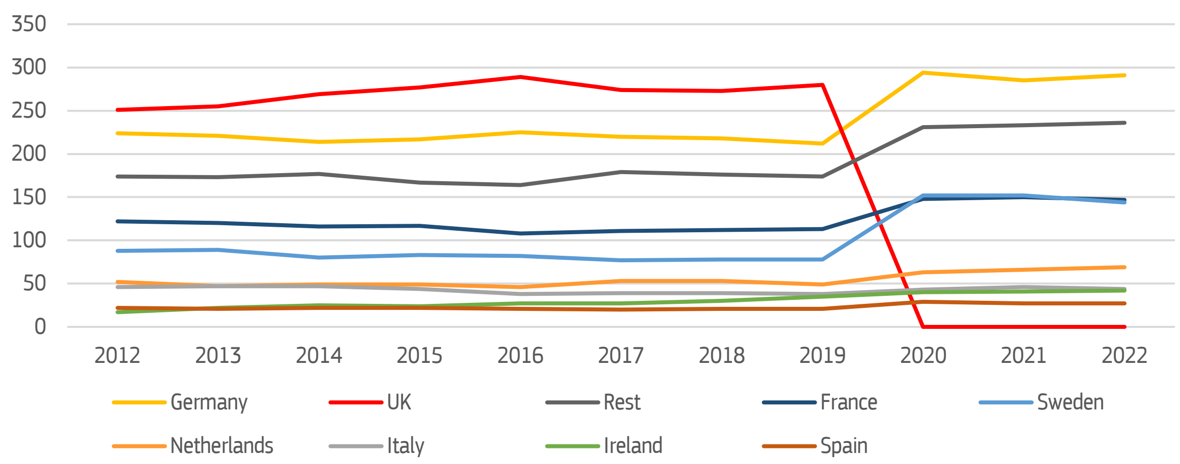


Note: 'Core' refers to the 367 companies in the global top 2 500, 'emerging' refers to the additional 633 companies that form the EU 1 000. The base year for the inflation adjustment is 2015 (GDP deflator in 2015 = 100).
Source: The 2023 EU Industrial R&D Investment Scoreboard, European Commission, JRC/DG R&I.

4.2 Impact of Brexit on the EU 1 000 sample

Overall, the country representation of the EU 1 000 sample varied only slightly over time, until the UK's exit from the EU (Brexit) caused a major reshuffle. Until 2019, the UK had the largest share of companies in the EU 1 000 (27%) and was responsible for approximately 15% of R&D, second after Germany (38% of R&D in 2019). While in 2012, 56.6% of UK firms were among the EU core companies, this share decreased to 43.2% in 2019. As in the EU 1 000, around 94% of R&D was performed by the British EU core companies and around 6% by the emerging sample UK companies. Figure 31 and Figure 32 below show how the composition of companies and R&D shares of the EU 1 000 have changed since 2012 and where the firms and R&D that filled up the gaps left by the UK come from.

Figure 31. EU 1 000 country composition: number of firms – Brexit effect

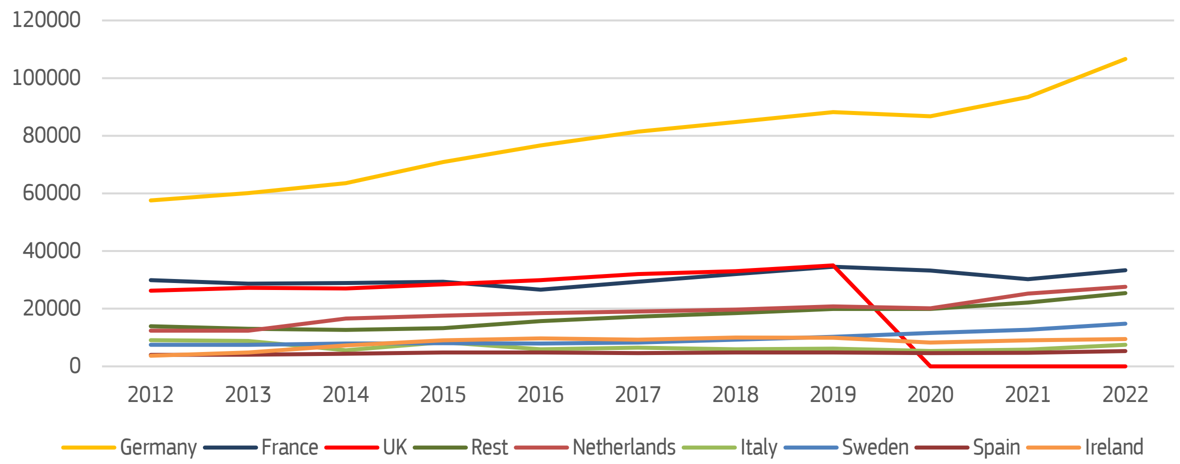


Note: 'Rest' contains the remaining EU countries listed in Table 28, plus Romania (2014, 2015) and Cyprus (2014).
Source: The 2023 EU Industrial R&D Investment Scoreboard, European Commission, JRC/DG R&I.

The 'empty seats' were filled mostly by companies headquartered in Sweden, Germany and France, as well as in the remaining countries ('Rest'); the largest increase is observed for Sweden where the number of companies in the EU 1 000 more than doubled after Brexit (from 78 in 2019 to 152 in 2020). Italy and Spain increased their number of companies less than proportionally given their size by 5 and 8 companies, while Denmark and Finland had an over-proportional increase (plus 18 and plus 16 companies). Companies from the EU widening countries[73] only marginally increased their representation in the EU 1 000. In 2012, there were 18 companies from 7 countries, and in 2022 the number stands at 20 companies from the same 7 countries. Even though the number of companies increased from 15 in 2019 to 21 in 2020, there is no discernible trend of a growing number of companies in these countries that have substantial R&D investments and provide publicly available information on their R&D investment (and are not subsidiaries or affiliates of companies with headquarters in other countries).

This descriptive analysis suggests that small R&D intensive innovative firms are founded mostly in western and northern European countries. Denmark is the current innovation leader and Finland a strong innovator in the European Innovation Scoreboard (EIS)[74], whereas Italy and Spain are moderate performers. The EIS also indicates that innovation performance by EU country varies only very slowly: northern and western Europe are home to the Innovation Leaders and most Strong Innovators, while southern and eastern European countries are mostly Moderate and Emerging Innovators.

Figure 32. EU 1 000 country composition: R&D investment – Brexit effect



Note: 'Rest' contains the remaining EU countries listed in Table 28, plus Romania (2014, 2015) and Cyprus (2014). R&D in EUR million.
Source: The 2023 EU Industrial R&D Investment Scoreboard, European Commission, JRC/DG R&I.

Brexit had a smaller effect on R&D investment, with the R&D share (ca. 15.5%) of the UK firms being around 12 percentage points less than its share of companies. Figure 32 shows the change of R&D investment in the EU 1 000 since 2012 (in nominal values). Due to Brexit, the EU 1 000 sample lost EUR 35 billion in R&D (in 2019) from UK firms, and together with the impact of the COVID-19 pandemic on R&D investments of EU companies, total R&D investment decreased by 17.4% between 2019 and 2020 (dropping from EUR 229.7 billion in 2019 to EUR 189.8 billion in 2020). The net decrease in R&D investment without the Brexit effect in 2020 was 2.5%. However, only 3 years later, in 2022, the total R&D of the EU 1 000 bounced back to its 2019 level (see Table 29). As can be seen in Figure 32, this increase was largely driven by German companies, with the German R&D share increasing from 38.4% in 2019 to 46.4% in 2022[75]. The Netherlands experienced the second largest increase in terms of R&D investment share from 9.1% in 2019 to 12% in 2022, and Sweden the third largest from 4.5%to 6.4%.

Looking at the growth rates of R&D investment, the data shows that the non-UK EU sample increased their R&D on average faster than the UK companies. For the years 2012-2019 the non-UK EU 1 000 companies raised their R&D on average by 5.5% per year, while it was only 3.8% for the UK EU 1 000 companies. In 2020, the COVID-19 pandemic affected UK firms (note that since 2020, we observe only the UK companies in

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[73] Widening countries with Scoreboard representation: Cyprus (only 2014), Czechia, Greece, Hungary, Malta, Poland, Portugal, Romania (only 2014 and 2015), Slovenia. Full list: https://rea.ec.europa.eu/horizon-europe-widening-who-should-apply_en

[74] https://research-and-innovation.ec.europa.eu/statistics/performance-indicators/european-innovation-scoreboard_en

[75] Please note that we refrain here from making 2019-2020 comparisons due to the effect of COVID-19 on R&D investment that affected the EU countries differently depending on their sectoral composition in the Scoreboard. The change in R&D shares in the EU 1 000 after the Brexit can be more reliably judged by comparing the 2019 with the 2021 or 2022 R&D investment shares.

the top 2 500 sample) more with a reduction of 3.5%, while the EU 1 000 R&D decreased by only 2.5%. Moreover, EU 1 000 companies recovered their R&D faster in the past 2 years with growth rates of 7.1% and 13.1%, while the UK companies increased their R&D investment by only 6.5% and 7.9%, respectively.

Table 29. Effect of Brexit on EU 1 000 R&D

	Share UK companies	EU 1 000 R&D	UK R&D	Share UK R&D	Absolute change R&D	Growth total R&D	Growth UK R&D	Growth non-UK R&D
2012	25.5%	164 282	26 293	16.0%	11 126	7.2%	0.7%	8.6%
2013	26.0%	166 719	27 273	16.4%	2 493	1.5%	3.7%	1.1%
2014	26.9%	173 752	27 002	15.5%	6 976	4.2%	-1.0%	5.2%
2015	27.7%	189 706	28 469	15.0%	15 953	9.2%	5.4%	9.9%
2016	28.9%	195 807	29 891	15.3%	6 102	3.2%	5.0%	2.9%
2017	27.4%	207 609	31 978	15.4%	11 801	6.0%	6.9%	5.8%
2018	27.3%	218 018	33 067	15.2%	10 409	5.0%	3.4%	5.3%
2019	28.0%	229 560	35 027	15.2%	11 739	5.4%	6.0%	5.2%
2020	0.0%	189 801	0	0.0%	**-39 956**	**-17.4%**	-100.0%	**-2.5%**
2021	0.0%	203 295	0	0.0%	13 493	7.1%		7.1%
2022	0.0%	229 991	0	0.0%	26 696	13.1%		13.1%

Note: R&D expressed in EUR million.
Source: The 2023 EU Industrial R&D Investment Scoreboard, European Commission, JRC/DG R&I.

On the sector composition of the EU sample, Brexit had only a limited effect: The share of ICT producers and companies in industrials increased slightly, while the number of companies in ICT services decreased somewhat. In the health sector, the EU 1 000 sample lost over 30 companies in the top group due to Brexit, while the number of health companies in the bottom group increased by almost the same number. Overall, the health sector was the same size in 2022 in terms of companies, but R&D investment was still EUR 4 billion lower than it was in 2019 when it included the large British pharmaceutical companies (GSK, AstraZeneca). In aerospace and defence, the gap left by the UK has not yet been closed. The number of firms in this sector fell from 24 in 2019 to 14 in 2020 (more in section 4.3).

There is little evidence of UK Scoreboard companies relocating their headquarters to EU countries. From the list of British companies that were in the EU 1 000 in 2019, most of the firms that exited the ranking for the UK did so because of acquisitions by other companies (in particular in the ICT services sector). The only significant relocation to the EU concerns Just Eat (R&D investment of EUR 91 million in 2022) which moved its headquarters to the Netherlands in 2021. Other UK companies that dropped out of the Scoreboard did not meet the lower bound for R&D investment, others did not publish R&D figures anymore or were delisted.

4.3 EU 1 000 R&D investors – sectoral overview

The distribution of R&D investment of the EU 1 000 companies by sector is shown in Table 30. The automotive sector accounts for the largest share – almost 32% of R&D, the health sector for the second largest (20.1%), followed by ICT producers (14.4%) and ICT services (8%). The construction and materials sector accounts for the lowest share of R&D, followed by chemicals. Compared to the top 2 500, the automotive, aerospace and defence, chemicals, energy, financial and industrials sectors have higher R&D shares in the EU 1 000, while ICT services, ICT producers and health have (partly considerably) lower shares.

Table 30. R&D by sector in the EU1000, 2022

	Countries	Firms	Share of firms	Core group	Emerging group	SMEs	R&D	Share R&D
Automotive	9	55	5.5%	35	20	0	73 395	31.9%
Health industries	14	207	20.7%	68	139	111	46 092	20.1%
ICT producers	12	119	11.9%	42	77	20	33 176	14.4%
ICT services	14	100	10.0%	30	70	14	18 293	8.0%
Industrials	12	152	15.2%	60	92	4	14 964	6.5%
Others	16	163	16.3%	48	115	15	12 334	5.4%
Aerospace & defence	6	17	1.7%	12	5	1	8 758	3.8%
Financials	12	70	7.0%	24	46	6	8 747	3.8%
Energy	15	37	3.7%	24	13	1	6 111	2.7%
Chemicals	9	41	4.1%	15	26	4	5 923	2.6%
Construction & materials	11	39	3.9%	9	30	4	2 192	0.9%

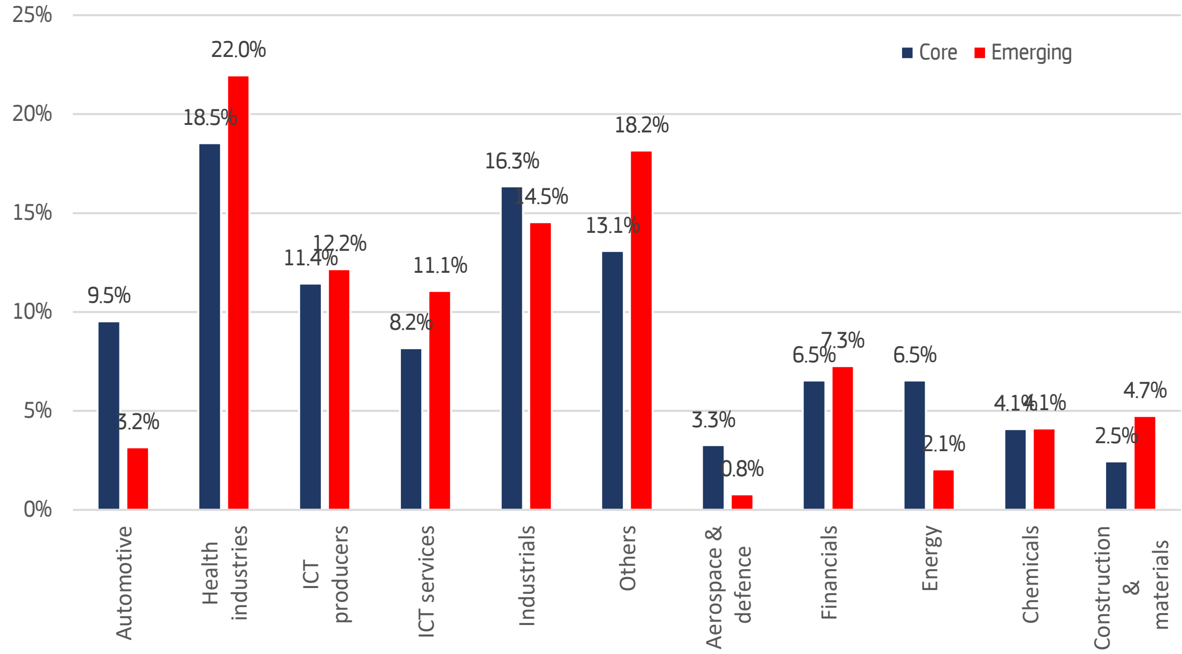
Notes: 'Core' refers to the 367 companies in the global top 2 500, 'emerging' to the additional 633 companies that form the EU 1 000 R&D investors. Countries refers to the number of EU countries with firms in a specific sector. R&D expressed in EUR million.

Source: The 2023 EU Industrial R&D Investment Scoreboard, European Commission, JRC/DG R&I.

In general, the sectoral concentration of R&D in the EU 1 000 sample resembles that of the top 2 500 R&D investors, but while the share of the top four sectors in terms of R&D is almost the same (74.3%), the share of firms is lower (48.1%). This is due to the large automotive companies that are small in number but highly important in aggregate R&D investment. Differences in concentration in the top 2 500 are mainly due to the large R&D investors in the ICT software and services sector, where the EU lags significantly behind. This is important because previous JRC research links these two ICT subsectors to the structural R&D intensity gaps of the EU with the US and China[76]. However, the fact that more than half of the EU 1 000 companies are outside the four top sectors indicates the EU corporate R&D is rooted in a broad sectoral base.

The distribution of the EU 1 000 companies by sector in 2022 for the core and extended group is shown in Figure 33. The extended group has higher shares in three of the four key sectors – ICT producers, ICT services and health, while in aerospace and defence, as well as in the automotive and energy sectors there are only few smaller R&D-investing companies in the EU ranking. This does not imply that the companies themselves are smaller in terms of sales or employment, but only that their R&D investment is comparably lower.

Figure 33. Sectoral distribution of EU 1 000 companies – EU core vs EU emerging, 2022

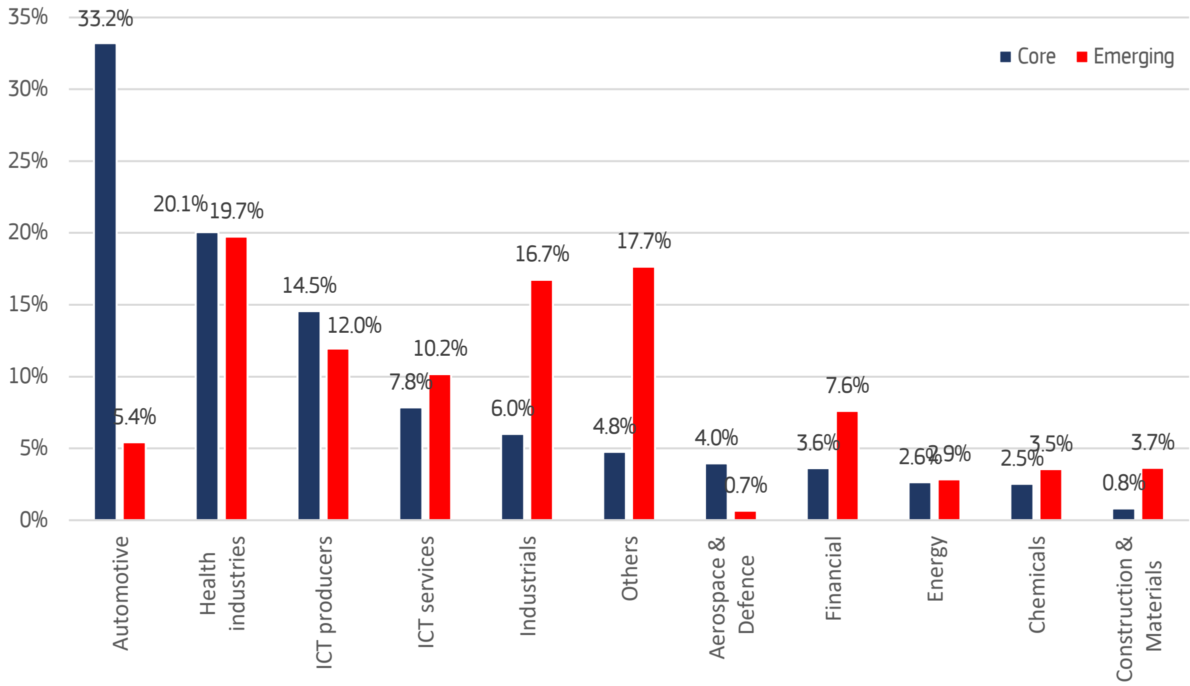


Note: 'Core' refers to the 367 companies in the top 2 500, 'extended' refers to the additional 633 companies that form the EU 1 000.
Source: The 2023 EU Industrial R&D Investment Scoreboard, European Commission, JRC/DG R&I.

Complementing the above, Figure 34 shows the distribution of R&D investment by sector in 2022 for the core and extended group of the EU 1 000 Scoreboard companies. The difference in R&D investment by sector between the core and the extended sample firms is considerable. While in the core group, the automotive sector accounts for the highest share of R&D investment, in the emerging group the high-tech sectors health industries, ICT services and ICT producers, 'others' and industrials account for the highest shares. Taken together, ICT services and ICT producers constitute the largest sector in the emerging group sample with 22.2% of R&D investment (in the core group the two ICT sectors add up to 22.3%).

[76] https://iri.jrc.ec.europa.eu/sites/default/files/2022-09/JRC%20Policy%20BRIEF_EU-US-China%20RD%20Gaps_September%202022_FINAL.pdf.

Figure 34. Sectoral distribution of EU 1 000 R&D Investment – EU core vs. EU emerging, 2022



Note: 'Core' refers to the 367 companies in the top 2 500, 'emerging' refers to the additional 633 companies that form the EU 1 000.
Source: The 2023 EU Industrial R&D Investment Scoreboard, European Commission, JRC/DG R&I.

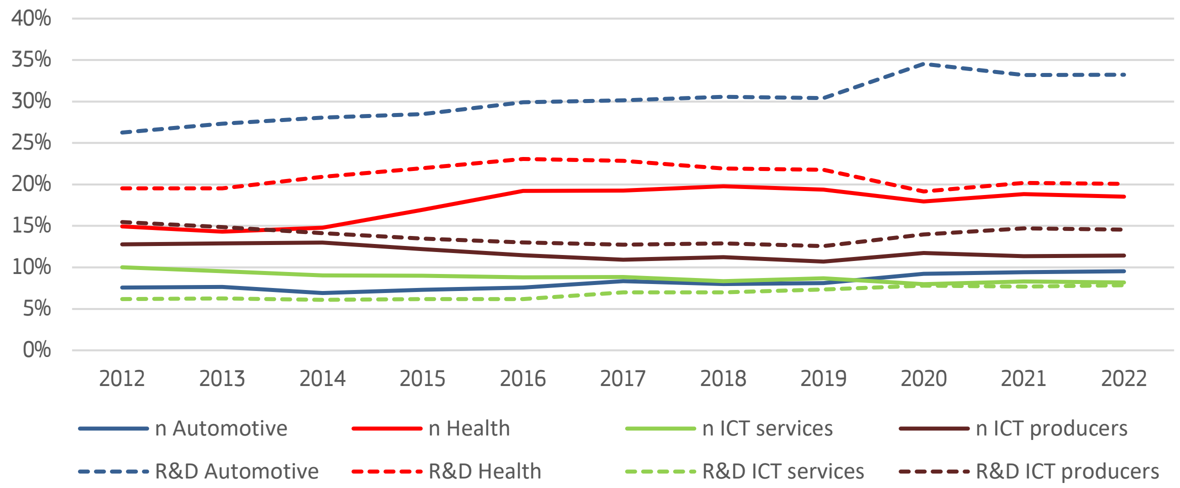
The emerging group's shares of R&D in ICT services and industrials are higher than those of the core group. In the emerging company sample, companies in health industries account for the highest share of R&D (19.7%), followed by 'others' (17.7%). Bearing in mind the small amount of R&D represented by the extended group, the analysis of the distribution of R&D by sector in this group can give insights into the role that small R&D investors play in key high-tech sectors in which the EU lags behind its competitors.

4.4 The top four sectors in the EU 1 000

This section focuses on the four top sectors by total R&D (ICT producers, ICT services, health and automotive) for both the EU core and EU emerging sample companies of the EU 1 000. In the core group, the top four sectors account for a similar share of R&D as in the top 2 500, but for a smaller share of companies. In 2022, the four sectors accounted for 74.3% of R&D but for only 48.1% of companies (top 2 500: 78.5% of R&D and 63.7% of companies), with some variation between individual sectors. The EU emerging sample, by contrast, has only 47.2% of its R&D and 48.3% of companies in these four sectors.

While in the global top 2 500 the automotive sector ranks fourth, in the EU it is by far the most important sector. In terms of firms, the automotive sector accounts for almost 10% in the **EU core group** but only 7% in the top 2 500. For R&D, the respective shares are 31.9% and 13.8%. In the EU core group, the health sector accounts for 20% of R&D, similar to the top 2 500. However, the share of companies is only 18.9% (compared to almost 24% in the top 2 500). The biggest differences are in the ICT sectors: for ICT producers the R&D share is 14%, which is 9 percentage points below the top 2 500, and in terms of companies ICT producers account for only 11.5% (18.7% in the top 2 500). The picture is similar for ICT services, where the R&D share of the EU core group stands at 7.8% and the share of companies at 8.2%. This is substantially below the top 2 500, where ICT service companies account for 20.7% of R&D and 14.5% of companies. More worryingly, the share of EU ICT service companies in the EU 1 000 declined since 2012, and the share of R&D increased only moderately from 6.3%.

Figure 35. Four top sectors in the EU 1 000, EU core companies – shares, 2012-2022

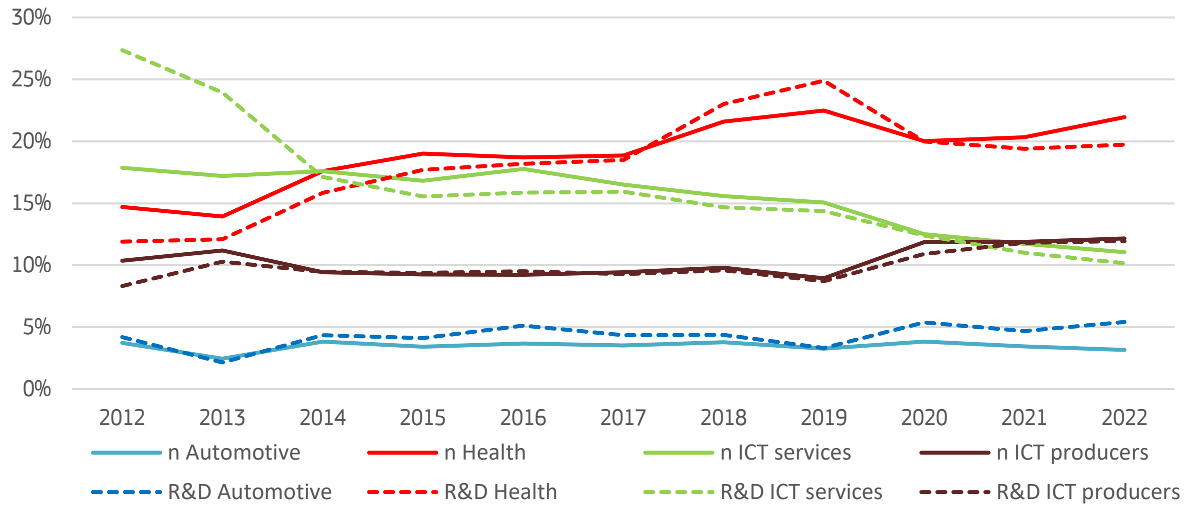


Source: The 2023 EU Industrial R&D Investment Scoreboard, European Commission, JRC/DG R&I.

Figure 36 presents the same information for the **EU emerging group**. Compared to the core group, the pattern is markedly different, both for the role of individual sectors, and for the development over time. In this group, the automotive sector plays only a marginal role, accounting for 5% of R&D and 3.3% of companies in 2022.

Since 2015, the health sector is the biggest of the four sectors in this sample. The health sector experienced a substantial growth in the share of companies, which peaked before Brexit to 25%, declined and then increased again to 22%. The share of health R&D developed in an interesting way. While it was lower than the share of companies, it exceeded it in 2018 and 2019 after which it declined to 19.7%. This appears to be a consequence of Brexit as the UK sample contained many firms in the health sector and these firms invested more in R&D than companies from other EU countries. Following Brexit, the 'empty seats' in the health sector were filled with health companies mainly from Sweden and France. Their R&D investment was lower than that of the companies dropping out, causing a further (albeit small) reduction of the health sector R&D share in the EU emerging sample. The example of small and often young firms from Member States replacing the UK companies in the emerging EU sample is an indication of the good basis of innovative firms in the health sector.

Figure 36. Four top sectors in the EU 1 000, EU emerging companies – shares, 2012-2022



Source: The 2023 EU Industrial R&D Investment Scoreboard, European Commission, JRC/DG R&I.

The ICT producers sector in the emerging EU sample ranks third, as in the EU core group. In 2022 it accounted for 11.9% of R&D and 12.2% of the companies. It experienced an upswing after 2019, with the share of producers increasing by 2 percentage points, and the share of R&D by 1. The newly entering firms were mainly from Germany and Sweden, and to a smaller extent from France. The share of ICT producers in the EU emerging group is significantly lower than in the global top 2 500. However, the sector appears relatively stable overall and shows signs of a positive trend.

The share of the ICT software and service sector in the emerging EU group is decreasing steadily. This is particularly worrisome as it is a key sector in the development of the structural R&D intensity gap between the EU and the US and China, as the EU has been lacking the growth of a sufficient number of firms over the past decade[77]. While in 2012 ICT services companies invested 27.4% of this group's R&D, the share decreased drastically to only 10.2% in 2022. The share of companies also decreased during this time from 17.8% to 11.1%. Due to Brexit, the EU 1 000 sample lost 46 companies in this sector. Some of the empty ranks were filled with companies from Germany, France and Sweden, but the number of companies has nevertheless continued to decrease in the past 2 years.

This is a highly critical development – in the top 2 500, the ICT software and services sector accounts for 14.5% of the companies and 20.8% of R&D and the shares are increasing sharply. This shows that the EU lacks a wider base of companies in the digital service sector (and in software development). The company exits from the EU 1 000 were mostly due to acquisitions (by companies from other sectors or from non-EU countries), but also to de-listings, and companies not meeting the R&D investment for entering the ranking. However, new companies for the ICT software and service sector did not fill the empty ranks, but instead companies from the health sector. The companies in general also did not move up to the EU core group since it also experienced a steady decrease in the share of ICT software and service firms.

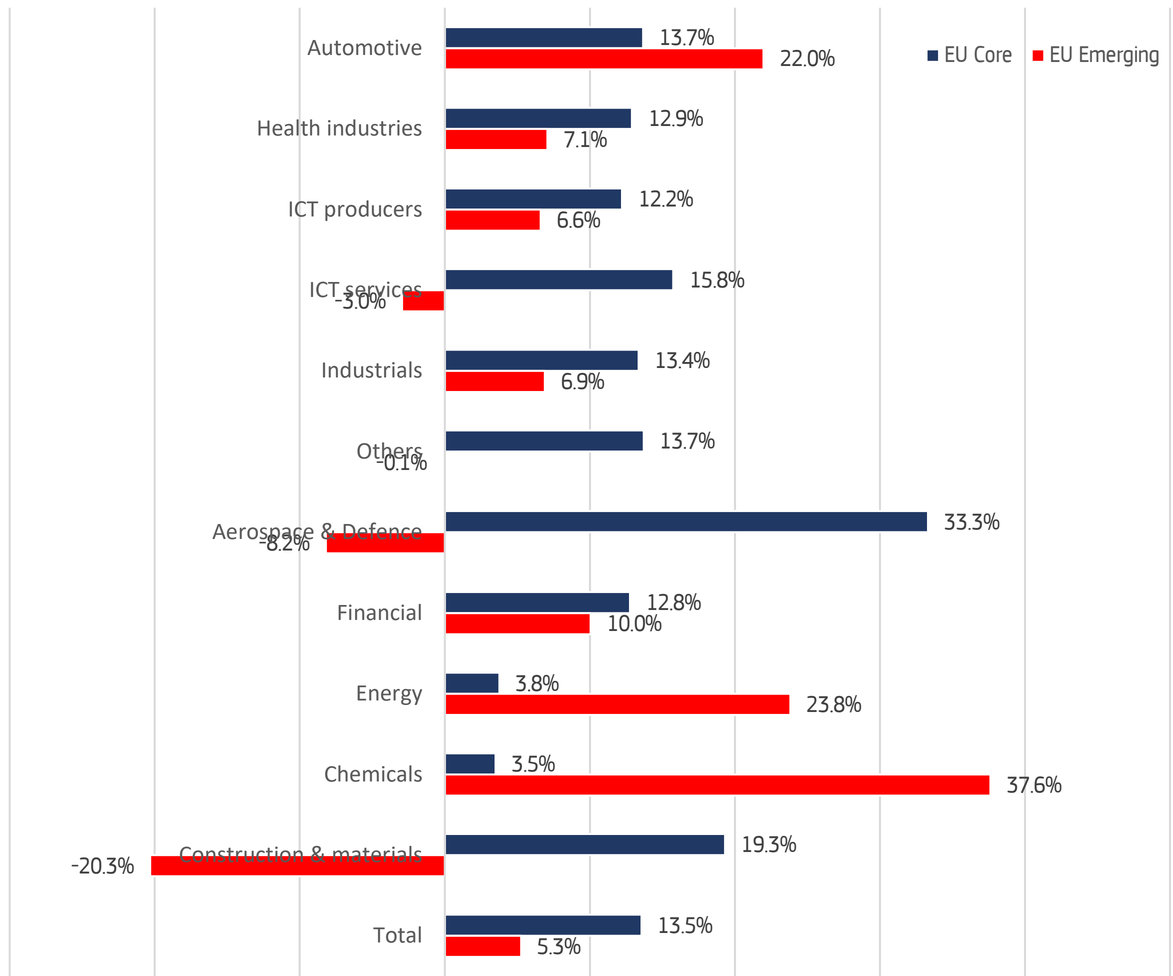
4.5 Development of other sectors in the EU 1 000 – core vs emerging group

The biggest share of the EU 1 000 R&D investment comes from companies in the **automotive sector.** In the core group, this sector invested EUR 8.7 billion more in 2022 (plus 13.7%) than in the previous year and thereby exceeded pre-Brexit and pre-COVID-19 investment levels by EUR 5.5 billion. The largest absolute amounts were invested by Volkswagen (also the top contributor in the top 2 500 automotive companies) which increased its R&D investment in 2022 by 21% (plus EUR 3.3 billion) to EUR 18.9 billion, and Robert Bosch with 18% (plus EUR 1.15 billion). The EU core sample also has a newcomer in this group that resulted from the Mercedes-Benz spin-off of the former Daimler Trucks & Buses segment. Daimler Trucks entered the EU ranking at position 30 (129 in the global ranking) and contributed EUR 1.8 billion to the EU automotive sector growth. Given the weight of this sector in the EU (almost 32% of the total EU 1 000 R&D), they are the main driver of development in the EU total. The 20 automotive companies in the emerging EU sample invested EUR 584 million in 2022; 12 of these 20 companies are in the subsector commercial vehicles and trucks, only 7 in automobiles and parts, and 1 in tyres. Automobiles and parts companies are all in the downstream components sector, while commercial vehicles and trucks companies cover a wide range of applications, from appliances to forestry vehicles.

The core firms in **health industries** continue their expansion in 2022 with a nominal increase in R&D of 12.9% (6.9% adjusted for inflation), while nominal growth for the emerging group companies was only 7.1% (1.7% adjusted for inflation). Health is the biggest sector in terms of companies for both the EU core and the EU emerging group (see Figure 33). The sectoral composition changed similar to the financial sector. The share of health companies in the core group fell from 65% in 2012 to 32.8% in 2022, and by 2022 67.2% of the 207 companies were in the emerging group. However, their R&D share is only 4.6% (up from 1.3% in 2012). The 68 EU health companies in the core group spent EUR 43.9 billion on R&D in 2022 and the emerging group another EUR 2.2 billion. Overall, health is the second biggest R&D sector in the EU after the automotive sector. The biggest EU companies in the sector are Sanofi (France, world rank 30, EU rank 6), Bayer (Germany, world rank 32, EU rank 7) and Boehringer Sohn (Germany, world rank 10, EU rank 10). Their R&D investment in 2022 ranged between EUR 6.7 billion and EUR 5 billion. These three companies are also top contributors to EU R&D growth, having increased their investments by a collective EUR 3.1 billion - 69% of the total increase of this sector in the EU. The health sector was considerably affected by Brexit, losing almost EUR 10 billion in R&D from the two largest UK health companies (GSK and AstraZeneca) alone. Therefore, R&D investment in 2022 is still below the 2019 level of EUR 50 billion.

[77] https://iri.jrc.ec.europa.eu/sites/default/files/2022-09/JRC%20Policy%20BRIEF_EU-US-China%20RD%20Gaps_September%202022_FINAL.pdf

Figure 37. Growth rate in R&D investment 2022, EU Core and Extended, across sectors



Note: 'Core' refers to the 367 companies in the top 2 500, 'emerging' refers to the additional 633 companies that form the EU 1 000.
Source: The 2023 EU Industrial R&D Investment Scoreboard, European Commission, JRC/DG R&I.

ICT producers is only the fourth largest sector in the EU with 11.9% of the companies, but the third largest in terms of R&D investment accounting for 14.5% of the total. The core group increased their R&D investment by 12.2% in nominal terms (6.7% adjusted for inflation), while the emerging group increased it by 6.6% (1.3% adjusted for inflation). While 65% of the EU 1 000 companies in this sector belong to the emerging group, they invested only 3.9% of the EUR 33 billion R&D investment in 2022. The biggest EU company in this sector is Siemens AG (Germany, world rank 38, EU rank 9) in the subsector electrical components and equipment, followed by two telecommunications equipment companies, Nokia (Finland, world rank 47, EU rank 11) and Ericsson (Sweden, world rank 49, EU rank 12). Three semiconductor producers are also among the top EU companies – the two Dutch companies ASML Holding (world rank 68, EU rank 14) and NXP Semiconductors (world rank 111, EU rank 24) and the German company Infineon (world rank 113, EU rank 25). These 6 companies account for 58% of the R&D investment in this sample and 65% of the additional investment in 2022. After Brexit, the number of ICT producers in the emerging group increased from 41 in 2019 to 71 in 2020. The new companies are mostly in electronic equipment, but also computer hardware and telecommunications equipment, and are headquartered mainly in Germany, Sweden, Denmark and the Netherlands. In contrast to other sectors, ICT producers reached the pre-COVID-19 and pre-Brexit R&D investment level already in 2020.

The **ICT services** sector developed well in 2022. With an R&D investment growth of 15.8% for the EU core group companies (9.7% adjusted for inflation), it thereby surpassed the 2019 R&D investment level. However, the emerging group companies reduced their R&D by 3% (-7.6% adjusted for inflation). The number of companies fell by 5 to 100. Both, in absolute and in relative terms, no other sector of the EU 1 000 lost more firms over the past decade than ICT services. In 2022 the sector accounted for only 10% of the companies. Of the remaining 100 companies, 30% are in the EU core group and 70% in the emerging group. At 94%, R&D investment is concentrated in the core group – a slight increased from 91% in 2012. The top companies in the

EU are SAP (Germany, world rank 34, EU rank 8) and Spotify (Luxembourg, world rank 175, EU rank 36), but with an R&D investment of EUR 6.1 billion SAP invests almost EUR 5 billion more than the second largest R&D investor Spotify. In the core and the emerging group, the number of software companies is declining and reached a new low in 2022 with only 12 companies in the core and 32 in the extended group, respectively. Brexit is one reason for this development, resulting in the EU losing many software firms in the ranking, but at least equally problematic is the fact that very few new firms entered the Scoreboard.[78]

The EU sample has a comparably strong representation in the **industrials sector**, accounting for 15.2% of companies and 6.5% of R&D (11.2% and 5% in the top 2 500). R&D investment increased by 12.5% in 2022 (6.7% adjusted for inflation), with the core group increasing more than the emerging group. The sector slightly surpassed the pre-COVID-19 R&D investment level.

Also the companies in the group "**others**" increased their R&D investment in 2022 overall, but with wide variation between the core and the emerging group. While the core companies increased their R&D by 13.4% (7.9% adjusted for inflation), the emerging group witnessed a decline of-0.1% (-5% adjusted for inflation). The development in the emerging group, however, also relates to a reduction in the number of companies.

The growth rates of R&D investment vary considerably across sectors and also between the two groups (see Figure 37). The core companies in **aerospace and defence** report a strong increase of 33.3%, and those in the extended group a decrease of 8.2% (28.5% and -12.5% adjusted for inflation). At EUR 8.7 billion, the sector's R&D investment is EUR 1.4 billion below the level of EUR 10.1 billion when the UK was still an EU member, but EUR 2.3 billion higher than in 2020. A supply of innovative firms from the EU is replacing the UK-based firms that exited. However, the 5 companies in the emerging group contributed EUR 84 million to this sector, which is less than 1% of the core group's R&D.

In the **financial sector** in the EU 1 000 the number of firms steadily increased to reach 70 companies, of which 65% are in the emerging sample. Companies invested in total EUR 8.7 billion, with the core companies expanding their R&D investment by 12.8% and the emerging group by 10% (7.2% and 3.4% adjusted for inflation). Company structure in this sector also changed over time – while in 2012 the EU core group companies constituted 70% of firms, the share of emerging group companies grew over time and accounted for 71.4% of firms in 2022. Over the same period, their share of total R&D rose from 2.3% to 11.5%. It is worth noting that the financial sector extended group contains many firms that are investment holdings or real estate developers.

R&D investment by EU companies in the **energy sector** increased moderately. The 24 companies in the core group increased their R&D by only 3.8%, which drops to -1.1% when considering inflation. The 13 emerging group companies increased their R&D by 23.8% (17% adjusted for inflation). In the energy sector the share of companies in the extended group increased from 15.2% in 2012 to 35.1% in 2022, and the share of R&D rose from less than 1% to 5% in the same period. While some companies from the core group reduced their R&D investment and moved into the emerging group, some new companies reached the R&D threshold. However, there is no discernible trend of predominantly companies in the renewables energy sector joining the EU 1 000. Overall, with 2.7% of the EU 1 000 R&D, the energy sector share in R&D is 1 percentage point higher than in the top 2 500.

For **chemicals**, R&D investment in the core group grew by 3.5% in 2022 (the lowest rate of all sectors in the core group, and even negative at -1.9% when considering inflation), and by 37.6% in the emerging group (31.3% adjusted for inflation). At EUR 5.5 billion, the core group's R&D investment is still below the 2019 level (by EUR 445 million). In the chemicals sector, the R&D of the EU 1 000 is highly concentrated. At EUR 2.33 billion, BASF – the largest chemicals company in the EU (Germany, world rank 95, EU rank 20) is responsible for over 42% of the (core group's) R&D investment. The emerging group contributes EUR 382.5 million or 5.9% to total R&D in this sector, up from 2.7% in 2012, and its share of companies increased from 39% to 60.5% between 2012 and 2022. The new firms mainly come from Germany and are integrated in the manufacturing value chains (e.g. polymers, pharmaceutical base materials).

Companies in **construction & materials** – the smallest sector accounting for 1.7% of EU 1 000 R&D - increased their R&D investment by 19.3% (13.9% adjusted for inflation) in the core group compared to 2021. However, in the emerging group their R&D investment decreased by 20.3% over the same period (-24.3%

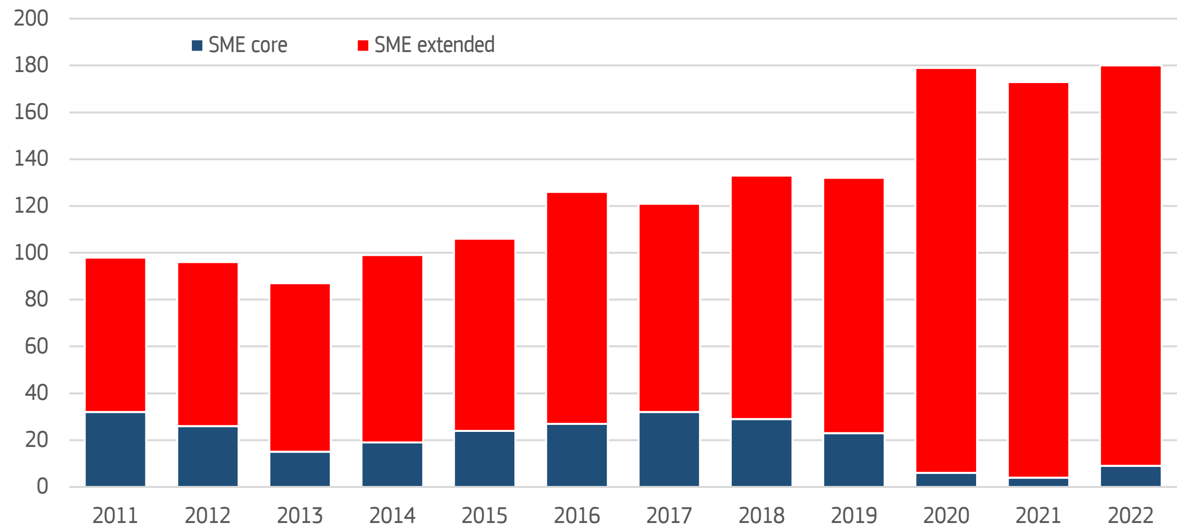
[78] One the one hand side, ICT software and service companies were lost due to Brexit, on the other hand side, EU companies were acquired (mostly by US companies), moved headquarter, went bankrupt, or did not publish R&D figures any more.

adjusted for inflation). While 77% of the firms in this sector belong to the extended group (the largest share for extended group firms across all sectors), they invest only 18.8% of the total R&D of EUR 2.2 billion.

4.6 SMEs in the EU 1 000

Of the 1 000 EU companies, 180 are small and medium sized enterprises (SMEs) with less than 250 employees[79] - 7 more than in the previous year. As shown in Figure 38, the total number of SMEs increased from 98 to 180 between 2012 and 2022. The UK traditionally had the largest number of SMEs in the sample – in 2012-2019 the UK accounted for on average 45% of the SMEs in the sample. After Brexit, the number of SMEs increased substantially as more SMEs replaced the larger UK firms that exited the ranking. However, a lasting effect of Brexit is that the number of SMEs in the core group dropped from 23 in 2019 to only 6 in 2020, while the number of SMEs in the emerging group increased from 109 to 173.

Figure 38. Number of SMEs in the EU 1 000 – core vs. emerging group



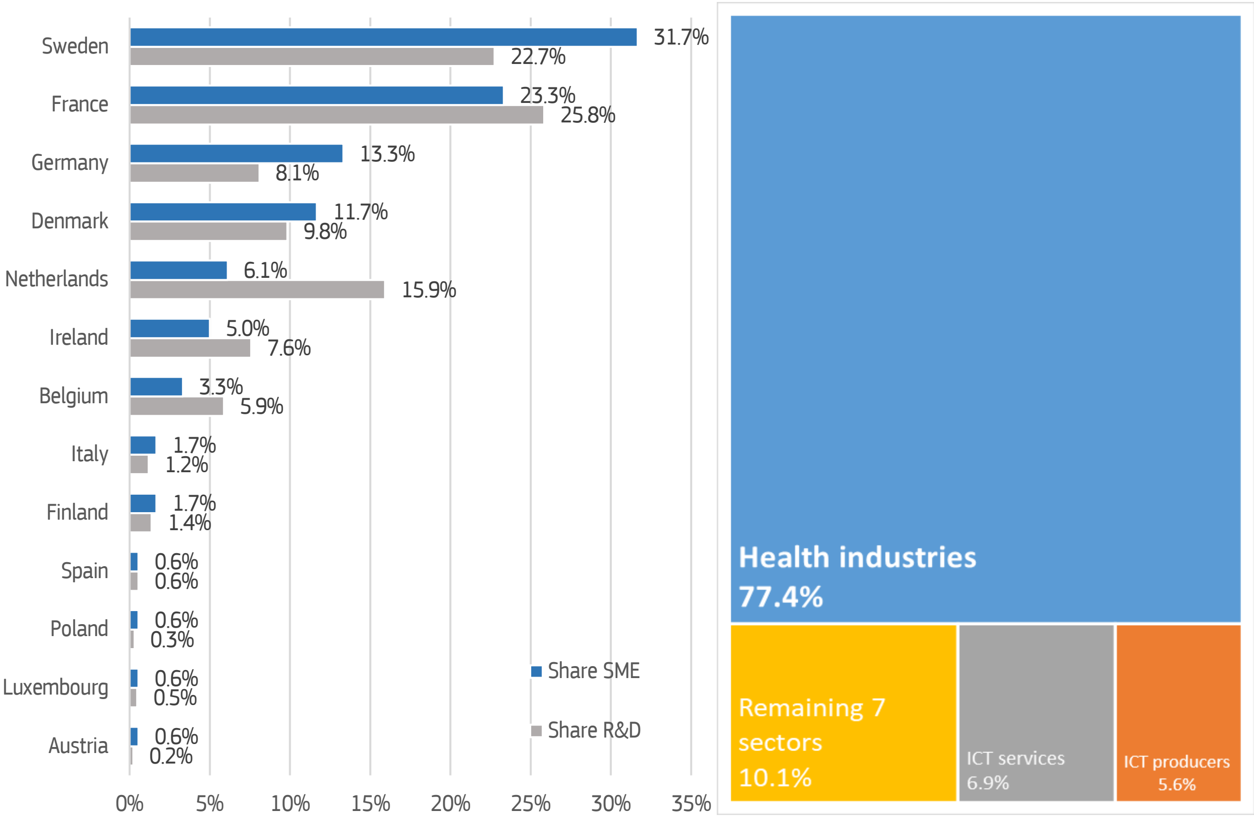
Note: 'Core' refers to the 367 companies in the top 2 500, 'emerging' refers to the additional 633 companies that form the EU 1 000.
Source: The 2023 EU Industrial R&D Investment Scoreboard, European Commission, JRC/DG R&I.

Together, the 180 SMEs invested EUR 2.6 billion in R&D in 2022 - 19.1% more than the previous year (13.7% adjusted for inflation). The growth rate of R&D investment in SMEs in the EU therefore exceeds that of the other EU companies, as well as the R&D investment growth of the global 2 500. The R&D of these 180 SME in 2022 is still below the level of 2019 when the UK was still an EU Member State. As mentioned above, the highest number of SMEs came from the UK, and many of them were also among the top 2 500 R&D investors (i.e. the EU core group). Whereas the 132 SMEs in 2019 invested EUR 3.3 billion in R&D, after Brexit this dropped to EUR 1.92 billion, even though the number of SMEs increased to 179.

The distribution of SMEs and their R&D investment across EU countries in 2022 is shown in Figure 39 , and the distribution of their R&D by sector is shown in the Treemap in the righthand panel of the figure. The distribution differs significantly from the EU 1 000 total. The largest number of SMEs comes from Sweden with 31.7%, followed by France with 23.3%, and Germany with 13.3%. Czechia, Greece, Hungary, Malta, Portugal and Slovenia do not have any SMEs in the EU 1 000. French SMEs account for the biggest R&D investment share at 25.8% of the total, followed by Sweden at 22.7% and the Netherlands at 15.9%.

[79] We use the EU SME definition: https://single-market-economy.ec.europa.eu/smes/sme-definition_en. Given that we do not have data on turnover or the balance sheet we only use the employment criteria for the SME definition.

Figure 39. SMEs in the EU 1 000 – Company and R&D shares across countries, 2022; Treemap of R&D across sectors



Source: The 2023 EU Industrial R&D Investment Scoreboard, European Commission, JRC/DG R&I.

The health sector accounts for 77.4% of the R&D investment of the 180 SMEs in the sample and 61.7% of the companies. Of the 103 health SMEs, 35% are in biotech, 46.6% in pharmaceuticals and the remaining 18.4% in other health areas. The second-largest sector by SME R&D investment is ICT services with 6.9% of R&D investment and 7.8% of companies. Overall, all sectors except for the automotive have at least 1 SME, with 1 each in aerospace and defence and energy, each 4 in chemicals, construction and industrials, 6 in financial, 14 in ICT services, 15 in others, 20 in ICT producers and 111 in health industries.

Of the SMEs, 9 also belong to the EU core group (the top 2 500), 8 are in health (6 in biotechnology, 2 in pharmaceuticals) and 1 in ICT services. The ICT services company is the French game developer Focus Home on world rank 1 697 (EU rank 265). Of the 8 health companies 4 are located in the Netherlands, and 1 each in Denmark, Ireland, Belgium and France. The EU core group SMEs occupy the EU ranks between 230 and 364, corresponding to a ranking in the top 2 500 in the range between position 1 392 and 2 483.

4.7 Top three sectors in the emerging group

The three biggest R&D-investing sectors in the emerging company group of the EU 1 000 are health industries, ‘others’ and industrials. These three sectors account for 347 of the 633 emerging group companies and EUR 5.8 billion of the group’s total R&D investment of EUR 10.7 billion (i.e. 54.1% of companies and 54.8% of R&D). The analysis of these sectors of the emerging company sample provided a deeper understanding of the most important sectors beyond the well-known top R&D investors.

Table 31 shows how the number of firms and R&D investment of the three sectors is distributed across EU Member States, as well as the growth rate of R&D investment per country compared to 2021. It is important to note that due to the low numbers, growth in R&D investment by country and by sector can be driven by the actions of few firms.

The companies in the health industries sector come from 11 Member States, 'others' from 15 and industrials from 12. In 2022, the R&D investment of these 347 firms developed less favourably than the previous year, with a nominal increase of 4.6%, resulting in an inflation-adjusted decrease of -0.6%. As in the previous year, the health sector increased its R&D investment the most (7.1%, or 1.7% adjusted for inflation), followed by industrials (6.9% or 1.8% adjusted for inflation), while R&D investment in 'others' did not change relative to 2021 (resulting in a real loss of -4.8%).

Table 31. EU emerging group – top 3 sectors, country overview, 2022

	Health industries			Others			Industrials		
	n	R&D	Growth	n	R&D	Growth	n	R&D	Growth
Belgium	8	178.9	38.8%	3	33.6	-36.4%	4	57.8	-11.2%
Denmark	15	140.1	-7.0%	7	118.6	-2.5%	3	95.2	9.6%
Germany	15	235.9	38.0%	35	596.3	6.2%	32	647.7	8.7%
Ireland	6	79.6	15.9%	3	60.7	10.4%	2	8.1	69.4%
Greece				1	7.8	18.8%			
Spain	4	46.7	-5.3%	2	10.9	-6.6%	3	39.7	9.2%
France	34	549.2	-1.7%	13	236.9	18.9%	11	236.4	7.0%
Italy	4	52.3	-17.3%	6	95.7	13.5%	6	188.5	28.6%
Luxembourg				3	47.9	-2.6%	5	114.8	1.0%
Netherlands	13	302.6	-8.2%	6	136.9	77.8%	3	73.9	-29.9%
Austria	3	46.5	60.1%	4	77.7	23.6%	4	54.0	38.1%
Poland				1	8.1	-84.1%			
Portugal				1	19.4	17.7%			
Finland	2	32.2	1.8%	10	145.0	-23.3%	5	105.1	54.1%
Sweden	35	463.6	14.1%	20	307.6	-16.2%	15	187.3	-10.3
Total	139	2 127	7.1%	115	1 903	-0.1%	93	1 808	6.9%

Note: R&D investment in EUR million

Source: The 2023 EU Industrial R&D Investment Scoreboard, European Commission, JRC/DG R&I.

Of the companies in the health industries sector, 103 or 74.1% (previous year: 75%) are SMEs with fewer than 250 employees, while this share is only 4.3% for industrials and 13.8% for 'others' (previous year: 3.2% and 14.4% respectively). Of the 180 SMEs in the EU 1 000, 103 are in the extended group in the health sector.

In health, Sweden, France and the Netherlands are the frontrunners in R&D investment and the number of companies. Of the 139 companies, 32.4% are biotech and 44.6% are pharmaceutical companies, with the corresponding R&D investment shares being 35.1% and 47.5%. The remaining companies are in other health sectors such as medical equipment. SMEs account for 30 out of 35 Swedish health-related companies, 29 out of 34 health companies in France, and of 7 out of 11 in the Netherlands. Every country with health companies in the extended sample also has at least one SME. R&D investment increased by 7.1%. While this was a slowdown compared to the previous year, the growing number of SMEs in this high-tech sector is an encouraging sign that this important sector is gaining prominence in the EU.

Industrials is the second biggest R&D-investing sector of the EU extended sample. The 93 companies in this sector increased their R&D investment by 6.9% between 2021 and 2022 (1.8% adjusted for inflation). Industrial machinery firms account for 49.5% of the companies in this group and for 47.5% of R&D investment. The second biggest subsector is general industrials, accounting for 13% of companies and 15.9% of R&D. This group also contains 19 companies in energy intensive sectors such as industrial metals and mining, coal, aluminium or iron and steel. These 19 companies account for 16.3% of the sector’s R&D investment.

The third biggest group, ‘others’ consists of a wide range of firms. The ‘support services’ sector accounts for 30% of companies and 31% of R&D. This sector covers logistics firms and companies providing ventilation and cooling systems. The next two largest sectors in this group are food producers and general retailers, each accounting for around 15% of companies and R&D investment. This group includes 15 SMEs, spread evenly across the different fields of activity. In the high-inflation environment of 2022, the small decrease in nominal R&D investment resulted in a real reduction of -5% compared to 2021.

Even though the total R&D investment of the three sectors is of a similar magnitude, the remaining financial indicators shown in Table 32 reveal how different they are. The health companies so far serve only a small market in terms of net sales, and relating this to their R&D investment results in an R&D intensity close of 13.7%, which is in a similar range as in the top 2 500 (12.9%, see Table 11).. Net sales rose by 20.3%, while aggregate profits remain negative (but less negative than in 2021). Aggregate profits are negative for this group as 102 of the 139 companies marked a loss in 2022 (previous year: 96 of 128). At the same time, capital expenditures and employment continued to increase at a comparable pace as in the previous year. Market capitalisation, as for the entire top 2 500 and EU 1 000, also fell in the EU extended group health sector, but to a lesser extent than in the other sectors. The strong development of this SME-dominated nascent group of R&D-intensive companies in the extended sample of the EU 1 000 is a positive sign for a growing biotechnology and pharmaceuticals sector in the EU.

Table 32. Emerging group – top 3 sectors: financial indicators, 2022

	Health industries	Others	Industrials
Net sales (EUR m)	15 547	233 107	360 036
One-year change	20.3%	15.3%	23.4%
R&D intensity	13.7%	0.8%	0.5%
Operating profits (EUR m)	-539.1	17 357	30 659
One-year change	-19.1%	30.1%	30.9%
Profitability	-3.5%	7.4%	8.5%
Capex (EUR m)	856.4	10 577	11 903
One-year change	48.3%	10.5%	16.7%
Capex/net sales	5.5%	4.5%	3.3%
Employment	65 667	753 986	1 359 918
One-year change	13.1%	-6.5%	0.6%
R&D per employee, EUR	32 399	2,524	1,329
Market capitalisation (EUR m)	47 855	114 407	195 810
One-year change	-17.6%	-40.9%	-21.9%

Note: R&D intensity is R&D over net sales, profitability is profits over net sales.
Source: The 2023 EU Industrial R&D Investment Scoreboard, European Commission, JRC/DG R&I.

The companies in the 'others' group continue their overall positive development in the main financial indicators compared to the previous year. Profits increased faster than sales, leading to a rise in profitability. Capital expenditures also increased further, but at a lower rate than in 2021. Whereas employment increased in 2021, in 2022 companies reduced their headcount by 6.5%. Market capitalisation decreased by over 40% following the 39% increase of the previous year. The R&D intensity of 0.8% for the EU extended group companies in these sectors is substantially below the 2.7% for the same sector in the top 2 500 R&D investors.

In terms of employment, sales and profits, the largest of the top three sectors in the EU extended group is industrials. Net sales increased by over 23% to more than EUR 360 billion, and operating profits increased by 30.9% to over EUR 30 billion, continuing the positive trend of 2021. Employment increased slightly to 1.35 million. In contrast to the industrial companies in the top 2 500, the R&D intensity of the EU extended group industrial companies is substantially lower at 0.5% compared to 2.3%.

4.8 Country focus – top 5 EU countries

Table 33 presents the main financial indicators for the companies headquartered in the top 5 R&D-investing countries in the EU 1 000 sample. The number of companies in the top 1 000 per country changed slightly: Germany gained 6 companies, Netherlands gained 3, Ireland gained 1, Sweden lost 8 and France lost 3 companies compared to 2021.

Companies headquartered in Germany are by far the biggest R&D investors: the German automotive sector alone invested EUR 52.4 billion in R&D in 2022, while in France - the number two R&D investor in the EU – all companies in the ranking spent a collective EUR 33.4 billion. With this value, France remains the only country in the top 5 whose level of R&D investment in 2022 is still below its pre-COVID value (EUR 34.5 billion).

In nominal terms, all five countries increased their R&D investment compared to 2021, but in Ireland, the inflation-adjusted change was negative. The highest growth rates were achieved by the companies in Sweden and Germany, followed by France and the Netherlands. The difference in nominal and real growth rates was the largest in Sweden (6.4%) and Germany (6.3%), followed by Ireland (5.8%), the Netherlands (5.1%) and France with the lowest inflation rate (4.0%).

German R&D efforts expanded massively in 2022 – by a total of EUR 13.2 billion. Over half (51%) of this increase relates to companies in the automotive sector that increasing their R&D investment by 14.8% (plus EUR 6.8 billion). The German automotive sector is responsible for 49% of all R&D investment by German Scoreboard companies. Other sectors in Germany with a substantial increase are health industries (19%) – the second-largest sector in terms of R&D with a total investment of EUR 19.7 billion, ICT services (17.2%), industrials (11.4%), others (11.5%) and ICT producers (10.3%). R&D investment only decreased in comparably small sectors such as energy and financials. Operating profits, net sales and capex continued to increase, leaving ratios such as R&D intensity, profitability, and the capex ratio unchanged. Sales and profits increased strongly for e.g. Commerzbank (thanks to rising interest rates), Thyssen Krupp and Salzgitter (higher steel prices), the energy companies (due to increasing energy prices), ICT producers Infineon (higher prices for semiconductors), while the profits of the German automotive companies flattened (after last year's surge), and BioNTech's profit decreased by EUR 2 billion to EUR 12.3 billion. Nevertheless, the profitability of the German top R&D investors was lower than of the companies in the other economies presented in Table 33.

Table 33. KPI for the Top 5 countries in the EU 1 000, 2022

	Germany	**France**	**Netherlands**	**Sweden**	**Ireland**
Companies	291	147	69	144	42
R&D investment (EUR m)	106 630	33 343	27 597	14 804	9 436
One-year change	14.2%	10.1%	9.5%	16.6%	4.5%
…adjusted for inflation	7.8%	6.0%	4.4%	10.2%	-1.3%
Net sales (EUR m)	2 483 687	1 465 963	637 660	311 670	294 289
One-year change	13.5%	24.6%	11.9%	19.3%	10.9%
R&D intensity	4.3%	2.3%	4.3%	4.7%	3.2%
Operating profits (EUR m)	190 895	131 125	64 315	36 249	31 909
One-year change	10.1%	-6.8%	-4.8%	-11.8%	-9.3%
Profitability	7.7%	8.9%	10.1%	11.6%	10.8%
Capex (EUR m)	125 955	92 401	28 291	13 018	10 384
One-year change	8.9%	10.3%	25.0%	17.8%	11.7%
Capex/net sales	5.1%	6.3%	4.4%	4.2%	3.5%
Employment	6 933 141	4 384 281	1 551 945	933 756	1 491 992
One-year change	0.4%	1.9%	-1.1%	1.1%	7.5%
R&D per employee, EUR	15 379	7 605	17 782	15 854	6,325
Market capitalisation (EUR m)	1 233 340	1 293 949	670 306	324 461	560 040
One-year change	-24.7%	-11.7%	-26.8%	-22.9%	-36.6%

Source: The 2022 EU Industrial R&D Investment Scoreboard, European Commission, JRC/DG R&I.

As previously mentioned, of the French firms in the top 1 000, 42 are SMEs. Of those, 30 of are in the health sector. France is after Sweden the country with most SMEs in the sample. French R&D investment increased in particular in the health sector (29.2% of total R&D investment) by 11.3%. It also increased in ICT services (the second-largest sector in France with EUR 3.6 billion), ICT producers and the automotive sector, with increases of 5.7%, 14.8% and 11.4% respectively compared to 2021. Positive developments were also observed in sectors such as chemicals and construction, but they remain quantitatively small.

The major increase in sales relates to energy companies, e.g. Total Energies increased sales by EUR 73.3 billion and Electricité de France by EUR 59 billion. The highest- selling non-energy company is Christian Dior, with an increase in sales of EUR 14.9 billion. However, an increase in sales does not necessarily imply an increase in profits – French companies lost 6.8% compared to 2021, and the biggest loss was incurred by the energy company Electricité de France. The increase in employment relates mainly to five companies: the construction company Bouygues (plus 71 500), Forvia (automotive supplier, plus 46 300), Veolia Environment (water and waste management, energy supply, plus 37 100), Capgemini (ICT services, plus 34 888) and again Christian Dior (luxury goods, plus 20 300).

Companies in the Netherlands expanded their R&D by EUR 2.4 billion, with the strongest absolute increase coming from semiconductor firms (ICT producers), which increased their investments by EUR 1.1 billion (plus 16.4%). Aerospace and defence also stepped up their R&D with an increase of 16.6%, while health sector companies reduced their investment by -27%. Only 66% of the Dutch Scoreboard companies reported an increase in R&D investment in 2022, well below the other countries and the top 2 500. While profits and employment decreased, capital expenditures continued to increase strongly (again) due to the expansion of Stellantis (plus EUR 3.8 billion to reach EUR 8.6 billion). The drop in employment relates to the split-up of CNH Industrials following a demerger that resulted in the establishment of Iveco Group and Stellantis. In total, these two companies reduced their employment by 40 000. The reduction in employment combined with the increase in R&D caused the R&D investment per employee to increase from EUR 15 500 to EUR 17 782.

The performance of Sweden, the fourth biggest R&D-investing country in the EU 1 000, is related to a strong increase in R&D investment of its companies given that their number fell between 2021 and 2022. In particular, the quantitatively large sectors (i.e. automotive, ICT producers and industrials) increased their R&D investment substantially, driving the overall increase. These three sectors are responsible for 78.8% of total Swedish R&D investment in 2022. Volvo and Geely Sweden Holdings are behind the major increase in the automotive sector, and Ericsson in ICT producers. Overall, 77% of the Swedish companies increased their R&D

investment in 2022. Moreover, Swedish companies have on average the highest R&D intensity of the five countries. As mentioned above, Sweden has the highest number of SMEs (57) in the EU 1 000 and this effect is visible in the total employment figure: Sweden has only few companies less than France, but they employ only 21% of the people as the French companies. The strong increase in sales is driven by the energy companies and construction & materials, both sectors that were significantly affected by the general price increases.

R&D investment growth in Ireland was sluggish and negative when considering inflation. All sectors reduced R&D investment in real terms, and only small sectors (with in total EUR 700 million R&D investment) experienced a real increase. The most important sector in Ireland, health industries (48% of total R&D by companies headquartered in Ireland) increased by only 4.5% (-1.3% adjusted for inflation). The strong growth in employment observed last year continues, and as last year the largest share of the increase relates to Accenture that raised its employment by 97 000, pushing its headcount to 721 000 worldwide. Irish companies experienced a strong reduction in market capitalisation, driven by Medtronic, Accenture (business support services) and Johnson Controls (industrials), losing together EUR 100 billion in market capitalisation.

4.9 Key points

- Compared to the global top 2 500, the sector distribution of R&D in the EU 1 000 sample is more focused on automotive, the EU stronghold, rather than ICT, the US stronghold. The majority of the EU 1 000 companies are outside the four top sectors, indicating a broader sectoral base. There 180 SMEs in the Scoreboard, almost two thirds of them in the health sector.
- The exit of the UK from the EU (Brexit) caused a major reshuffle in the Scoreboard sample. The empty seats were mostly filled with firms from Germany, Sweden, and France. Denmark and Finland increased their share of Scoreboard firms over-proportionally, and Spain and Italy under-proportionally. The number of firms from EU widening countries (e.g., Czechia, Hungary, Poland, Slovenia) remained stable, there is no indication of Brexit-induced relocations in the Scoreboard sample.
- After Brexit, the share of ICT producers and companies in industrials increased slightly, while the number of companies in ICT services decreased somewhat. Brexit also left a gap in health industries and aerospace and defence that has not yet been filled (for health in terms of R&D investment, and for aerospace and defence in terms of number of companies and R&D investment).
- The UK companies on average increased their R&D at lower rates than the EU companies. For the years 2012-2019, the non-UK EU 1 000 companies raised their R&D on average by 5.5% per year, while it was only 3.8% for the UK EU 1 000 companies. In 2020, the COVID-19 pandemic affected UK firms more with a reduction of 3.5% (the EU 1 000 R&D decreased by 2.5%). In the past 2 years, EU 1 000 companies recovered their R&D faster with growth rates of 7.1% and 13.1%, while the UK companies increased their R&D investment by only 6.5% and 7.9%.
- The largest R&D-investing sector is automotive, which is responsible for almost 32% of R&D in the sample. The second largest is health with 19.7% of R&D, followed by ICT producers (14.4%) and ICT services (8%). Compared to the top 2 500, the automotive, aerospace and defence, chemicals, energy, financial and industrials sectors have higher R&D shares in the EU 1 000, while ICT services, ICT producers and health have (sometimes considerably) lower shares.
- The most significant driver of the EU 1000 R&D investment comes from the companies in the automotive sector. The core group invested 13.7% more in 2022 than in the previous year, exceeding pre-Brexit and pre-COVID-19 investment levels by EUR 5.5 billion.
- Health is the largest sector in terms of companies for both the EU core and the EU emerging group. The core firms in health industries continued their expansion with a nominal increase in R&D of 12.9%, while nominal growth for the emerging group companies was only 7.1%. The health sector was considerably affected by Brexit, losing several large British health companies, and in 2022 R&D investment is still below the 2019 level.
- ICT producers is the third largest R&D-investing sector with 14.5% of the total, but has only 11.9% of the companies (fourth largest in the EU). The core group continued to grow sharply, by 12.2% in nominal terms, while the emerging group increased R&D by 6.6%. After Brexit, the number of ICT producers in the emerging group increased. The new companies are mostly in electronic equipment, but also computer hardware and telecommunications equipment, and are headquartered mainly in Germany, Sweden,

Denmark and the Netherlands. The ICT producers reached the pre-COVID-19 and pre-Brexit R&D investment level already in 2020.

— The ICT software and services sector developed well in 2022 with R&D investment increasing by 14.4%, thereby surpassing the 2019 level. In parallel, the number of companies continued to fall. No other sector of the EU 1 000 lost more firms over the past decade, and in 2022 the sector accounts for only 10% of the companies. Of the remaining 100 companies, 30% are in the EU core group and 70% in the emerging group. In the core and emerging group, the number of software companies is declining and reached a new low with only 12 companies in the core, and 32 in the emerging group. One reason for this development is Brexit, which caused the EU to lose many software firms, but at least equally problematic is the fact that only few new firms entered the Scoreboard.

— The ICT service company exits from the EU 1 000 were mostly due to acquisitions, but also to de-listings, and companies not meeting the R&D threshold. However, no new companies for the ICT software and service sector filled the empty ranks. Instead, these gaps were filled by companies from the health sector. This indicates that there are not many new innovative companies in this sector in the EU. This is a very worrying development, as it shows that the EU lacks a wider base of companies in the digital service sector (and in software development).

— Moderate progress is recorded for the EU companies in the energy sector, where the core group companies increased their R&D by only 3.8%, or -1.1% adjusted for inflation. The 13 emerging group companies increased their R&D by 22.8%. In the energy sector the share of extended group companies increased from 15.2% in 2012 to 35.1% in 2022, and the share of R&D rose from less than 1% to 5%. However, there is no discernible trend that predominantly companies in the renewable energy sector joined the EU 1 000. Overall, with 2.7% of the EU 1 000 R&D, the energy sector share in R&D is 1 percentage point higher than in the top 2 500.

5 Corporate R&D investment trends over 20 years and resilience to crises

The R&D landscape has evolved substantially over the past two decades, reflecting the dynamic forces of globalisation, economic crisis, and the emergence of new technological areas (e.g. semiconductors, biotechnology, artificial intelligence, batteries). This section delves into the structural changes in corporate R&D during 2003-2022. In particular, our analysis focuses on two key dimensions: (5.1) the evolution of corporate R&D investment by region and by sector, (5.2) the strategic response of top R&D investors to the financial crisis (2008) and the COVID-19 pandemic (2019).

This section uses a panel dataset of 801 Scoreboard firms ('panel sample') between 2003 and 2022 to analyse R&D trends and shifts over time. This dataset is combined with other indicators such as net sales, capital expenditure, and environmental, social, and governance (ESG) dimensions, which allows us to understand changes in R&D intensity, total factor productivity and sustainable practices. Firms that do not have R&D data for the entire 20 years were excluded from the panel[80]. However, some comparisons with the top 2 500 Scoreboard firms (annual cross-sections) are made in section 5.1 to contextualise these results in relation to the rest of the report.

Overall, we find that the EU has faced challenges in generating new R&D-leading firms compared to China and the United States, despite hosting established R&D leaders. Over the 20-year period, the ICT services (software) sector has shown remarkable dynamism, marked by an increase in R&D global share, R&D intensity, and new entrants displaying higher R&D intensity than established firms. Moreover, US and Chinese R&D investors recovered more swiftly after crises than their EU counterparts, with software, hardware, and healthcare sectors playing significant roles. Interestingly, companies that showed resilience during the financial crisis, increased their R&D investments after the COVID-19 pandemic, showing that these learning companies view crises as pivotal moments to step up their innovation activity. Finally, the two crises also accelerated the adoption of greener technologies and improved social and governance standards, with European firms leading in environmental responsibility throughout the analysis period.

This section is organised as follows: Section 5.1 analyses trends in the share of R&D performed by the panel sample compared to the top 2 500 Scoreboard performers, total R&D performed by the business sector (Eurostat), and global expenditure on R&D (Eurostat). Next, subsection 5.1.1 analyses whether firms from specific regions have gained/lost R&D share during the last two decades. Subsection 5.1.2 analyses sectoral changes, and subsection 5.1.3 examines the evolution of R&D intensity and how incumbents and new entrants in the Scoreboard have adapted their R&D strategies to this dynamic landscape. In section 5.2, subsection 5.2.1 examines how the two crises influenced R&D investment and capital expenditure by top R&D investors. Subsection 5.2.2 presents the influence of the crises on R&D investment among the different profiles of Scoreboard companies. Subsection 5.2.3 underscores the significant role of R&D in the economic output of top R&D investors, specifically in terms of sales growth and productivity, before and after the crises. Finally, subsection 5.2.4 delves into how Scoreboard companies modified their investments in environmental, social, and governance aspects during the two crises.

5.1 Evolution of corporate R&D investment in the last 20 years

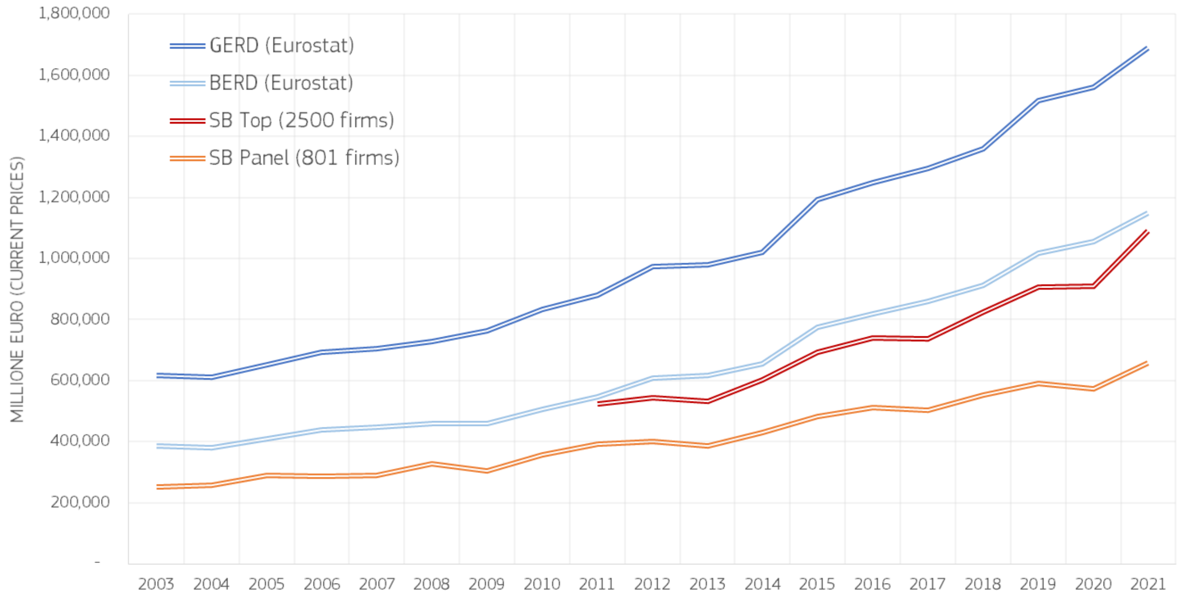
Figure 40 compares the amount in euros of R&D invested by the panel firms (801), with the total R&D invested by our top 2 500 firms (cross-section), the total R&D performed by the business sector (Eurostat) and total R&D (Eurostat). The annual R&D growth rate of the panel firms has averaged 5.8% per year since 2003. The slowdowns in 2009, 2013 and 2020 are related to the financial crisis, sovereign debt crisis and COVID-19 crisis, respectively (see Section 5.2). The share of R&D performed by the panel firms compared with the cross-section (top 2 500) decreased from 75% in 2011 to 60% in 2022, indicating the entry of new firms in the Scoreboard after 2003 that steadily increased their share of total R&D (e.g. Alibaba, Huawei, LG electronics, Meta, Tesla, Uber, Xiaomi).

The panel firms accounted for 72% of total business enterprise expenditure on R&D (BERD) in 2011. This share declined to 57% in 2021. For the total (all sources of funds) gross domestic expenditure on R&D (GERD), the panel firms accounted for 44% of the total GERD in 2011 and for 39% in 2021. The relatively smaller decline in the GERD share is associated with the fall in the global share of R&D funding by the

[80] For example, 384 firms have R&D data only for 19 of the 20 years, and 239 firms that have R&D data only for 18 of the 20 years.

government sector.[81] These two comparisons (against BERD and GERD) give an excellent indication that the panel represents a very significant share of all R&D performed, which can in turn provide insights into the last 20 years of global R&D.

Figure 40. Total R&D performed by panel Scoreboard firms vs top 2 500 Scoreboard firms and total BERD in million euros (current prices)



Note: GERD refers to Gross Expenditure on R&D (all sectors and source of funds). BERD refers to Business Expenditure on R&D (business enterprise sector of performance and source of funds).

Source: The 2023 EU Industrial R&D Investment Scoreboard. European Commission, JRC/DG R&I. Eurostat (rd_e_gerdfund).

Although the R&D values (in euros – current prices) in Figure 40 shed light on the role of the top 2 500 firms and of panel firms in global R&D, they are is less informative about changes in the regional and sectoral composition of R&D over time, as different countries have different relative costs of R&D (see Box 1). To make a more robust comparison between countries and sectors, we use R&D values in constant (2015) PPP (USD) in the next two subsections. First, we analyse the regional composition of the panel in relation to the cross-sectional dataset of top 2 500 firms (2013-2022). Then, we analyse sectorial shifts.

5.1.1 Trends in R&D investment across global regions

The positive impact of R&D and innovation activities on the international competitiveness of both countries and industries is generally acknowledged in the literature (Fagerberg & Srholec 2008[82]; Nelson & Winter 1982[83]). Recently, it has been argued by the Economist[84] that technological innovation has become the main battlefield in geopolitics and that "China and the West are in a race to foster innovation".

Figure 41 shows how the R&D race has unfolded in panel firms, and compares it to the top 2 500 Scoreboard firms (cross-section). This comparison reveals how this fixed set of firms (panel) from specific regions has increased/decreased its R&D investment compared to the other regions and, as well as how the Scoreboard's regional composition changed compared to that of the panel.[85] The panel allows a better evaluation of changes within firms from specific regions/sectors, the top 2 500 allow a more updated and macro estimate of regional/sectoral differences.

81 https://ec.europa.eu/eurostat/statistics-explained/index.php?title=R%26D_expenditure&oldid=551418#R.26D_expenditure_by_sector_of_performance

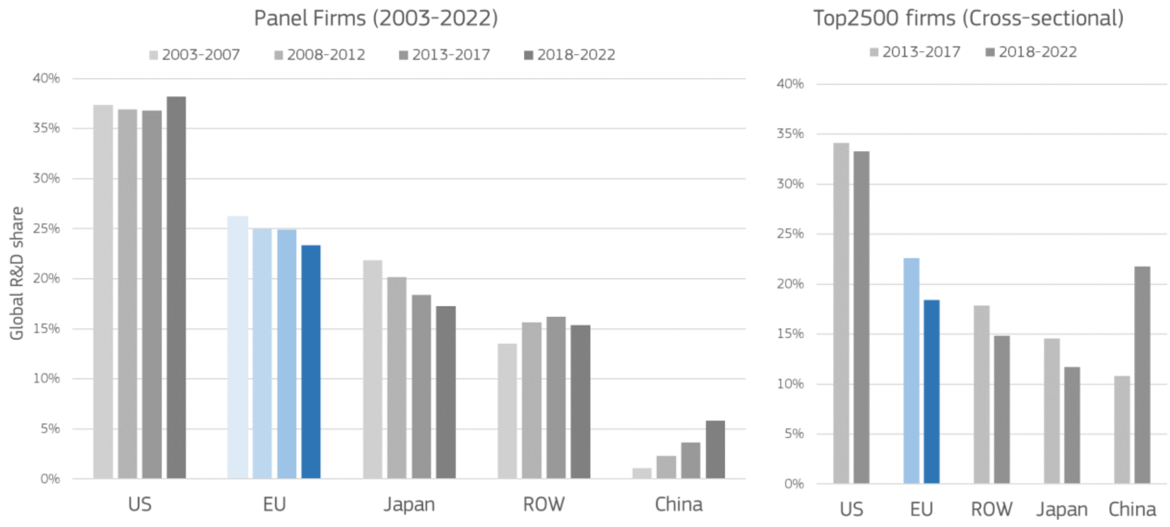
82 Fagerberg, J., & Srholec, M. (2008). 'National innovation systems, capabilities and economic development', *Research Policy*, 37/9: 1417–35. North-Holland. DOI: 10.1016/J.RESPOL.2008.06.003

83 Nelson, R. R., & Winter, S. G. (1982). *An evolutionary theory of economic change*. Belknap Press of Harvard University Press.

84 https://www.economist.com/briefing/2022/10/13/china-and-the-west-are-in-a-race-to-foster-innovation

85 The top 2 500 Scoreboard firms (cross-section) includes both firms that made their entry and exit in the Scoreboard between 2013 and 2022, thereby making it more representative of the regional/sectoral composition in each year.

Figure 41. Evolution of R&D share by region (panel vs. top 2 500)



Note: R&D values are in PPP constant (2015) $. The regions are ordered by number of companies per region in the panel.
Source: The 2023 EU Industrial R&D Investment Scoreboard. European Commission, JRC/DG R&I.

In our panel analysis, while EU (285) and Japanese (177) firms lost total R&D share during the 20-year period, China (22) and the RoW (122) gained ground. In 2003-2007, the 22 Chinese firms in the panel accounted for nearly 1% of total R&D performed, while in 2018-2022 their share increased to 6%. Chinese firms with higher R&D growth include Tencent, Baidu and BYD. Moreover, if we compare panel Chinese firms with the top 2 500 Scoreboard firms (cross-section), in 2018-2022 Chinese top 2 500 (22) firms accounted for a much higher share of total R&D. This difference is mostly because the relative number of Chinese firms in the top 2 500 is much higher than in the panel – 679 (out of 2 500) vs 22 (out of 801).

Although the EU still has several global tech firms, the share of EU firms in the top 2 500 R&D investors has fallen over time. Interestingly, when we compare our panel dataset with the top 2 500 dataset (2013-2022) we verify that only 82 new EU firms have made it to the last edition of the Scoreboard. In comparison, China has 657 new firms in the 2022 Scoreboard that are not in the panel, US 634 new firms, RoW 276, and Japan only 52. This shows that although the EU (and Japan) still host many prominent incumbent R&D leaders, it seems to be less successful at hosting new firms entering the Scoreboard that take up new leading R&D positions (Veugelers 2018[86]).

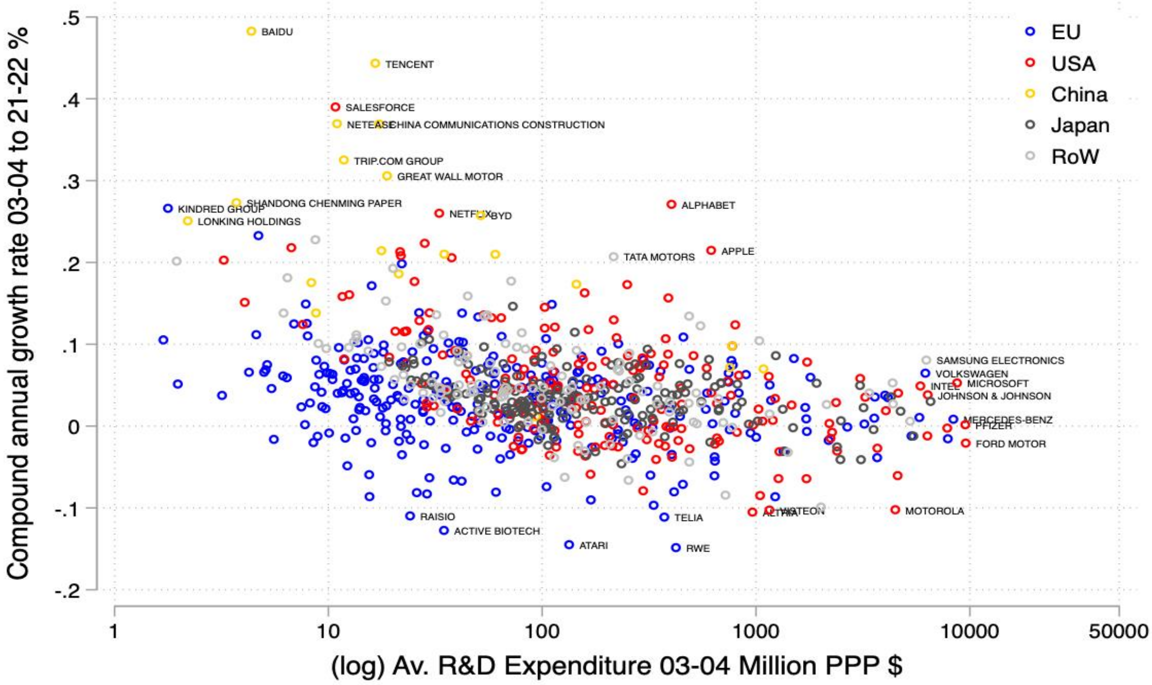
Figure 42 shows specific firms' R&D annual growth rate between 2003-2004 and 2021-2022 (vertical axis) and their absolute R&D investment in 2003-2004 (horizontal axis). This graph allows us to analyse whether firms that performed less R&D in the past had higher growth rates than incumbents (conditional convergence).

Several interesting insights emerge from this figure. First, there are many EU firms in the bottom-left corner (e.g. Telia, RWE[87], Atari), indicating that these firms (and regions) are the ones that have lost more ground during this period. This partially explains the loss of EU R&D share in Figure 14. Second, most firms with higher annual growth rates (>30%) are from China. For example, Tencent (China) and Baidu (China) are now among the top 75 R&D performers, having had an annual growth rate above 40% during this period (which implies a 1 000-fold increase in their R&D during this period). Salesforce is the only non-Chinese firm to have experienced this extremely high annual R&D growth rate during this period, although, it is important to note that Salesforce acquired other important R&D performers like Tableau and Slack in recent years.[88] Third, among the second layer of firms with higher annual R&D growth rates (between 20% and 30%), we see firms like Alphabet, Apple, BYD, Netflix, and Tata Motors that are now among the most prominent firms within their sectors. Fourth, we observe some dynamism and catch-up within this sample. Although the top 5% R&D performers in 2003/2004 (40 firms) represent over 50% of the total R&D in this period, their growth rate was

86 Veugelers, R. (2018). 'Are European firms falling behind in the global corporate research race ?', April.
87 Note that Telia and RWE were partially acquired by other firms during this period.
88 https://www.salesforceben.com/the-10-biggest-salesforce-acquisitions/

1.3% during the 20 years, below the average yearly growth rate of the panel (4%). This indicates that these top 40 firms have grown their R&D investment less than the other firms in the panel dataset on average. The growth in R&D of Chinese and some US firms that started from low ranks in 2003 partially explains this pattern of conditional convergence.

Figure 42. Annual R&D investment growth of panel firms by region



Note: R&D values are in PPP constant (2015) USD. The x-axis is in log-scale.
Source: The 2023 EU Industrial R&D Investment Scoreboard. European Commission, JRC/DG R&I

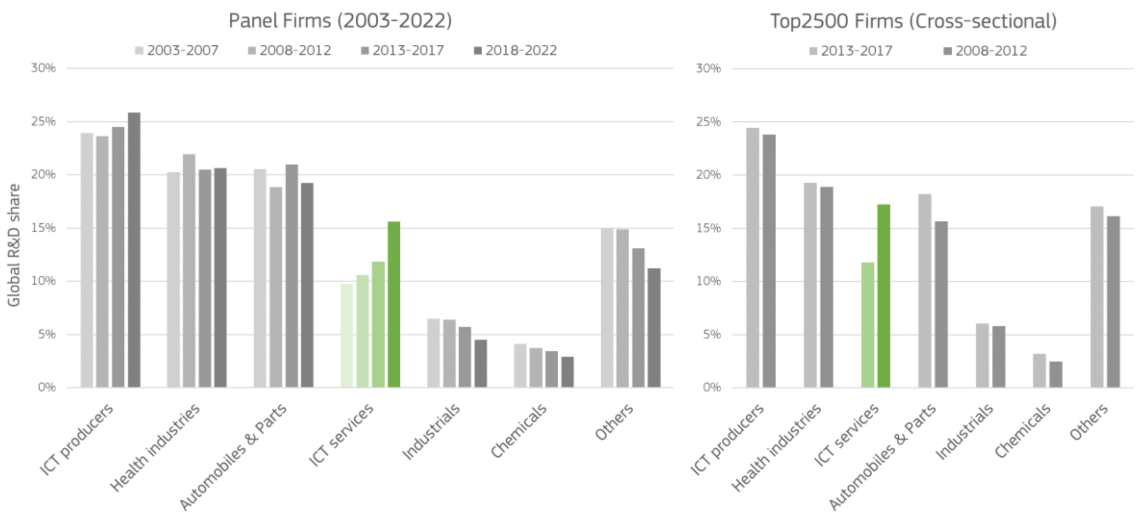
5.1.2 Trends in R&D investment across sectors

One of the lessons from the 20 years of the Scoreboard is that regional changes in R&D leadership derive from sectoral specialisation in certain regions (Moncada-Paternò-Castello 2022[89]). EU firms have been less able to be competitive in new high-tech sectors (e.g. ICT services and producers) and exploit the growth opportunities offered by first movers in these sectors. In Figure 43, we analyse how much R&D distribution across sectors has changed. We show the evolution of R&D share per sector between 2003-2007 and 2018-2022 for our panel section and display that distribution for our SB2022 sample between 2013-2017 and 2018-2022.

While industrials (118) and automobiles & parts (72) firms lost R&D total share during these 20 years, ICT services (66) and ICT producers (166) gained significant ground in the same time period. In the EU some exceptional cases of R&D growth in ICT-related sectors during these 20 years include Ubisoft (software, 15% annual growth), ASML (semiconductors, 11% annual growth), SAP (software, 8% annual growth). In the other countries some of the top companies in ICT services that have increased their R&D by more than 30% per year during this period include Alphabet and Salesforce from the USA, and Tencent and Baidu from China. Some top ICT producers that increased their R&D by more than 10% a year during this period include Apple, Qualcomm and Nvidia from the US and TSMC from Taiwan. The sector that has lost most ground during these 20 years is chemicals, with a slight decrease also in both automotive and industrials. As shown in Figure 17 and Table 12 from section 3.1, these are sectors which EU firms are relatively well represented.

[89] Moncada-Paternò-Castello, P. (2022). *Top R&D investors, structural change and the R&D growth performance of young and old firms. Eurasian Business Review*, Vol. 12. Springer International Publishing. DOI: 10.1007/s40821-022-00206-3

Figure 43. Evolution of R&D share by sector (panel vs top 2 500)



Note: R&D values are in PPP constant (2015) $. The sectors are ordered by higher R&D share in 2018-2022.
Source: The 2023 EU Industrial R&D Investment Scoreboard. European Commission, JRC/DG R&I.

5.1.3 Trends in R&D intensity across sectors

R&D intensity is usually defined as the ratio of R&D investment to an output measure (e.g. gross output or net sales) (OECD 2015[90]). This indicator is commonly used at an economy, sector or firm level to measure the relative R&D effort of a particular country/sector/firm in relation to another. Emerging sectors (and firms) might reveal higher R&D intensity as they seek to establish themselves and gain new ground in the market. On the contrary, more mature industries tend to have lower R&D intensity because they have already developed and optimised their products and processes and have lower returns to R&D (Breschi & Malerba, 1997[91]).

Although in this section we are primarily interested in understanding changes in time for R&D intensity across industries, it is essential to acknowledge that some industries, like pharmaceuticals and biotechnology, inherently require high levels of R&D intensity to develop and improve products. Other sectors, such as agriculture or retail, may have lower R&D intensity because their products and processes are less dependent on R&D investment to generate innovations (Galindo-Rueda & Verger 2016[92]; Malerba 2005[93]; Pavitt 1984[94]).

The regulatory environment, industry concentration, market structure and access to capital are also factors that influence R&D intensity by sector (Aghion et al. 2005[95]; Crepon et al. 1998[96]). At the micro-level, Dosi (1988)[97], for example, argues that the commitment of firms to R&D is mostly based on two elements: the perception of opportunities and the existing incentives (appropriability mechanisms, relative prices, market and broader socio-economic conditions).

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[90] OECD. (2015). *Frascati Manual 2015: Guidelines for Collecting and Reporting Data on Research and Experimental Development. The Measurement of Scientific, Technological and Innovation Activities*. DOI: 10.1787/9789264239012-en.

[91] Breschi, S., & Malerba, F. (1997). Sectoral innovation systems: technological regimes, Schumpeterian dynamics, and spatial boundaries. Chapter 6. In: Edquist, C. (Ed.), *Systems of innovation: Technologies, institutions and organizations*, *1*, 130-156.

[92] Galindo-Rueda, F., & Verger, F. (2016). *OECD taxonomy of economic activities based on R&D intensity. OECD Science, Technology and Industry Working Papers*, Vol. 4.

[93] Malerba, F. (2005). 'Sectoral systems of innovation: A framework for linking innovation to the knowledge base, structure and dynamics of sectors', *Economics of Innovation and New Technology*, 14/1–2: 63–82. Taylor & Francis. DOI: 10.1080/1043859042000228688.

[94] Pavitt, K. (1984). 'Sectoral patterns of technical change: Towards a taxonomy and a theory', *Research Policy*, 13/6: 343–73. DOI: 10.1016/0048-7333(84)90018-0.

[95] Aghion, P., Bloom, N., Blundell, R., Griffith, R., & Howitt, P. (2005). 'Competition and Innovation: an Inverted-U Relationship', *The Quarterly Journal of Economics*, 120/2: 701–28. DOI: 10.1093/qje/120.2.701.

[96] Crepon, B., Duguet, E., & Mairesse, J. (1998). 'Research, Innovation And Productivity: An Econometric Analysis At The Firm Level', *Economics of Innovation and New Technology*, 7/2: 115–58. DOI: 10.1080/10438599800000031.

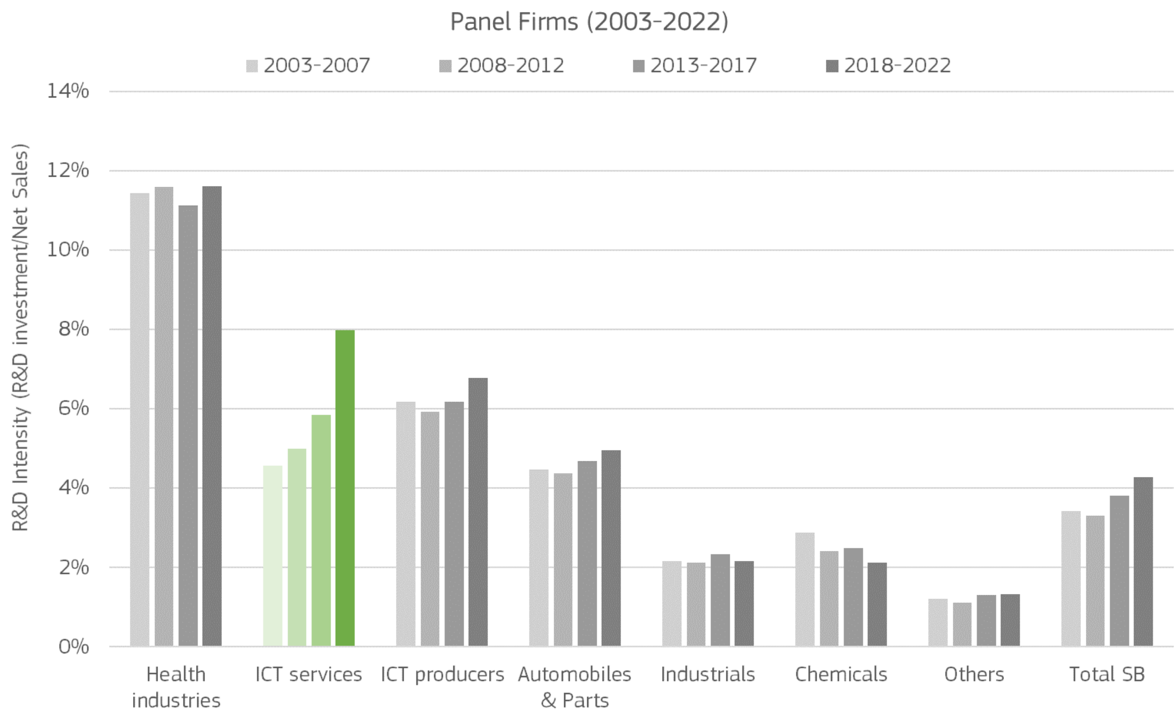
[97] Dosi, G. (1988). 'Sources, Procedures, and Microeconomic Effects of Innovation', *Journal of Economic Literature*, 26/3: 63–114. DOI: 10.4337/9781782541851.00008.

This section analyses both sectoral variations of R&D intensity in time (20 years) for our panel firms (801), and the distribution of R&D intensity of Scoreboard incumbent/panel firms (801) versus entries/exits (1 816) per sector during 2013-2022. It helps reveal if there have been dynamic changes in R&D intensity by sector, and if new firms (or incumbent firms) are potentially driving those changes.

Figure 44 shows the evolution of the panel firms' average R&D intensity (R&D investment over net sales in constant PPP 2015 USD) in six major sectors between 2003-2007 and 2018-2022. We observe a doubling of R&D intensity in ICT services from 4% in 2003-2007 to 8% in 2018-2022 and a slight increase in ICT producers in the last 5-year period.

The sector with the most significant decrease in R&D intensity was chemicals, from 3% in 2003-2007 to 2% in 2018-2022. All other sectors remained relatively stable, indicating that the average increase in R&D intensity for the panel firms, from 3.4% (2003-2007) to 4.3% (2018-2022), was driven by ICT services.

Figure 44. Evolution of sectoral R&D intensity. 2003-2022



Notes: R&D values are in PPP constant (2015) $. The sectors are ordered by higher R&D share in 2018-2022. Others include sectors such as energy, construction, aerospace & defence, and financials.
Source: The 2023 EU Industrial R&D Investment Scoreboard. European Commission, JRC/DG R&I.

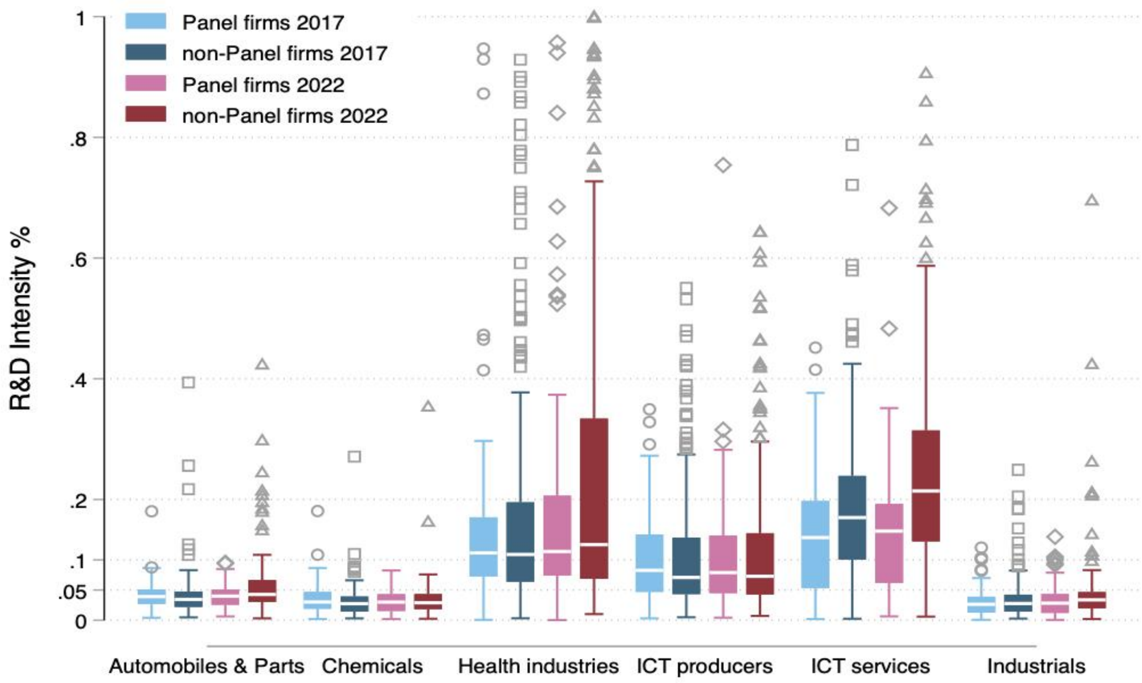
ICT services is on average the sector with the highest absolute R&D growth and intensity in the last 20 years. However, even within ICT services, there are firms with much higher R&D intensity than others. Coad (2019)[98], for example, shows how heterogeneity in firm-level R&D intensities is an empirical fact and that this property is resistant to sectoral disaggregation.

R&D intensity is critical to market dynamics since it allows emerging firms to challenge the industry leaders, thus promoting competition and growth (Cattaruzzo et al. 2022[99]). Given the structure of our panel and the possibility to compare, within the same sector, the R&D intensity of the panel firms with the top 2 500 Scoreboard firms that are not in the panel (entries or exits in the Scoreboard), we explore two research questions in Figure 45: i) Are new entrants in a specific industry more or less R&D-intensive compared to incumbent firms? Ii) How does this phenomenon vary across different sectors?

[98] Coad, A. (2019). 'Persistent heterogeneity of R&D intensities within sectors: Evidence and policy implications', *Research Policy*, 48/1: 37–50. DOI: 10.1016/j.respol.2018.07.018

[99] Cattaruzzo, S., Segarra-Blasco, A., & Teruel, M. (2022). 'Firm-level contributions to the R&D intensity distribution: evidence and policy implications', *Economics of Innovation and New Technology*, 1–21. DOI: 10.1080/10438599.2022.2140658

Figure 45. Firm-level R&D intensity by sector in 2017 and 2022. Panel firms (incumbents) vs non-panel firms (entries in the top 2 500)



Note: In this analysis we removed firms with more than 100% R&D intensity because they can be considered outliers that have almost non-existent sales for the R&D they are performing. This phenomenon happens mostly with firms in sectors such as biotechnology and pharmaceuticals (e.g. Argenx, BeiGene) due to the significant R&D investment that is needed before a new product is released.
Source: The 2023 EU Industrial R&D Investment Scoreboard. European Commission, JRC/DG R&I.

The analysis in Figure 45 comprises the six sectors with highest R&D intensity in two periods (2017 and 2022). Each box plot represents the distribution of firms' R&D intensity in each sector/year. The white horizontal line in the box plots is the median firm R&D intensity for each sector/year (not the sectoral average as in Figure 44), the top and lower limits of the box are the 75th and 25th percentiles, respectively, and the grey dots are outliers in the distribution.

The higher median R&D intensity (white horizontal line) of firms in health industries, ICT services and ICT producers, compared to other sectors, mirrors the results of Figure 44. However, an interesting finding in Figure 45, is that non-panel firms in ICT services show higher median R&D intensity than panel firms (incumbents). This heterogeneity (Coad, 2019[100]; Srholec and Verspagen, 2012[101]) indicates a significant level of dynamism and innovation within the sector, which stems from the window of opportunity presented by the emergence of the new information and digital age.

This era is characterized by the rapid proliferation of digital technologies, increased connectivity, and the digitalization of various aspects of business and daily life. Some of these non-panel firms exhibit high R&D intensity because they aim to position themselves as early innovators in their niche and gain a competitive edge in a rapidly evolving and fiercely competitive landscape. Some of these firms with high R&D intensity in some niches include Sensetime and C3.AI (artificial intelligence); Aurora Innovation and TuSimple (self-driving vehicles); Atlassian, Asana and Tuya (business software); and Ubisoft (videogames).

The range of R&D intensities of firms in a sector (distance between the 75th and 25th percentiles of each boxplot) also reveals some interesting insights. Health industries, ICT services and ICT producers have larger distributions indicating a considerable variability of R&D intensity across firms. In health industries, this distribution is even higher for non-panel firms. New firms in this sector, particularly in biotech and pharmaceuticals, often exhibit extremely high R&D intensity for several reasons: First, bringing a new drug or

[100] Coad, A. (2019). 'Persistent heterogeneity of R&D intensities within sectors: Evidence and policy implications', *Research Policy*, 48/1: 37–50. DOI: 10.1016/j.respol.2018.07.018

[101] Martin Srholec, Bart Verspagen, The Voyage of the Beagle into innovation: explorations on heterogeneity, selection, and sectors, *Industrial and Corporate Change*, 21/5, 1221–1253. https://doi.org/10.1093/icc/dts026

medical treatment to market involves lengthy and complex processes. From initial discovery to clinical trials and eventual commercialization, the development cycle can span many years before having any sales. Second, patents, intellectual property and regulatory requirements are crucial in these industries and also imply heavy investment before the product hits the market. Finally, events such as the COVID-19 pandemic, can accelerate R&D investments in biotech and pharmaceuticals. These events create a sense of urgency and drive companies to intensify their efforts to develop solutions.

In automotive, the distribution of R&D intensity is in 2022 higher for non-panel firms than for panel firms, indicating the emergence of new automotive firms that are more R&D intensive (e.g. Li Auto, NIO, Rivian Automotive). Currently, this sector faces multiple sources of technological ambiguity, given the rise of electric/hybrid vehicles and the emergence of new software applications in vehicles (Teece 2018[102]; The Economist 2022[103]).

Demand for electric cars is booming (IEA 2023) both due to a strong push by governments in many regions, and the appearance of firms like Tesla that have transformed the sector. This paradigm shift has also opened a window of opportunity for the Chinese automotive industry to establish a more equal competitive footing with EU's well-established internal combustion engine technological leaders (Altenburg et al. 2022[104;] Thun 2018[105]).

5.2 Innovation through adversity: analysing strategic investment after the financial and COVID-19 crises

The crises of 2009 (the financial crisis) and 2020 (the COVID-19 pandemic) have had a profound effect on the strategic investments of top R&D investors in the EU and beyond. Strategic investments are those that aim to increase the long-term competitiveness and sustainability of firms, such as capital expenditure (capex), R&D investment, and investments aimed at enhancing environmental, social, and governance (ESG) dimensions. These investments are crucial for fostering innovation, productivity and growth in the context of the green and digital transitions. However, they are also vulnerable to external shocks and uncertainties that may affect the availability of funds and the cost of financing, as well as the incentives for investing.

This section analyses how the top R&D investors in various sectors and global regions have adjusted their strategic investments in response to the two crises. The analysis builds upon the work to consolidate data from the past 20 editions of the Scoreboard, ensuring a consistent transformation of R&D time-series data for meaningful comparisons. Importantly, the R&D and capex series were converted to 2015 US purchasing power parity dollars (PPP$), enabling effective cross-country comparisons and addressing the impact of recent inflation spikes worldwide. To maximise the number of companies available for analysis and to extract meaningful insights, the 20-year panel was divided into two separate subsamples corresponding to the two crises: 2005-2013 for the financial crisis and 2017-2021 for the COVID-19 crisis.[106]

Box 3. Methodological points – R&D during times of crises

This section explores the effects of the economic crises in 2009 and 2020 on the strategic investments of the world's top R&D investors. The analysis is underpinned by a strong methodology, with a keen emphasis on providing a comprehensive, yet understandable insight into the dynamics of R&D, capital expenditure, and ESG indicators during the specified periods. This box explains the main technical aspects of the analysis.

102 Teece, D. J. (2018). 'Tesla and the Reshaping of the Auto Industry'. *Management and Organization Review*. Cambridge University Press. DOI: 10.1017/mor.2018.33

103 The Economist. (2022). 'The race to reinvent the car industry?'. *The Economist.*

104 Altenburg, T., Corrocher, N., & Malerba, F. (2022). China's leapfrogging in electromobility. A story of green transformation driving catch-up and competitive advantage. Technological Forecasting and Social Change, 183, 121914.

105 Thun, E. (2018). Innovation at the middle of the pyramid: State policy, market segmentation, and the Chinese automotive sector. Technovation, 70, 7-19.

106 The exclusion of the year 2022 from the analysis was a deliberate choice to ensure coherence across the analysis conducted in Section 5.2.4. The ESG measures were sourced from Refinitiv's Eikon database, which were not available for 2022 at the time of the analysis. The decision to exclude this year was necessary to maintain consistency in data sources and maintain the integrity of the analysis.

Currency standardisation. To maintain the integrity of the analysis, R&D and capital expenditure figures were converted to 2015 USD PPP. This transformation controls for the inflation spikes observed in recent years and for the different relative costs of R&D and capital expenditure across countries in the world. In contrast, net sales data has been transformed to 2015 US dollars but not converted to PPP$. The decision not to convert the sales data into Purchasing Power Parity (PPP) dollars is a deliberate choice aimed at preventing potential biases stemming from the diverse economic conditions within the geographical locations of a company's subsidiaries. As these subsidiaries are typically operating in various sales markets across different countries, converting their sales to a PPP basis solely for the parent company could introduce distortions. This is because such a conversion would overlook information about the relative cost of living and other economic factors in each country. Moreover, it would implicitly assume that all sales are conducted in the country where the company's headquarters are located, which may not accurately reflect the global nature of the company's operations.

Time periods and company selection. The analysis primarily focuses on two significant periods: 2005-2013, encompassing the financial crisis, and 2017-2021, covering the COVID-19 pandemic. These timelines have been chosen to provide a clear picture of investment trends before and after each economic crisis. The study only includes companies that had R&D data for at least two observations before and two (or one for the COVID-19 crisis) observations after each respective crisis event. The differing timeframes for the two crises are attributed to data availability. For the financial crisis, a 2005-2013 window is utilised to ensure an extended temporal horizon before and after the crisis, allowing for observation of potential medium-term effects (post 2 years). The period preceding 2020 is intentionally kept shorter to prevent overlap of effects stemming from the long-term impacts of the financial crisis and the debt crisis that affected the EU over an extended period.

Regional representation. When breaking down the data by world region, it should be noted that Chinese companies are not represented in the analysis of the financial crisis period, given the insufficient number of companies (fewer than 100) available for a valid analysis during this time. Chinese companies, on the other hand, are included in the analysis concerning the COVID-19 crisis. Recognising the potential influence of Brexit on the findings, our analysis of EU data omits companies with headquarters in the UK for the duration of both time periods, while including the UK in the rest of the world (RoW) group. It is worth noting that distinguishing the effects of Brexit from those of COVID-19 presents a complex challenge due to the time overlap. While the direct consequences of Brexit, such as the UK's formal exit from the EU, have been addressed by excluding UK companies from the EU sample in the dataset, discerning the indirect impacts of Brexit on EU companies is more intricate and remains a challenge with the data currently available.

Inclusion criteria for the company ranking. To reduce bias and ensure the study’s reliability, only companies that ranked among the top 2 500 R&D investors at least once during the observed periods have been included. This step is particularly critical to avoid bias that could be introduced by the inclusion of the EU Top 1000 firms.

Data winsorisation. All variables have undergone winsorisation at the top and bottom 1%, and at the top 95% and bottom 1% for ESG indicators. This process is instrumental in reducing the potential influence of outliers on the analysis outcomes.

Missing employment data. Employment data for Scoreboard companies suffers from missing values (5% of the observations with R&D information have missing employment data). To address this, employment information has been imputed using a 3-year moving average. This helps to provide a more complete dataset for the analysis, ensuring that employment figures are as accurate as possible given the available information.

Regression analysis. Unless specified otherwise, the graphs plot coefficients from analyses regressing the relevant dependent variable on a set of year dummies and controlling for company fixed effects and net sales (transformed to 2015 US dollars). This analytical approach ensures accurate comparisons before and after the crises at firm level, accounting for fluctuations in company size over time.[107]

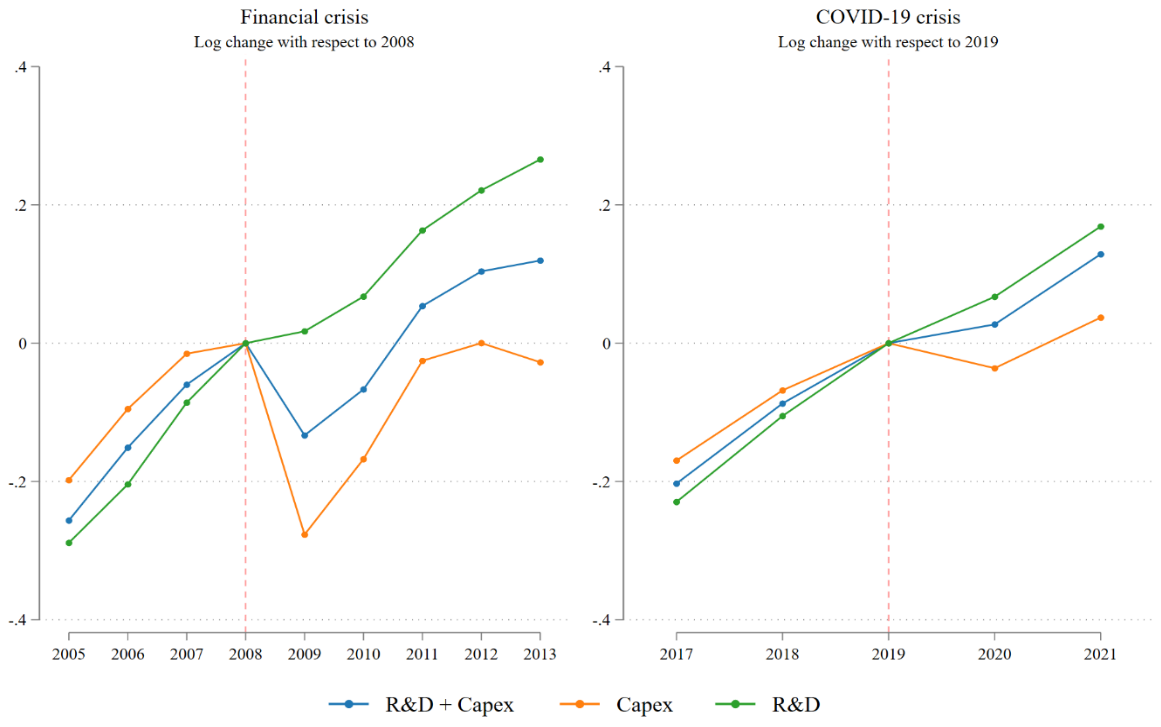
[107] In the absence of a random assignment of R&D investment across companies, it is crucial to stress that the findings might not establish causal relationships. The gold standard to show causal relationship in an econometric framework is via random assignment (Angrist, J. D., and Pischke, J. S. The credibility revolution in empirical economics: How better research design is taking the con out of econometrics. Journal of economic perspectives, 24(2), 3-30. 2010), so it is plausible that the observed associations are a function of underlying factors, which are not adequately captured in the current analysis. Therefore, readers are advised to

Total factor productivity. Values of total factor productivity are calculated as the residual from a Cobb-Douglas production function that includes values of net sales, capital expenditure and the number of employees. A rich set of fixed effects are included in the analysis: sector, year, region, as well as interactions between year and sector, and year and region (Benassi et al., 2021)[108].

5.2.1 Crisis-induced fluctuations in R&D investment and capital expenditure

The overall investment (R&D investment and capital expenditure) of the top innovators worldwide changed before and after the financial crisis of 2009 and the COVID-19 pandemic of 2020 (Figure 46). The graph reveals that the financial crisis had a negative effect on overall investment, which dropped by more than 15% in 2009. Recovery to the pre-crisis level did not happen until 2011. This drop was mostly driven by a huge decline in capital expenditure, which is more sensitive to financial constraints. Capital expenditure fell by more than 20% in 2009 and returned to pre-crisis levels only in 2012. By contrast, R&D investment was quite resilient, with close to zero growth in 2009 and then positive growth rates starting from 2010 onwards. This suggests that R&D investment of top R&D investors is less elastic to crises compared to capital expenditure. This interpretation is in line with existing evidence showing how managers pursued a two-pronged approach of: i) saving their way out of the financial crisis by curtailing the company's workforce and capital expenditure; and ii) investing their way out of the crisis by maintaining the company's investment in R&D.[109],[110]

Figure 46. R&D investment and Capex before and after major crises, by investment type



Notes: The graph plots coefficients of year fixed effects from regressions controlling for net sales and firm fixed effects. All values are in 2015 PPP$, except for net sales, which are in 2015$. Values x100 are % changes compared to the base year (2008 or 2019).
Source: own elaboration on data from The 2023 EU Industrial R&D Investment Scoreboard, European Commission, JRC/DG R&I

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interpret the results with caution and to consider them as a basis for future analysis that employs methods equipped to discern causality.

108 The available data (lack of data on output and materials) does not allow to estimate either a value-added production function (with value added as output and labour and capital as inputs) or a revenue production function (with revenues as output and labour, capital and materials as inputs). Instead, the analysis is constrained to a hybrid model that combines aspects of both approaches. While this may not provide a complete picture, it still offers insights into the interplay of various factors within the constraints of the dataset.

109 Flammer, C., & Ioannou, I. (2020). Strategic investments during crises: A test of the innovation and stakeholder perspectives. Academy of Management Journal, 63(6), 1975-2004.

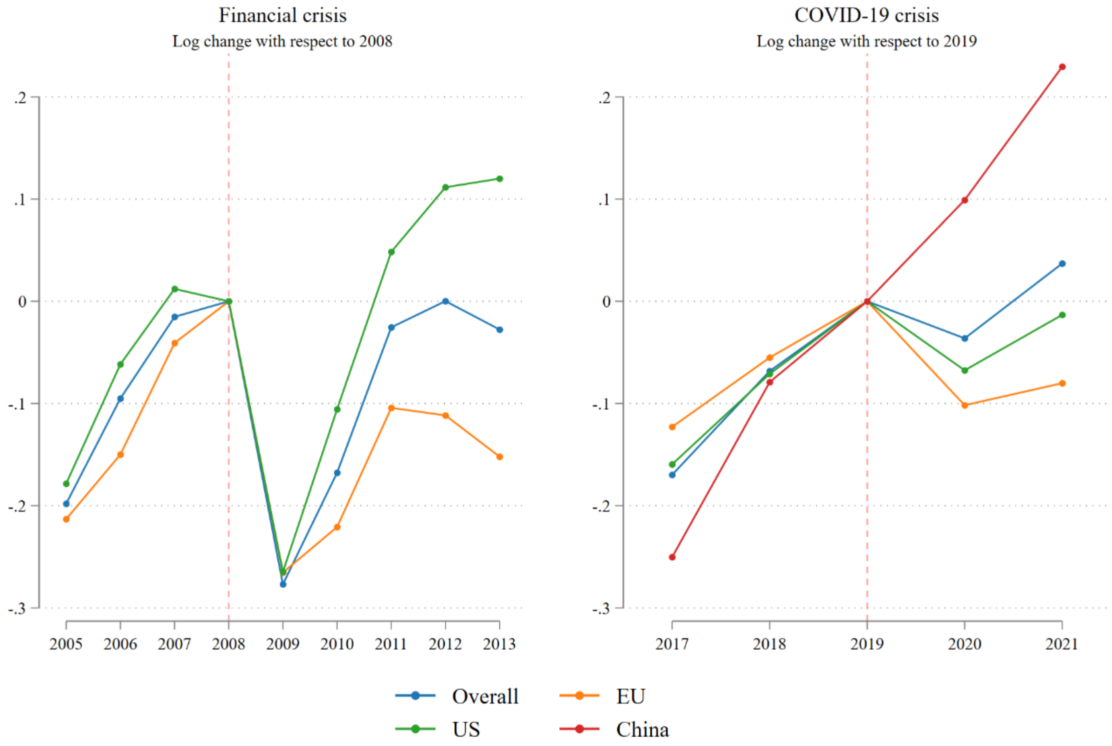
110 https://www.mckinsey.com/capabilities/strategy-and-corporate-finance/our-insights/innovative-growers-a-view-from-the-top?cid=eml-web

Figure 46 also shows that the COVID-19 pandemic had a different effect on overall investment, which increased in both 2020 and 2021. The year 2021 seems particularly good, with increases of more than 10% across the board. This is in line with figures for other relevant economic indicators.[111] Capital expenditure saw a small decrease in 2020, following closures, but rebounded strongly in 2021. R&D investment was very resilient to this type of crisis and already started benefiting from worldwide COVID-19 recovery packages in 2021.

Figure 47 shows how the capital expenditure of the top R&D investors worldwide changed by region after the financial crisis of 2009 and the COVID-19 pandemic of 2020. The graph reveals that capital expenditure dropped for all regions soon after the financial crisis, but the recovery was unequal across regions. US-based mother companies witnessed a steady increase after the drop in 2009 and by 2011 reached a level higher than the one in 2008. EU companies, by contrast, saw an increase of a lower magnitude and by 2013 did not recover to the pre-crisis level yet. One possible reason for this difference is the long-term effects of the debt crisis in the euro area following the tight budgetary policies implemented and the sectoral composition that favoured the US industry structure (mostly services and software, which rely less on capital expenditure). [112]

The graph also shows a similar picture to the above in the aftermath of the COVID-19 crisis, with some additional evidence coming from the inclusion of Chinese-based top R&D investors.[113] In fact, Chinese companies experienced a steady increase in capital expenditure, while companies based in the EU and the US witnessed a drop in 2020 and a recovery in 2021.

Figure 47. Capex before and after the crises, by region



Notes: The graph plots coefficients of year fixed effects from regressions controlling for net sales and firm fixed effects. All values are in 2015 PPP$, except for net sales, which are in 2015$. Values x100 are % changes compared to the base year (2008 or 2019). For example, capital expenditure by EU companies was 5% lower in 2018 and 10% lower in 2020 than in the pre-crisis year 2019.
Source: own elaboration on data from The 2023 EU Industrial R&D Investment Scoreboard, European Commission, JRC/DG R&I

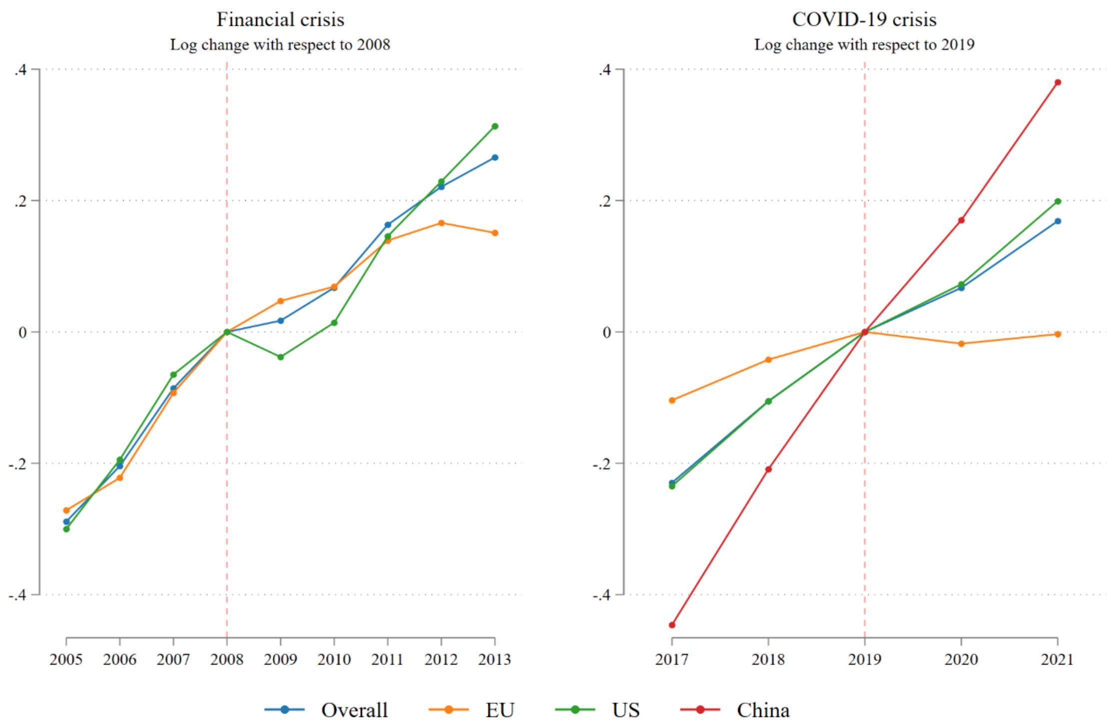
A historical pattern of robust capital expenditure investment in China relative to other world regions is evident. This is showcased by the significant growth between 2017-2018 (a surge of 17 percentage points), which

[111] Autor, D., Dube, A., & McGrew, A. (2023). The unexpected compression: Competition at work in the low wage labor market (No. w31010). National Bureau of Economic Research.
[112] Lane, P. R. (2012). The European sovereign debt crisis. Journal of economic perspectives, 26(3), 49-68.
[113] Chinese companies are not represented in the analysis of the financial crisis period, given the insufficient number of companies (fewer than 100) available for a valid analysis during this time (see the Box 3).

persisted even after the pandemic. When evaluating EU Capex investments across both periods, it is observed that top EU R&D investors managed the aftermath of COVID-19 more effectively than the 2009 financial crisis. This was due to a less pronounced reduction in capex investments in the year succeeding the crisis event (-25% vs -10% relative to the pre-crisis benchmark).

Figure 48 illustrates how the R&D investment of leading R&D companies worldwide changed by region following the financial crisis of 2009 and the COVID-19 pandemic in 2020. The graph indicates that R&D investment increased overall, displaying a lower sensitivity to financial crises compared to capital expenditure. Companies based in the EU continued to invest in R&D at levels exceeding those of 2008, underscoring their dedication to innovation. However, from 2011 onwards, US-based companies caught up and outperformed their EU counterparts, potentially due to the debt crisis affecting the euro area. The graph presents a similar scenario in the aftermath of the COVID-19 crisis. The primary catalyst for R&D growth was the upsurge in Chinese companies, following their historical positive trend in catching up with Western economies in terms of technology. Conversely, the EU appeared to have a somewhat slower recovery. This is mostly attributed to the significant contraction of the automotive sector in 2020 and its subsequent moderate growth in 2021, it is noteworthy that the health sector in the EU exhibited robust performance during this period, although it holds a relatively small share in the EU aggregate.

Figure 48. R&D investment before and after the crises, by region



Notes: The graph plots coefficients of year fixed effects from regressions controlling for net sales and firm fixed effects. All values are in 2015 PPP$, except for net sales, which are in 2015$. Values x100 are % changes compared to the base year (2008 or 2019). For example, Investment in R&D by US companies was 10% lower in 2018 and 8% higher in 2020 than in the pre-crisis year 2019.
Source: own elaboration on data from The 2023 EU Industrial R&D Investment Scoreboard, European Commission, JRC/DG R&I

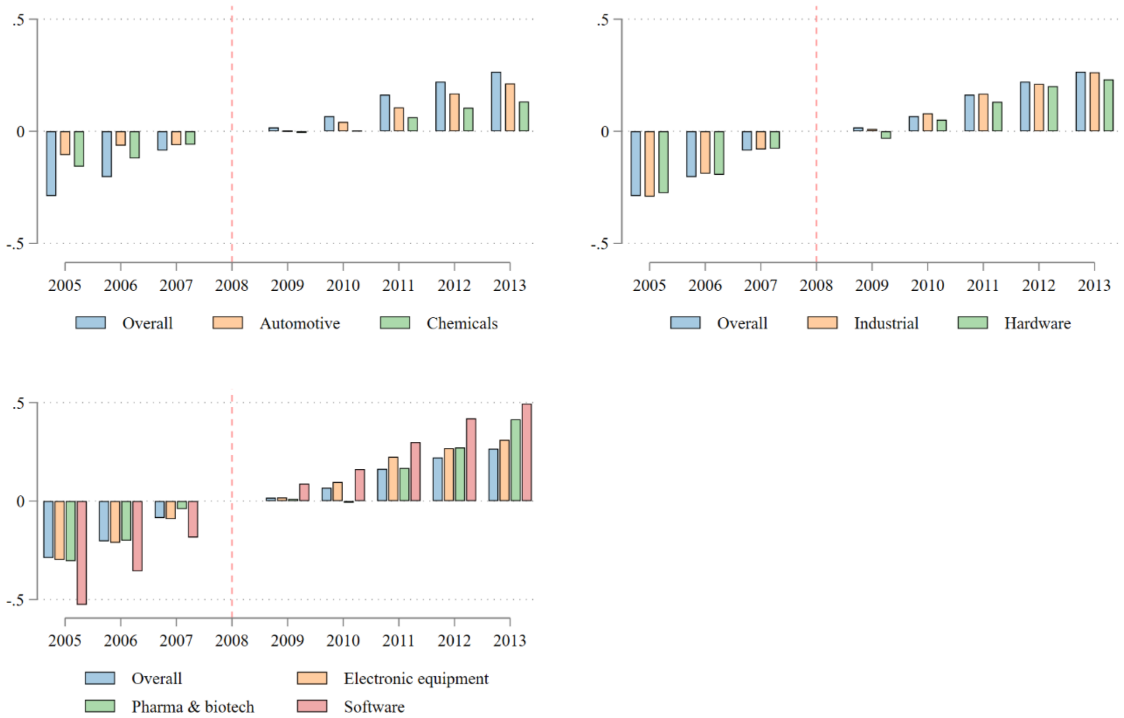
Figure 49 and Figure 50 show the industry breakdown of R&D investment around the two crises. In the aftermath of the financial crisis (Figure 49), different sectors exhibited diverse patterns in their R&D investment. Notably, the software industry displayed remarkable resilience, maintaining consistent growth throughout the period (reaching +50% compared to pre-crisis levels). Other sectors across managed to return to their R&D growth paths by 2010/2011 (automotive, chemicals, hardware), highlighting these sectors' resilience and ability to recover. The pharmaceutical and electronics sectors also performed strongly, establishing themselves as influential players in the post-crisis recovery phase. By contrast, the chemicals and automotive sectors experienced a more gradual recovery, regaining momentum by 2010/2011 and achieving over 10% growth by 2013, albeit at a slower pace compared to companies from other sectors.

In 2020, as the world grappled with the COVID-19 pandemic, a more pronounced response in R&D investment was observed across various industries (Figure 50). Although the automotive sector appeared to lag, other sectors swiftly increased their R&D investment as early as 2020, underscoring their improved ability to innovate and adapt rapidly. Particularly noteworthy was the pharmaceutical and biotech sector, which emerged as clear leader, accompanied by significant growth in the software and electronics sectors. This highlights a nuanced regional and sectoral response by companies to the global crisis, offering policymakers a potential pathway for strategic repositioning in the future.

Segmenting the results by region and sector provides a more nuanced understanding of the changes in R&D investment by top R&D investors before/after both crises. However, it is important to note that this approach may lead to less reliable results due to the reduced number of companies in each segment. With that in mind, the key trends observed are:

- During the financial crisis, EU-based companies invested more in R&D compared to their US counterparts in the automotive, electronics, and pharmaceutical sectors. On the other hand, US companies excelled in the software and chemical sectors, surpassing the investment of EU entities.
- In response to the COVID-19 pandemic, US companies increased R&D investment in the software and pharmaceutical sectors. In contrast, EU companies showed stronger results in the automotive sector, while other sectors did not exhibit a clear advantage for either region.

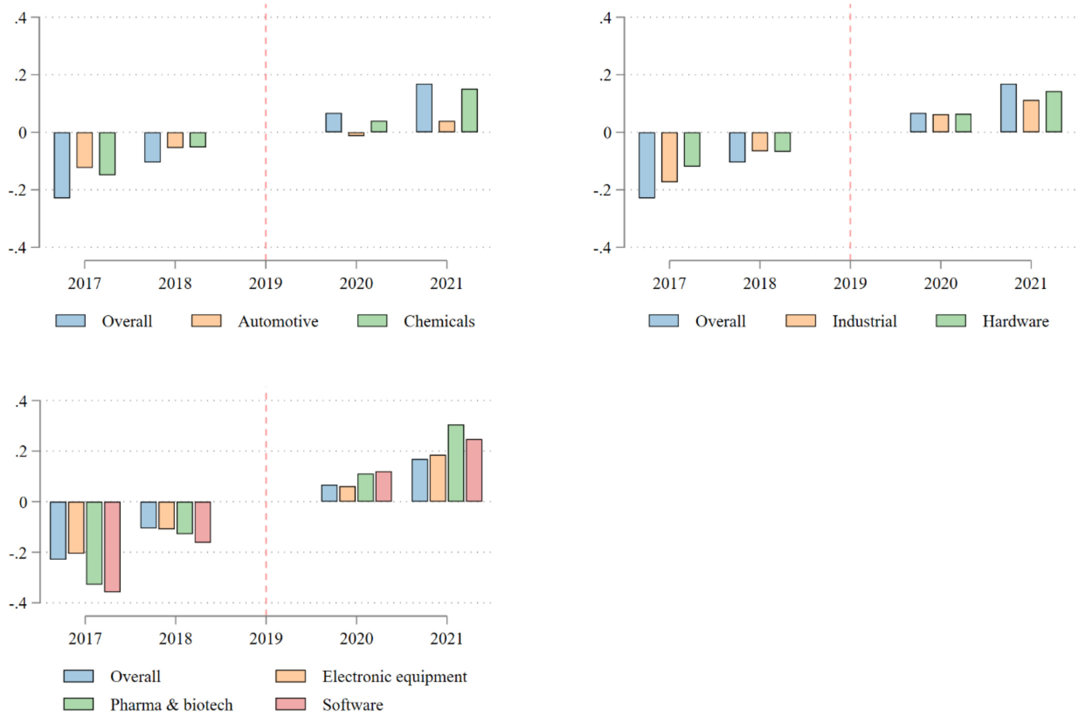
Figure 49. R&D investment before and after the financial crisis, by sector



Notes: The graph plots coefficients of year fixed effects from regressions controlling for net sales and firm fixed effects. All values are in 2015 PPP$, except for net sales, which are in 2015$. Values x100 are % changes compared to the base year (2008). E.g., investment in R&D by companies in the automotive sector was 10% lower in 2005 and 20% higher in 2013 than in 2008.

Source: own elaboration on data from The 2023 EU Industrial R&D Investment Scoreboard, European Commission, JRC/DG R&I

Figure 50. R&D investment before and after the COVID-19 crisis, by sector



Notes: The graph plots coefficients of year fixed effects from regressions controlling for net sales and firm fixed effects. All values are in 2015 PPP$, except for net sales, which are in 2015$. Values x100 are % changes compared to the base year (2019). For example, R&D investment by automotive companies was 10% lower in 2017 and 3% higher in 2021 than in the year 2019.

Source: own elaboration on data from The 2023 EU Industrial R&D Investment Scoreboard, European Commission, JRC/DG R&I

5.2.2 R&D investment by company profile: top vs bottom R&D spenders and resilient companies

When examining the dynamics of R&D investment, we observe significant differences in the behaviour of firms at opposite ends of the R&D investment spectrum. A comparative analysis between firms situated in the top and bottom terciles of the R&D distribution offers a nuanced perspective on the landscape. Figure 51 depicts the changes in R&D investment before/after the two crises for these two groups and provides a comparison relative to the pre-crises years (2008 and 2019 respectively)[114].

A silver lining emerged amidst the economic challenges posed by both the 2009 financial crisis and the 2020 COVID-19 pandemic. Both, top and bottom R&D spenders exhibit a positive trend of R&D investment through time. Moreover, firms at both the top and bottom ends of the R&D distribution managed to exceed their pre-crisis levels of R&D investment. This resilience was particularly notable among the bottom R&D spenders, who not only recovered quicker than their top-performing counterparts but also displayed a steep upward trajectory in investment. This surge, prominently visible in 2013, marked a reversal of the situation observed before the financial crisis. A similar pattern is observed in the aftermath of the 2020 COVID-19 crisis, with bottom R&D spenders experiencing a significant immediate increase in 2020 compared to 2019 levels. Furthermore, in 2021, both top and bottom R&D spenders exhibit similar growth trends, indicating a collective commitment to R&D as they respond to the challenges posed by the pandemic.

[114] For example, in 2007 top R&D companies invested approx. 5% less than in 2008, while in the same year bottom R&D companies invested approx. 18% less compared to 2008.

Figure 51. R&D investment before and after crises – top vs bottom R&D spenders

Notes: The graph plots coefficients of year fixed effects from regressions controlling for net sales and firm fixed effects. All values are in 2015 PPP$, except for net sales, which are in 2015$. Values x100 are % changes compared to the base year (2008 or 2019). For example, in 2007 top R&D companies invested approx. 5% less than in 2008, while in the same year bottom R&D companies invested approx. 18% less compared to their 2008 level.

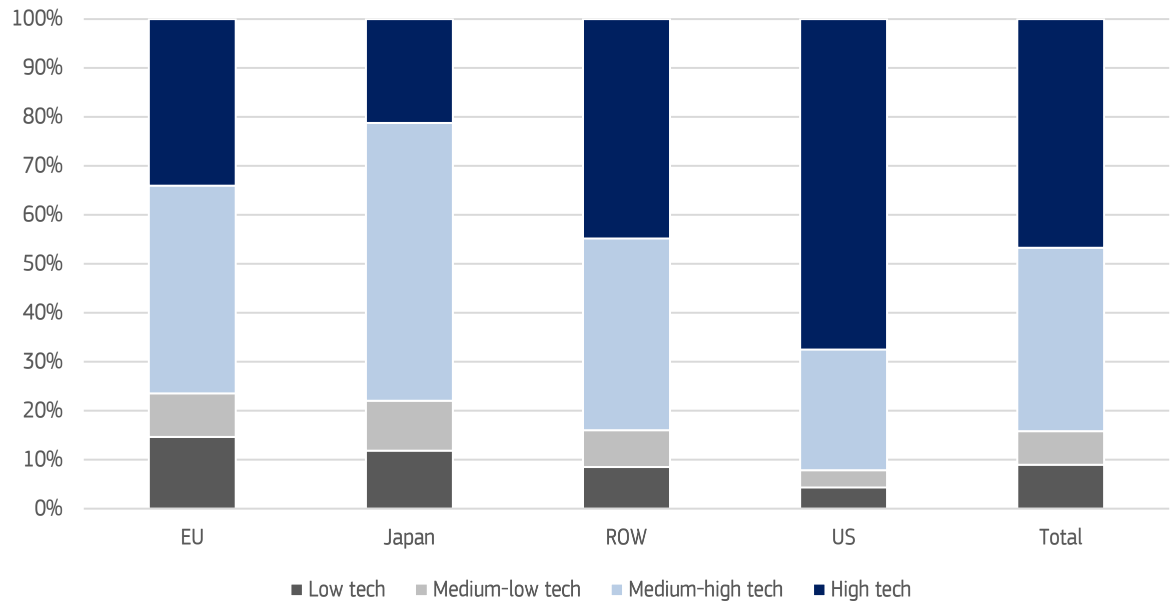
Source: own elaboration on data from The 2023 EU Industrial R&D Investment Scoreboard, European Commission, JRC/DG R&I

This remarkable increase in R&D by bottom R&D spenders is worth a closer look. Figure 52 and Figure 53 show the distribution of bottom R&D spenders across world regions and sector[115] for the two crises. During both crises, EU companies showcase a strong presence in the low tech sector, closely followed by Japan. Conversely, when observing the medium-low and medium-high tech domains, Japan takes the lead, with the EU slightly trailing. However, the picture changes when looking at the high tech sector. The US emerges as the clear leader, with its high-tech share far surpassing other regions. The RoW also exhibits a substantial presence in this high-tech domain, even exceeding both the EU and Japan.

This remarkable upswing by bottom R&D spenders was facilitated by their lower initial investment levels, which provided fertile ground for substantial growth. This illustrates the untapped potential of lower-performing R&D firms and signals a promising path for innovation and development in the aftermath of economic crises.

[115] The sector classification takes into account the average R&D intensity of all companies aggregated by ICB3-digits sectors: high is above 5%; medium between 1% and 5%; and low below 1%. To compensate for the insufficient representativeness of the Scoreboard in some sectors, they are adjusted using the OECD definition of technology intensity for manufacturing sectors. Chinese companies are not represented given the low number of companies (<50) available for a valid inference during this time period.

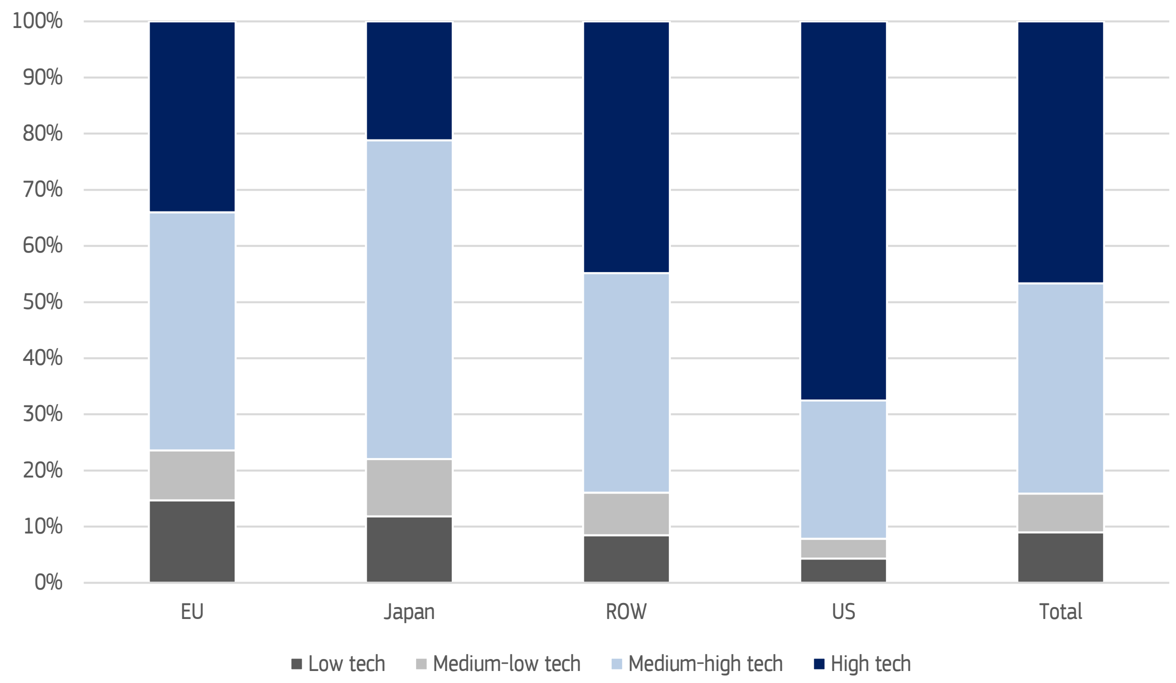
Figure 52. Distribution of bottom R&D spenders by Sector and Region during the financial crisis



Notes: The graph shows the distribution of bottom R&D spenders across world regions and sector during the financial crisis. The sectorial classification takes into account the average R&D intensity of all companies aggregated by ICB 3-digits sectors using the OECD definition of technology intensity for manufacturing sectors.

Source: own elaboration on data from The 2023 EU Industrial R&D Investment Scoreboard, European Commission, JRC/DG R&I

Figure 53. Distribution of bottom R&D spenders by Sector and Region during COVID-19 crisis



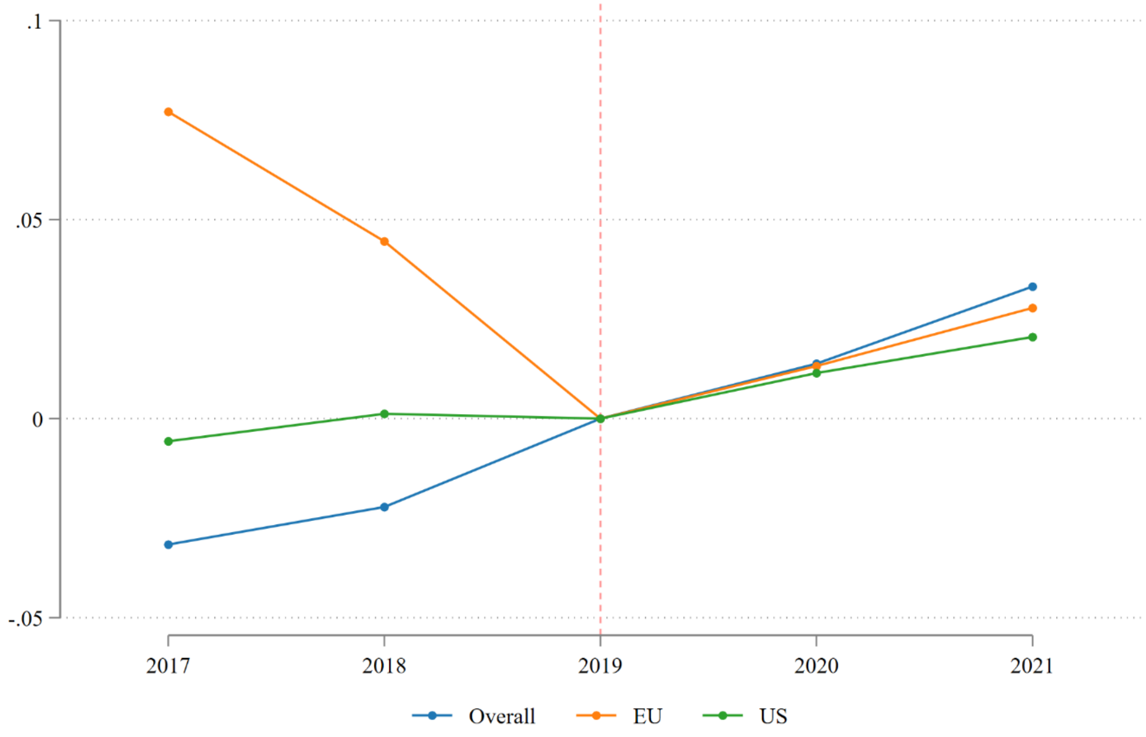
Notes: The graph shows the distribution of bottom R&D spenders across world regions and sector during the COVID-19 crisis. The sectorial classification takes into account the average R&D intensity of all companies aggregated by ICB 3-digits sectors using the OECD definition of technology intensity for manufacturing sectors.

Source: own elaboration on data from The 2023 EU Industrial R&D Investment Scoreboard, European Commission, JRC/DG R&I

In examining the dynamics of R&D investment during economic downturns, a discerning approach helps to distinguish between firms that demonstrate resilience in their R&D investment and those that do not.[116] Resilient investors are defined as companies that managed to increase their R&D investment by more than 20% in the aftermath of the financial crisis (2009-2013), compared to their average pre-crisis period. This definition takes into account financial aspects and underscores the ability of these firms to navigate and adapt during economically turbulent times. They embrace a learning curve that has the potential to foster innovation and growth[117].

Figure 54 shows for the period of the COVID-19 crisis the overall R&D dynamics of companies that showed resilience to the financial crisis (blue line). Compared to the 2019 pre-crisis level, in 2021 resilient companies invested 4% more in R&D expenditure than non-resilient companies. By looking at regional disaggregation (green and orange lines in Figure 54), companies based in the EU and the US and classified as resilient displayed a significant overall increase in their R&D investment compared to their non-resilient counterparts. This trend reflects a broader narrative of economic resilience, where learning companies view crises as pivotal moments to step up their innovation activity. This approach may set them on a path that promises not only recovery but also substantial development beyond their pre-crisis capacity. This points to the merits of sustained R&D investment as a strategic tool for navigating economic challenges, offering a potential solution for nurturing a resilient industrial economy.

Figure 54. R&D investment before and after the COVID-19 crisis – resilient vs non-resilient companies



Note: The graph plots coefficients of the interaction of resilient indicator variable with year fixed effects from regressions controlling for net sales and firm fixed effects. All values are in 2015 PPP$, except for net sales, which are in 2015$. Values x100 are % changes compared to the base year (2008 or 2019). For example, compared to the 2019 pre-crisis level, in 2021 resilient companies invested 4% more in R&D expenditure than non-resilient companies (blue dot corresponding to year 2021).

Source: own elaboration on data from The 2023 EU Industrial R&D Investment Scoreboard, European Commission, JRC/DG R&I

5.2.3 R&D contribution to the growth of sales and productivity

The analysis of R&D's effect on sales growth has revealed critical patterns that vary significantly across different time frames and geographical regions. Figure 55 reports the firm growth elasticities of R&D

[116] Amore, M. D. (2015). Companies learning to innovate in recessions. Research Policy, 44(8), 1574-1583 and D'Este, P., Marzucchi, A., & Rentocchini, F. (2018). Exploring and yet failing less: learning from past and current exploration in R&D. Industrial and Corporate Change, 27(3), 525-553.

[117] Amore, M. D. (2015). Companies learning to innovate in recessions. Research Policy, 44(8), 1574-1583

benchmarked against the pre-crisis year 2008 or 2019. The values indicate how a 1% increase in R&D investment contributes to the percentage growth of net sales in the following year, compared to the same values in years 2008 or 2019. For instance, a 1% rise in R&D investment in 2009 resulted in a growth in sales that was 0.02 percentage points higher compared to a 1% increase in R&D investment in 2008 (blue line).

In the aftermath of the global financial crisis that gripped the markets around 2009, a discernible trend emerged, highlighting the positive influence of R&D on firm growth. This effect continued to grow progressively until 2011. Companies based in the US and the EU displayed positive values in this regard, utilising R&D as a powerful catalyst for fostering firm growth. However, it is crucial to note that the EU later experienced a slowdown, potentially due to the implications of the subsequent debt crisis, which may have introduced financial constraints that tempered the contribution of R&D to sales growth.

Fast forward to the period encompassing the COVID-19 pandemic, and the dynamics appeared to shift significantly. The years 2020 and 2021 witnessed a relative decline in the contribution of R&D to sales growth compared to the pre-pandemic era. A significant part of this trend was led by Chinese companies, which exhibited a steadily declining trajectory. During this period, companies appeared to deprioritise investments in R&D as a means to enhance sales growth. The short-term shock may have prompted companies to reallocate resources away from long-term and relatively uncertain investments in favour of initiatives deemed essential for short-term survival. Firms in the US and the EU displayed a contrasting trend. This variation could be attributed to the different timing and impact of COVID-19 restrictions across these regions and the sudden interruption of global supply chains, especially hitting China, leading to distinct responses and adaptations that influenced R&D investment and its subsequent effects on firm growth.

Figure 55. Contribution of R&D investment to company sales growth before and after the crises

Notes: The graph plots coefficients of the interaction of R&D with year fixed effects from regressions controlling for Capex and firm fixed effects. All values are in 2015 PPP$, except for net sales, which are in 2015$. Values are percentage change points compared to the base year (2008 or 2019). For example, a 1% rise in R&D investment in 2009 resulted in a growth in sales that was 0.02 percentage points higher compared to a 1% increase in R&D investment in 2008 (blue dot corresponding to year 2009).

Source: own elaboration on data from The 2023 EU Industrial R&D Investment Scoreboard, European Commission, JRC/DG R&I

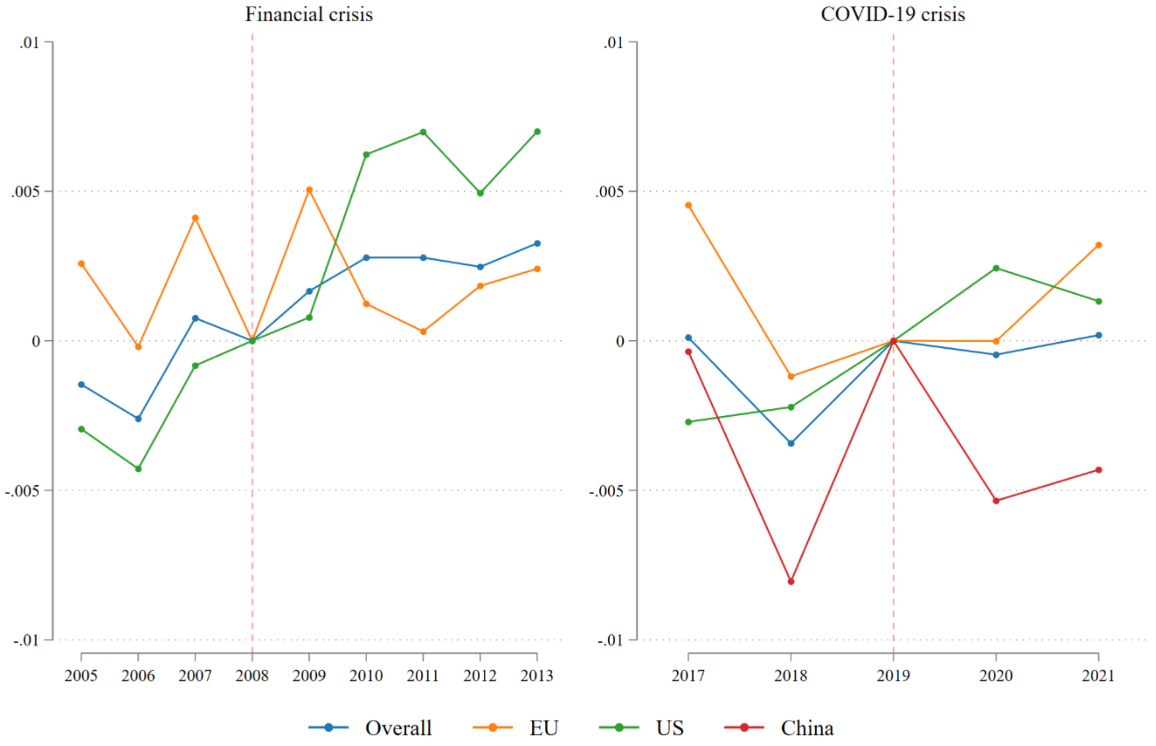
The analysis of the effect of R&D investment on total factor productivity (TFP) provides valuable insights into Scoreboard companies' overall productive and organisational efficiencies before and after periods of economic stress. Figure 56 shows the percentage growth of TFP for a 1% increase in R&D investment, comparing each year to the relevant pre-crisis year (2008 or 2019), depending on the specific analysis.

Looking back at the period following the financial crisis, we notice a general upward trend in R&D's contribution to TFP growth. During this time, there was a significant rise in the contribution of R&D to TFP growth for EU companies, followed by a gradual decline, although the R&D contribution to TFP growth remained above that of 2008. In contrast, US companies exhibited a consistent and stable growth trajectory, indicating a positive contribution of R&D investment to productivity growth.

The COVID-19 years presented a distinctly different landscape, with the overall contribution of R&D to TFP growth appearing somewhat muted, hovering close to zero. However, this seemingly stagnant trend conceals a complex array of divergent patterns observed at regional level. On the one hand, both the EU and the US demonstrated resilience in the ability to transform R&D investment into productivity growth, although their behaviour was opposite to that observed during the financial crisis. This pattern may be influenced by the different timing of COVID-19 restrictions and economic measures implemented in these regions. Notably, in 2021, the EU companies lead in accelerating TFP growth through R&D investment. In fact, the contribution of R&D investment to TFP growth in 2021 was the highest for EU companies. On the other hand, China presented a somewhat concerning narrative, characterised by a sharp decline in TFP growth contributions following the COVID-19 crisis, eventually stabilising but maintaining a negative profile compared to pre-crisis levels.

This analysis and results resonates well with the positive contribution of R&D investment to sales and productivity growth[118], thus offering further insights to guide future strategic decisions to counteract the secular global productivity slowdown[119].

Figure 56. Contribution of R&D investment to TFP before and after the crises



Notes: The graph plots coefficients of the interaction of R&D with year fixed effects from regressions controlling for firm fixed effects. All values are in 2015 PPP$, except for net sales, which are in 2015$. Values are percentage change points compared to the base year (2008 or 2019). For instance, a 1% increase in R&D investment by EU companies in 2009 led to a TFP growth rate that was 0.005 percentage points higher compared to the TFP growth rate following a 1% increase in R&D investment in 2008 (as indicated by the yellow dot corresponding to the year 2009).

Source: own elaboration on data from The 2023 EU Industrial R&D Investment Scoreboard, European Commission, JRC/DG R&I

118 European Commission, Science, research and innovation performance of the EU 2022: Building a sustainable future in uncertain times. Available at https://op.europa.eu/en/publication-detail/-/publication/52f8a759-1c42-11ed-8fa0-01aa75ed71a1

119 https://www.mckinsey.com/mgi/overview/in-the-news/turning-around-the-productivity-slowdown

5.2.4 Environmental, social and governance performance around the two crises

Environmental, Social, and Governance (ESG) criteria have emerged as pivotal metrics in understanding a company's broader impacts and its long-term sustainability. Considering the urgency of the climate crisis, the ripple effects of socio-economic challenges like the COVID-19 pandemic and the lingering effects of past financial crises, as well as other global uncertainties, there is a greater impetus on private organisations to think beyond just profits. Looking to ESG dimensions as complementary key strategic investments offers a more comprehensive view of a company's position in the market, its potential risks, and its opportunities for growth.

For this reason, this subsection analyses how the ESG performance of the top R&D investors has adapted in response to the two crises. Specifically, the section will concentrate on the changes in the carbon intensity of top R&D investors, the role of R&D investment in driving these changes, and potential enhancements in key social and governance indicators.

Box 4. ESG measures

The ESG measures employed in this analysis are sourced from Refinitiv's Eikon database. This is a widely recognised database with extensive use in financial analysis, academic research, and policy reporting. It serves as a valuable resource by offering transparent, objective, and auditable extra-financial information sourced from public disclosures made by companies. Eikon's extensive coverage spans over 12 000 global companies across 76 countries, encompassing more than 85% of the world's market capitalisation. Additionally, Eikon provides data dating back to 2002, making it a comprehensive and reliable tool for a wide range of analytical purposes[120]. Due to variations in coverage between Eikon and Scoreboard, the analysis is conducted using a reduced number of companies (455 for the financial crisis and 996 for the COVID-19 crisis). Below is a description of the measures derived from Refinitiv's Eikon database and employed in the analysis.

Carbon intensity scores. Carbon intensity scores are computed from CO_2 emissions and energy use of Scoreboard companies. CO_2 emissions include total CO_2 and CO_2 equivalent emissions in tonnes. Energy use is defined as total direct and indirect energy consumption in gigajoules. It includes the total amount of energy consumed (purchased and produced) as part of the company's operations. The analysis uses indicators developed in the past edition of the Scoreboard[121] and comprises carbon intensity (ratio between CO_2 emission and net sales), carbon energy intensity (ratio between emissions and energy use) as well as energy intensity (ratio between energy use and net sales). Carbon intensity measures a company's carbon footprint weighted by company size. Carbon energy intensity measures how clean the energy sources used by a company are. A decrease implies that a company has adopted breakthrough carbon-saving technologies/production processes (e.g. circular economy principles) or has started to use new green energy sources (e.g. renewables, hydrogen). Energy intensity is an indicator of a company's energy efficiency. A fall in this term suggests the adoption of (mostly incremental) energy-saving technologies/practices (e.g. low-energy light bulbs, energy-saving machinery).

Social and governance measures. Three main measures are employed in the analysis. First, a metric to assess workplace safety performance: the total number of injuries and fatalities (including no-lost-time injuries) per one million hours worked. Second, a key diversity and inclusion metric that measures the representation of women in managerial roles in the company: the percentage of women managers. Finally, the percentage of non-executive board members, which is a corporate governance metric that assesses the proportion of board members who are not actively involved in the day-to-day management of the company. These non-executive board members typically include independent directors and outside experts who provide oversight and guidance to the company's executive management team.

Looking at the period following the financial crisis, we notice significant fluctuations in carbon intensity scores (Figure 57). Initially, there was a sharp increase, followed by a notable decrease, resulting in a 10% overall reduction in carbon intensity. Interestingly, this shift was mainly due to a significant decrease in carbon

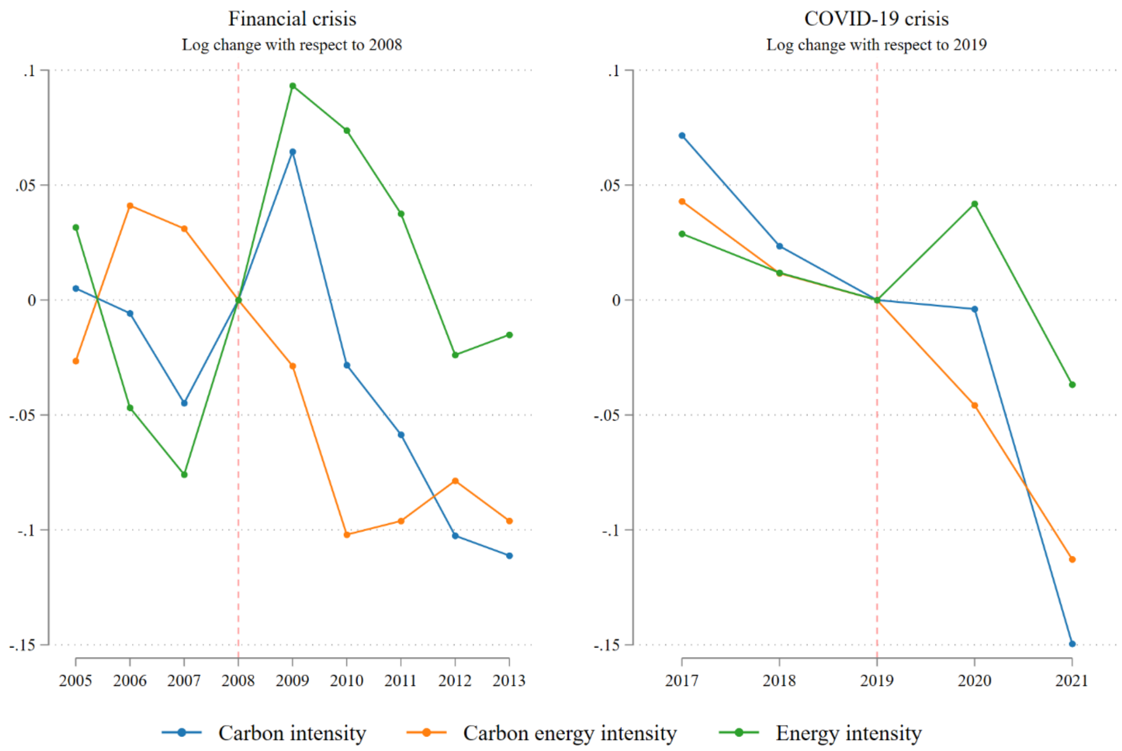
[120] Ortiz-De-Mandojana, N. and Antolín-López, R., How do companies measure and report corporate sustainability A comparison among the most innovative European companies, Publications Office of the European Union, Luxembourg, 2023, ISBN 978-92-76-99454-1, doi:10.2760/935191, JRC132579.

[121] European Commission, Joint Research Centre, Grassano, N., Hernandez Guevara, H., Fako. P. et al., The 2022 EU Industrial R&D Investment Scoreboard, Publications Office of the European Union, 2022.

energy intensity, indicating a move towards cleaner energy sources and the adoption of carbon-saving technologies and processes. These changes may involve using circular economy principles and incorporating green energy sources, such as renewables. At the same time, energy intensity initially went up but later decreased, falling below pre-crisis levels, suggesting a gradual shift towards more energy-efficient practices.

Turning to the period encompassing the COVID-19 pandemic, the carbon intensity story takes a slightly different path. Initially, the scores remained relatively stable before experiencing a significant drop, reaching a 15% reduction. This decline was a result of both reduced carbon energy intensity and an initial rise in energy intensity, which later decreased in 2021. These trends likely reflect the sharp reduction in emissions and sales coming from the halt of production during the COVID-19 pandemic.

Figure 57. Carbon intensity scores before and after the two crises



Notes: The graph plots coefficients of year fixed effects from regressions controlling for firm fixed effects. All values are in 2015 PPP$, except for net sales, which are in 2015$. Values x100 are % changes compared to the base year (2008 or 2019). For example, the carbon intensity was 6% higher for top R&D investors in 2009 compared to the pre-crisis level of 2008 (as indicated by the blue dot corresponding to the year 2009)

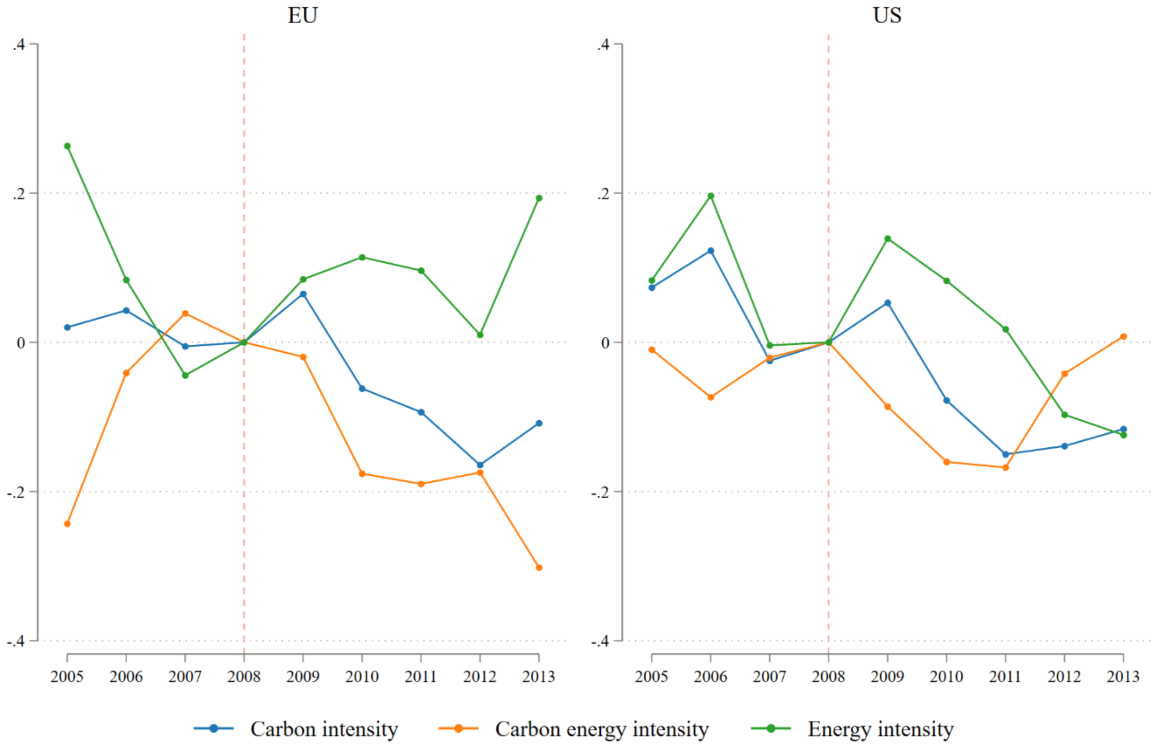
Source: own elaboration on data from The 2023 EU Industrial R&D Investment Scoreboard, European Commission, JRC/DG R&I and Refinitiv's Eikon database.

We examine the geographical breakdown of carbon intensity scores (Figure 58), with a specific focus on changes for headquarter companies based in the EU and the US following the financial crisis. This offers a nuanced perspective on regional disparities in environmental achievements of top R&D investors during this timeframe. In retrospect, it becomes evident that both EU and US companies were compelled to reduce their carbon emissions in the aftermath of the financial crisis. The EU emerged as a pioneer in this movement, demonstrating an impressive commitment to environmental responsibility. EU-based companies were on the cusp of achieving a significant milestone, as they approached a remarkable 20% reduction in carbon intensity by 2012 when compared to 2008 levels. This substantial decrease can be attributed mostly to the decline in carbon energy intensity. This signifies a promising shift towards cleaner energy consumption and a notable adoption of innovative carbon-saving technologies and initiatives, including renewable and alternative energy sources.

US companies exhibited a more intricate pattern. Initially, the decline in carbon intensity was driven by a simultaneous decrease in both carbon energy intensity and energy intensity, suggesting a dual focus on adopting cleaner energy sources and implementing energy-efficient operational practices. However, this trend underwent a notable reversal starting from 2011. The US experienced a resurgence of carbon energy intensity, possibly indicating a temporary shift back towards conventional energy sources. Meanwhile, the downward trajectory in energy intensity persisted, indicating sustained action to increase energy efficiency.

This action included integrating energy-saving technologies and operational protocols to substantially reduce energy consumption.

Figure 58. Carbon intensity scores before and after the financial crisis, by region

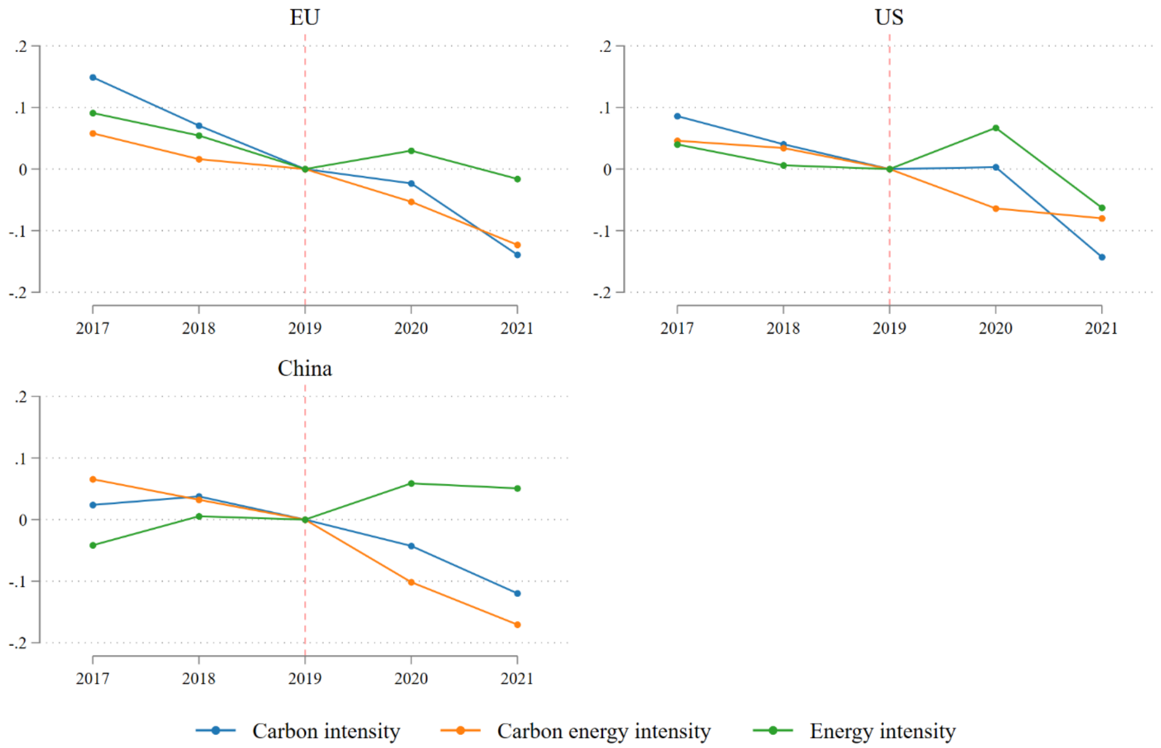


Notes: The graph plots coefficients of year fixed effects from regressions controlling for firm fixed effects. All values are in 2015 PPP$, except for net sales, which are in 2015$. Values x100 are % changes compared to the base year (2008 or 2019). For example, the carbon intensity was nearly 20% lower for EU companies in 2012 compared to the pre-crisis level of 2008 (as indicated by the blue dot corresponding to the year 2012)

Source: own elaboration on data from The 2023 EU Industrial R&D Investment Scoreboard, European Commission, JRC/DG R&I and Refinitiv's Eikon database.

The effect of the COVID-19 pandemic on carbon intensity scores is depicted in Figure 59. It shows how this unprecedented global event has spurred significant changes in environmental practices and policies of large corporations across the world. EU companies have experienced an overall reduction in carbon intensity, marked by a sharp decline in 2021, where the figures dropped by more than 10% compared to pre-crisis levels. This positive environmental response was largely driven by a decrease in carbon energy intensity, supplemented by a slight reduction in energy intensity observed during the same year. In contrast, companies based in the US adopted a two-phase approach to reducing carbon intensity. Initially, the reduction was primarily attributed to a decline in carbon energy intensity observed in 2020. Subsequently, the focus shifted towards reducing energy intensity, while carbon energy intensity remained relatively stable. Turning the attention to Chinese headquarter companies, there is a pattern closely resembling the initial response seen in US companies. The reduction in carbon intensity was primarily driven by a substantial decrease in carbon energy intensity.

Figure 59. Carbon intensity scores before and after the COVID-19 crisis, by region



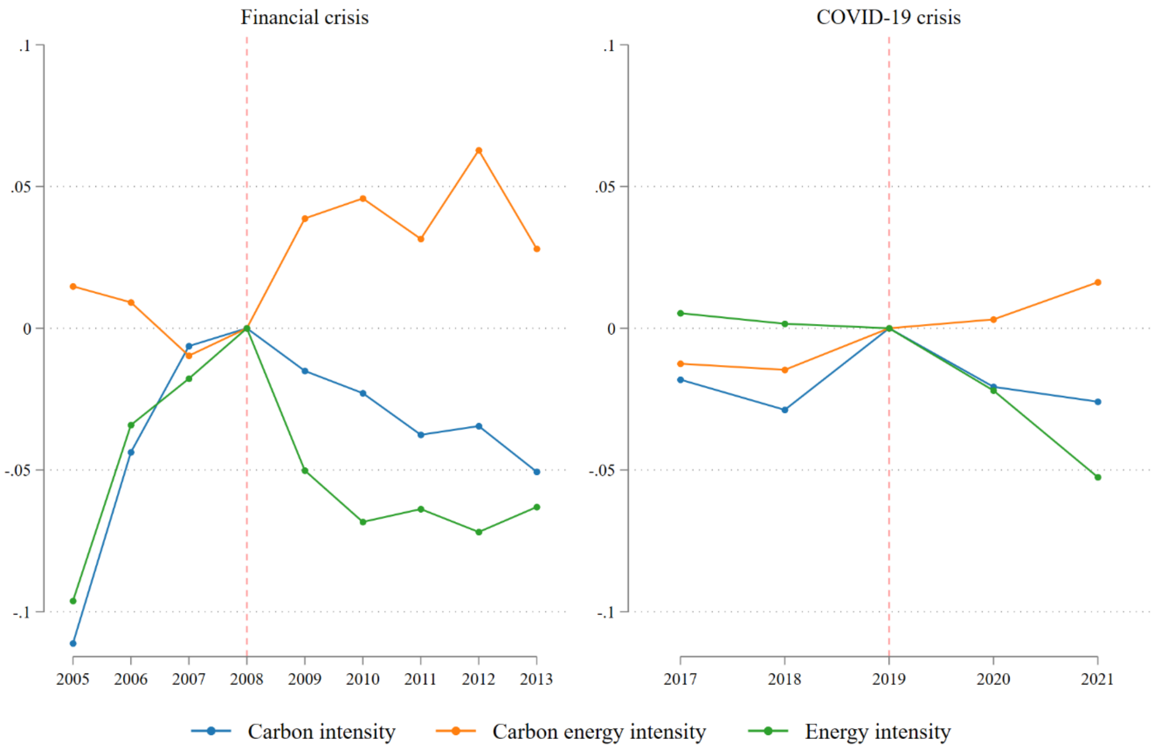
Notes: The graph plots coefficients of year fixed effects from regressions controlling for firm fixed effects. All values are in 2015 PPP$, except for net sales, which are in 2015$. Values x100 are % changes compared to the base year (2008 or 2019). For example, the carbon intensity was more than 10% lower for EU companies in 2021 compared to the pre-crisis level of 2019 (as indicated by the yellow dot corresponding to the year 2021)

Source: own elaboration on data from The 2023 EU Industrial R&D Investment Scoreboard, European Commission, JRC/DG R&I and Refinitiv's Eikon database.

Figure 60 shows the contribution of overall R&D investment to carbon intensity scores, which suggests an association with a company's environmental footprint, particularly in the context of the two major recent crises. It should be noted, however, that this does not necessarily imply causation, and the data encompasses general R&D expenditures, not exclusively those targeted towards environmental enhancements. In the periods following the 2008 financial crisis and the 2019 COVID-19 pandemic, there is a clear emphasis on using R&D to reduce overall carbon intensity. This trend reflects a growing awareness among corporations, and commitment to drive innovation with a strong environmental focus, as also evidenced in recent work.[122] Primarily, this R&D activity has been directed towards reducing energy intensity, indicating a targeted investment in incremental technologies (e.g. low-energy light bulbs, energy-saving machinery). This trajectory highlights the incremental advancements being pursued to optimise energy consumption, thus helping to achieve an overall reduction in carbon intensity. In conclusion, the noticeable influence of R&D on reducing carbon intensity scores presents an encouraging narrative. It illustrates the synergistic relationship between innovation and the green transition, providing a promising way for corporations to foster sustainable growth and development, particularly in the aftermath of significant economic and societal disruptions.

[122] Huang, J., Xiang, S., Wang, Y., & Chen, X. (2021). Energy-saving R&D and carbon intensity in China. Energy Economics, 98, 105240.

Figure 60. Carbon intensity scores elasticities of R&D investment before and after the two crises



Notes: The graph plots coefficients of the interaction of R&D with year fixed effects from regressions controlling for firm fixed effects. All values are in 2015 PPP$, except for net sales, which are in 2015$. Values x100 are % changes compared to the base year (2008 or 2019). For example, a 1% rise in R&D. investment by top R&D investors in 2021 led to a 5% decrease in energy intensity compared to a 1% increase in R&D investment in 2019 (as indicated by the green dot corresponding to the year 2021).

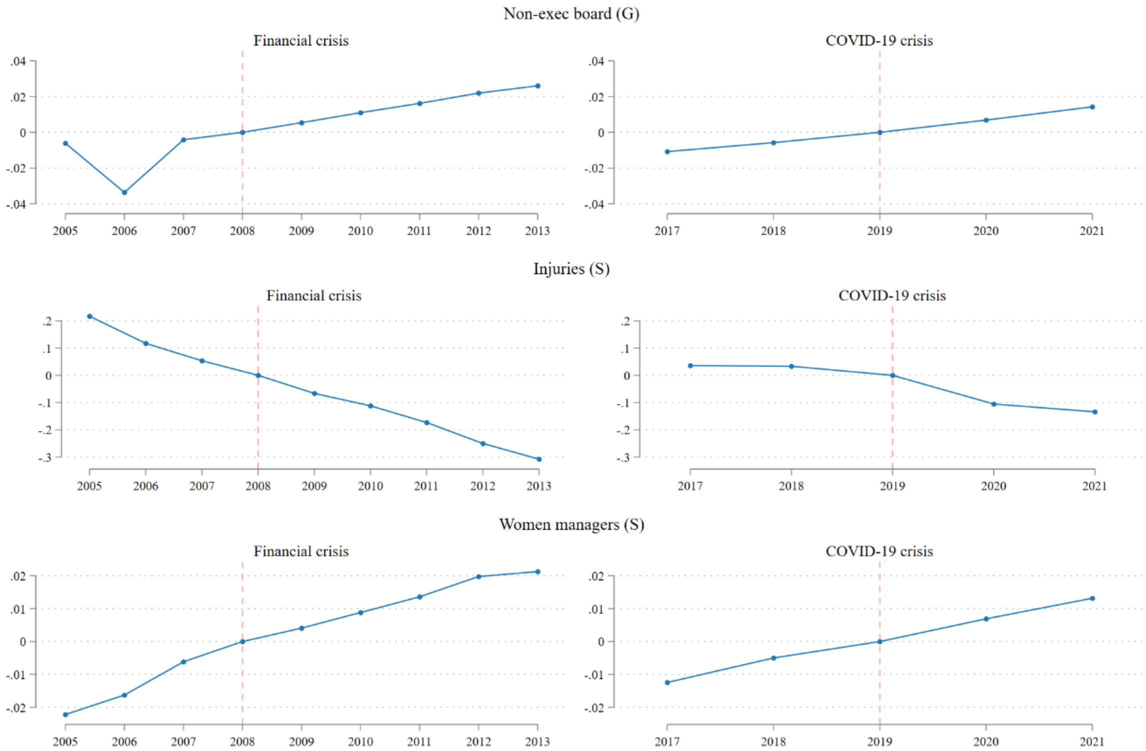
Source: own elaboration on data from The 2023 EU Industrial R&D Investment Scoreboard, European Commission, JRC/DG R&I and Refinitiv's Eikon database.

In the turbulent aftermath of the 2009 financial crisis and the 2020 COVID-19 pandemic, the corporate world underwent a notable transformation in the realm of social and governance dynamics, reflecting a progressive trend among top R&D investors, globally. Exploring these dynamics, we uncover a remarkable trajectory of improvement across key social and governance indicators, highlighting a potential recalibration of corporate strategies and cultures in response to these significant crises. Figure 61 presents time changes in three significant Social and Governance (S&G) dimensions—job safety, gender bias, and corporate governance. These changes are adjusted for time-invariant firm-level effects and net sales. The values, multiplied by 100, represent percentage changes compared to the base (pre-crisis) year (2008 for the financial crisis and 2019 for the COVID-19 crisis).

The data clearly indicates a positive historical trend across all the presented indicators, including the number of injuries and fatalities per one million hours worked, the proportion of women in managerial roles, and the percentage of non-executive members on the board of directors. This trend is evident both before and after each crisis, underscoring the commitment of top R&D investors to enhance their social and governance dimensions over time.

Firstly, job safety, measured as the total number of injuries and fatalities per one million hours worked, has shown a promising decline, signifying a more meticulous approach towards ensuring workplace safety. Figure 61 reveals a substantial decrease, plummeting by 30% in 2013 (compared to 2008) and 10% in 2021 (compared to 2019). Interestingly, while the reduction following the financial crisis aligns with a pre-existing downward trend, the decrease observed in 2021 can be attributed to production halts induced by COVID-19 restrictions, pointing towards an incidental yet welcome improvement in this area.

Figure 61. Social (S) and governance (G) indicators before and after the two crises



Notes: The graph plots coefficients of year fixed effects from regressions controlling for net sales and firm fixed effects. All values are in 2015 PPP$, except for net sales, which are in 2015$. Values x100 are % changes compared to the base year (2008 or 2019). For example, the number of injuries per million hours worked in 2020 was approximately 10% lower compared to the pre-crisis year of 2019.

Source: own elaboration on data from The 2023 EU Industrial R&D Investment Scoreboard, European Commission, JRC/DG R&I and Refinitiv's Eikon database.

Figure 61 also shows the progress made in reducing gender bias in the corporate sphere, assessed through the proportion of women holding managerial positions. Here, there is a gradual yet significant upward trajectory, with increases of 2% in 2013 and 1% in 2021 compared to the base levels of 2008 and 2019, respectively. This upward trend indicates a slow but steady shift towards inclusivity and gender parity, paving the way for a more diverse and equitable workspace.

Finally, in relation to governance, depicted by the percentage of non-executive members on the board of directors, we observe a picture of increased independence and improved checks and balances in corporate leadership. Figure 61 shows that this metric achieved a 2% increase in both 2013 and 2021 compared to pre-crisis years (2008 and 2019, respectively). This suggests a stronger emphasis on safeguarding the interests of minority shareholders and other stakeholders, fostering a more transparent and accountable governance structure.

5.3 Key points

- Although the EU still hosts a significant share of incumbent R&D leaders, it has experienced a decline in the representation of its firms among the top 2 500 R&D investors, suggesting a relative difficulty in hosting new R&D-leading firms compared to China and the US.
- The most dynamic sector during this period has been ICT services. It has experienced increases in R&D global share, R&D intensity, and notably, it is the sector in which new entrants have shown higher R&D intensity than incumbent top R&D firms, indicating a vibrant environment driven by the rapid advancement of digital technologies and connectivity.
- The automotive and health sectors also display signs of dynamism as new firms within the Scoreboard exhibit higher R&D intensity than established incumbents, possibly driven by the paradigm shift towards electric vehicles and the increased R&D investments in the health sector during the COVID-19 pandemic.

- The major winners of this 20-year global tech race are Chinese firms (incumbents and new entrants) which have gained global R&D share in sectors that have been more dynamic.
- R&D investments by top R&D investors exhibit greater resilience during crises compared to capital expenditure. This resilience suggests that companies view R&D investment as a means to mitigate the impact of crises, considering it a strategic investment that reliably contributes to their long-term competitiveness.
- R&D investment by leading R&D investors shows a significant impact on companies' economic recovery following both the 2009 financial crisis and the COVID-19 pandemic. Notably, it has a positive effect on sales and productivity growths. Regional disparities are evident in this context. For instance, the capital and R&D expenditures of US companies rebounded more swiftly, as did those of Chinese companies during the post-COVID-19 period, in comparison to their EU counterparts.
- Sectoral differences are apparent concerning R&D investment during crises. Sectors such as ICT services, ICT producers, and health industries exhibit greater resilience in maintaining their R&D investment levels. Consequently, these sectors make significant contributions to the overall recovery of corporate R&D investment following both crises.
- Companies resilient during the financial crisis increased their R&D investments after the COVID-19 pandemic crisis, showing a commitment to long-term growth and technological advancements.
- The crises accelerated the reduction of carbon footprints among Scoreboard companies, with EU firms taking the lead in this regard. EU firms have exhibited a remarkable commitment to environmental responsibility throughout the analysis period.
- In the wake of the crises, Scoreboard companies have taken steps to enhance their social and governance practices, building on ongoing improvements in areas such as workplace safety, gender balance, and board independence.

PART II

6 Patenting trends in green and clean transport technologies

This section presents the annual update of patenting trends in climate change mitigation technologies (CCMTs) and analyses the patenting trends in clean transport technologies (CTTs). In addition, it offers patenting trends in clean transport and clean energy technologies used in the Scoreboard automotive industry. Among other, the patenting trends presented in the section also monitor inventions related to electromobility and the relative positioning of the EU industry compared to other major economies.

Section 1 provides an update on trends in CCMTs in the EU compared with other major economies. Section 2 presents an analysis of global trends in CTT inventions and further insights on EU Member States' patenting activity. Section 3 provides an update on clean transport and clean energy patenting trends within the Scoreboard automotive industry. The final section 4 offers key points in terms of findings and conclusions.

6.1 Relevance and policy context

The transport sector is responsible for a quarter of the EU's greenhouse gas (GHG) emissions; road transport accounts for around 72% of the sector's GHG emissions followed by civil aviation (14%) and waterborne transport (13%). In 2019, sustainable and smart mobility was one of the main action areas of the European Green Deal[123]. Sustainable transport, in the form of more sustainable, innovative and efficient transport systems, is also one of the four core research priorities of the Energy Union's research, innovation and competitiveness dimension[124]. The priority is further reflected in the strategic energy technology (SET) plan by means of actions on batteries and e-mobility and renewable fuels[125], and receives the greatest share of research & innovation (R&I) investment across all priorities. It attracts 45% of the public and 54% of the private R&I funding; in 2020, this reached an estimated total of EUR 11.5 billion[126].

The 2020 sustainable and smart mobility strategy[127] prioritises the uptake of zero-emission vehicles, renewable and low-carbon fuels and related infrastructure in its action plan. The plan calls for prioritising already available zero-emission solutions for road transport, such as battery electric vehicles and hydrogen fuel-cell vehicles. It underlines the need to respect the CO_2 and pollution standards for the transitional technological solutions. In addition to road transport, the plan emphasises the further need to electrify rail transport and use hydrogen as an alternative fuel. For air and waterborne transport, the plan calls for priority access to alternative fuels given the lack of zero-emission technologies that are market-ready.

In October 2017, the European Battery Alliance (EBA) was launched to build a domestic supply of clean energy for zero-emission transport solutions. Since its launch, the EBA has attracted investment from inside and outside the EU for technology development and R&I activities for batteries in the EU through the Batteries Europe Platform[128]. Following the success of the EBA, the European Clean Hydrogen Alliance was launched in 2020 and, more recently, the European Commission launched the Renewable and Low-Carbon Fuels Value Chain Industrial Alliance to boost the production and supply of renewable and low-carbon fuels in the air and waterborne transport sectors.

The European Commission's Net Zero Industry Act (NZIA)[129] underlines battery/storage technologies and fuel cells among the strategic net-zero technologies that are critical for the EU to achieve its climate and energy objectives according to its 2030 Climate target plan[130]. To meet the goals of this plan and to achieve climate neutrality by 2050, electric vehicles (EVs) are perceived as the long-term technological solution for the automotive industry – the EU's leading industry in private R&D investments and where the EU Scoreboard companies are global leaders. The NZIA expects the lion's share of investments to increase the EU battery

123 COM (2019) 640 final, 'The European Green Deal'.
124 European Commission, Energy Union Package – A Framework Strategy for a Resilient Energy Union with a Forward-Looking Climate Change Policy, COM (2015) 80 final, Brussels, 25 February 2015.
125 European Commission, Towards an Integrated Strategic Energy Technology (SET) Plan: Acceleration the European Energy System Transformation, COM(2015) 6317 final, Brussels, 15 September 2015.
126 European Commission, SET Plan Progress Report 2023 - Coordinated energy research and innovation for a competitive Europe, forthcoming and JRC SETIS https://setis.ec.europa.eu/publications/setis-research-and-innovation-data_en.
127 COM (2020) 789 final, 'Sustainable and Smart Mobility Strategy – putting European transport on track for the future'.
128 European Commission, Joint Research Centre, Bielewski, M., Pfrang, A., Bobba, S. et al., Clean Energy Technology Observatory, Batteries for energy storage in the European Union – Status report on technology development, trends, value chains and markets – 2022, Publications Office of the European Union, 2022, https://data.europa.eu/doi/10.2760/808352.
129 SWD (2023) 219 final, 'Net Zero Industry Act'.
130 COM(2020) 562 final, 'Stepping up Europe's 2030 climate ambition - Investing in a climate-neutral future for the benefit of our people'.

manufacturing capacity due to expected high demand for the EVs, which will support the EBA's objective of European manufacturers producing 90% of the EU's annual battery deployment needs. The NZIA also acknowledges the role that generous subsidies played in China in expanding battery manufacturing to include the cell manufacturers. In the State of the European Union address from September 2023, the European Commission President announced an anti-subsidy investigation into the electric vehicles coming from China into Monitoring inventive trends in clean transport technologies has gained particular importance in the current political and economic landscape. With an annual revenue stream estimated to reach EUR 7 trillion by 2050, transport attracts disruptive technology companies, which will introduce new technologies and business models that have the potential to not only transform transport, but also impact other sectors, such as electronics, software, telecommunications, and data services[131].

This section presents the annual update of patenting trends in CCMTs and analyses the patenting trends in CTTs. In addition, it presents patenting trends in clean transport and clean energy technologies used in the Scoreboard automotive industry[132]. Among other CTTs, the patenting trends presented also monitor inventions related to electromobility and the relative positioning of the EU industry compared to other major economies.

We use the CCMT patent classes of the Corporate Patent Classification (CPC) for green technologies and more specifically the transport technology group to analyse CTTs (see Box 6.1). This approach provides an analysis consistent with the monitoring of research innovation and competitiveness for the Energy Union's governance, one of the European Green Deal's pillars[133], and the annual progress reports on competitiveness of clean energy technologies[134] produced as part of this pillar. In addition, it is in line with, and therefore connects the Scoreboard with the work carried out under the strategic energy technology plan[135] and that carried out by the Clean Energy Technologies Observatory[136] on related technologies.

6.2 Update on overall trends in CCMTs

The global share of green inventions, not just high-value but all patent applications, remained stable from 2018 to 2019 at around 9% of all filings, driven by very high numbers of Chinese inventions that were only protected domestically, which account for 47% of all green filings. Globally, in 2019, green high-value inventions made up 10% of all high-value patent filings. South Korea and the EU had the highest green shares in their overall high-value patent portfolio with 13% and 12%, respectively. In terms of high-value inventions in green patent filings, Japan and the EU maintained the highest shares of 58% in 2019 with no change on 2018 (Figure 62).

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131 European Commission, Joint Research Centre, The future of road transport – Implications of automated, connected, low-carbon and shared mobility, Publications Office, 2019, https://data.europa.eu/doi/10.2760/668964.

132 The section revisits the analysis from the 2019 Scoreboard 'Automotive industry for green transport and energy inventions in 2012-2015'.

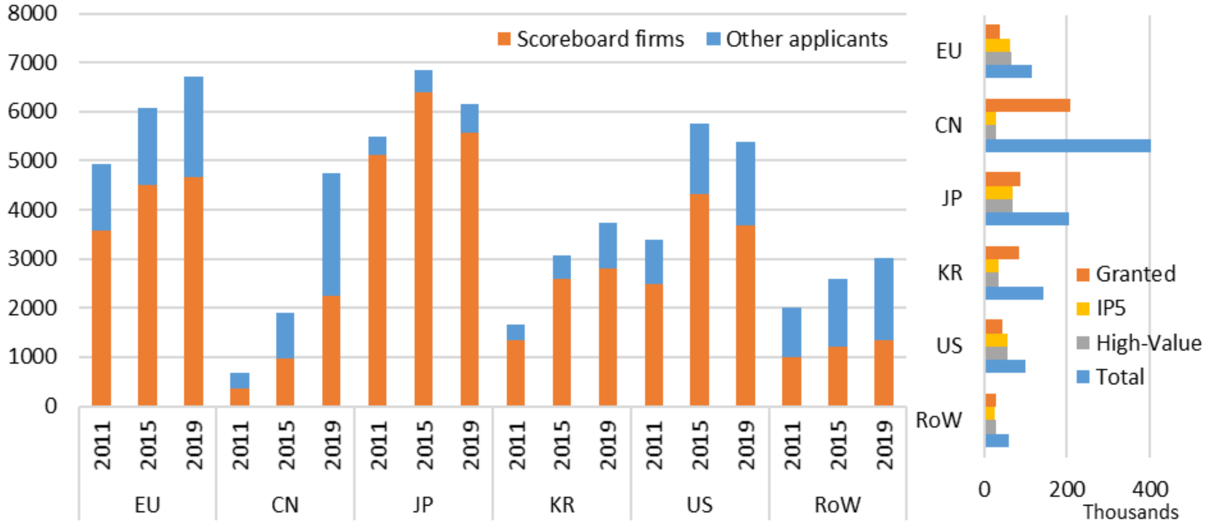
133 Factsheets on the European Green Deal: https://ec.europa.eu/info/publications/factsheets-european-green-deal_en

134 European Commission, Energy, Climate change, Environment, Energy, Clean energy competitiveness

135 Strategic Energy Technology Plan Information System (SETIS) Research and Innovation

136 Clean Energy Technologies Observatory (CETO) Technology Reports Repository

Figure 62. Trends in high-value green inventions: All applicants (Scoreboard firms and other applicants)



Source: The 2023 EU Industrial R&D Investment Scoreboard, European Commission, JRC/DG R&I.

In 2019, the Scoreboard companies had a reduced share of 68% of green high-value inventions compared with 73% in 2018. From 2018 to 2019, Japanese Scoreboard firms continued to file the highest number of patents for high-value CCMT inventions, but when taking into account filings from all types of applicants, the EU continued to lead for high-value inventions (Figure 62). Compared to 2018, in 2019, Japan, the EU and the US experienced a decrease in high-value green inventions whereas China experienced a substantial increase of 20% and South Korea 7%. In the EU, the US and China, there was a more diverse contribution to green inventions from applicants beyond the Scoreboard, whereas green inventions continued to come mainly from the Scoreboard companies in Japan and South Korea.

Table 34 shows the specialisation index[137] for the nine subclasses of green technologies in major economies and changes over the 2010-2019 period. Green subclasses (in rows) are related to the patent classification of CCMTs. In 2019, the EU had a positive specialisation index among major economies in most of the CCMTs. The EU led the specialisation in the categories of buildings, production, transportation and waste. China was the most specialised in ICT, South Korea in energy and the US in adaptation and carbon capture and storage (CCS). Compared with the previous year's specialisation level, in addition to ICT, the EU's specialisation index became negative for adaptation technologies.

Table 34. Specialisation index by CCMT group for major economies (2019) and change over 2010-2019: All applicants.

CCMTs	**EU**		**CN**		**JP**		**KR**		**US**		**RoW**	
	Index	**Change**	**Index**	**Change**	**Index**	**Change**	**Index**	**Change**	**Index**	**Change**	**Index**	**Change**
Adaptation	-0.1	-0.2	0.0	0.4	-0.5	0.1	0.0	0.4	0.2	-0.4	0.7	0.2
Buildings	0.2	0.1	0.0	0.1	-0.1	0.0	-0.1	-0.5	-0.2	0.1	0.2	0.0
CCS	0.2	0.0	0.8	0.0	-0.1	0.4	-0.1	0.4	0.4	-0.2	0.7	0.3
ICT	-0.5	0.1	0.6	-0.7	-0.6	-0.5	0.5	-0.3	0.5	0.3	-0.4	-0.4
Energy	0.1	0.0	0.1	0.2	0.1	0.0	0.9	0.5	-0.4	-0.3	-0.3	-0.1
Production	0.3	0.3	0.2	0.1	0.1	0.1	0.0	-0.2	0.0	-0.1	-0.1	-0.1
Transport	0.6	0.3	0.7	0.2	0.1	-0.1	0.0	0.3	0.0	0.0	-0.2	0.4
Waste	0.5	0.2	0.1	0.1	-0.4	0.0	-0.4	-0.2	-0.2	-0.3	0.6	0.3
Systems	0.2	0.3	0.4	0.1	-0.2	0.0	0.1	-0.4	0.2	-0.1	0.4	0.3

Note: Based on high-value inventions. See Box 5 to understand categories.
Source: The 2023 EU Industrial R&D Investment Scoreboard, European Commission, JRC/DG R&I.

[137] The share of high-value inventions in the technology sub-class of interest among all high-value inventions within a country's portfolio, compared to the respective global average share.

Box 5. Clean transport technology patent analysis – methodology

Patenting trends are produced following the methodology developed by the JRC[138] to derive indicators on global inventions in clean energy technologies[139]. Patent data are retrieved from the PATSTAT 2022 Autumn Edition. As data are not as complete from 2020 onwards; the latest figures in the analysis are from 2019.

The analysis is restricted to CCMTs[140]. CCMTs – referred to as green technologies in this study - are identified through the Y02 and Y04 schemes of the CPC.

Table B5 1 Y02 and Y04 schemes of the CPC classes

CCMT	Y scheme	Y02 and Y04 description
Adaptation	Y02A	Technologies for adaptation to climate change
Buildings	Y02B	CCMTs related to buildings
CCS	Y02C	CCS, sequestration or disposal of greenhouse gases
ICT	Y02D	CCMTs related to ICT
Energy	Y02E	Reduction of greenhouse gas emissions, related to energy generation, transmission or distribution
Production	Y02P	CCMTs in the production or processing of goods
Transport	Y02T	CCMTs related to transportation
Waste	Y02W	CCMTs related to wastewater treatment or waste management
Systems	Y04S	Systems integrating technologies related to power network operation, communication or information technologies, e.g., smart grids

Fractional counting is also used to quantify international collaborations in patenting activity. Co-inventions are calculated based on a matrix of all combinations among co-applicants, for inventions that have been produced by at least two entities resident in two different countries. Shares of co-inventions in the same country are not considered.

The analysis of EU Scoreboard companies focuses on those headquartered in the EU. The portfolio of these companies' inventions includes those inventions produced by all subsidiaries, irrespective of their location. The matching of subsidiaries to applicant names in PATSTAT currently covers 60% of the Scoreboard companies, which, however, account for 97% of R&D investments.

Y02T subclasses of the Y scheme enable the definition of CTTs under CCMTs. As shown in Table B5 2, we use the most disaggregated technology classes of Y02T subclasses and represent them in technology groups. Patent classes are aggregated as: i) aeronautics & air transport (t.), ii) alternative fuels, iii) hybrid vehicles, iv) electromobility, v) charging stations, vi) plug-in electric vehicles (EV), vii) ICT for EVs, viii) grid interoperability, ix) hydrogen for transport, x) internal combustion engine (ICE) improvement, xi) maritime & waterways transport, and xii) other CTTs for road transport and railways. To enable the results to be shown, in certain instances, hybrid and electromobility are aggregated as electromobility technologies, and charging stations, plug-in EV, ICT for EV and grid interoperability are aggregated as EV charging enabling technologies following the methodology and technology descriptions in the CPC.

[138] Pasimeni, F., Fiorini, A., and Georgakaki, A. (2021). International landscape of the inventive activity on climate change mitigation technologies. A patent analysis. Energy Strategy Reviews, 36, 100677. https://doi.org/10.1016/j.esr.2021.100677
Pasimeni, F. and Georgakaki, A. (2020). Patent-Based Indicators: Main Concepts and Data Availability. JRC121685, https://setis.ec.europa.eu/patent-based-indicators-main-concepts-and-data-availability_en
Pasimeni, F., Fiorini, A., and Georgakaki, A. (2019). Assessing private R&D spending in Europe for climate change mitigation technologies via patent data. World Patent Information, 59, 101927. https://doi.org/10.1016/j.wpi.2019.101927
Pasimeni, F. (2019). SQL query to increase data accuracy and completeness in PATSTAT. World Patent Information, 57, 1-7. https://doi.org/10.1016/j.wpi.2019.02.001
Fiorini, A., Georgakaki, A., Pasimeni, F. and Tzimas, E. (2017). Monitoring R&I in Low-Carbon Energy Technologies. EUR 28446 EN, Publications Office of the European Union, Luxembourg. ISBN 978-92-79-65591-3, https://doi.org/10.2760/434051.

[139] SETIS Research & Innovation data: https://setis.ec.europa.eu/publications/setis-research-innovation-data .

[140] CPC classification. https://www.cooperativepatentclassification.org/cpcSchemeAndDefinitions.

Table B5 2 Concordance of CTTs and CPC classes

Technology groups		CPC Y02T technology classes
Level 1	**Level 2**	
Aeronautics & air transport	Aeronautics & air transport	Y02T 50/40; Y02T 50/50; Y02T 50/60; Y02T 50/80
Alternative fuels	Alternative fuels	Y02T 10/30; Y02T 50/678; Y02T 70/5218; Y02T 70/5236
Electromobility	Hybrid vehicles	Y02T 10/62
	Electromobility	Y02T 10/64; Y02T 10/70; Y02T 10/7072; Y02T 10/72
Electric vehicles (EV) charging enabling	Charging stations	Y02T 90/12
	Plug-in EV	Y02T 90/14
	ICT for EV	Y02T 90/16
	Grid interoperability	Y02T 90/167
Hydrogen for transport	Hydrogen for transport.	Y02T 90/40
Internal combustion engine (ICE) improvement	ICE improvement	Y02T 10/10; Y02T 10/12; Y02T 10/40
Maritime & waterways transport	Maritime & waterways transport	Y02T 70/00; Y02T 70/10; Y02T 70/50
Other CTTs for road transport	Other CTTs for road transport	Y02T 10/00; Y02T 10/60; Y02T 10/80; Y02T 10/82; Y02T 10/84; Y02T 10/86; Y02T 10/88; Y02T 10/90; Y02T 10/92
Railways	Railways	Y02T 30/00

Note: Adapted from the Y02T class descriptions in the CPC.

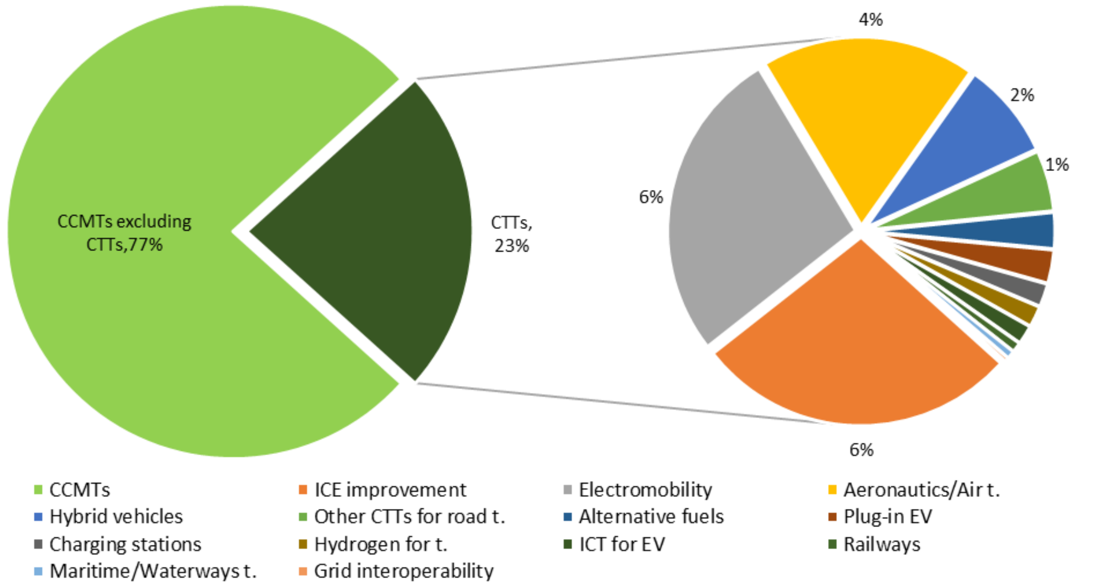
6.3 Trends in clean transport technologies

This section uses high-value patent statistics, to present the state of play in CTTs for the EU compared with other major economies. It also provides insights on the performance of the Scoreboard companies and their subsidiaries from the EU and other major economies, as these companies are the applicants for the majority (87%) of high-value CTT patents.

6.3.1 Global Trends

Globally, patenting activity in CTTs accounted for about 23% of total green high-value inventions between 2010 and 2019 (Figure 63). During this period, CTT inventions we concentrated in ICE improvement (29%), electromobility (27%), aeronautics and air transport (15%) and hybrid vehicles (12%). The private sector is the major actor in patenting activity, while the public sector and universities are together responsible for only around 2% of global high-value CTT inventions. Scoreboard companies file the most patents in this technological domain with a share of around 87% of the global high-value inventions.

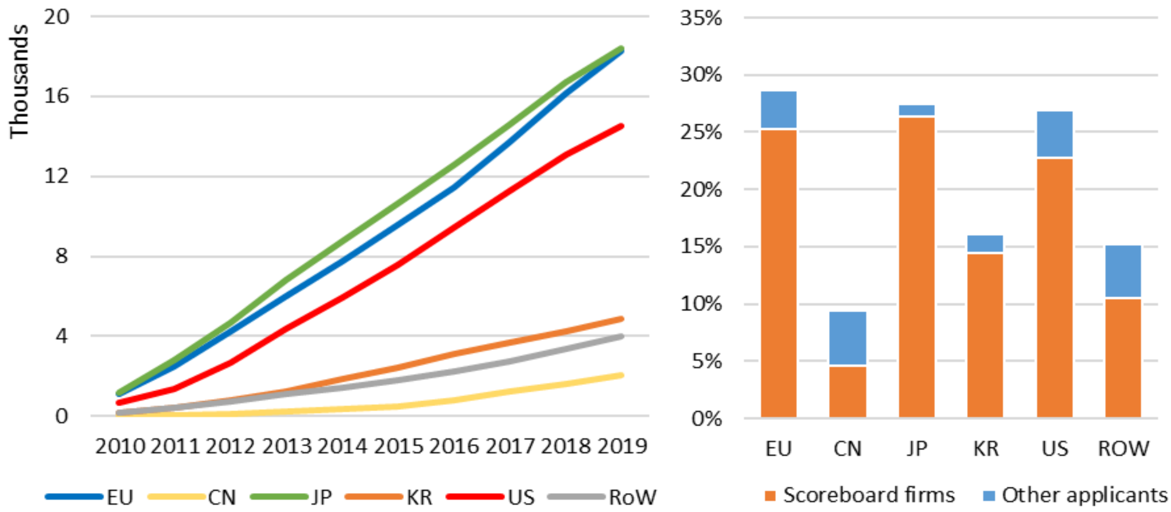
Figure 63. Share of CTTs in high-value green inventions in major economies (2010-2019): All applicants.



Source: The 2023 EU Industrial R&D Investment Scoreboard, European Commission, JRC/DG R&I.

Between 2010 and 2019, Japan and the EU led in CTT inventions followed by the US, both in absolute terms and as a share in high-value green inventions of each major economy (Figure 64). In absolute terms, Japan, the EU and the US together account for more than 80% of these filings globally every year (Figure 64 left). As in the case of overall green patenting, China is overwhelmingly active in patenting in CTTs when taking into account all inventions including domestic applications, and it also experienced the highest growth rate in high-value patenting. During this period, the highest share of CTTs in green high-value inventions for each economy was in the EU at 29%, followed by Japan and the US, both with shares of 27% (Figure 64 right). Inventions in CTTs constitute smaller shares in the high-value green patent portfolios of other major economies; around 16% in South Korea and 9% in China. The Scoreboard companies are responsible for most CTT patents in all major economies except for China.

Figure 64 High-value inventions in CCTs in major economies. All applicants.



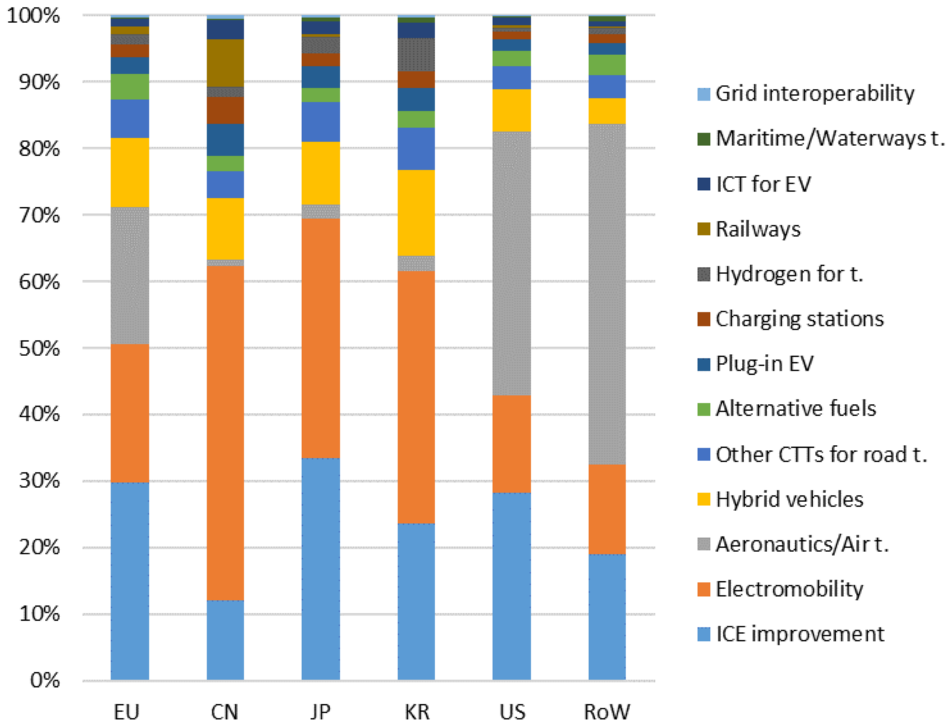
Source: The 2023 EU Industrial R&D Investment Scoreboard, European Commission, JRC/DG R&I.

Figure 65 provides a breakdown of the CTT patent portfolios of major economies per technology group. Among major economies, the EU has the largest number of high-value CTT inventions in the hybrid vehicles, alternative fuels and railway categories, and the US in aeronautics and air transport. Apart from these four technologies, Japan carried out the most activity in high-value patenting for each technology globally. China comes second in railways after the EU, and South Korea comes third for hydrogen for transport and maritime and waterways transport after Japan and the EU.

As for the technological distribution of patent portfolios, for both the EU and the US the largest technological categories are ICE improvement, electromobility, aeronautics and air transport, and hybrid vehicles. ICE improvement is the largest category for the EU, and aeronautics and air transport is the largest for the US. Electromobility comes top for the major Asian economies followed by ICE improvement and hybrid vehicles. Aeronautics & air transport constitutes a very small part (less than 4%) of the patent portfolios of each major Asian economy. Portfolio distributions reveal China's focus on the EV industry. Among major economies, it dedicates the highest shares in a patent portfolio to the electromobility, plug-in EV, charging stations and ICT for EV categories. This is supported by trends observed in global corporate venture capital (CVC) investment where nearly 70% of China's CVC was channelled to batteries, making it a major location for scaling up energy storage and electric vehicle companies[141].

For China, developing new energy vehicles is a strategic target in addressing the environmental and economic challenges of the transition to sustainability. Through years of policy support – including incentives and tax breaks for patent filings and rewards for patents approved, which drove the increase in domestic filings – it has created conditions for its industry to dominate the domestic market, while imposing market restrictions for international firms. While, at least initially, Chinese vehicles and components may have lacked in quality and consistency, a captive, cost-conscious domestic market provides the perfect ground for advancement through incremental learning by doing or joint ventures, or by establishing R&D facilities abroad to train Chinese engineers[142].

Figure 65 Industrial distribution of high-value CTT inventions in major economies (2010-2019), all applicants.



Source: The 2023 EU Industrial R&D Investment Scoreboard, European Commission, JRC/DG R&I.

Among major economies in 2019, the EU had a positive specialisation index in most of the industrial categories for CTTs followed by Japan and South Korea (Table 35). The EU also leads in specialisation in CTT inventions related to alternative fuels, charging stations, hybrid vehicles, ICE improvement, other CTTs for road transport and railways. Japan leads in grid interoperability, South Korea leads in hydrogen for transport and ICT for EV, and the US leads in aeronautics and air transport.

[141] S. Letout and A. Georgakaki (2023), 'Role of corporate investors in the funding and growth of clean energy tech ventures', 9th European Conference on Corporate R&D and Innovation, CONCORDi 2023.

[142] European Commission, Joint Research Centre, Rancan, M., Rondinella, V., Gkotsis, P. et al., China – Challenges and prospects from an industrial and innovation powerhouse, Fákó, P.(editor), Jonkers, K.(editor), Goenaga Beldarrain, X.(editor), Hristov, H.(editor), Preziosi, N.(editor), Publications Office, 2019, https://data.europa.eu/doi/10.2760/445820 .

Table 35. Specialisation index in CTTs (2019): All applicants.

Industry	EU Index	EU Change	CN Index	CN Change	JP Index	JP Change
Aeronautics/Air t.	0.7	0.3	-1.0	0.0	-0.8	0.0
Alternative fuels	1.2	0.3	-0.6	0.3	0.1	0.2
Charging stations	0.7	0.1	-0.5	-0.1	0.0	0.1
Electromobility	0.4	0.4	-0.4	0.1	0.4	-0.3
Grid interoperability	0.5	0.4	-0.8	-0.9	0.6	0.9
Hybrid vehicles	1.3	0.9	-0.8	0.0	0.3	-0.1
Hydrogen for t.	0.7	0.7	-0.8	0.0	0.5	0.0
ICE improvement	0.5	0.2	-0.8	0.1	0.4	-0.1
ICT for EV	0.0	0.1	-0.4	-0.2	0.5	0.5
Maritime/Waterways t.	0.5	0.5	-0.6	0.4	0.1	-0.5
Other CCMTs for road t.	0.8	0.0	-0.7	0.1	0.4	0.2
Plug-in EV	0.7	0.1	-0.3	0.0	0.2	0.1
Railways	1.1	-0.8	0.8	1.3	-0.7	-0.3

Industry	KR Index	KR Change	US Index	US Change	RoW Index	RoW Change
Aeronautics/Air t.	-0.8	0.2	1.1	-0.4	0.9	0.8
Alternative fuels	-0.2	-0.2	-0.3	-0.2	-0.4	-0.1
Charging stations	0.6	0.6	-0.4	-0.4	0.0	0.4
Electromobility	0.3	0.0	-0.3	0.0	-0.5	0.2
Grid interoperability	0.1	0.2	-0.4	-0.5	0.0	-0.2
Hybrid vehicles	0.0	-0.7	-0.3	0.1	-0.8	0.0
Hydrogen for t.	1.3	-0.8	-0.6	0.0	-0.5	0.2
ICE improvement	-0.1	0.1	0.1	0.1	-0.4	0.3
ICT for EV	0.7	0.8	-0.3	-0.6	-0.4	0.0
Maritime/Waterways t.	-0.1	-0.8	-0.6	0.1	1.3	0.8
Other CCMTs for road t.	0.2	0.1	-0.2	0.1	-0.6	-0.1
Plug-in EV	0.1	-0.1	-0.4	-0.2	-0.2	0.4
Railways	-0.9	0.1	-0.4	0.1	-0.3	0.0

Source: The 2023 EU Industrial R&D Investment Scoreboard, European Commission, JRC/DG R&I.

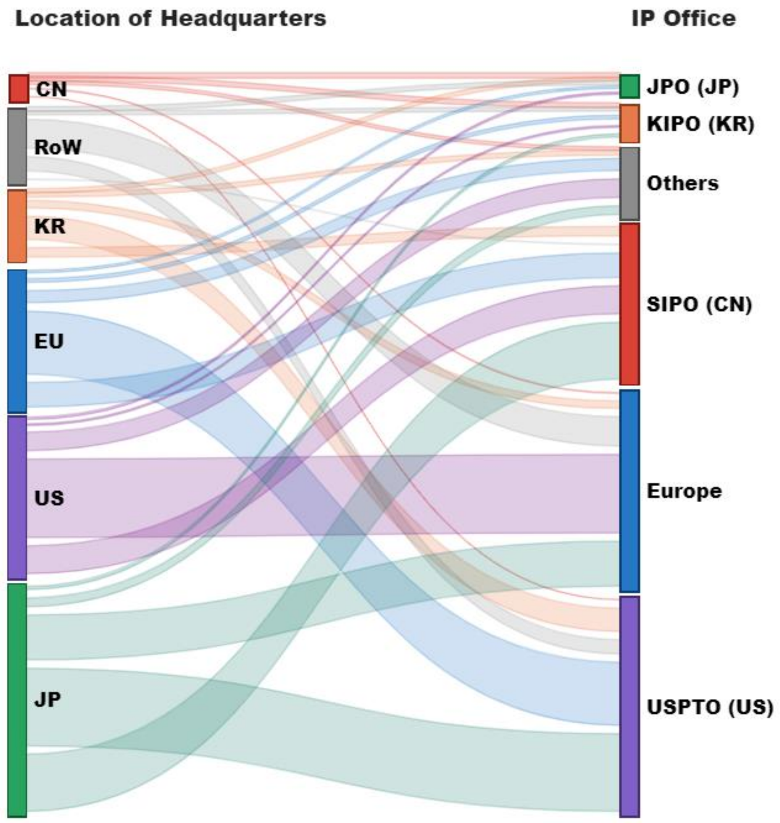
In 2010-2019, the largest amount of international cooperation in CTT patenting globally took place between Germany and the US, accounting for around 45% of total international high-value co-applications (Figure 66). At country level, the US has the lead in terms of international cooperation on CTT inventions. However, the EU, taken as a whole, would surpass this. Germany is the leading EU Member State when it comes to international cooperation, and second in the world, after the US. The US cooperates with the highest number of countries, 43 in total, including 19 EU Member States. Patent applicants in the EU Member States primarily cooperated with US applicants, followed by other EU Member States. Major Asian economies primarily cooperate with EU Member States, followed by the US. Japan cooperates mostly with France; South Korea and China cooperate mostly with Germany. Among ROW countries, UK-US cooperation is the largest, followed by Canada and the US. Concerning Europe, France and Switzerland cooperate the most, followed by Germany and the UK. Among Scoreboard companies, the largest amount of international cooperation took place between BMW (DE) and General Motors (US); Robert Bosch (DE) and Samsung SDI (KR); and Renault (FR) and Nissan Motor (JP).

Figure 66. Co-operation network in high-value CTT inventions (2010-2019): All applicants.

Source: The 2023 EU Industrial R&D Investment Scoreboard, European Commission, JRC/DG R&I.

In 2010-2019, the US and EU were the most targeted economies for international CTT inventions, followed by China (Figure 67). Japan filed the highest number of high-value CTT patents in other jurisdictions, targeting mainly the US and China, with Europe as its third main destination. However, as with the general trend in overall green inventions, Japan attracts only a small share of international applications. As mentioned in the previous Scoreboard editions, the strong industry and technology base in Japan, coupled with very specific regulations, tend to make it a rather difficult and insular market for foreign technology providers. Similar to the pattern observed in international co-applications, US applicants target mostly European jurisdictions and EU applicants target mostly the United States Patent and Trademark Office (USPTO) at international level. South Korean and Chinese shares in international filings remain small both for inflows and outflows.

Figure 67. International flow of high-value CTT inventions by major economies (2010-2019): All applicants.

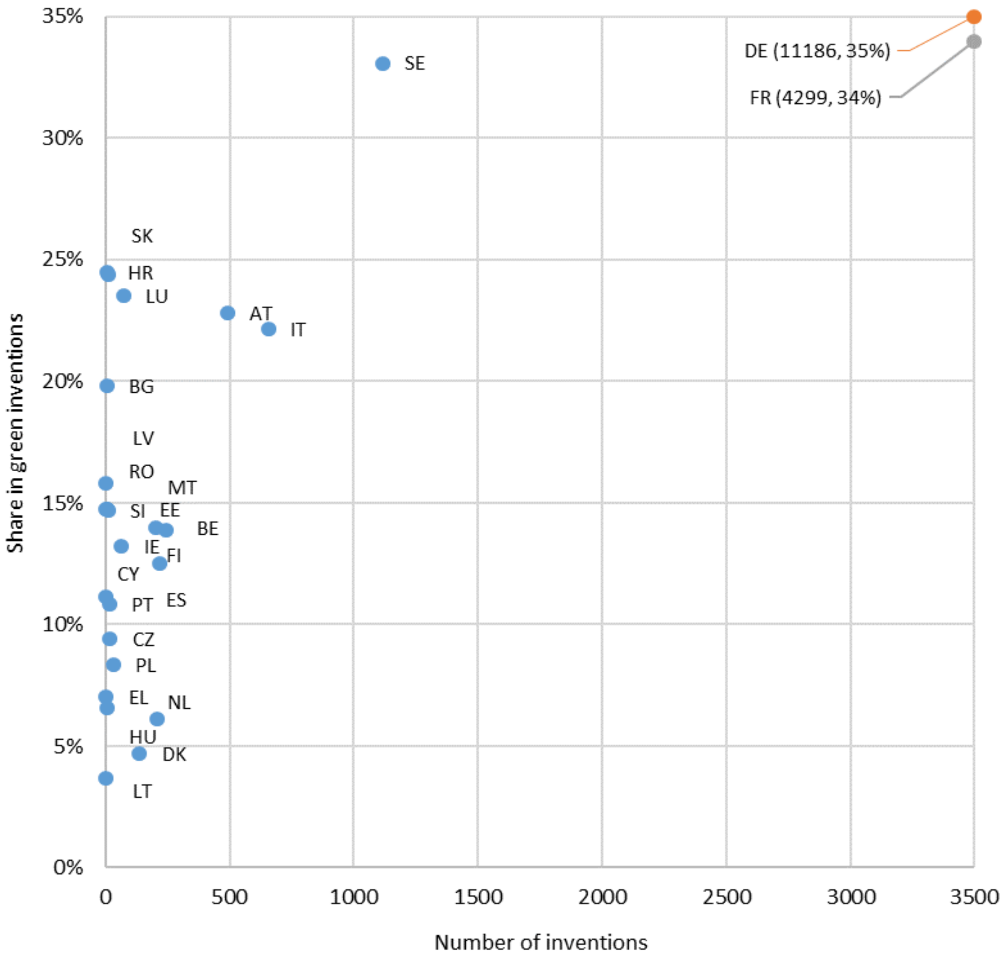


Note: Country of applicant (left) and origin authorities, targeted for protection (right). Europe as destination refers to the European Patent Office (EPO) and national IP offices of EPO members.
Source: The 2023 EU Industrial R&D Investment Scoreboard, European Commission, JRC/DG R&I.

6.3.2 EU trends

Between 2010 and 2019, Germany and France led the patenting in CTTs, followed by Sweden, both in absolute and relative terms (Figure 68). These three Member States held around 87% of all EU high-value patent filings and their green patent portfolio appeared to be the most specialised in these technologies. Germany alone holds 59% of the EU's CTT inventions, followed by France with 23% and Sweden with 6%. CTT inventions account for around one-third of the high-value green patent portfolio of these three Member States, with Scoreboard companies accounting for more than 90% of high-value patent applications of the each Member State. The biggest applicants from Germany are the large automobile manufacturers of Robert Bosch, Volkswagen and BMW. Safran, a manufacturer of aerospace and defence related equipment and components held around the 34% of high-value CTT inventions from France. Most high-value CTT inventions from Sweden came from a subsidiary of Volkswagen and the Swedish automobile manufacturer Volvo. Among other EU Member States, Italy and Austria hold sizable patent portfolios in CTTs, with smaller shares in their high-value green portfolios than the leading Member States. In addition, Italy and Austria had larger shares of applicants beyond the EU top 1 000 Scoreboard companies in high-value CTT inventions, with around 36% and 29%, respectively.

Figure 68. The EU Member States' high-value inventive activity in CTTs (2010-2019): All applicants.

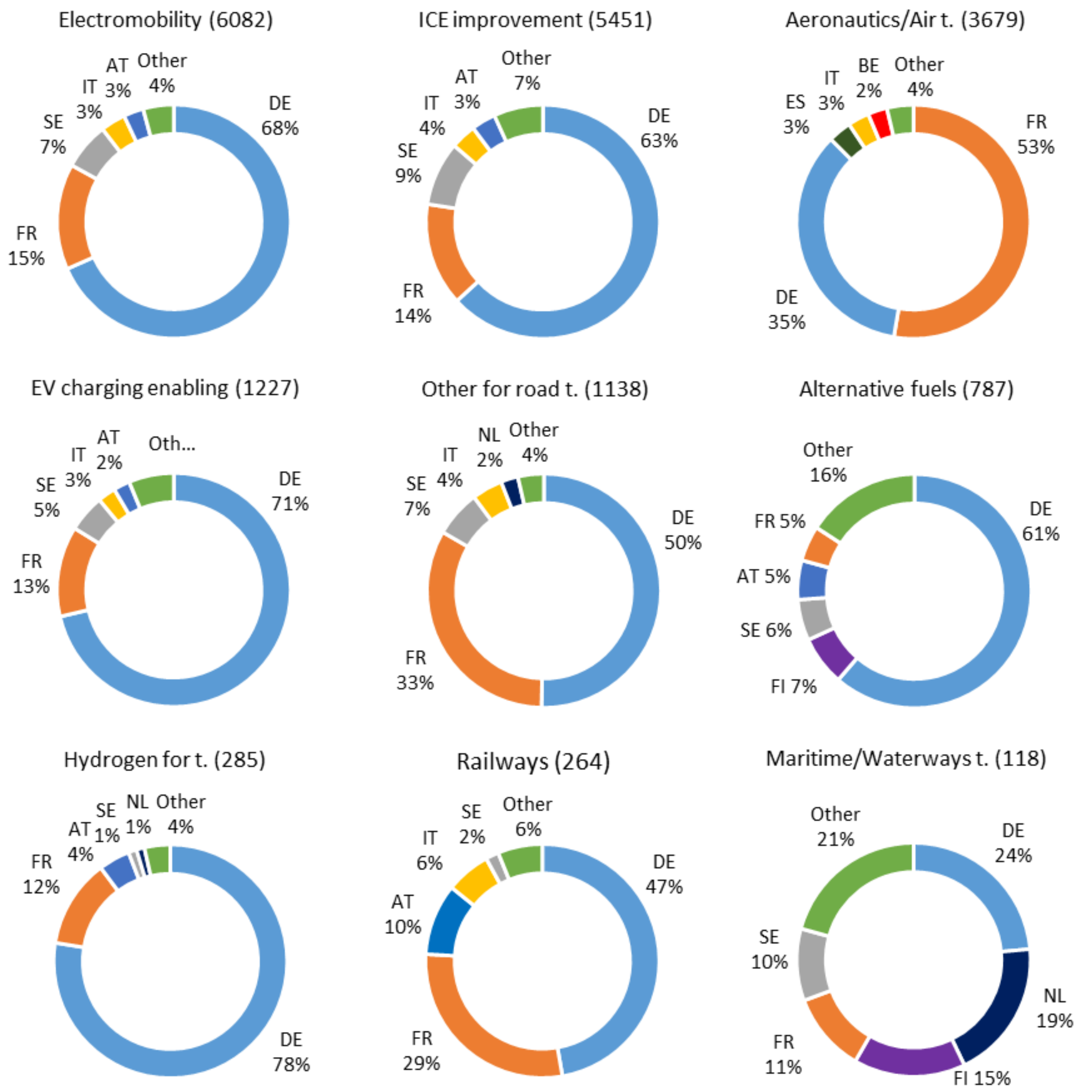


Source: The 2023 EU Industrial R&D Investment Scoreboard, European Commission, JRC/DG R&I.

Figure 69 represents the share of EU Member States in the EU's patent portfolio in CTTs aggregated into technology groups at Level 1[143]. In accordance with Figure 69, Germany and France always rank among the top five inventing countries in each of the CTT categories. Sweden ranks among the top five EU applicants in all the categories, except for aeronautics and air transport. Germany is the leader in all the categories, except for aeronautics and air transport, which are led by France. France comes after Germany in most of the CTTs except for alternative fuels and maritime and waterways transport. Finland comes second in alternative fuels and the Netherlands comes second in maritime and waterways transport. Italy appears among the top five patenting EU Member States in all CTTs, except for alternative fuels, hydrogen for transport and maritime and waterways transport. Austria is among the top five in all categories except for aeronautics and air transport, other CTTs for road transport and maritime and waterways transport; and Spain and Belgium are in the top five for aeronautics and air transport.

143 Splitting electromobility and EV charging enabling categories further into subcategories, Germany remains the leader in all subcategories, followed by France and Sweden.

Figure 69. Share of high-value inventions in CTTs per industry and EU Member State (2010-2019): All EU applicants.

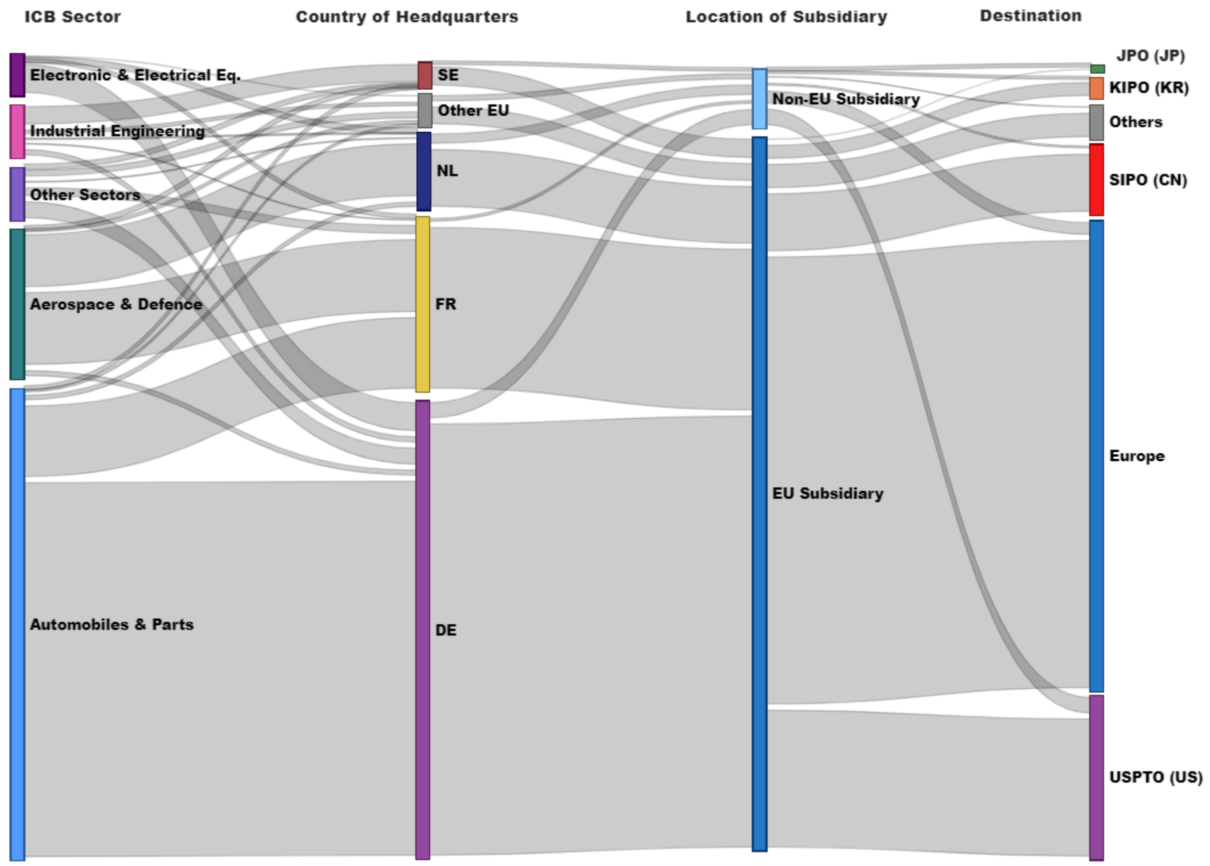


Note: Total number of CTT inventions in the EU for each industrial category is given in parentheses.
Source: The 2023 EU Industrial R&D Investment Scoreboard, European Commission, JRC/DG R&I.

In 2010-2019, EU Scoreboard firms from the automobiles and parts and aerospace and defence sectors accounted for 93% of high-value CTT inventions (Figure 70). Companies active in CTT patenting from the automobiles and parts sector and the electronic and electrical equipment sector are mostly headquartered in Germany. French and Dutch Scoreboard companies active in CTTs are mostly from the aerospace and defence sector[144]. Swedish Scoreboard companies patenting in CTTs are mostly from the industrial engineering sector. Almost all the high-value CTT inventions are filed by subsidiaries located in the EU. 61% of patent applications target a jurisdiction in Europe followed by the US with 21% and China with 9%.

[144] Having registered headquarters in the Netherlands, Airbus's operational headquarters is located in France.

Figure 70. EU scoreboard companies' high-value patenting activity in CTTs by ICB sector, locations of headquarter and subsidiary, and targeted jurisdiction (2010-2019).



Note: Inventions by ICB sectors (1st column), country of headquarters (2nd column), region where subsidiaries are domiciled (3rd column) and IPO jurisdictions targeted (4th column). Europe as a 'destination' refers to the EPO and the national IP offices of EPO members.
Source: The 2023 EU Industrial R&D Investment Scoreboard, European Commission, JRC/DG RTD.

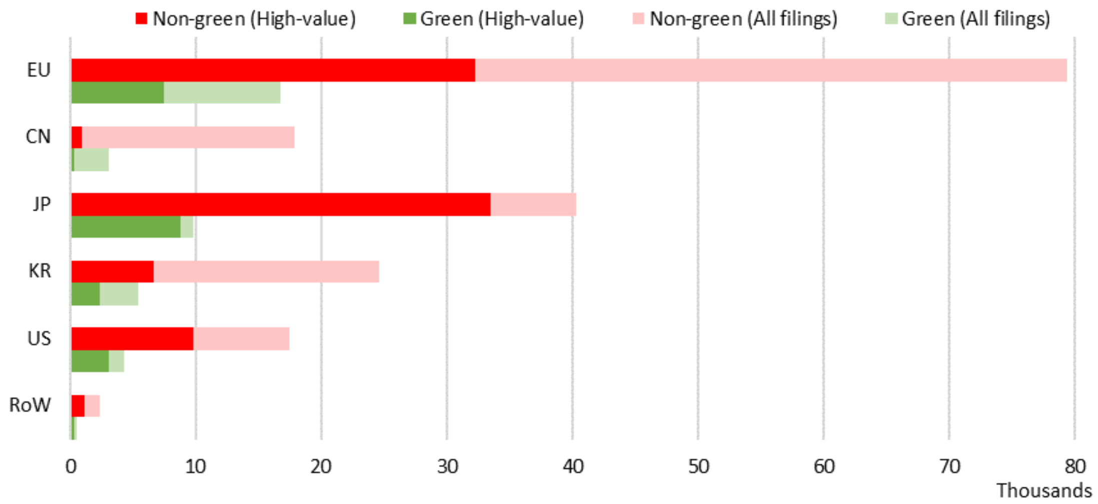
6.3.3 Top Scoreboard companies in the automotive industry

This section takes a closer look at the Scoreboard companies from the automotive industry[145]. It provides an update on global trends in high-value green inventions in the automotive industry, comparing the most recent patenting trends in green technologies with those presented in the 2019 Scoreboard edition.

In 2016-2019, Scoreboard automotive companies from Japan filed the highest number of high-value patents for both CCMTs and other technologies, just ahead of the EU (see Figure 71). Around 84% of Japanese companies' inventions are of high-value, the highest percentage among the major economies. EU and Japanese automotive companies, however, lag behind their counterparts from the US, South Korea and China in the share of green patents in their overall high-value patenting, with the EU companies having the lowest share 19%.

[145] Automotive Industry refers to the Automobiles & other transport (o.t.) industry at ICB 2-digit sector codes.

Figure 71. Scoreboard automotive industry patenting by major economies (2016-2019).



Source: The 2023 EU Industrial R&D Investment Scoreboard, European Commission, JRC/DG R&I.

Companies from the automotive industry filed the second highest number of high-value CCMT inventions following the ICT producers' industry (Table 36). As expected the focus was on technologies relevant to transport with energy being the second area of application.

Table 36. Share of high-value CCMT inventions by the Scoreboard industry groups.

Sectors	Adaptation	Buildings	CCS	ICT	Energy	Production	Transport	Waste	Systems	Total
Aerospace & defence	3%	3%	3%	1%	2%	4%	16%	2%	2%	6%
Automotive	**16%**	**9%**	**7%**	**2%**	**19%**	**8%**	**57%**	**4%**	**11%**	**26%**
Chemicals	13%	1%	25%	0%	8%	8%	1%	20%	1%	5%
Health industries	25%	1%	4%	1%	2%	3%	0%	4%	1%	3%
ICT producers	16%	44%	15%	78%	32%	35%	8%	17%	43%	30%
ICT services	3%	2%	1%	9%	2%	2%	0%	1%	8%	2%
Industrials	12%	13%	23%	2%	18%	26%	15%	17%	17%	17%
Others	13%	28%	20%	7%	16%	13%	3%	34%	17%	12%
Total	4%	7%	1%	9%	33%	16%	29%	1%	1%	100%

Source: The 2023 EU Industrial R&D Investment Scoreboard, European Commission, JRC/DG R&I.

The top high-value patenting companies of the Scoreboard automotive industry are among the largest R&D spenders in the industry, which also filed the highest number of patent applications in green inventions. Similar to the 2012-2015 period, between 2016 and 2019, the top 10 patenting Scoreboard companies in CCMTs remained stable with changes in their ranking except for BMW (EU), which appeared in the list for the first time, and Nissan Motor (KR) which dropped lower in the rankings (Table 37).

Table 37. Automotive top 10 companies in high-value CCMT inventions (2016-2019).

Company name	Country	Inventions	Rank change
Toyota Motor	JP	4084	0
Robert Bosch	EU	2080	3
Ford Motor	US	2011	-1
Honda Motor	JP	1740	3
Volkswagen	EU	1667	1
Hyundai Motor	KR	1314	-3
KIA Motors	KR	925	3
Denso	JP	860	0
BMW	EU	844	22
General Motors	US	581	-6

Source: The 2023 EU Industrial R&D Investment Scoreboard, European Commission, JRC/DG R&I.

None of the companies in Table 37 are among the top 10 automotive industry companies with the highest green shares in their high-value patent portfolio, listed in Table 38. Instead, newer and younger Scoreboard firms from the automotive industry, top the ranking with more than 50% of green filings in their high-value patent portfolio. Within the EU top 1000 listing, Bollore is the EU automotive industry company with the highest green share of 69% and followed by Tesla (US), Weichai Power (CN) and NIO (CN). Elringklinger and Ferrari are the other EU companies that appear among the top 10 companies with the highest green shares. Among the top patenting EU automotive industry companies, Robert Bosch has a green share of 19%, Volkswagen, 30% and BMW, 27%. In the US, Garrett Motion comes second after Tesla with a share of 43%. Ford Motor, the largest US automotive company has a green share of 29%, and General Motors, as the second largest US company, 25%. In Japan, there are changes in the listings among the established automotive industry companies. Mitsubishi Motors has the highest green share of 46%, followed by Mazda Motor with 33%. Toyota Motor, the top high-value patenting firm in CCMTs, also a green share of around 33% among its overall high-value patent portfolio.

Table 38. Automotive top 10 companies with highest green shares in high-value patent portfolios (2016-2019).

Company name	Country	Green Share
Bollore	EU	69%
Tesla	US	57%
Weichai Power	CN	51%
NIO	CN	51%
Elringklinger	EU	48%
Mitsubishi Motors	JP	46%
Garrett Motion	US	43%
Ferrari	EU	40%
Guangzhou Automobile	CN	34%
Mazda Motor	JP	33%

Note: Companies with high-value green inventions that remain less than 50 during the period 2016-2019 are not considered.
Source: The 2023 EU Industrial R&D Investment Scoreboard, European Commission, JRC/DG R&I.

Table 39 shows the most patented clean transport CPC classes identified under Y02T technology group. Similar to the 2012-2015 period, in 2016-2019, the Scoreboard automotive industry continued to channel efforts to improving ICE efficiencies. However, efforts in shifting towards electromobility technologies intensified with more codes in the top 10 list and higher ranking among the technologies compared to 2012-2015.

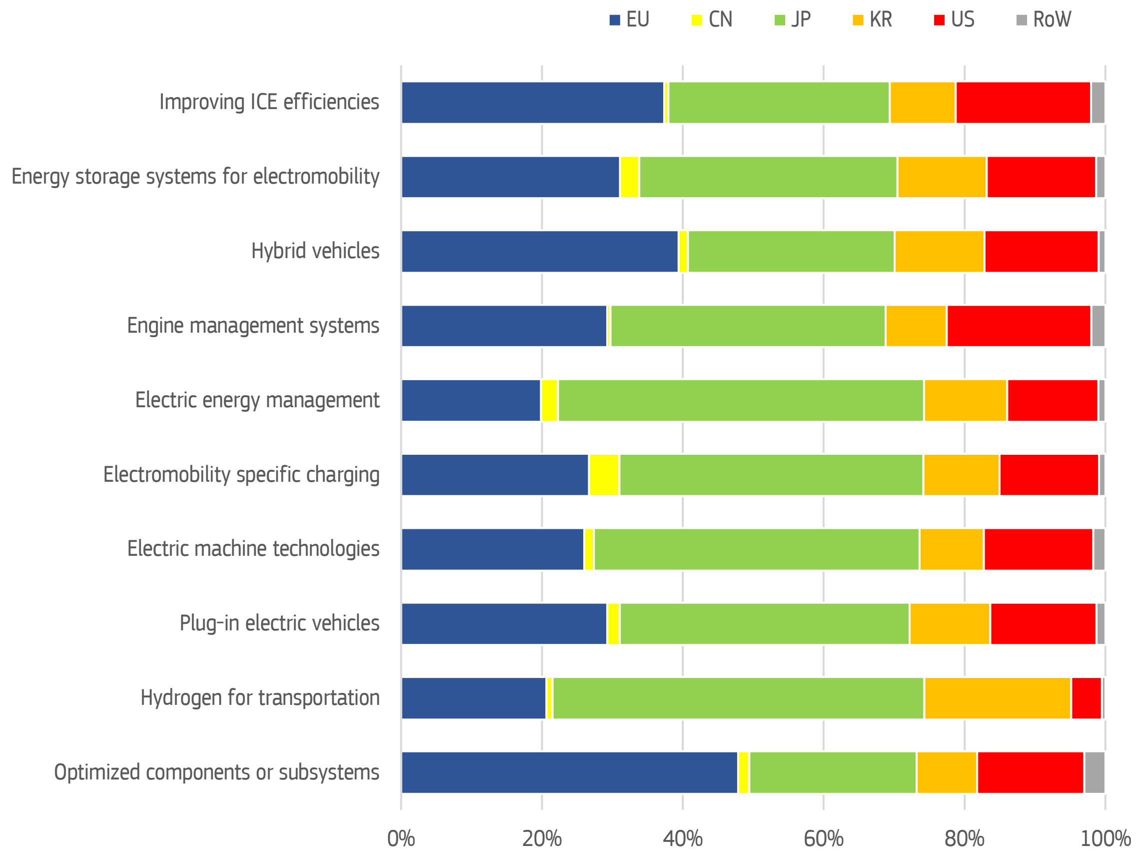
Table 39. Automotive top 10 patented clean transport CPC classes (2016-2019).

CPC class symbol	Technological description	Inventions	Portfolio share
Y02T 10/12	Improving ICE efficiencies	2971	21%
Y02T 10/70	Energy storage systems for electromobility	2281	16%
Y02T 10/62	Hybrid vehicles	1990	14%
Y02T 10/40	Engine management systems	1946	14%
Y02T 10/72	Electric energy management in electromobility	838	6%
Y02T 10/7072	Electromobility specific charging systems or methods	756	5%
Y02T 10/64	Electric machine technologies in electromobility	569	4%
Y02T 90/14	Plug-in electric vehicles	522	4%
Y02T 90/40	Hydrogen for transportation, e.g. using fuel cells	390	3%
Y02T 10/88	Optimised components or subsystems	327	2%

Source: The 2023 EU Industrial R&D Investment Scoreboard, European Commission, JRC/DG R&I.

Subsequently, Figure 72 looks at the split of high-value filings in the most patented clean transport CPC classes of the Scoreboard automotive industry among major economies. In 2016-2019, Japanese Scoreboard firms continued to lead in high-value inventions related to electromobility. EU Scoreboard firms, on the other hand, led in improving ICE efficiencies and hybrid vehicles technologies that are the short- and medium-term solutions for the industry. Consistent with the policies and incentives mentioned above, Chinese Scoreboard firms have their highest shares in technologies related to electromobility, as well as the highest growth trend in high-value patenting in electromobility although the size of their high-value patent portfolios remained small in all the top 10 technologies until 2019.

Figure 72. Automotive top 10 patented clean transport CPC classes by region (2016-2019).



Source: The 2023 EU Industrial R&D Investment Scoreboard, European Commission, JRC/DG R&I.

Table 40 lists the most patented technology codes in green energy CPC classes grouped under Y02E, the second biggest green technology group for the automotive industry. Similar to the 2012-2015 period, in 2016-2019, the Scoreboard automotive industry's inventive efforts remained focused on electric energy storage and hydrogen transportation and storage technologies in clean energy technologies. The top two most patented CPC codes among clean energy technologies accounted for around 88% of the industry's inventive actions in this technological domain. Apart from batteries and fuel cells (and to some extent hydrogen storage) contribution to other areas is very small.

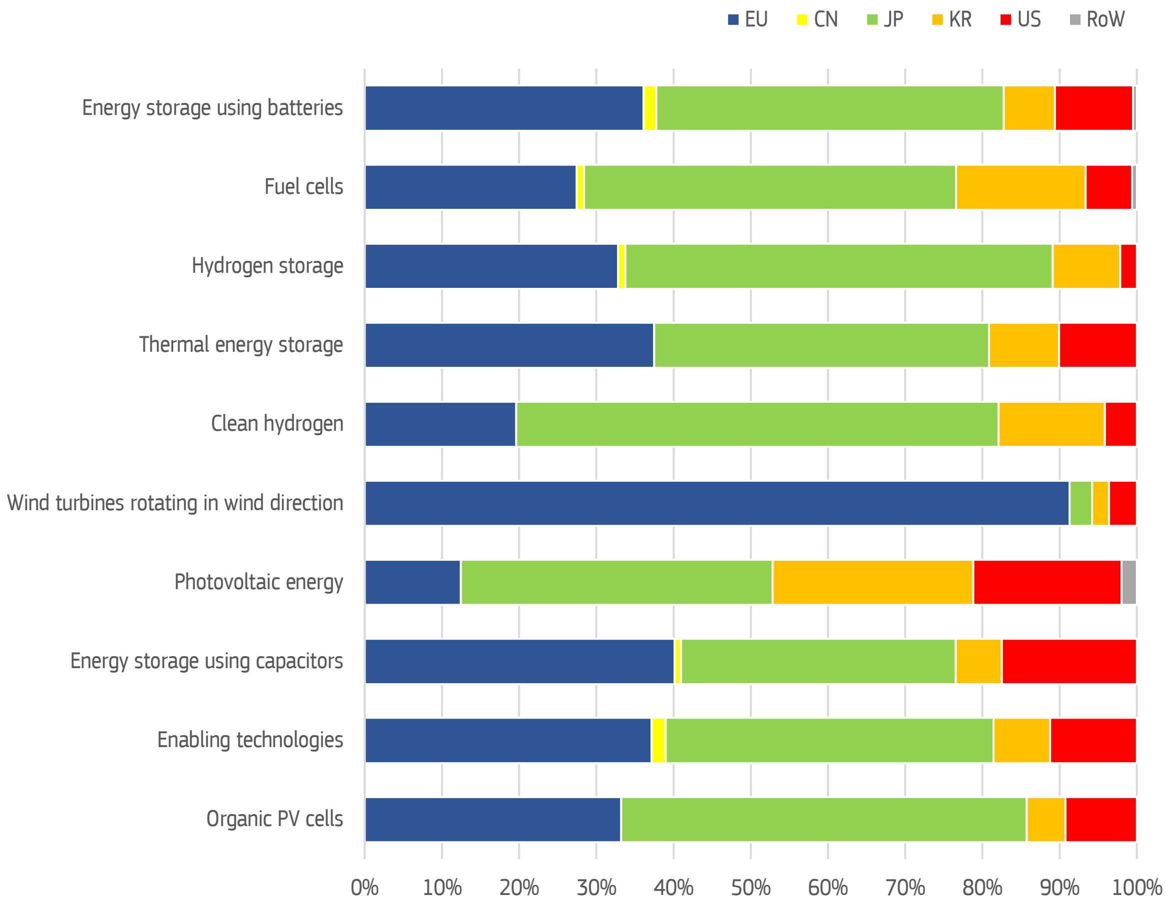
Table 40. Automotive top 10 patented clean energy CPC classes (2016-2019).

CPC class symbol	Technological description	Inventions	Portfolio share
Y02E 60/10	Energy storage using batteries	3369	62%
Y02E 60/50	Fuel cells	1397	26%
Y02E 60/32	Hydrogen storage	204	4%
Y02E 60/14	Thermal energy storage	76	1%
Y02E 60/36	Clean hydrogen	67	1%
Y02E 10/72	Wind turbines with rotation axis in wind direction	60	1%
Y02E 10/50	Photovoltaic energy	50	1%
Y02E 60/13	Energy storage using capacitors	40	1%
Y02E 60/00	Enabling technologies	32	1%
Y02E 10/549	Organic PV cells	23	0%

Source: The 2023 EU Industrial R&D Investment Scoreboard, European Commission, JRC/DG R&I.

As before, in 2016-2019, Japanese Scoreboard firms led in the top patented clean energy technologies for batteries and fuel cells (Figure 73). EU Scoreboard companies came second in these solutions. The share of Chinese Scoreboard companies, in high-value clean energy inventions is still at a low level and almost non-existent in technology classes apart from electric energy storage, hydrogen transportation and storage, and enabling technologies for electromobility. However, as for CTTs, Chinese companies are highly active as regards domestic patenting in these technologies.

Figure 73. Automotive top 10 patented clean energy CPC classes by major economy (2016-2019).



Source: The 2023 EU Industrial R&D Investment Scoreboard, European Commission, JRC/DG R&I.

Similar to the 2012-2015 period, in 2016-2019 the development of clean technologies was highly concentrated in the automotive industry (Table 41). For the most patented clean transport technology classes, the top patenting companies were the main applicants, with some exceptions such as Schaeffler (DE) and ZF (DE) that specialise in hybrid vehicles technology in their high-value CCMT inventions or Valeo (FR) in optimised components or subsystems. For the most patented clean energy technology classes, the top patenting companies from Japan, the EU and South Korea stand out as the main patent applicants in major technology areas of energy storage using batteries, fuel cells and hydrogen storage. Y02E technologies are defined with a wider scope than mobility. Other Scoreboard companies such as LG Chemical and Samsung SDI lead in high-value inventions in batteries technologies whereas, for the fuel cells technology, the Scoreboard automotive industry is in lead in high-value inventions both globally and in the EU[146]. Automotive industry companies have carried out a rather negligible amount of inventing activities in the rest of the clean energy domains both in absolute terms and as a share of their high-value green inventions, except for Miba (AT) with most of its high-value inventions applied in the field of wind energy. This is not surprising given the limited applications of these technologies in the automotive field.

[146] Kuokkanen, A., Georgakaki, A., Mountraki, A., Letout, S., Długosz, M., Tapoglou, E., Parera Villacampa, O., Kapetaki, Z., Quaranta, E., Saveyn, H., Volt, J., Prior Arce, A., Marmier, A. and Motola, V., European Climate Neutral Industry Competitiveness Scoreboard (CINDECS) - Annual Report 2022, Black, C. editor(s), Publications Office of the European Union, Luxembourg, 2023, doi:10.2760/959357, JRC134499.

Table 41. Automotive top 5 patenting companies in clean transport and clean energy CPC classes (2016-2019).

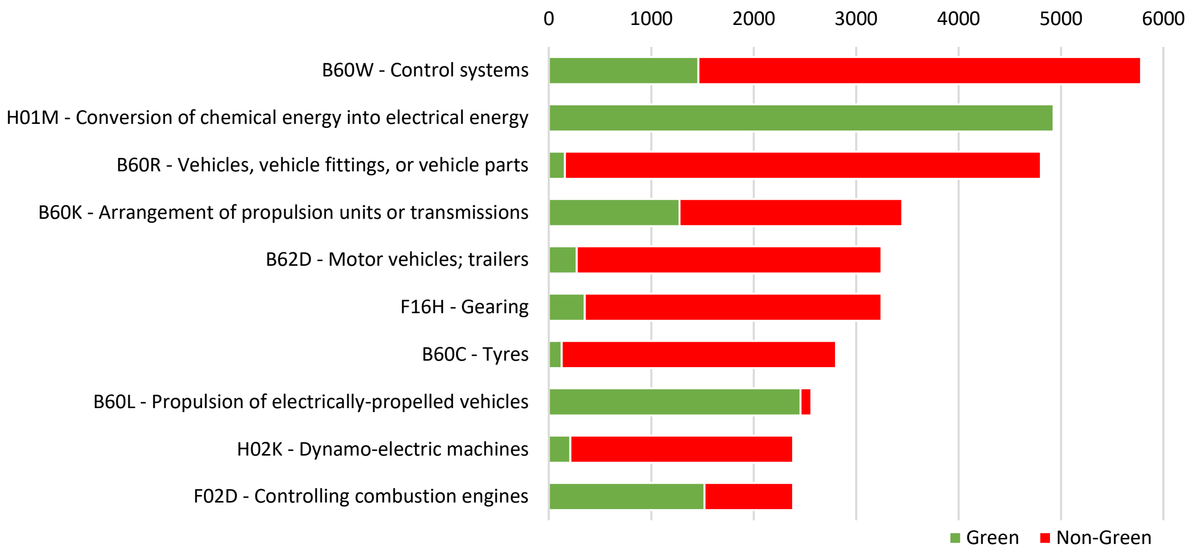
	TRANSPORT TECHNOLOGIES				ENERGY TECHNOLOGIES			
Rank	Company	Country	Inventions	Share	Company	Country	Inventions	Share
	Improving ICE efficiencies				Energy storage using batteries			
1	TOYOTA MOTOR	JP	405	10%	TOYOTA MOTOR	JP	844	21%
2	FORD MOTOR	US	319	16%	ROBERT BOSCH	DE	452	22%
3	VOLKSWAGEN	DE	287	17%	HONDA MOTOR	JP	295	17%
4	ROBERT BOSCH	DE	232	11%	VOLKSWAGEN	DE	236	14%
5	HYUNDAI MOTOR	KR	160	12%	BMW	DE	187	22%
	Energy storage systems for electromobility				Fuel cells			
1	TOYOTA MOTOR	JP	376	9%	TOYOTA MOTOR	JP	337	8%
2	FORD MOTOR	US	279	14%	ROBERT BOSCH	DE	233	11%
3	VOLKSWAGEN	DE	226	14%	HONDA MOTOR	JP	177	10%
4	HONDA MOTOR	JP	209	12%	HYUNDAI MOTOR	KR	131	10%
5	HYUNDAI MOTOR	KR	151	11%	KIA MOTORS	KR	98	11%
	Hybrid vehicles				Hydrogen storage			
1	TOYOTA MOTOR	JP	303	7%	TOYOTA MOTOR	JP	77	2%
2	FORD MOTOR	US	254	13%	HONDA MOTOR	JP	30	2%
3	SCHAEFFLER	DE	245	79%	ROBERT BOSCH	DE	29	1%
4	ZF	DE	172	67%	BMW	DE	17	2%
5	HYUNDAI MOTOR	KR	154	12%	VOLKSWAGEN	DE	9	1%
	Engine management systems				Thermal energy storage			
1	TOYOTA MOTOR	JP	324	8%	VALEO	FR	19	5%
2	FORD MOTOR	US	315	16%	DENSO	JP	16	2%
3	ROBERT BOSCH	DE	184	9%	TOYOTA MOTOR	JP	8	0%
4	MAZDA MOTOR	JP	119	32%	FORD MOTOR	US	7	0%
5	DENSO	JP	115	13%	HANON SYSTEMS	KR	4	4%
	Electric energy management				Clean hydrigen			
1	TOYOTA MOTOR	JP	182	4%	HONDA MOTOR	JP	19	1%
2	HONDA MOTOR	JP	85	5%	TOYOTA MOTOR	JP	11	0%
3	FORD MOTOR	US	75	4%	ROBERT BOSCH	DE	9	0%
4	HYUNDAI MOTOR	KR	54	4%	DENSO	JP	6	1%
5	ROBERT BOSCH	DE	50	2%	HYUNDAI MOTOR	KR	6	0%
	Electromobility specific charging				Wind turbines rotating in wind direction			
1	TOYOTA MOTOR	JP	154	4%	ZF	DE	17	7%
2	FORD MOTOR	US	87	4%	MIBA	AT	16	61%
3	VOLKSWAGEN	DE	85	5%	VOLKSWAGEN	DE	6	0%
4	HONDA MOTOR	JP	79	5%	CONTINENTAL	DE	5	1%
5	HYUNDAI MOTOR	KR	44	3%	MAHLE	DE	3	2%
	Electric machine technologies				Photovoltaic energy			
1	HONDA MOTOR	JP	89	5%	TOYOTA MOTOR	JP	15	0%
2	FORD MOTOR	US	68	3%	KIA MOTORS	KR	8	1%
3	TOYOTA MOTOR	JP	63	2%	HYUNDAI MOTOR	KR	5	0%
4	ROBERT BOSCH	DE	49	2%	TESLA	US	4	6%
5	DENSO	JP	43	5%	HONDA MOTOR	JP	3	0%
	Plug-in electric vehicles				Energy storage using capacitors			
1	TOYOTA MOTOR	JP	111	3%	ROBERT BOSCH	DE	10	1%
2	FORD MOTOR	US	64	3%	TOYOTA MOTOR	JP	9	0%
3	VOLKSWAGEN	DE	62	4%	GENERAL MOTORS	US	4	1%
4	HONDA MOTOR	JP	50	3%	HONDA MOTOR	JP	3	0%
5	HYUNDAI MOTOR	KR	32	2%	TESLA	US	2	3%
	Hydrogen for transportation				Enabling technologies			
1	TOYOTA MOTOR	JP	121	3%	HONDA MOTOR	JP	9	1%
2	HONDA MOTOR	JP	58	3%	TOYOTA MOTOR	JP	4	0%
3	HYUNDAI MOTOR	KR	49	4%	VOLKSWAGEN	DE	3	0%
4	ROBERT BOSCH	DE	33	2%	FORD MOTOR	US	3	0%
5	KIA MOTORS	KR	31	3%	BMW	DE	2	0%
	Optimized components or subsystems				Organic PV cells			
1	VALEO	FR	82	22%	HONDA MOTOR	JP	4	0%
2	FORD MOTOR	US	28	1%	MICHELIN	FR	4	4%
3	TOYOTA MOTOR	JP	22	1%	TOYOTA MOTOR	JP	3	0%
4	PEUGEOT	FR	22	7%	VOLKSWAGEN	DE	2	0%
5	VOLKSWAGEN	DE	22	1%	FORD MOTOR	US	2	0%

Note: The 'inventions' column shows the total number of high-value patent families for 2016-2019; the 'share' column shows the share of high-value inventions shown in the 'inventions' column for 2016-2019.

Source: The 2023 EU Industrial R&D Investment Scoreboard, European Commission, JRC/DG R&I.

Looking beyond green inventions, the top 10 most patented CPC technology groups for high-value inventions in the Scoreboard automotive industry are represented in Figure 74. The two most patented technologies in the areas of control systems and conversion of chemical to electrical energy (batteries) apply to smart and green mobility technologies, as prioritised by the EU. The green focus of the technologies highly differs from one another. As expected, batteries and propulsion of electrically-propelled vehicles are the most green technology groups of the automotive industry as they are related to EV technologies. Among the other top 10 patented technology groups, nearly two-thirds of the inventions (64%) related to the 'controlling combustion engines' group are considered as green, i.e. the group has applications for improving ICE efficiency. For the remaining technology groups, around 25% of high-value patenting in control systems and ca. 37% of high-value patenting in 'arrangement of propulsion units or transmissions' are tagged as green while the focus on green for the other technology groups accounts for less than 15%.

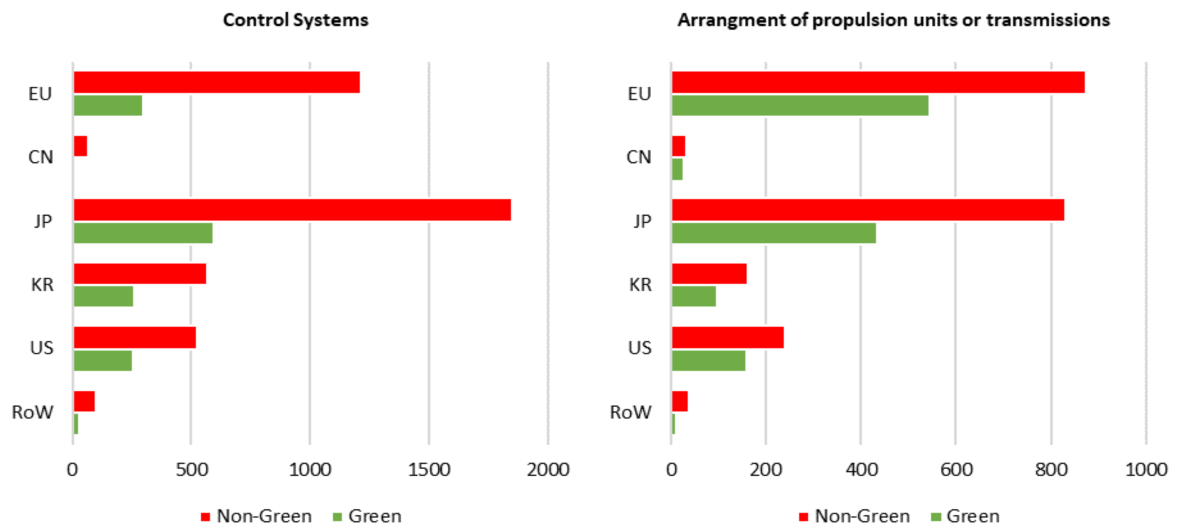
Figure 74**.** Top 10 most patented CPC technology groups (CPC 4-digit) by Scoreboard automotive companies (2016-2019).



Source: The 2023 EU Industrial R&D Investment Scoreboard, European Commission, JRC/DG R&I.

Figure 75 shows the figures for green and non-green high-value patenting in the 'control systems' and 'arrangement of propulsion units or transmissions technologies' groups by major economies. Scoreboard automotive companies from Japan are by far the leaders in high-value patenting in control systems technologies both in green and non-green inventions. The EU is second in patenting both in green and non-green high-value inventions. However, the US and South Korea have a higher share of green inventions in their high-value patenting. For propulsion units or transmissions technologies, the EU leads in absolute terms followed by Japan, while China leads in terms of green share followed by the US and South Korea.

Figure 75. Automotive industry B60W and B60K patenting by major economies (2016-2019).



Source: The 2023 EU Industrial R&D Investment Scoreboard, European Commission, JRC/DG R&I.

Table 42 shows the companies patenting the most in control systems and propulsion units or transmission. Toyota Motor leads in both technologies, followed by Honda Motor and Ford Motor in control systems. There are three EU companies in the ranking for high-value patenting in control systems, all from Germany: Robert Bosch, Volkswagen and BMW. For propulsion technology, Volkswagen comes second in the high-value patenting. There are five EU companies in the ranking: Schaeffler, ZF and BMW from Germany, and Valeo from France.

Table 42. Companies that patented the most in B60W and B60K (2016-2019).

Control Systems			**Propulsion units or transmissions**		
Company name	Country	Inventions	Company name	Country	Inventions
Toyota Motor	JP	878	Toyota Motor	JP	436
Honda Motor	JP	722	Volkswagen	DE	387
Ford Motor	US	577	Honda Motor	JP	315
Hyundai Motor	KR	384	Ford Motor	US	244
Robert Bosch	DE	356	Schaeffler	DE	178
Volkswagen	DE	347	ZF	DE	155
Kia Motors	KR	292	Denso	JP	149
Denso	JP	233	BMW	DE	145
BMW	DE	225	Valeo	FR	144
Nissan Motor	JP	164	Hyundai Motor	KR	139

Source: The 2023 EU Industrial R&D Investment Scoreboard, European Commission, JRC/DG R&I.

Table 43, in contrast, shows the Scoreboard automotive companies that have the biggest green focus in their high-value patenting. For both technologies, the EU company, Schaeffler tops both groups. Mitsubishi Motors is also in the top 3 in both technologies. Hyundai Motor, Ford Motor and Toyota Motor also appear in the listings for both technology groups. For propulsion units or transmission technologies, Schaeffler, Valeo and Ford Motor appear among the most green companies and among the companies that produce the most patents. Major automotive firms Toyota, Ford, Hyundai and KIA appear in both rankings.

Table 43. Companies with the highest green shares in B60W and B60K (2016-2019)*.

Control Systems			**Propulsion units or transmissions**		
Company name	Country	Green share	Company name	Country	Green share
Schaeffler	DE	80%	Schaeffler	DE	74%
Mitsubishi Motors	JP	70%	NIO	CN	65%
Fiat Chrysler**	NL	44%	Mitsubishi Motors	JP	61%
Suzuki Motor	JP	44%	Aisin Seiki	JP	61%
Hyundai Motor	KR	39%	Geely Automobile	CN	59%
Ford Motor	US	39%	Subaru	JP	56%
KIA Motors	KR	37%	Valeo	FR	54%
Toyota Motor	JP	36%	ZF	DE	52%
Guangzhou Automobile	CN	34%	Nissan Motor	JP	49%
Peugeot**	FR	31%	Ford Motor	US	46%

Note: * Companies with fewer than 10 filings are not considered; ** Now part of STELLANTIS.
Source: The 2023 EU Industrial R&D Investment Scoreboard, European Commission, JRC/DG R&I.

6.4 Key points

Trends in CCMTS

- In 2019, the EU, Japan and the US experienced a decrease in high-value green inventions whereas China experienced a substantial increase of around 20% compared with the previous year.
- The EU continued to file the highest number of patents for high-value inventions when taking all applicants into account, and China continued to have the highest number of filings for green patents (not high-value but all inventions, including domestic applications). Japanese Scoreboard firms continued to file the highest number of patents for high-value green inventions.

Trends in CCTs

- In 2010-2019, high-value CTT inventions represented 23% of overall high-value green inventions globally. Japan and the EU led in these inventions both in absolute terms and as a share of high-value green inventions. Japan, the EU and the US together accounted for more than 80% of these filings globally.

- As in the case of overall green patenting, China overwhelmingly carries out the most patenting activity in CTTs if all inventions including domestic applications are taken into account, and it experienced the highest growth rate in high-value patenting in 2010-2019.
- High-value CTT inventions related to ICE improvement accounted for the largest category in the EU's CTT patent portfolio, aeronautics & air transport in the US, and electromobility in the major Asian economies. Portfolio distributions reveal China's focus on the EV industry with the country giving the highest shares to the EV-related categories among CTTs.
- The largest amount of international cooperation in high-value inventions in CTTs took place between Germany and the US, accounting for around 45% of total international co-applications. Major Asian economies (Japan and South Korea) primarily cooperated with the EU. As for the rest of the world, the largest amount of cooperation was between the UK and the US.
- Among the EU Member States, Germany had the highest number of high-value CTT inventions, followed by France and Sweden both in absolute terms and as a share of overall high-value green inventions. Together, the three Member States accounted for around 87% of EU filings in CTTs.
- EU Scoreboard companies from the automobiles & parts and aerospace & defence sectors accounted for around 93% of high-value CTT inventions by the EU Scoreboard companies. Almost all of these were filed by subsidiaries located in the EU.

The Scoreboard automotive industry:

- In 2016-2019, EU Scoreboard firms led in improving ICE efficiencies and Hybrid vehicles technologies, the short & medium term solutions for the industry. Similar to 2012-2015, Japanese Scoreboard firms from the automotive industry continued to lead in high-value inventions related to electromobility.
- New firms from the EU, the US and China had higher green shares in high-value inventions than their established counterparts in the Scoreboard. Within the EU top 1000 listing, Bollore (FR) is the automotive industry company with the highest green share of 69%. Tesla (US) is the company in the World top 2500 Scoreboard with the highest green share in its patent portfolio followed by Weichai Power (CN) and Nio (CN).
- Similar to the 2012-2015 period, in 2016-2019, improving ICE efficiencies was the most patented clean transport CPC class. However, efforts for a shift towards electromobility technologies intensified with more codes in the top 10 list and higher ranking among the technologies. Activities as regard inventions in clean energy CPC classes concentrated on electric energy storage and hydrogen transportation and storage. Japanese companies led in high-value inventions in these technologies followed by the European companies.

7 Automotive business model transformation and the global value chain

The section looks automotive business model transformation and provides a global value chains analysis, based on the multiregional input-output methodology, leveraging data from the European Commission's Figaro database. It first presents the policy relevance (section 7.1), then looks at the R&D intensities of different automotive companies (section 7.2) and then analyses the global value chains for motor vehicles, putting a focus on value added retained by the EU along the whole value chain, EU final demand and the evolution over the last decade (section 7.3). The section concludes with key points (section 7.4).

7.1 Relevance and policy context

As the largest manufacturing sector in the EU, the automotive industry has long been a mainstay of EU's competitiveness, contributing significantly to employment, trade, and technological advancement. Even though its importance varies from one EU country to another, in 2022, the automotive sector accounted for: i) 4% of the EU's total economic production, ii) 7% of the EU's total employment[147] and 10% of its exports[148], iii) 32% of EU private R&D investment[149]. With its long history, focus on quality and innovation, and an ability to manufacture a wide range of vehicles – from small, fuel-efficient cars to luxury and sports vehicles, as well as electric and hybrid models – the European automotive sector has many prominet manufacturers such as Volkswagen, BMW, Mercedes-Benz, Renault, and Stellantis. In 2021, 20.5% of motor vehicles manufactured worldwide were manufactured in one of the 194 automobile assembly and production plants located in the EU[150]. The sector is expected to grow globally. According to data from the International Organization of Motor Vehicle Manufacturers (OICA), approximately 1.6 billion vehicles were in use worldwide in 2020[151]. The US Energy Information Administration (EIA) yields similar results, projecting to increase this figure to 2.21 billion by 2050[152].

Despite its strengths, the EU automotive industry faces challenges such as the transition to electric vehicles, stricter emission regulations, global competition, and, in some cases, shortages of electronic chips. The European Commission's policy actions set out in the Green Deal industrial plan will impinge upon the automotive industry. For example, changes to state aid rules may cover support for zero-emission vehicles, hydrogen, recharging and refuelling infrastructures, skills and possibly new important projects of common European interest for batteries and hydrogen. But the challenge posed by the green transition is so great that it cannot succeed without taking into account competitiveness and strategic autonomy / technological sovereignty at the same time.

The Commission is currently drafting a transition pathway[153] for the mobility industrial ecosystem as a policy action introduced in 2021 as part of the update to the EU industrial strategy[154]. A transition pathway is a co-creation exercise together with Member States, industry and other relevant stakeholders, guiding and supporting the twin transition of the EU industrial ecosystems, including the mobility ecosystem[155]. The mobility industrial ecosystem includes the automotive, water, rail and cycling subsectors. The mobility ecosystem is expected to potentially be propelled by significant economic growth on the one hand (demand for passenger and freight transport is expected to increase three-fold between 2015 and 2050), while on the other there is an increasingly shared sense of urgency to address the climate challenge (road transport is the only sector to have increased its CO_2 emissions since 1990)[156]. For these reasons, the mobility industry ecosystem has innovated and invested heavily in the green and digital transformation. The automotive sector is key to Europe's mobility ecosystem. Furthermore, the Scoreboard shows the automotive sector to be Europe's last stronghold among the four biggest R&D sectors, accounting for 41% of total global automotive R&D.

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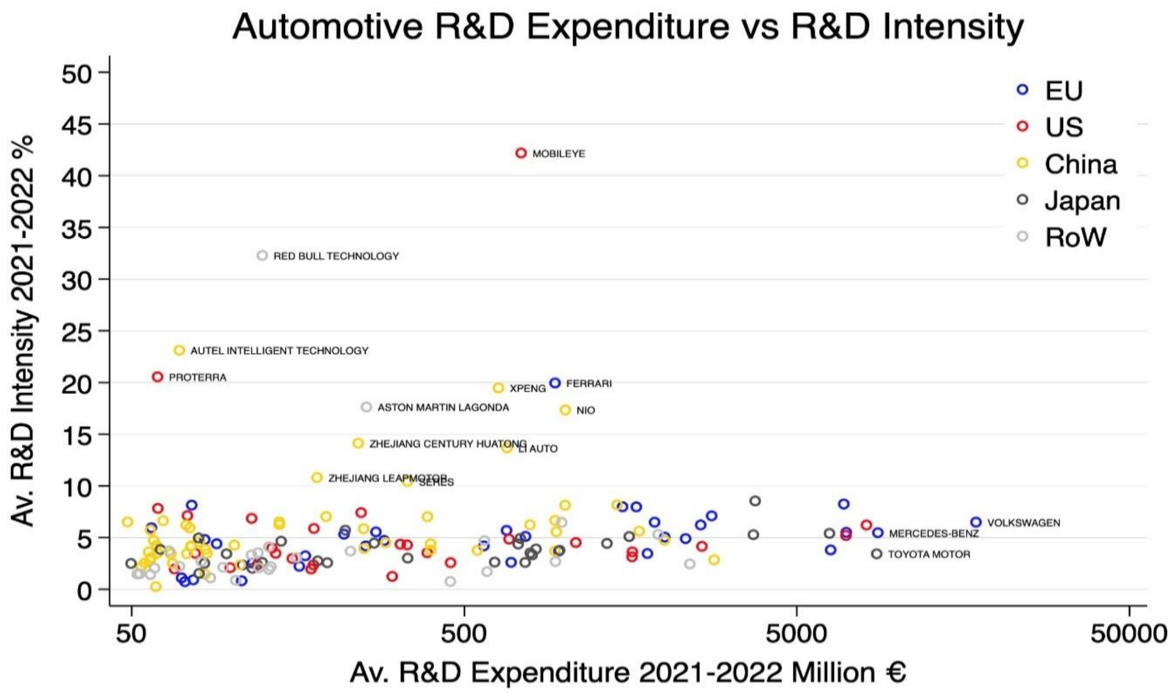
147 13 million jobs (https://www.acea.auto/figure/employment-in-eu-automotive-sector/)
148 https://www.worldstopexports.com/european-unions-top-10-exports/
149 Own calculation based on Scoreboard Panel for 2022.
150 The Automotive Industry Pocket Guide 2022/2023 - ACEA (2023) ACEA_Pocket_Guide_2022-2023.pdf.
151 https://www.oica.net/wp-content/uploads/Total-World-vehicles-in-use-2020.pdf
152 https://www.eia.gov/todayinenergy/detail.php?id=50096
153 Forthcoming in December 2023.
154 COM(2021) 350 final.
155 SWD(2022) 16 final establishes the precise boundaries, objectives and structure of this co-creation process.
156 *Which factors? What are their impacts on a 30-year period?* - Transport emissions trends in the EU Analyst Brief – September 2022 https://d1owejb4br3l12.cloudfront.net/publications/executive-briefing/transport-emissions-trends.pdf.

7.2 Shift in business models

The automotive industry faces multiple sources of technological ambiguity given the rise of electric/hybrid vehicles and the emergence of new software applications in vehicles (Teece, 2018[157]; The Economist, 2022[158]). Demand for electric cars is booming, both due to a strong push by governments in many regions, and the market success of disruptive and innovative firms like Tesla. The need for low/zero emissions transport also opened an opportunity for the Chinese auto industry to establish a more equal competitive footing with the EU's well-established technological leaders in the internal combustion engine (Altenburg et al. 2022[159]; Thun 2018[160]). Chinese electric vehicle companies have been able to thrive in large part due to substantial government support (e.g. subsidies, tax breaks, and other favourable regulations), a large domestic market and partnerships with foreign companies. At the same time, other potential paradigm shifts are emerging in this sector, related, for example, to smart factories or connected, autonomous and shared driving (Paunov and Planes-Satorra, 2019[161]). These changes threaten EU jobs[162] and the viability of many EU automotive firms (Brown et al., 2021[163]).

Figure 76. R&D investment (log scale) vs R&D intensity (R&D/net sales - %) of top R&D performers by region



Note: The sample includes also racing teams. Firms with more than 100% of R&D intensity or with net sales of less than EUR 1 million were excluded from this graph because we considered them as outliers (e.g. Rivian Automotive, Lucid, Nikola – all from the US).
Source: The 2023 EU Industrial R&D Investment Scoreboard, European Commission, JRC/DG R&I.

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157 Teece, D. J. (2018). 'Tesla and the Reshaping of the Auto Industry'. *Management and Organization Review*. Cambridge University Press. DOI: 10.1017/mor.2018.33

158 The Economist. (2022). 'The race to reinvent the car industry?'. *The Economist.*

159 Altenburg, T., Corrocher, N., & Malerba, F. (2022). 'China's leapfrogging in electromobility. A story of green transformation driving catch-up and competitive advantage', *Technological Forecasting and Social Change*, 183: 121914. North-Holland. DOI: 10.1016/J.TECHFORE.2022.121914.

160 Thun, E. (2018). 'Innovation at the middle of the pyramid: State policy, market segmentation, and the Chinese automotive sector',*Technovation*, 70–71: 7–19. Elsevier. DOI: 10.1016/J.TECHNOVATION.2018.02.007.

161 Paunov, C., & Planes-Satorra, S. (2019). *How are digital technologies changing innovation? Evidence from agriculture, the automotive industry and retail. Oecd Science, Technology and Industry Policy Papers*, Vol. No. 74. Paris. Retrieved from <https://www.oecd-ilibrary.org/docserver/67bbcafe-en.pdf?expires=1667737958&id=id&accname=guest&checksum=7CAF3454B84F5ED7C3E426B8EFF0EB35>

162 The exposure is different across European countries, with a higher potential impact in Germany, France and Italy (Pavlínek, 2022).

163 Brown, D., Flickenschild, M., Mazzi, C., & Gasparotti, A. (2021). *The future of the EU automotive sector. European Parliament's committee on Industry, Research and Energy (ITRE).* Luxembourg. DOI: 10.1017/cbo9780511844041.029.

The shift in business models is also R&D driven. Over the past decade, automotive R&D intensity remained at around 5% of net sales, but there are now many Chinese and some US firms with a different business model specialised in electric vehicles with much higher R&D intensities. In Figure 76, EU automotive Scoreboard firms are mainly positioned in the lower right quadrant of large R&D investors, showing a prevalence of established organisations and business models. US and Chinese firms in the upper quadrants entered the Scoreboard recently, and their high R&D intensity indicates that they are developing proprietary technologies and business models that might shape this sector's future.

The EU's challenge is to support established European R&D investors in carrying out substantial action in transforming their business models, while at the same time ensuring that EU-based R&D performers increase in size and reach a sufficient number in the new business models (electro mobility, autonomous driving, etc.).

7.3 The global value chain for motor vehicles

The examination of the EU's automotive industry from the perspective of global value chains is based on the multiregional input-output methodology, leveraging data from the European Commission's FIGARO database[164], to trace and map the generation of domestic (EU) value added in the global demand for vehicles[165]. This analysis focuses on the final demand of NACE sector C29 – motor vehicles, trailers and semi-trailers (hereafter referred to as motor vehicles), and the necessary upstream production inputs[166]. The analysis sometimes focuses on the global final demand for motor vehicles, and at other times on specific fractions referring to the EU (19%) or non-EU (81%) final demand.

7.3.1 Value added retained by the EU along the whole value chain

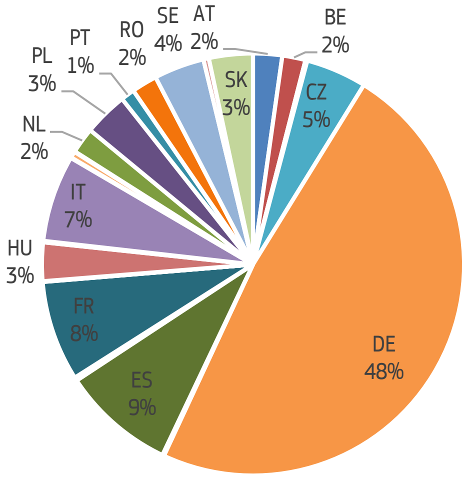
In 2019, the total EU value added in the global final demand for motor vehicles amounted to EUR 511.2 billion. This is more than twice the sector's value added, and represents 4.3% of the total EU value added for that year, and 4% in terms of total production. Germany alone accounts for almost half of the EU value added (both total and indirect) in the global final demand. Other significant contributors include Spain, which hosts many EU and foreign brands like Citroën, Renault, Ford, Nissan, and Volkswagen, France with Citroën and Peugeot, Italy with Fiat, Lancia, Alfa Romeo, and exclusive brands like Ferrari and Lamborghini, and Czechia, home to Škoda and Toyota's production plants. 6 Member States - Germany, Spain, France, Italy, Czechia, and Sweden - account for 80% of the value added in the vehicle supply chain.

164 Remond-Tiedrez, I. and Rueda-Cantuche, J.M. (eds.), *EU inter-country supply, use and input-output tables — Full international and global accounts for research in input-output analysis (FIGARO)*, EUR 30215 EN, Publications Office of the European Union, Luxembourg, 2019, doi:10.2785/00878.

165 For more detail see Arto, I., Rueda-Cantuche, J.M., Román, M. V., Cazcarro, I., Amores, A.F. and Dietzenbacher, E., *EU Trade in Value Added*, EUR 30215 EN, Publications Office of the European Union, Luxembourg, 2015, doi:10.2760/778748.

166 Related industries, such as NACE G45 (wholesale and retail trade and repair of motor vehicles and motorcycles), are only partially captured.

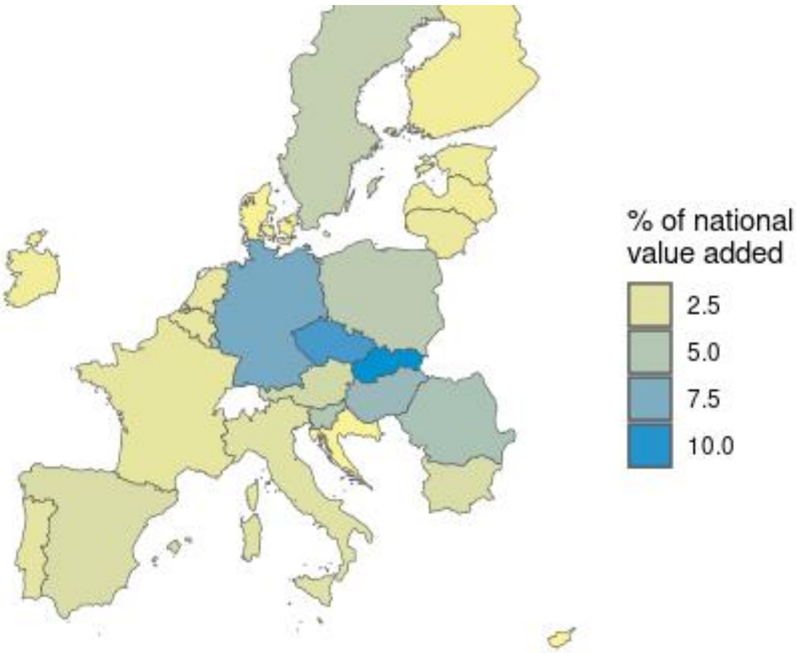
Figure 77. EU value added in global final demand for motor vehicles by Member State in 2019.



Source: Authors based on FIGARO.

The relative importance of the motor vehicle value chain for each EU economy is presented in Figure 78, which shows the percentage of the vehicle value chain relative to the national gross value added in 2019. In Slovakia and Czechia, more than 10% and 9%, respectively, of their value added is linked to the automotive industry. This is followed by Germany with 8% and Hungary with 6%. In Slovenia, Romania, and Luxembourg, the automotive industry contributes around 5% to the national gross value added. On average, the value added of the motor vehicle chain represents 4% of EU the gross value added.

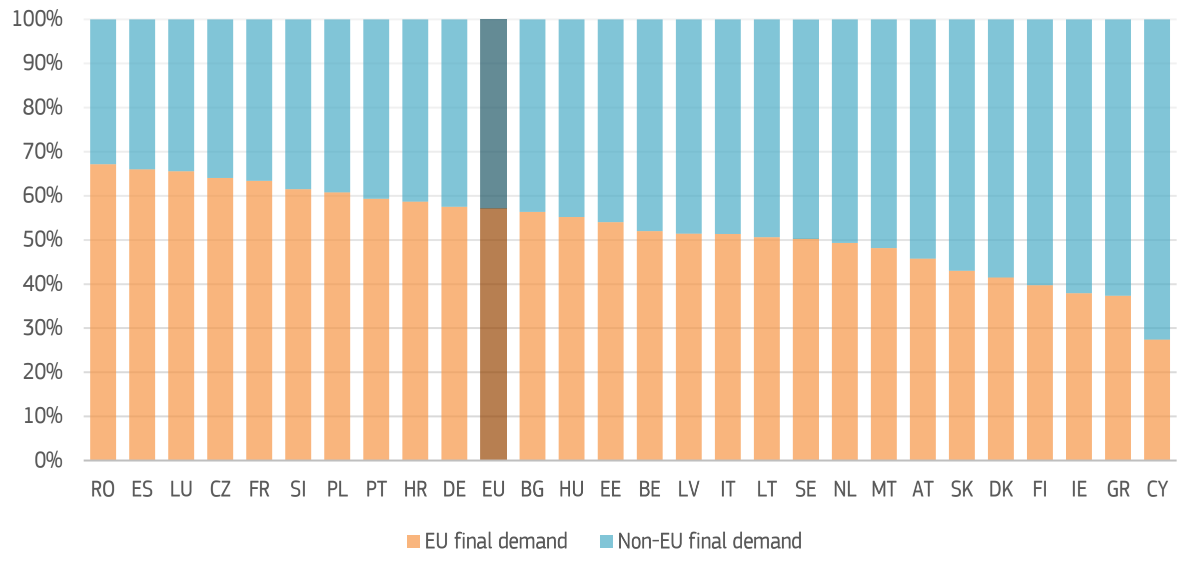
Figure 78. Share of national value added due to global final demand of motor vehicles compared with total national value added in 2019.



Source: Authors based on FIGARO.

Figure 79 provides information on the relevance of domestic vs non-EU final demand for motor vehicles by Member State. A country located closer to the y-axis (left axis) signifies that the EU final demand plays a more significant role in driving the national value added generated from the sales of vehicles. Conversely, a position closer to the right of the chart indicates a higher significance of vehicle purchase by non-EU consumers in value added generation. The range varies, with figures surpassing 65% for Romania, Spain, and Luxembourg, and falling below 40% in Finland, Ireland, Greece and Cyprus, which can be considered more export-dependent. The EU average is 57% domestic vs 43% foreign, meaning that 43% of the EU value added relates to foreign sales of vehicles. Of the largest players, only France, Spain, and Czechia have a domestic final demand relevance above 60%, while Italy and Sweden gear themselves more towards foreign markets.

Figure 79. EU value added by Member State in EU and non-EU final demand of motor vehicles in 2019.

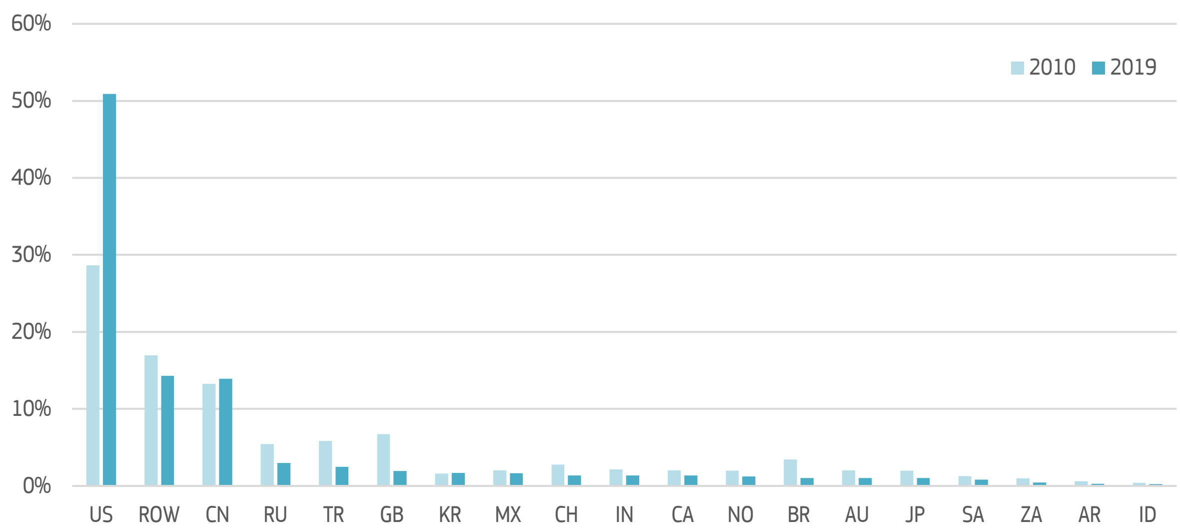


Source: Authors based on FIGARO.

Figure 80 and Figure 81 provide a breakdown of the information presented in Figure 79 in two different ways. Firstly, Figure 80 breaks down the domestic value added resulting from non-EU final demand, based on the final consumer country, comparing values for 2019 and 2010. Secondly, Figure 81 breaks down the EU final demand based on national final demand vs final demand from other Member States in 2019.

In 2019, the domestic value added generated by non-EU customers amounted to EUR 219 billion, which is 64% higher than in 2010 (EUR 133 billion). Figure 80 reveals that US final demand was the primary driver of domestic value added in vehicle exports, accounting for over 50% of the total value added generated in the EU. This represents an increase of 22 percentage points compared to 2010. When China is included, both countries together account for over two thirds of the EU value added resulting from foreign sales of vehicles. Furthermore, Figure 80 indicates a drop in the relative importance of the UK market, which in 2019 made up 2% of the EU value added exported in vehicles, 5 percentage points lower than the 2010 levels.

Figure 80. EU value added by non-EU final demand for motor vehicles by trade partner in 2010 and 2019, % of the total.

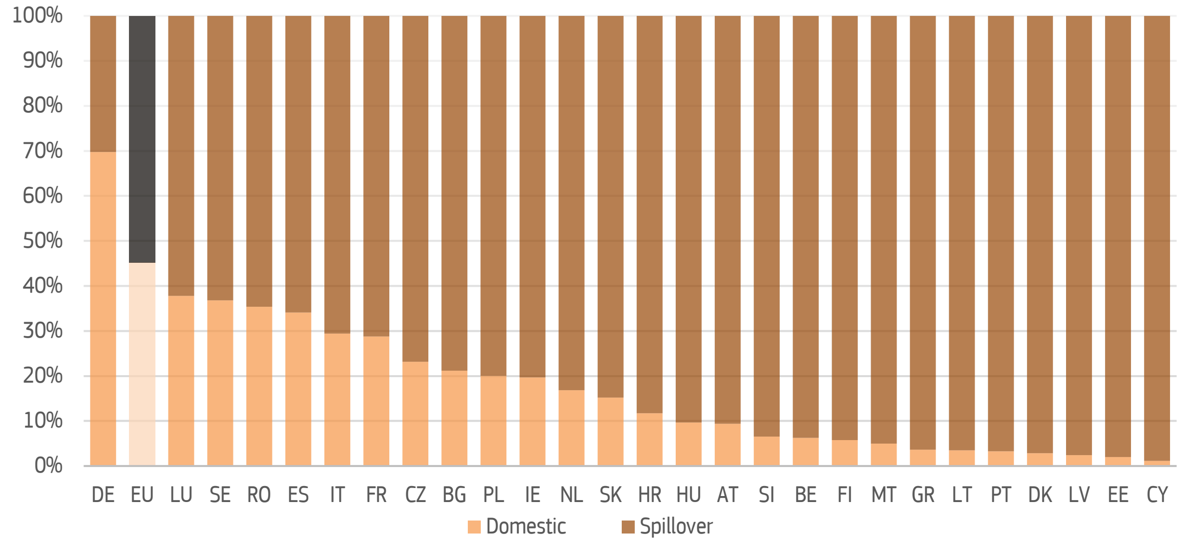


Source: Authors based on FIGARO.

Figure 81 breaks down the EU value added resulting from domestic final demand into two components: domestic or EU effects and spillover or indirect effects in other EU countries. These indirect effect correspond to the imports made by EU manufacturers when producing motor vehicles. As an example, for every EUR 100 of the value of a Swedish motor vehicle, EUR 67 would correspond to value added generated in other EU countries that supply inputs to the Swedish manufacturers. In 2019, the EU value added due to domestic final demand amounted to EUR 292.2 billion. Of this, 45% (EUR 132 billion) was attributed to domestic effects, while 55% (EUR 160 billion) were attributed to spillover effects.

The domestic fraction is more significant for Germany, accounting for 70% of the total EU value added. In contrast, for the rest of the Member States, the domestic share is below 40%. Only four countries – Luxembourg, Sweden, Romania, and Spain – have a domestic share of between 30-40%.

Figure 81. EU value added in EU final demand for motor vehicles by Member State in 2019 (by domestic vs spillover effects in %)



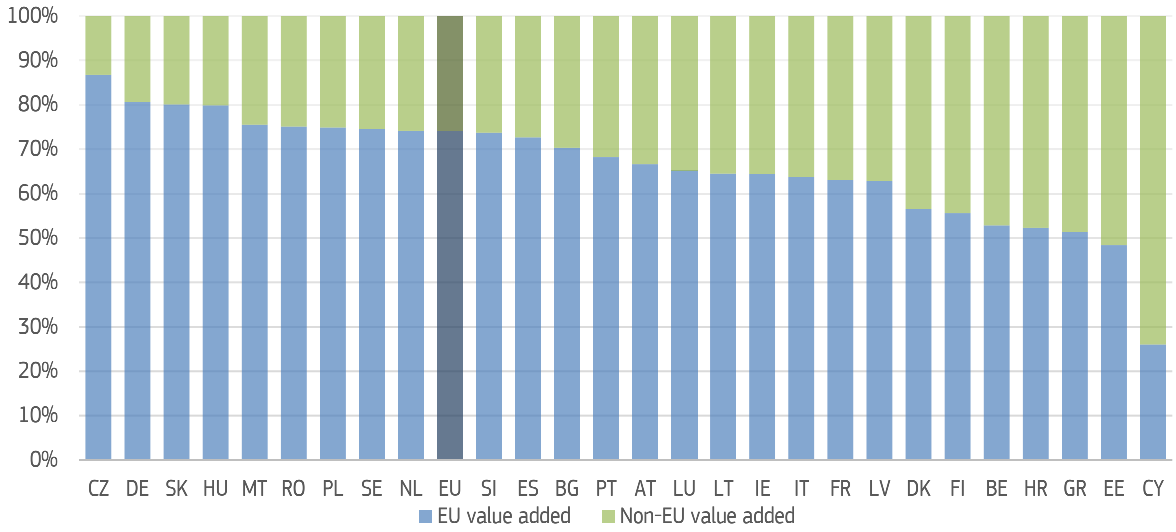
Source: Authors based on FIGARO.

7.3.2 The EU final demand as driver of value added generation

In Figure 81, the focus was on the EU origin of the value added for EU final consumption of motor vehicles. Figure 82 offers a different perspective as it focuses on the source of value added (EU and non-EU) for each Member State's final demand. The positioning along the y-axis indicates the share of value added generated within the EU per euro spent on vehicles. For example, for every EUR 100 spent on vehicles purchased through German final demand, EUR 80 represent value added generated within the EU. In contrast, a positioning closer to the right indicates that final demand in this Member State generates more value added outside the EU.

If we exclude the results for Cyprus, the EU final demand embodies domestic value added ranging from 87% in Czechia, to below 50% in Estonia. The EU average reveals that 74% of the value added in the final demand for vehicles originates domestically, while the remaining 26% is generated abroad. This means that approximately 25% of the EU's final demand for vehicles incorporates value added that is generated outside the EU, upstream in the global value chain, coming either from i) imported cars, and/or ii) imported components, where no EU value added has contributed in the production process along the global value chains.

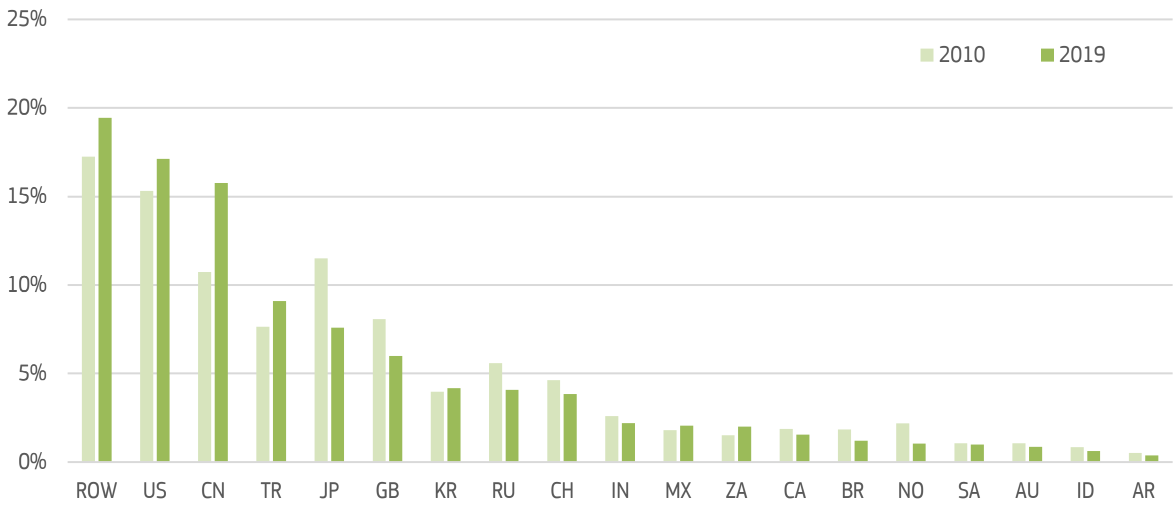
Figure 82. EU and non-EU value added by Member State final demand of motor vehicles in 2019.



Source: Authors based on FIGARO.

Figure 83 provides a breakdown of the one fourth of value added generated outside the EU, based on the EU's final demand, which amounts to EUR 101.8 billion. The ROW region, the US, and China collectively accounted for more than 50% of this value added in 2019. In particular, Chinese input producers for the motor vehicle industry experienced the highest growth, with an increase of 5 percentage points compared with previous years.

Figure 83. Non-EU value added due to EU final demand for motor vehicles in 2019 by source country.



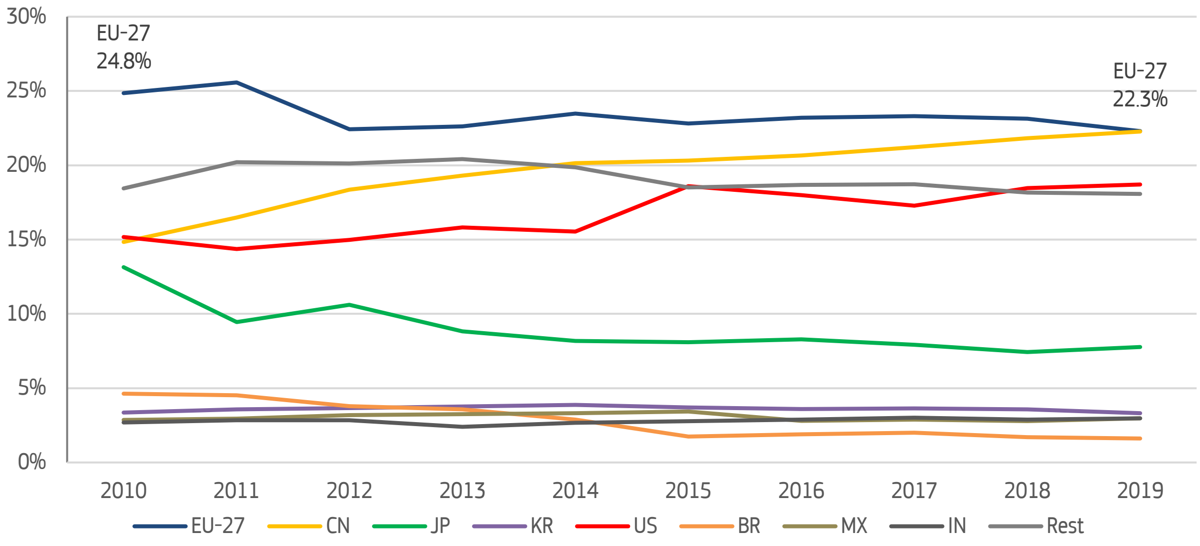
Source: Authors based on FIGARO.

7.3.3 Evolution during the last decade

Figure 84 shows data on the retention of global value added resulting from the sale of motor vehicles by major economies between 2010 and 2019. The EU continues to maintain its dominance in the global market, accounting for 11.3% of the value added in 2019. However, this figure has fallen by 2.5% compared to 2010. This decline is relatively smaller than that of Japan (-5.4%) and Brazil (-3.0%).

In contrast, the remaining large economies have seen their shares increase. China experienced the most significant increase, with a 7.4% rise in value added over the decade. Therefore, it reached the same level as the EU in 2019. According to the OICA, China produced 27 million vehicles in 2022, compared to 18.2 million in 2010[167]. China is followed by the US with a 3.5% increase.

Figure 84. % of domestic value added by economy due to the global final demand for motor vehicles during 2010-2019.



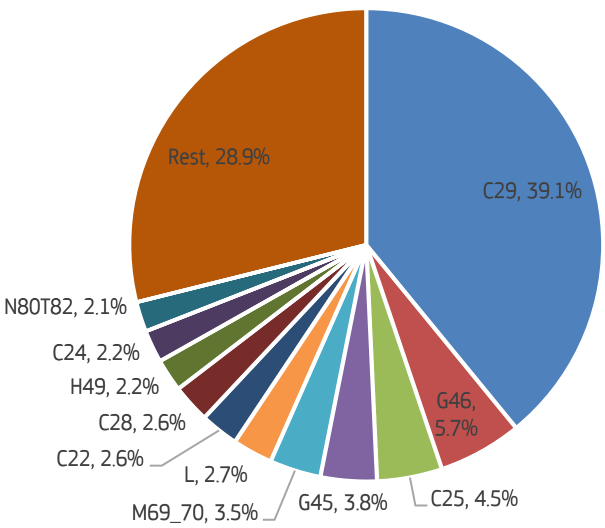
Source: Authors based on FIGARO.

7.3.4 EU industries more heavily involved in the GVC of motor vehicles

Figure 85 disaggregates the EU's value added into global final demand for motor vehicles by different activities indirectly involved (NACE A64 industry classification), measured in percentages for 2019. As mentioned earlier, the EU managed to account for 22.3% of the value added generated globally in 2019, equal to EUR 511.2 billion. 39% of this amount (EUR 199.8 billion) is the domestic value added generated within the motor vehicle industry itself. The remaining 61% (EUR 311.4 billion) is the value added generated in other industries upstream in the global value chain. Excluding the motor vehicles industry (NACE code C29), 61% of the value added is generated in the services sector, 38% in manufacturing, and a mere 1% in primary sectors.

[167] https://www.oica.net/production-statistics/

Figure 85. EU value added in global final demand for motor vehicles by industry in 2019 as % of the total.



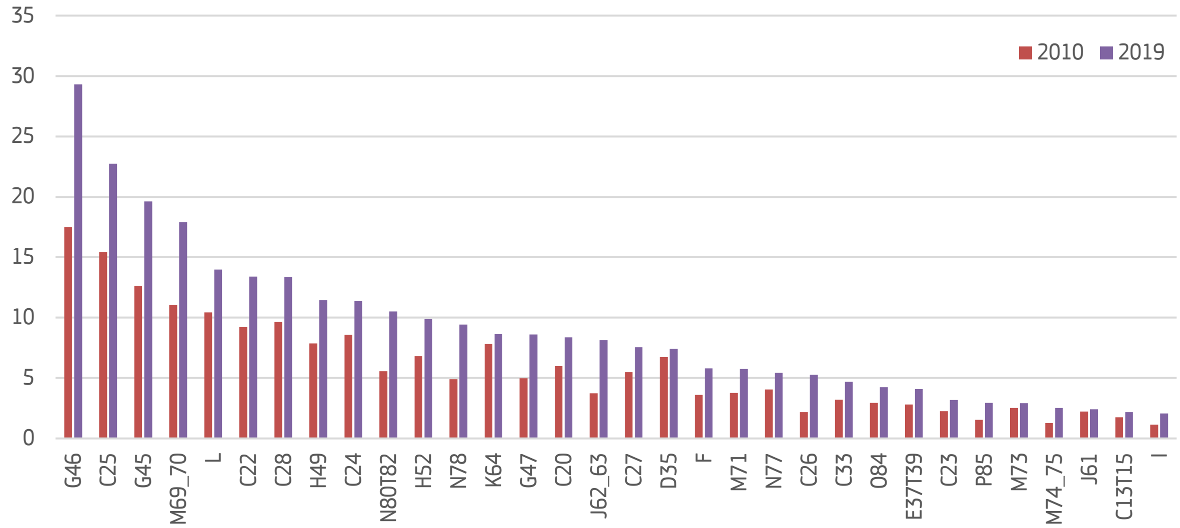
Note: C29: Motor vehicles, trailers and semi-trailers. G46: Wholesale trade services, except of motor vehicles and motorcycles. C25: Fabricated metal products, except machinery and equipment. G45: Wholesale and retail trade and repair services of motor vehicles and motorcycles. M69_70: Legal and accounting services; services of head offices; management consultancy services. L: Real estate services. C22: Rubber and plastic products. C28: Machinery and equipment n.e.c. H49: Land transport services and transport services via pipelines. C24: Basic metals. N80T82: Office administrative, office support and other business support services. For a description of the NACE codes please see https://ec.europa.eu/eurostat/web/esa-supply-use-input-tables/information-data

Source: Authors based on FIGARO.

The economic impact arising from the global demand for motor vehicles creates value added that distributes across the entire EU economy, more specifically, 39.1% of the own sector. In fact, 28.9% of this value is generated in industries with shares below 2%. The remaining 32.0% occurs in 10 industries, each with shares above 2% in 2019. These span across both the services and manufacturing sectors. In the services sector, the wholesale trade (G46), wholesale and retail trade of motor vehicles (G45), legal and accounting activities; activities of head offices; management consultancy activities (M69_70), and real estate activities (L) account for over 15.7% of total value added. In the manufacturing sector, the manufacture of fabricated metal products (C25), the manufacture of rubber and plastic products (C22), and the manufacture of machinery and equipment n.e.c. (C28) together account for 9.7% of the total value added.

Figure 86 focuses on the upstream industries providing inputs to the motor vehicle industry, showing how much value added was generated and embodied in C29 products in 2010 and 2019. All industries increased their contribution in 2019 compared with 2010. Increases above 100% are observed in industries related to the digital economy, more precisely C26 (manufacture of computer, electronic and optical products) and J62_63 (computer programming, consultancy, and information service activities). In the four main industries supplying inputs to C29, the increase was above 55% over the decade. Despite the generalised increased observed in 2019, this does not mean that the total share of non-C29 industries has increased. In fact, spillover effects in other industries in 2019 were 60.9%, slightly below the 63.1% obtained in 2010.

Figure 86. EU value added in global final demand for motor vehicles by industry (excluding motor vehicles) in billions of euros 2019.

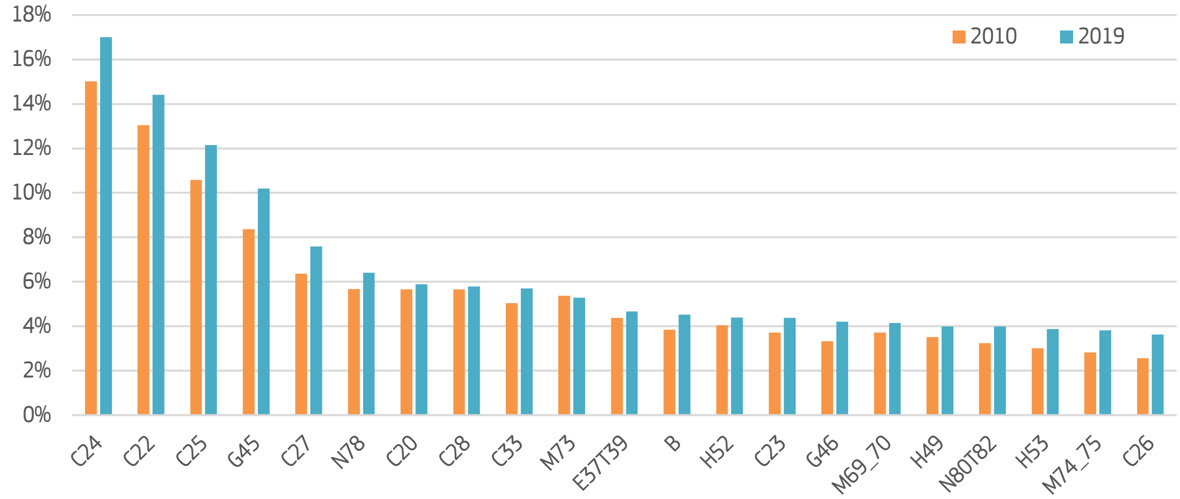


Note: G46: Wholesale trade services, except of motor vehicles and motorcycles. C25: Fabricated metal products, except machinery and equipment. G45: Wholesale and retail trade and repair services of motor vehicles and motorcycles. M69_70: Legal and accounting services; services of head offices; management consultancy services. L: Real estate services. C22: Rubber and plastic products. C28: Machinery and equipment n.e.c. H49: Land transport services and transport services via pipelines. C24: Basic metals. N80T82: Office administrative, office support and other business support services. H52: warehousing and support services for transportation. N78: employment services. K64: Financial services, except insurance and pension funding. G47: Retail trade services, except of motor vehicles and motorcycles. C20: Manufacture of chemicals and chemical products. J62_63: Computer programming, consultancy, and information service activities. C27: Manufacture of electrical equipment. D35: Electricity, gas, steam and air conditioning supply. F: Construction. M71: Architectural and engineering activities; technical testing and analysis. N77: Rental and leasing activities. C26: Manufacture of computer, electronic and optical products. C33: Repair and installation of machinery and equipment. O84: Public administration and defence; compulsory social security. E37T39: Sewerage, waste management, remediation activities. C23: Manufacture of other non-metallic mineral products. P85: Education. M73: Advertising and market research. M74_75: Other professional, scientific and technical activities; veterinary activities. J61: Telecommunications. C13T15: Manufacture of textiles, wearing apparel, leather and related products. I: Accommodation and food service activities.
Industries below EUR 2 million in 2019 are not shown.

Source: Authors based on FIGARO.

Figure 87 provides information on the relative importance of the automotive industry for the supplier industries, showing the percentage of industry's value added which is directly or indirectly related to the purchase of motor vehicles. For the manufacture of basic metals (C24), manufacture of rubber and plastic products (C22), and manufacture of fabricated metal products, except machinery and equipment (C25), more than 10% of their respective gross value added was driven by demand for motor vehicles. Not surprisingly, wholesale and retail trade and repair of motor vehicles and motorcycles (G45) is also linked to the manufacture of motor vehicles, trailers and semi-trailers (C29).

Figure 87. EU value added in global final demand for motor vehicles by industry different to C29 as % of industry's gross value added.



Note: Industries below 3.5% in 2019 are not shown.
Source: Authors based on FIGARO.

7.4 Key points

— EU motor vehicle demand constituted nearly one fifth of the global total in 2019 (EUR 548.3 billion). Outside final demand corresponded to 81% corresponding, showing the significance of the global automotive markets for EU vehicle exporters.

— On average, value added of the motor vehicle chain represents 4% of EU gross value added. However, strong economic integration since the turn of the millennium has led central and eastern European countries to move up in the value chain, becoming key players for the EU automotive industry. In Slovakia and the Czechia, more than 10% and 9% respectively of their value added is linked to the automotive industry. This is followed by Germany with 8% and Hungary with 6%. In Slovenia, Romania, and Luxembourg, the automotive industry contributes around 5% to the national gross value added.

— The domestic value added generated by purchases from non-EU customers was driven by US demand, accounting for over 50% of the total EU value added in 2019 (plus 22 percentage points compared to 2010). Including China, both countries together account for over one third of the EU value added resulting from foreign demand of EU vehicles. There is a decrease in the relative importance of the UK market, which in 2019 accounted for 2% of the EU value added exported in vehicles, 5 percentage points lower than the 2010's levels.

— Approximately 25% of the EU's final demand for vehicles incorporates value added that is generated outside the EU, upstream in the global value chain. In 2019, the US and China together accounted for more than one third of this value added. In particular, Chinese input producers for the EU motor vehicle industry experienced the highest growth, with an increase of 5 percentage points compared to previous years.

— Between 2010 and 2019, the EU continued to lead in the global market, holding more than one fifth of the value added from the global automotive sector in 2019. However, this figure has decreased by 2.5% compared to 2010, in parallel with declining shares for Japan (-5.4%) and Brazil (-3.0%). This is due to the emergence of China, which increased its value added by 7.4% to 22%, followed by the US share with an increase of 3.5% to approximately 18%.

— The economic impact arising from the global demand for motor vehicles creates value added across the entire EU economy. There are four main services sectors accounting for over 15.7% of total value added (wholesale trade (G46); wholesale and retail trade in motor vehicles (G45); legal and accounting activities; activities of head offices; management consultancy activities (M69_70) and real estate activities (L)). There are three manufacturing sectors together contributing 9.7% of the total value added (manufacture of fabricated metal products (C25); manufacture of rubber and plastic products (C22), and manufacture of machinery and equipment not elsewhere classified (C28)). Furthermore, 28.9% of this value is generated in a large variety of industries with a share below 2%.

— Regarding the upstream industries providing inputs to the motor vehicle industry, all industries grew their contribution in 2019 compared with 2010 levels. Increases above 100% are observed in industries related to the digital economy, more precisely C26 (manufacture of computer, electronic and optical products) and J62_63 (computer programming, consultancy and information service activities). In the four main industries supplying inputs to C29, the increase was always above 55% during the decade. Despite the generalised increase observed in 2019, this does not mean that the share of non-C29 industries has increased. In fact, spillover effects in other industries in 2019 were 60.9%, slightly below the 63.1% obtained in 2010.

— Examining the relative importance of the automotive industry for supplier industries, for the manufacture of basic metals (C24), manufacture of rubber and plastic products (C22), manufacture of fabricated metal products, except machinery and equipment (C25), and wholesale and retail trade and repair of motor vehicles and motorcycles (G45), more than 10% of their respective gross value added was driven by demand for motor vehicles.

— During the last decade, the EU value added of the GVC of motor vehicles increased its specialisation towards a higher participation in services such as wholesale trade, computer programming, consultancy, and information services, security and investigation, office administrative and support activities, employment activities, and legal and accounting services, activities of head offices and management consultancy activities.

— The EU industries that have increased most their integration into the GVC of motor vehicles were the manufacture of basic metals (Germany), rubber and plastic products (Poland), fabricated metal products (Poland), electrical equipment (Germany), computer and electronics (Ireland) and trade and repair of motor vehicles (Germany).

8 Innovation in deep technologies – advanced materials

The section investigates trends in advanced materials patenting and is structured as follows: section 8.1 presents the policy relevance, section 8.2 examines global trends in patenting for advanced materials, providing a geographical breakdown. Moving on to section 8.3, we rank the top companies on the Scoreboard based on their applications for advanced materials patents. Additionally, we analyse which sectors and headquarters regions exhibit a higher degree of technological specialization in advanced materials. Finally, section 8.4 delves into a discussion of key points highlighted in this section.

8.1 Relevance and policy relevance

Since the adoption of the New European Innovation Agenda[168] in 2022, there has been a surge of interest toward policies aimed at leveraging existing European skills to harness innovation in deep technologies ('deep tech'), i.e. innovation in fields requiring cutting edge science, technology and engineering to solve substantial social challenges such as promoting sustainability, competitiveness, and technological sovereignty.[169,170]

On March 27, 2023, the Commission workshop 'Leveraging the deep-tech green transition and digital solutions to transform EU industrial ecosystems' discussed the importance of deep tech for the green and digital transitions[171]. An important insight from the workshop was how crucial it is to identify the right investments in new production techniques and materials for a wide variety of industries in order to diminish the need for extraction of raw materials and pave the way for a more circular economy.

In this context, one of the advanced technological areas that are a priority for European industrial policy is advanced materials (others include robotics, artificial intelligence, big data, nanotechnology, etc.)[172]. Advanced materials can lead both to new reduced cost substitutes to existing materials and to new higher added-value products and services. They can offer major improvements in a wide variety of different fields, e.g. in aerospace, transport, building and health care; and facilitate recycling, lowering the carbon footprint and energy demand while limiting the need for raw materials that are scarce.

The Materials Initiative 2030 Manifesto[173] sets out a vision to develop a strong European materials ecosystem, driving the green and digital transitions and creating a sustainable, inclusive European society. To achieve this vision, the Materials 2030 roadmap presents the current needs and monitors progress in selected materials innovation markets (MIM), one of which relates to advanced materials. The raw materials Communication[174] recognises the important role of advanced materials in substituting critical raw materials, with a coordinated action plan with Member States currently underway. The Advanced Materials Initiative 2030 (AMI2030[175]) partnership is a new, jointly programmed, complementary funding instrument between the European Commission and industry. Beyond bringing together matching funds from the European Commission and industry, AMI2030 tackles the fragmentation of the materials sector, leverages the creation of the European ecosystem for advanced materials, and provides a platform for all stakeholders along the entire advanced material value chain and innovation cycle.

Given the major role of patents in the innovation process in sectors related to advanced materials, a patent-based approach using advanced materials was chosen to assess the deep tech potential of Scoreboard firms relevant for a wider range of goals in the New Innovation Agenda. Historically, deep tech has been mainly associated with startups, with projects[176] and action in this domain aiming to improve access to finance[177] and

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168 SWD/2022/187 final

169 https://op.europa.eu/en/publication-detail/-/publication/1799d398-9d8d-11ed-b508-01aa75ed71a1/language-en/format-PDF/source-294603385

170 https://op.europa.eu/en/publication-detail/-/publication/e9058375-fe64-11ec-b94a-01aa75ed71a1/language-en/format-PDF/source-294603385

171 Tübke, A., Evgeniev, E., Gavigan, J., Compaño, R. & Confraria, H.: Leveraging the Deep-Tech Green Transition & Digital Solutions to Transform EU Industrial Ecosystems, European Commission, Seville, 2023, JRC133774

172 https://ati.ec.europa.eu/sites/default/files/2021-11/ATI%20Methodological%20Report%20Indicator%20framework%20and%20data%20calculations_0.pdf

173 See MATERIALS 2030 MANIFESTO: Systemic Approach of Advanced Materials for Prosperity – A 2030 Perspective; https://www.ami2030.eu/wp-content/uploads/2022/06/advanced-materials-2030-manifesto-Published-on-7-Feb-2022.pdf

174 See COM/2023/165 final

175 See https://www.ami2030.eu/

176 https://op.europa.eu/en/publication-detail/-/publication/0f9b5d3b-adb1-11ed-8912-01aa75ed71a1/language-en/format-PDF/source-280724890v

177 https://eic.ec.europa.eu/system/files/2022-01/EIC-report-deep-tech-2021-DIGITAL-11012022.pdf

framework conditions for innovation, to create a strong network of European R&I players and to attract talent. Against this backdrop, large private innovators such as the Scoreboard companies are an integral part of the innovation ecosystem in which deep tech innovators operate and are likely to be directly or indirectly involved in creating the enabling conditions to advance deep tech through, e.g. acquisitions or the provision of venture capital.

8.2 Regional trends in Advanced materials patenting

This section focuses on patented inventions by Scoreboard companies. We rely on expert knowledge to select the inventions connected to advanced materials. The analysis aims to produce a bird's eye view of the evolution of patenting in advanced materials over time and its relevance across the geographical and sectoral dimensions.

Box 6. Advanced materials patent analysis methodology

To identify the patents of Scoreboard companies, we rely on COR&DIP, a database that matches Scoreboard companies with their high-value patented inventions. High-value inventions are defined as the patent families containing applications filed at multiple patent offices, at least one of which belongs to the IP5 consortium (EPO, USPTO, JPO, KIPO, CNIPA). Throughout this section, when we mention patents or patented inventions, we refer to IP5 families. Families are attributed to the year in which the first patent was filed. The database is the result of a collaboration between the JRC and the OECD. The latest version, COR&DIP v4, is based on the 2021 *Scoreboard* ranking and the 2023 Spring Edition of the EPO PATSTAT database.

To filter patents in advanced materials (AM), we rely on a recently published classification from a report on advanced technologies for industry employing expert knowledge to expand the previously existing definition of key enabling technologies list of IPC technology codes associated to "advanced materials" as published in the *Advanced Technologies for Industry – Methodological report**: B32B 9, B32B 15, B32B 17, B32B 18, B32B 19, B32B 25, B32B 27, B82Y 30, C01B 31, C01D 15, C01D 17, C01F 13, C01F 15, C01F 17, C03C, C04B 35, C08F, C08J 5, C08L, C22C, C23C, D21H 17, G02B 1, H01B 3, H01F 1/0, H01F 1/12, H01F 1/34, H01F 1/42, H01F 1/44, H01L 51/30, H01L 51/46, H01L 51/5.

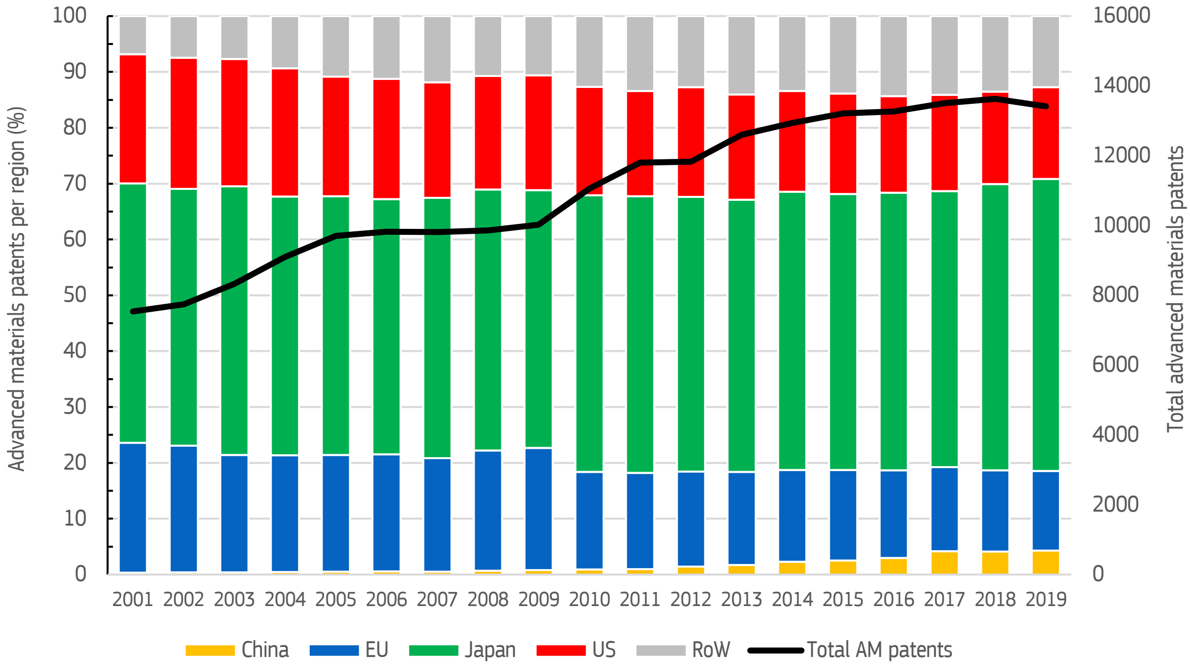
*https://ati.ec.europa.eu/sites/default/files/202111/ATI%20Methodological%20Report%20Indicator%20framework%20and%20data%20calculations_0.pdf

The black plot in Figure 88 reports the number of advanced material patents filed yearly by Scoreboard companies directly or through their subsidiaries between 2001 and 2019[178]. The time series shows a steady increase in advanced material patents from 8 000 in 2001 to nearly 14 000 in 2019, corresponding roughly to a 75% increase[179]. This increase is substantial but in line with the global growth in patent filings. As a consequence, the proportion of advanced materials patents accounts for around 7% of all IP5 families patented by Scoreboard firms throughout the period under analysis. The bar chart in Figure 88 breaks down patents in advanced materials geographically by attributing patents to the country of the corresponding mother company. Japan (in red) is the clear frontrunner in terms of the number of advanced materials patents filed with a share exceeding 40% of the total every year and growing in recent years; the EU (blue) and the US (red) have similar and declining shares of advanced materials patents. China is by far the region with the lowest number of AM patents, though its share grew noticeably in the 2010s.

[178] Due to a lag in patent data coverage, it is not possible to carry out a comprehensive analysis beyond 2019.

[179] The drop in 2020 is in line with the decline in coverage that affects patent databases in recent years due mostly to a lag between the time at which patent applications are filed and when they are published.

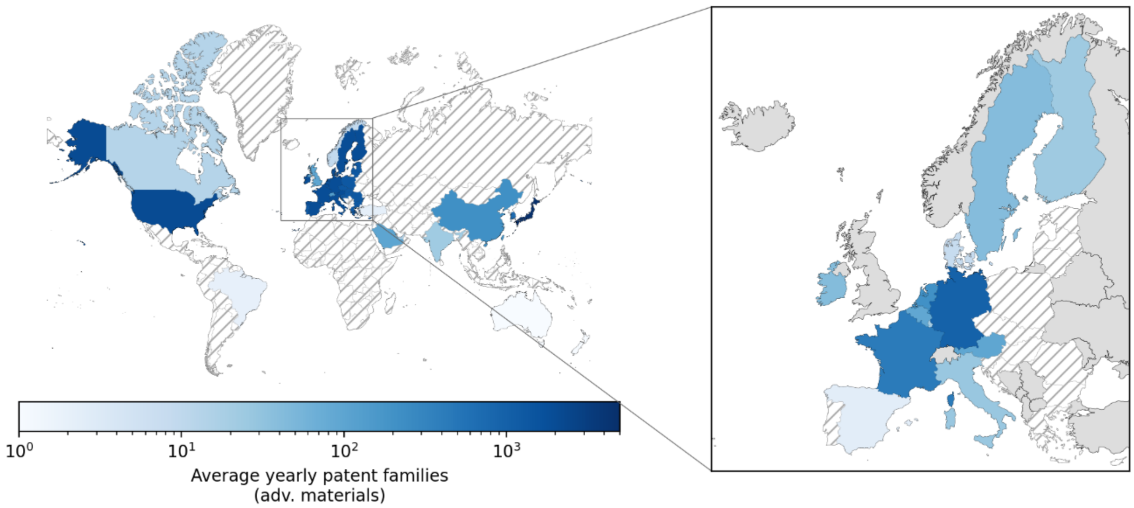
Figure 88. Advanced materials patents across regions



Notes*:* Black line: number of AM patents filed by Scoreboard companies. Bar chart: share of AM patents filed by applicants belonging to each region. Patents are allocated to the region in which the Scoreboard company applying for the patent is headquartered
Source: JRC based on COR&DIP v4 and PATSTAT 2023 Spring Edition.

Figure 89 further breaks down the bar chart in Figure 88 by reporting the average yearly number of AM patents filed by Scoreboard companies in 2001-2020. Darker shades of blue represent larger values. The world map on the left, in which the EU is represented as a unique block, confirms the leading role of Japan (over 5 000 advanced materials patents per year) followed by the US (close to 2 100 such patents per year) and the EU (close to 2 000). China-headquartered Scoreboard companies instead produced on average less than 300 AM patents per year during the same period. The hatched pattern identifies countries for which no data are available (i.e. countries that do not host headquarters of Scoreboard companies patenting in AM according to the COR&DIP database), which is consistent with the well-known fact that in general Scoreboard company headquarters are quite concentrated geographically. The inset on the right zooms onto the EU, which is divided into its Member States. It shows that there is a noticeable heterogeneity in the EU, with companies headquartered in Germany and France responsible for the bulk of advanced materials patents filed by EU Scoreboard companies.

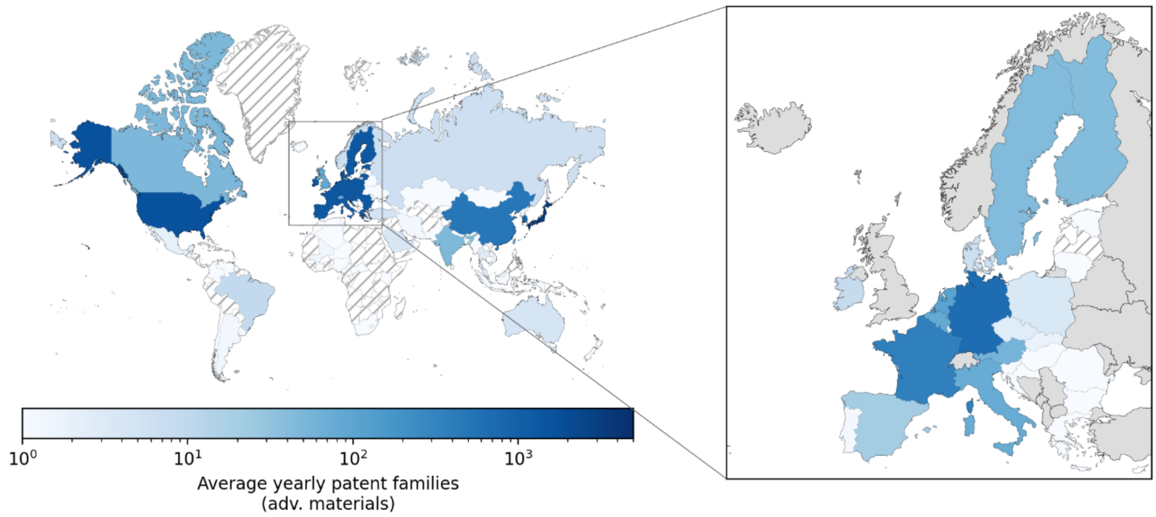
Figure 89. Advanced materials patents company headquarters



Notes: Average number of AM patents filed by Scoreboard companies per year, 2001-2019. Patents are attributed to the company headquarter only.
Source: JRC based on COR&DIP v4 and PATSTAT 2023 spring edition.

Figure 90 reports a similar geographical breakdown as Figure 89, with the difference that AM patents are allocated to the countries of residence of the inventors. The regional ranking is unchanged, confirming the leading role of Japan (over 3 500 yearly AM patents), the US (around 1 500) and the EU (around 1 300), while China is still lagging substantially (around 500). However, the distribution is noticeably less skewed, suggesting that research conducted by international company branches plays a relevant role in deep tech. This observation is consistent with the fact that the number of countries with no patents is much smaller when patents are allocated based on inventor residence instead of applicant headquarters. In line with this observation, comparing the world map of the two figures shows that although headquarters are very concentrated geographically, their inventive activities are quite distributed. Looking at the EU, there is still a noticeable heterogeneity between countries, with Germany and France still responsible for more filings than other Member States. Nevertheless, more countries play a significant role in AM patenting and are allocated at least some high-value AM inventions.

Figure 90. Advanced materials patents by inventor residence



Notes: Average number of AM patents filed by Scoreboard companies per year, 2001-2019. Patents are attributed to the country of residence of the inventor.
Source: JRC based on COR&DIP v4 and PATSTAT 2023 spring edition.

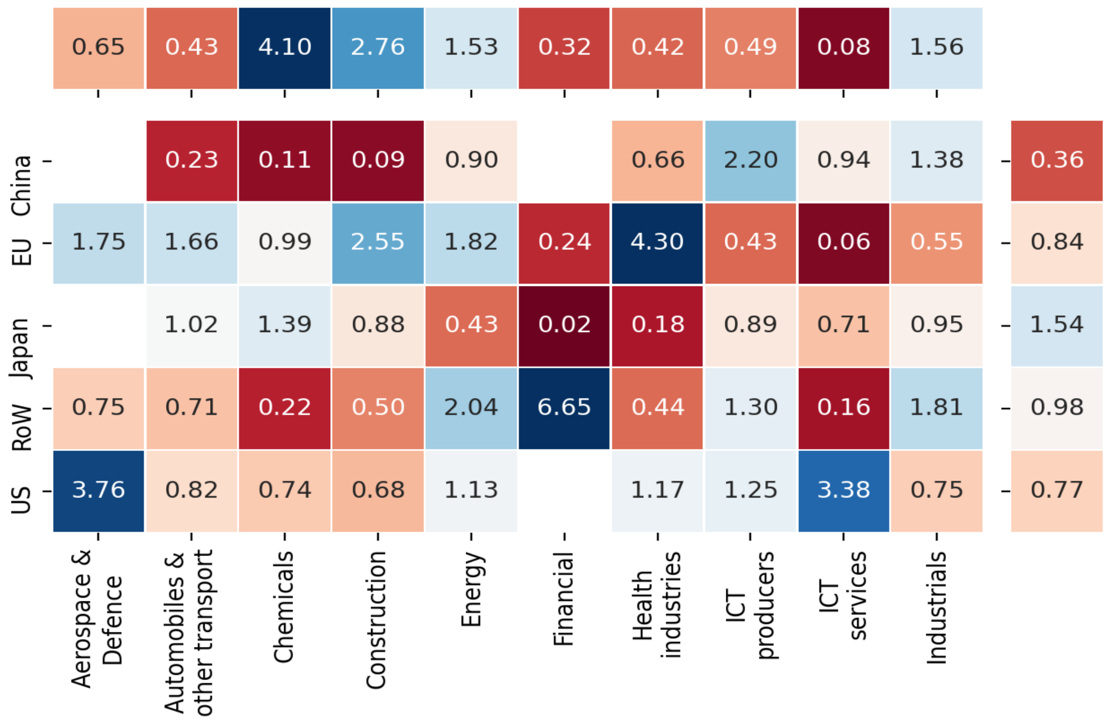
8.3 Technological specialisation patterns in advanced materials

Figure 91 uses a breakdown of the sample of AM patents by Scoreboard companies by headquarter region and industrial sector to compute a measure of their relative specialisation in AM innovation. Relative specialisation is computed by using the index of revealed comparative advantage; the values are reported in the large heatmap at the bottom left.

The index tells us whether the weight of AM patents filed by Scoreboard companies operating in a given sector and headquartered in a given region relative to the total number of AM patents produced within that region is higher or lower than the weight of AM patents produced globally within the same sector relative to the total number of AM patents. In a nutshell, an index value higher than one indicates that Scoreboard companies operating in that sector and region produce more than their fair share of AM patents. The figure shows that EU-headquartered Scoreboard companies operating in health, construction, aerospace, energy, and automotive have had high relative specialisation in AM patents between 2016 and 2019.

The heatmaps at the top and at the right of the figure help further interpret the results the values of the RTA index (revealed technological advantage). The heatmap on the right reports the relative specialisation of regions in AM, i.e. the weight of AM patents within the total regional patent basket relative to the weight the AM patents have within COR&DIP v4[180]. The heatmap at the top of the figure reports the results of the same computation carried out on sectoral patent portfolios instead of regional ones. The regional specialization measures suggest that AM innovation is relatively more present in Japan than in any other region. Based on the sectoral specialization indices, the chemicals, construction, industrials, and energy industries are the leading sectors in developing AM patents.

Figure 91. Relative technological specialisation in advanced materials



Notes: Blue cells indicate region-industry combinations for which the revealed technological advantage in AM patents is greater than 1; darker shades of blue stand for higher values of the index. Red cells indicate region-industry combinations for which the revealed technological advantage in AM patents is lower than 1; darker shares of red stand for lower values of the index.

Source: JRC based on COR&DIP v4 and PATSTAT 2023 spring edition

Table 44 reports the top 10 Scoreboard companies in terms of the number of AM patents filed between 2001 and 2019. In line with the geographical breakdown in Figure 89 and Figure 90, we observe a strong prevalence of Japan- and US-headquartered Scoreboard companies; these operate mostly in ICT, chemicals

[180] COR&DIP contains a broad selection of all IP5 patent families contained in Patstat, accounting for around two thirds of the total. COR&DIP also accounts for around 58% of all advanced materials patents identified through the method used in this section.

and industrials. The only EU company in the list is the chemical company BASF. It is interesting to note that if we considered a shorter time window (e.g. the last 5 or 10 years, instead of the past 20), BASF would still be in the top 20, but would fall out of the top 10. This suggests that the landscape around advanced materials is not static, and that the regions or sectors leading in this area of deep tech could change in the coming years.

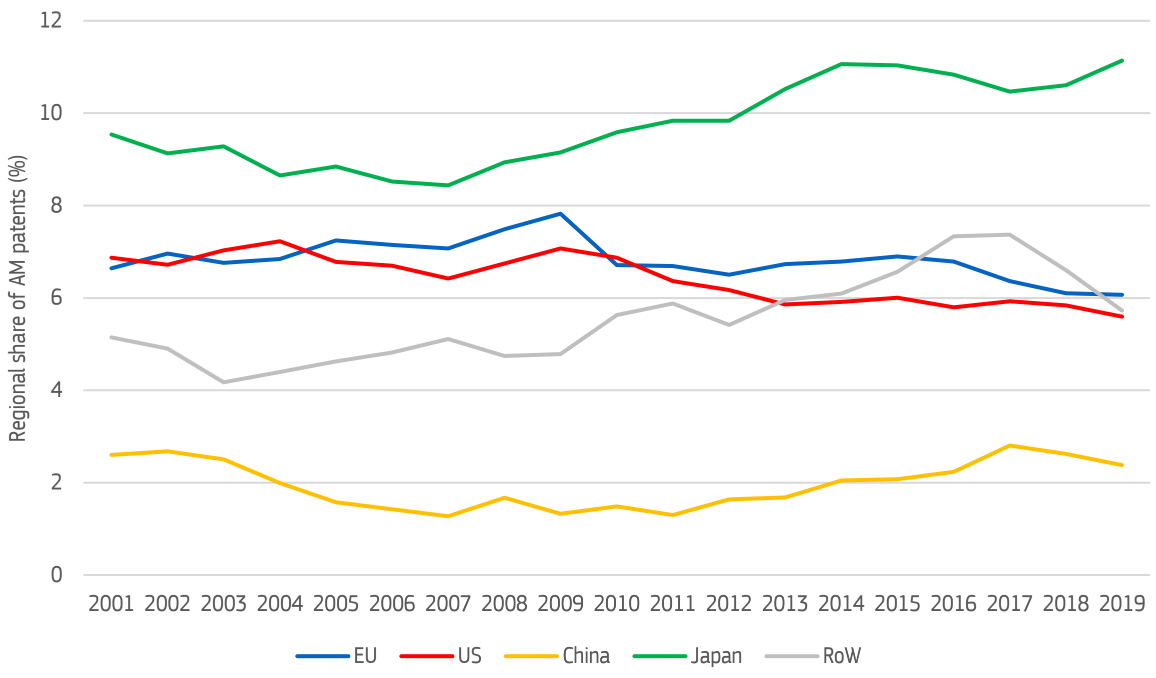
Table 44. Top 10 Scoreboard companies in terms of advanced materials patents

Company name	Region	ICB 3 Sector	Avg. AM patents per year
Fujifilm	Japan	ICT producers	296.82
Dow	US	Chemicals	250.72
BASF	EU	Chemicals	238.61
Samsung Electronics	ROW	ICT producers	226.66
Tokyo Electron	Japan	ICT producers	200.33
Sumitomo Chemical	Japan	Chemicals	197.97
Nitto Denko	Japan	Chemicals	186.93
3M	US	Industrials	180.81
LG Chem	ROW	Industrials	173.55
Shin-Etsu Chemical	Japan	Chemicals	166.99

Note: Average number of AM patents filed between 2001 and 2019
Source: JRC based on COR&DIP v4 and PATSTAT 2023 spring edition

Figure 92 and Figure 93[181] support this view in part, especially concerning the geographical dimension. In fact, though the share of AM patents within sectoral portfolios (bottom panel) is quite heterogeneous (e.g. high for chemicals and construction, lower for ICT and automotive), it is also quite stable over time. The main exception in this sense is the construction sector, in which the weight of AM patents has been falling in recent years. Along the geographical dimension we also observe some heterogeneity between regions, albeit less pronounced. At the same time, there seems to be a slow but steady growth of the relevance of AM in the patenting portfolio of Japanese Scoreboard companies, which is mirrored by a similarly slow and steady decline in the weight of AM patents in the portfolio of EU- and US-based Scoreboard companies.

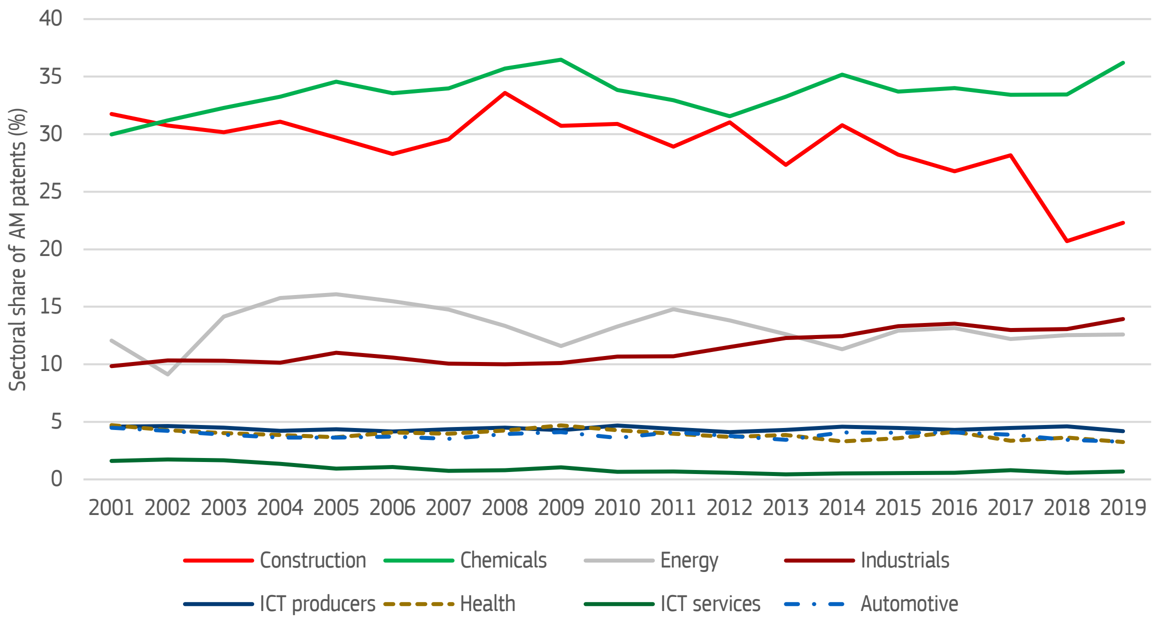
Figure 92. Regional weight of AM patents over time



Source: JRC based on COR&DIP v4 and PATSTAT 2023 spring edition

[181] In the interest of readability, we excluded from Figure 92 sectors (e.g. aerospace and defence, financials) with a low share of AM patents on their global portfolio.

Figure 93. Sectoral weight of AM patents over time



Source: JRC based on COR&DIP v4 and PATSTAT 2023 spring edition

8.4 Key points

— Advanced materials are a priority in European industrial policy, with potential for reduced cost substitutes, higher added-value products, and significant improvements in aerospace, transport, building, and healthcare.

— A patent analysis reveals that global growth in advanced materials (AM) patents aligns with the global trend. Japanese firms lead with 40% of all AM patent filings, followed by the US and the EU. Notably, China has experienced significant growth in the last decade.

— Within the EU, there are substantial regional differences, with German and French firms being responsible for the majority of AM patents filed by EU Scoreboard companies.

— Sectors demonstrating higher relative specialization in AM patents include chemicals, construction, industrials, and energy industries. The strong specialization of Japanese firms in chemical patents contributes to Japan's dominance in the AM patent landscape.

— BASF, a chemical company, is the sole EU representative in the top 10 Scoreboard companies with the highest number of AM patents. This underscores the need for further incentives in the EU as the advanced materials innovation landscape continues to evolve.

9 Artificial intelligence: an ecosystem perspective

Artificial intelligence (AI) is increasingly being employed in a vast number of industrial sectors. This chapter proposes an overview of the AI domain as mapped by the Digital Techno-Economic ecoSystem (DGTES) methodological approach. This approach allows us to compile a unique database from heterogeneous data sources[182], covering the technological, geographical and financial dimensions, as well as the interlinkages and interconnections between players involved in AI-related activities. It also allows to us identify the Scoreboard companies that engage in AI-related activities.

The section is organised as follows: first, the digital techno-economic ecosystem approach is introduced in section 9.1, then the identified actors are presented and analysed along geographical (section 9.2) and sectoral (Section 9.3) characteristics. The trends and specialisation patterns in the global AI landscape over the time period 2009-2022 are presented in section 9.4, and section 9.5 zooms in on the Scoreboard companies in the AI ecosystem. The final section 9.6 summarises the key points of the analysis.

9.1 Artificial intelligence as digital techno-economic ecosystem

In DGTES, the activities that form the AI domain include research, development and innovation (R&D&I) processes and general economic processes related to producing AI-related goods or other services (see Box 7). Following Samoili et al. (2020)[183], patenting and publications are considered the most representative R&D&I outcomes: patents are intended to proxy for innovation and industrial developments in the field, while scientific publications should capture the most important theoretical advancements and other results of academic research. Thanks to the granularity of the DGTES database, it is possible to look at individual players' features, such as organisational type, and so identify firms, universities, research institutes and governmental institutions that are actively engaging in AI-relevant activities, and their geographical location. By comparing different geographical areas as well as the same area over time, DGTES can offer an original overview of the evolving international industrial and research landscape for AI[184].

Box 7. The digital techno-economic ecoSystem (DGTES)

In the digital techno-economic ecoSystem (DGTES) we apply the TES analytical approach[185] to the study of the digital ecosystem. The main aim of DGTES is to map the digital ecosystem and provide an analysis of its elements, structure and features from a holistic, multidimensional and policy-relevant perspective. The JRC Technical Reports by Calza et al. (2022; 2023)[186] describe in detail the application of the JRC's TES methodology to the worldwide digital ecosystem, explaining the steps leading to the generation of the DGTES graph database and introducing its main metrics and indicators.

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182 The data sources for this work are repositories of documents that carry textual information on patents and journal articles (EPO Patstat and Scopus), firm-level databases (i.e. BvD Orbis Crunchbase, Dealroom, and Dow Jones), and EU funded projects (Cordis, for Framework Programmes: FP7, Horizon 2020, Horizon Europe). Only documents issued between 2009 and 2022 are considered.

183 Samoili, S., Righi, R., Cardona, M., Lopez Cobo, M., Vazquez-Prada Baillet, M., & De Prato, G. (2020). *TES analysis of AI Worldwide Ecosystem in 2009-2018* (JRC Technical Report No. JRC120106). Publications Office of the European

184 The DGTES methodology can also be employed to study and analyse the web of collaborations across players. In this way, by looking at the global and European networks of collaboration in R&D&I activities, it can contribute to shedding light on the interlinkages occurring across AI players – both at individual and aggregate level - as well as on their relative strategic positioning.

185 Techno-Economic ecoSystems (TES) is a replicable methodological approach developed by the JRC Digital Economy Unit to analyse dynamic complex segments of rapidly evolving and emerging technologies. It has been applied to several techno-economic segments such as photonics, earth observation technologies, and artificial intelligence.

186 Calza, E., Dalla Bennetta, A., Kostic, U., Mitton, I., Moraschini, M., Vazquez-Prada Baillet, M., Cardona, M., Papazoglu, Michail, Righi, R., Torrecillas Jodar, J., Lopez Cobo, M., Cira, P., & De Prato, G. (2023). *Analytical insights into the global digital ecosystem (DGTES)* (JRC Technical Report No. JRC132991). Publications Office of the European Union. https://publications.jrc.ec.europa.eu/repository/bitstream/JRC132991/JRC132991_01.pdf and Calza, E., Dalla Bennetta, A., Kostic, U., Mitton, I., Vazquez-Prada Baillet, M., Carenini, M., Cira, P., De Prato, G., Righi, R., Papazoglu, Michail, Lopez Cobo, M., & Cardona, M. (2022). *A policy oriented analytical approach to map the digital ecosystem (DGTES)* (JRC Technical Report No. JRC130799). Publications Office of the European Union. https://publications.jrc.ec.europa.eu/repository/bitstream/JRC130799/JRC130799_01.pdf

The technological perimeter of the DGTES digital ecosystem is defined by 15 digital areas, which correspond to internally-coherent, forward-looking, policy relevant techno-economic categories used to cluster digital technologies that relate to the same technological domain (e.g. "Artificial Intelligence"). Each digital area encompasses a set of technologies that are associated to a unique dictionary of keywords, which constitutes the "semantic space" characterising the digital ecosystem. These keywords serve as the foundation for more complex queries to search for relevant documents in selected heterogeneous data sources. In DGTES, the considered data sources correspond to repositories of documents that carry textual information, as it is the case of patents and journals repositories (i.e. EPO, PATSTAT and Scopus) and firm-level databases (i.e. BvD Orbis and Crunchbase, among others). The detection of relevant documents through text search allows us to generate the DGTES database.

In DGTES, each 'activity' shaping the digital ecosystem corresponds to one document (e.g. a business description or the abstract of a patent application) containing detailed textual information about the activity itself and its characteristics (attributes) as well as about the players that perform them (e.g. the firms that participated in a patent application).

DGTES activities include:

i) ***business*** activities, derived from information on firms' core business and on the production, supply or exchange of goods or services, and/or on investments and funds financing industrial and business initiatives (e.g. venture capital deals);
ii) ***innovation*** activities, corresponding to outputs of R&D activities in the form of patenting initiatives (i.e. filing priority patents) and/or participation in innovative research projects (i.e. EU-funded research programme projects such as FP7, Horizon 2020 (H2020) and Horizon Europe[187]);
iii) ***research*** activities, reflecting academic contributions to frontier research, such as publications in selected journals.

Using the information contained in each activity, DGTES is able to identify the players engaging in the production and exchange of knowledge, goods or services in the digital realm.

DGTES players include:

i. *firms*;
ii. *academic institutions and research centres*;
iii. *governmental authorities and bodies.*

Since the information about each individual player's location is collected as geographical coordinates, DGTES also allows us to focus on different levels of geographical agglomeration (e.g. country level, regional level, city level). In this respect, players belonging to the same entity, but based in different locations, are considered as distinct individual players (e.g. a subsidiary company appears in DGTES as a separate individual player from the mother company).

Thanks to this unique database, DGTES allows us to generate indicators and metrics suitable for investigating and better understanding the geographical distribution, technological development and evolution of the complex and dynamic digital ecosystem. These also include network indicators, to account for the detection of strategic positioning and dependencies.

Mapping the digital ecosystem and analysing its elements, structure and features from a holistic, multidimensional and policy-relevant perspective, DGTES can offer novel analytical insights for Europe's competitiveness and digital leadership, knowledge flows, research networks, and innovation performance.

Thus, DGTES can serve as policy-relevant analytical instrument to inform, assess and ultimately improve policies aiming to promote both the digital and green transitions.

9.2 Mapping the global AI ecosystem

In DGTES, the digital domain of AI entails various technological solutions, such as natural language processing, machine learning, deep learning, human-machine interaction, visual and speech recognition, neural networks, etc. This AI ecosystem analysis, however, excludes other technologies or applications that may be

[187] The information regarding EU-funded research programme projects in AI is considered only when analysing the situation of EU Member States (MS) (see Calza et al 2023).

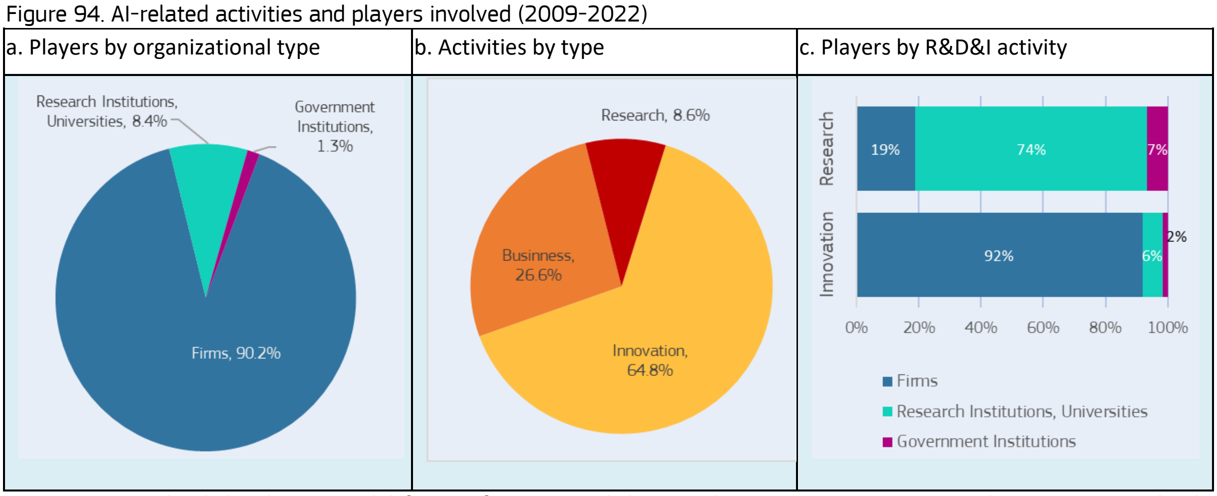
enabled or enhanced by AI but are not an integral part of the AI technology ecosystem, such as robotics, virtual or augmented reality and high-performance computing. These technologies are covered under their corresponding digital areas in DGTES.

Over the considered period (2009-2022), the number of players (firms, universities, research institutions and governmental organisations) that are involved in one or more AI-related R&D, innovation or industrial activities exceed 110 000 worldwide. This is more than one fifth of all digital players (600 000) mapped by DGTES. These players are involved in about 190 000 activities, corresponding to 16% of all activities in the global digital ecosystem.

Figure 94 breaks down the number of players and activities in the AI domain in the period 2009 to 2022 by (a) type of organisation and (b) type of activity. Three out of four activities are related to R&D&I (i.e. patents and journal articles); the remaining activity corresponds to businesses producing or commercialising products or services that apply or provide AI-related technological solutions (Figure 94, panel a). This represents a larger share of R&D&I activities in AI with respect to the whole digital ecosystem, where R&D&I represents 60% of activities, indicating that AI is more “R&D&I-oriented” than the rest of the digital ecosystem. This is consistent with what emerges from the composition of AI players (Figure 94, panel b): the share of research institutions and universities engaging in AI-related activities is double than in the entire digital ecosystem (8% and 3% of players, respectively), confirming a stronger presence of frontier research in the AI domain. Firms represent the vast majority of players (more than 90%) in AI, similar to the digital ecosystem overall.

Focusing on R&D&I activities, panel (c) in Figure 94 shows to what extent different types of players engage in innovation and research activities. While firms represent 80% of all players engaging in R&D&I activities in AI, there are remarkable differences between innovation and research activities. Patents are mostly filed in by firms (92% of players involved in innovation activities), with a smaller – but not negligible - contribution from research institutions and universities (about 6% of players). In contrast, research institutions and universities represent a large majority of the players participating in research activities (about 74%), while firms play a smaller but relevant role (19%). The fact that government institutions play a certain role only in research activities (7% of players) can be explained by the higher level of uncertainty that typically characterises frontier research in emerging and dynamic technological domains, which may benefit from the participation of governmental organisations or similar bodies, which are able to bear the risks of exploratory research. For comparison, in the global digital ecosystem, 94% of all players engaged in innovation activities and 2022% of the players in research activities are firms.

Figure 94. AI-related activities and players involved (2009-2022)



Note: For a more detailed explanation and definition of activities and players in the AI ecosystem, see Box 7 in this section. In panel c, the same individual player can engage in more than one of the three types of activity (i.e. the same firm engaging in both business and innovation activities). Thus, the sum of the number of players in each type of activity can exceed the total number of individual players.

Source: The 2023 EU Industrial R&D Investment Scoreboard, European Commission, JRC/DG R&I.

Table 45 breaks down the number of players active in AI by industrial sector. The AI ecosystem is not limited to specific sectors and includes players from various industries. The top two sectors where AI players operate are ‘information and communication’ (29% of all players) and ‘education’ (18%). These are followed by ‘professional, scientific and technical activities’ (15%) and ‘manufacturing’ (12%), which remain notably ahead of all other sectors.

However, the sector composition differs quite remarkably by the nature of performed activities. Most AI players engaging in research and innovation activities are from the 'education' sector; this holds in particular for players engaging in research activities, which is 55% of players in this sector. This confirms the 'R&D&I-oriented' character of the AI domain, characterised by above-average participation by research institutions and universities and relatively few firms (i.e. spin-offs of universities).

Besides 'education (23%), one fifth of players with AI-related patents operates in 'information and communication' and another 20% in 'manufacturing'. On the other side, for AI-related business activities, the composition of players confirms the strong 'ICT orientation' of the AI domain, as half of these players operate in the 'information and communication' sector. Other relatively strong sectors are 'professional, scientific and technical activities' (20%), 'wholesale and retail trade' (6%), 'administrative and support service activities' (6%), and 'manufacturing' (5%).

This sectoral composition shows the orientation of business activities towards the provision of AI-related services to end consumers and other firms operating in any economic sector. In turn, the latter can be regarded as an indication of AI adoption and uptake in the economy.

Table 45. Players in the AI domain, by industrial sector (%), 2009-2022

	Sector	All activities	Research	Innovation	Businesses
C	Manufacturing	**12.2%**	2.8%	**20.5%**	**6.1%**
D	Electricity, gas, steam and air conditioning supply	2.0%	0.1%	4.2%	0.1%
E	Water supply; sewage, waste management and remediation activities	0.1%	0.0%	0.1%	0.1%
F	Construction	1.3%	0.2%	1.1%	1.7%
G	Wholesale and retail trade; repair of motor vehicles and motorcycles	**7.1%**	3.1%	**8.5%**	**6.7%**
H	Transportation and storage	0.9%	0.3%	0.9%	1.1%
I	Accommodation and food service activities	0.9%	1.2%	0.6%	1.1%
J	Information and communication	**29.1%**	1.0%	**19.1%**	**47.8%**
K	Financial and insurance activities	2.9%	0.2%	3.5%	2.9%
L	Real estate activities	0.6%	0.5%	0.4%	0.9%
M	Professional, scientific and technical activities	**14.9%**	**10.5%**	**11.4%**	**19.8%**
N	Administrative and support service activities	3.4%	1.6%	2.1%	**5.4%**
O	Public administration and defense	2.2%	**13.8%**	1.0%	0.1%
P	Education	**17.8%**	**54.8%**	**22.7%**	2.0%
Q	Human health and social work activities	2.6%	3.7%	2.8%	2.0%
R	Arts, entertainment and recreation	0.4%	0.9%	0.1%	0.7%
S	Other service activities	1.8%	**5.4%**	0.9%	1.7%
T	Activities of households as employers	0.0%	0.0%	0.0%	0.0%

Note: Share of IA players broken down by NACE Rev.2 industrial classification. The same individual player can engage in more than one of the three types of activity (i.e. the same firm engaging in both business and innovation activities). Thus, the sum of the number of players in each type of activity can exceed the total number of individual players.

Source: The 2023 EU Industrial R&D Investment Scoreboard, European Commission, JRC/DG R&I.

From a time perspective, firms have played a dominant role in the AI domain, and their share has been increasing markedly since the beginning of the observation period in 2009 (Figure 95, panel a).

As the number of players, the number of activities has also risen (Figure 95, panel b), whereby the R&D&I activities have been growing faster than business activities during the past decade. In particular, within R&D&I activities, the number of patents has grown at a much faster rate than any other type of activity. This is mostly due to a marked increase in the number of Chinese patent applications since 2015, as a result of Chinese government's policies (Righi et al., 2020, 2021)[188]. Also, the growth of research activities in AI has accelerated since 2020.

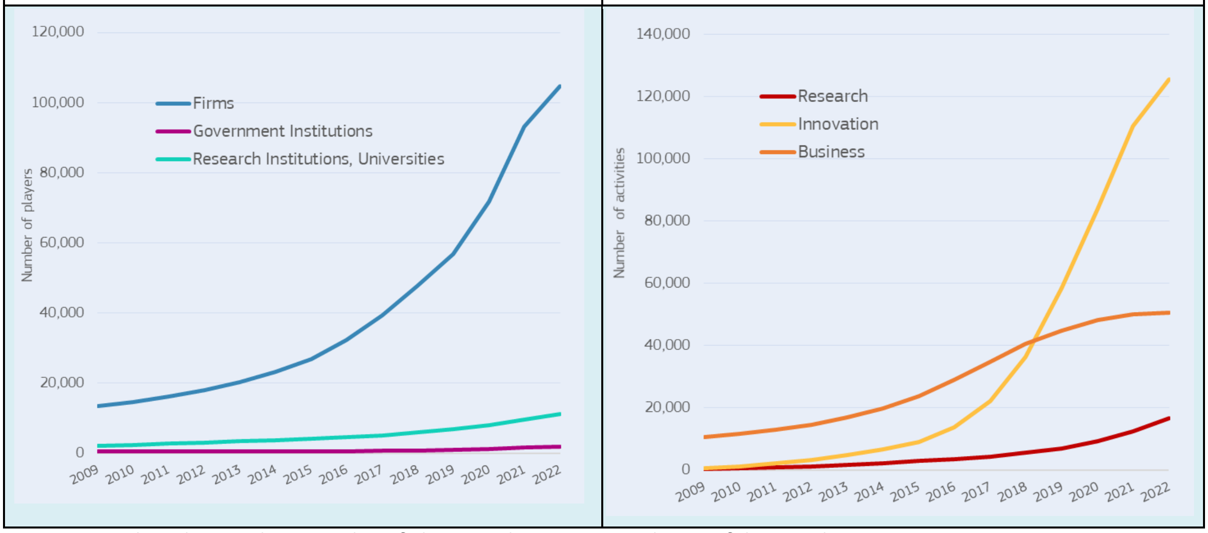
However, there is controversy about the quality of Chinese patents with respect to other advanced countries in terms of patent quality, value or business impact capacity. In fact, several studies analyse the issue and

[188] Righi, R., Samoili, S., Lopez Cobo, M., Vazquez-Prada Baillet, M., Cardona, M., & De Prato, G. (2020). The AI techno-economic complex System: Worldwide landscape, thematic subdomains and technological collaborations. *Telecommunications Policy*, *44*(6). https://www.sciencedirect.com/science/article/pii/S0308596120300355 and Righi, R., Lopez Cobo, M., Samoili, S., Vazquez-Prada Baillet, M., & De Prato, G. (2021). *EU in the global Artificial Intelligence landscape* (Science for Policy Brief No. JRC125613). European Commission. https://publications.jrc.ec.europa.eu/repository/bitstream/JRC125613/JRC125613_01.pdf

find overall lower performance for Chinese patents (Fisch et al., 2017[189]; Christodoulou et al., 2018[190]; Boeing at al., 2019[191]).

Figure 95. Number of players and activities in the AI domain in the period 2009 to 2022

a. Players by organizational type	b. Activities by type



Note: Figures show the cumulative number of players and activities in each year of the period in question.
Source: The 2023 EU Industrial R&D Investment Scoreboard, European Commission, JRC/DG R&I.

9.3 The geography of AI

One indicator of a country or region's involvement in AI-related processes (Samoili et al., 2020) is the number of players and their activities. Figure 96 displays the top 10 geographical areas per absolute number of players and activities and their respective composition. In this regard, the AI domain reflects the geographical concentration observed in the global digital ecosystem (Calza et al. 2023), with the US, China and the EU jointly hosting about 70% of worldwide players and 76% of activities in AI.

China has the highest number of AI players (38% of all AI players), followed by the US (20%) and the EU (11%) (Figure 96, Panel a). Firms represent the vast majority of players (above 90% in all regions except in China (88%) and in the EU (87%)). Interestingly, both China (9.5%) and the EU (11%) display a higher share of research institutions engaging in AI activities than the US (4%).

The presence of research institutions is particularly noticeable in China, whose absolute number almost triplicates the number in the EU (4 074 vs 1 414) and is more than four times the number in the US (859). Even if this does not allow us to assess the quality of conducted research, the relatively larger participation by research institutes and universities seems to be a relevant feature of the AI domain, potentially increasing the links between research and innovative outcomes (Righi et al., 2021). Government institutions occupy a small role in all considered regions, even in China, which is the area with the highest share (1.8% of Chinese players).

The location of players indicates the spatial distribution of AI activities. Figure 96 (panel b) confirms the leading position of China (50% of AI activities), the US (18%) and the EU (8%). Yet, the ranking changes by type of activity: China accounts for about 66% of global R&D&I activities, but the Chinese share rises to 72% if only innovation (patent) activities[192] are considered. This can be related to the fact that patenting in China

189 Fisch, C., Sandner, P. and Regner, L., 2017. The value of Chinese patents: An empirical investigation of citation lags. *China Economic Review*, 45, pp.22-34.

190 Christodoulou, D., Lev, B. and Ma, L., 2018. The productivity of Chinese patents: the role of business area and ownership type. *International Journal of Production Economics*, 199, pp.107-124.

191 Boeing, P. and Mueller, E., 2019. Measuring China's patent quality: Development and validation of ISR indices. *China Economic Review*, 57, p.101331.

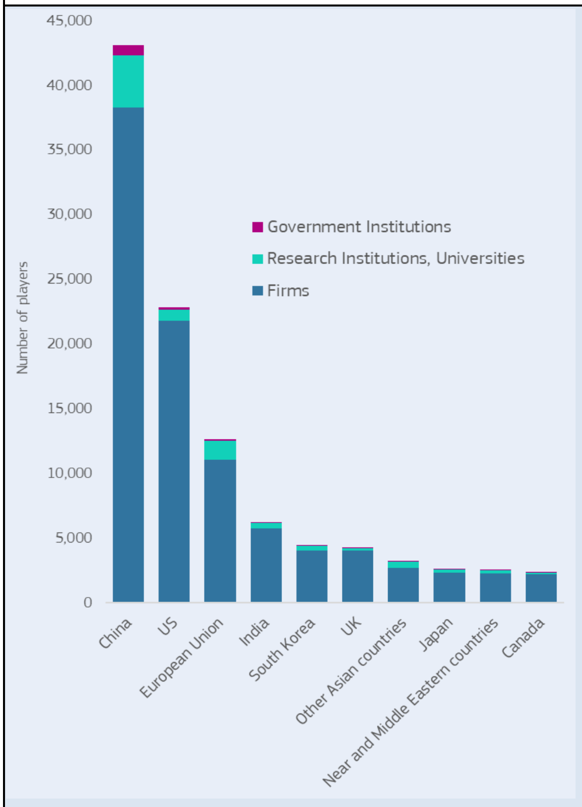
192 DGTES considers priority patent applications to proxy innovation activities, without filtering for the specific office the patent is registered in. This is in line with the methodological focus of DGTES, whose aim is to identify all digital players (in the sense that leave any "digital footprint") all other the world, to be able to track knowledge flows.

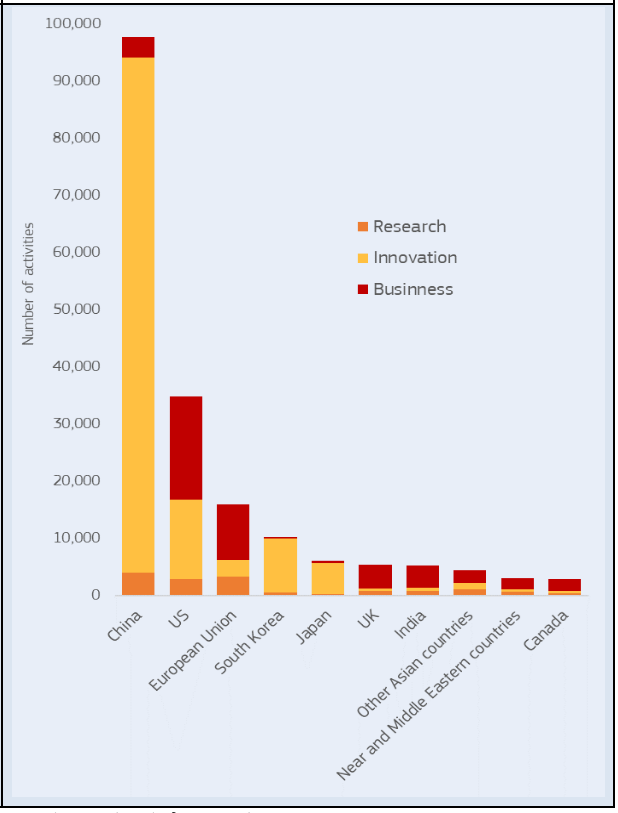
increased remarkably since 2015, as a result of Chinese government's policies supporting patent applications (Righi et al., 2020, 2021).

Similarly, South Korea and Japan have produced large numbers of patents (more than 90% of their AI activities), ranking ahead of the EU if only innovation activities are considered. China leads also in terms of AI research activities; yet the EU leads jointly with China, having almost the same number of journal articles on AI (resulting in a higher share in the EU). Finally, the US and the EU – together with the UK and India - are characterised by a majority of AI-related business activities, leading the ranking based on AI industrial activities.

Figure 96. Composition of players and activities in the AI domain for the top 10 regions (2009-2022)

a. Players by organisational type	b. Activities by type



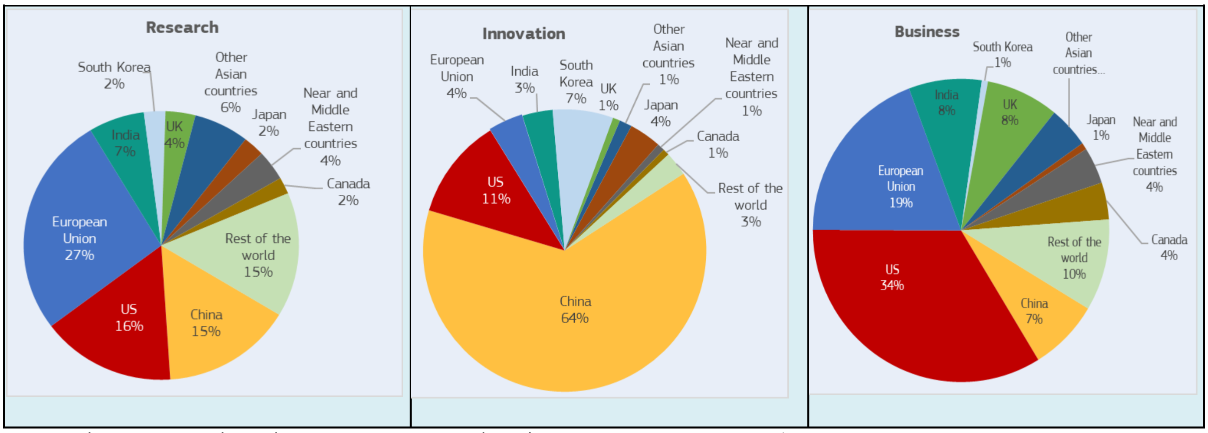


Note: In panel b., the number of activities in each geographical area is obtained with fractional counting.
Source: The 2023 EU Industrial R&D Investment Scoreboard, European Commission, JRC/DG R&I.

The location of AI players also varies by type of activity (Figure 97), specifically on research (panel a) and innovation (panel b). When considering AI-relevant publications (panel a), the EU (27%) comes on top, followed by the US and China. Regarding patents (panel b), however, China (63%) comes first followed by the US and South Korea. The EU share of players with patents (4%) is low and similar to that of India and Japan (4%). Finally, the US (34%) has highest number of firms involved in AI-related industrial activities, followed by the EU (19%). This may reveal the long-term, significant role of AI in the US economy, as private commercial initiatives are already mature and active in the AI market (Samoili et al., 2020).

Figure 97. Players by geographical area in the AI domain, all activities and R&D activities (2009-2022)

Panel a. Research	Panel b. Innovation	Panel c. Business



Source: The 2023 EU Industrial R&D Investment Scoreboard, European Commission, JRC/DG R&I.

9.4 Trends and specialisation in the global AI landscape

AI has become a digital domain of strategic importance, entailing about 16% of all activities in the DGTES digital ecosystem[193]. Its importance is visible in the main geographical areas considered; still, some regional differences are noticeable (Figure 98, panel a). For instance, Asian countries such as China, Japan, South Korea and India display a larger-than-average share of AI activities, while the US, the EU and UK remain slightly below this threshold.

Moreover, during the past decade, the importance of AI has grown remarkably in the whole digital ecosystem. This is revealed by the increasing number of AI-related activities with respect to all activities considered in the DGTES digital ecosystem (Figure 98, panel b): the share of AI-related activities increased by three times between 2009 and 2022 (from 6% to 17%) and by four times (from 5% to 20%) in the case of R&D&I activities.

However, while AI has been an important domain in research activities since the beginning of the considered period, the share of AI-related patents has grown significantly since the mid-2010s, and currently represents 20% of patents in DGTES.

Figure 98. Number of AI activities over total number of activities in DGTES

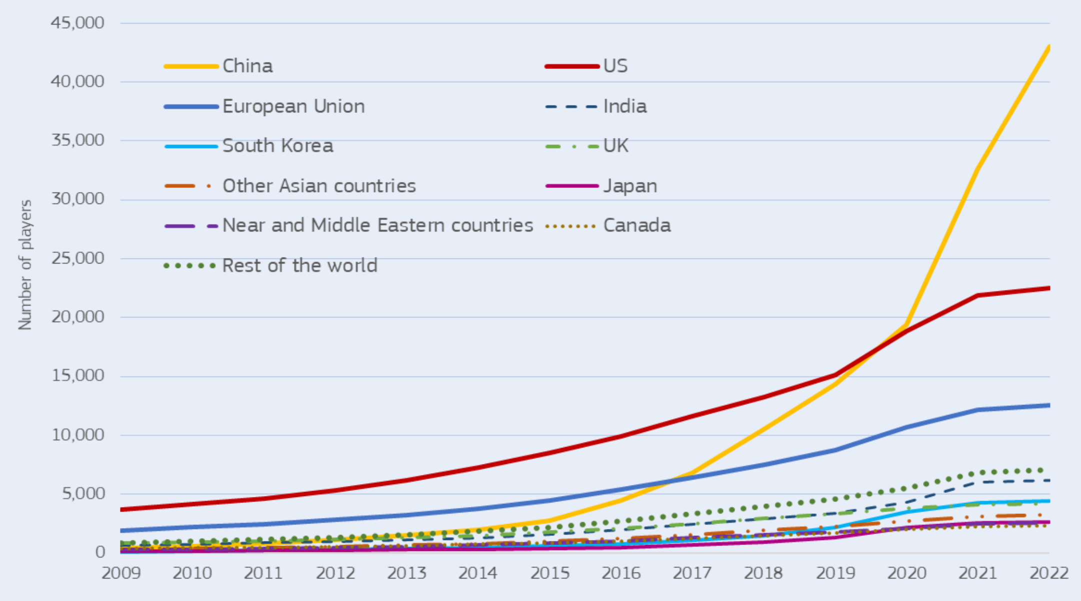
Panel a. By top 10 geographical areas | Panel b. By year

Source: The 2023 EU Industrial R&D Investment Scoreboard, European Commission, JRC/DG R&I.

Although the number of players engaging in AI-related activities constantly increased from 2009 to 2022 in all main geographical areas, this growth has accelerated since 2019 (Figure 99). The evolution of the number of players over time shows a large increase in Chinese players particularly in recent years, exceeding the US since 2020. While the United States was at the forefront of AI activity hosting the largest number of AI-related players, China has been rapidly catching up since mid-2010s (mostly driven by innovation).

193 For a more detailed explanation and definition of activities and players in the AI ecosystem, see Box 7 in this section.

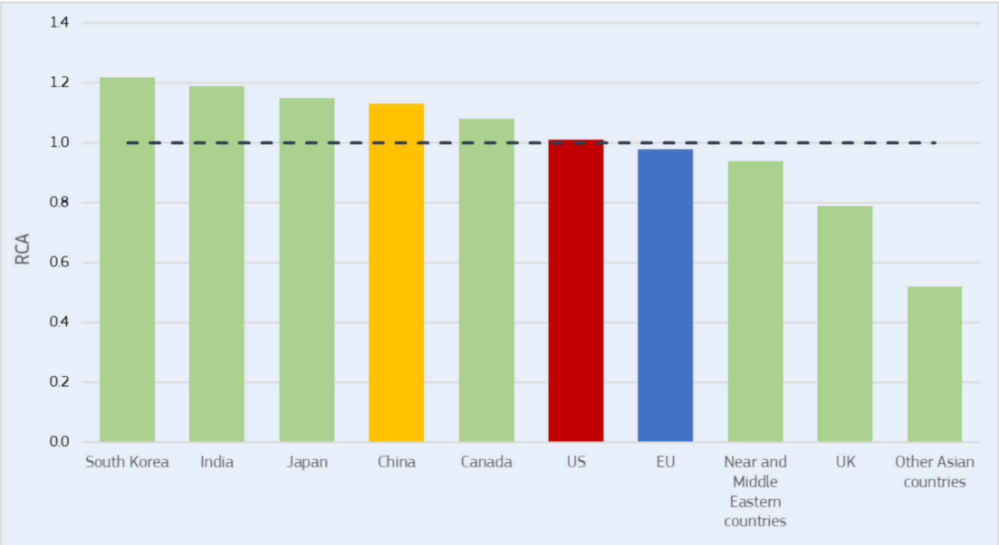
Figure 99. Number of players in the AI domain in top 10 geographical regions in the period 2009 to 2022



Source: The 2023 EU Industrial R&D Investment Scoreboard, European Commission, JRC/DG R&I.

The revealed comparative advantage (RCA) measures the relative specialisation of a geographic area within the global digital ecosystem. This indicator is calculated by comparing the geographical area's share of activities in a specific digital area (AI in this case) against the global average in that same digital area (Samoili et al., 2020). RCA is a measure for the relative engagement of a certain geographical area in the AI domain in comparison with the world average specialisation in AI. An RCA value of 1 represents the world average in AI and a value of RCA higher (or lower) than 1 means that the geographical area has a higher-than-world (or lower-than-world) average proportion of activities in AI, indicating possible relative comparative advantage (or disadvantage). Figure 100 displays the RCA scores in AI of the top geographical areas in terms of absolute number of AI activities. Six of the ten top regions have a RCA higher than 1, including China and the US. The EU has a RCA slightly lower than 1, hence the EU is less specialised in AI than other advanced economies.

Figure 100. RCA in the AI domain, by geographical area (2009-2022)



Source: The 2023 EU Industrial R&D Investment Scoreboard, European Commission, JRC/DG R&I.

9.5 The Scoreboard firms in the AI ecosystem

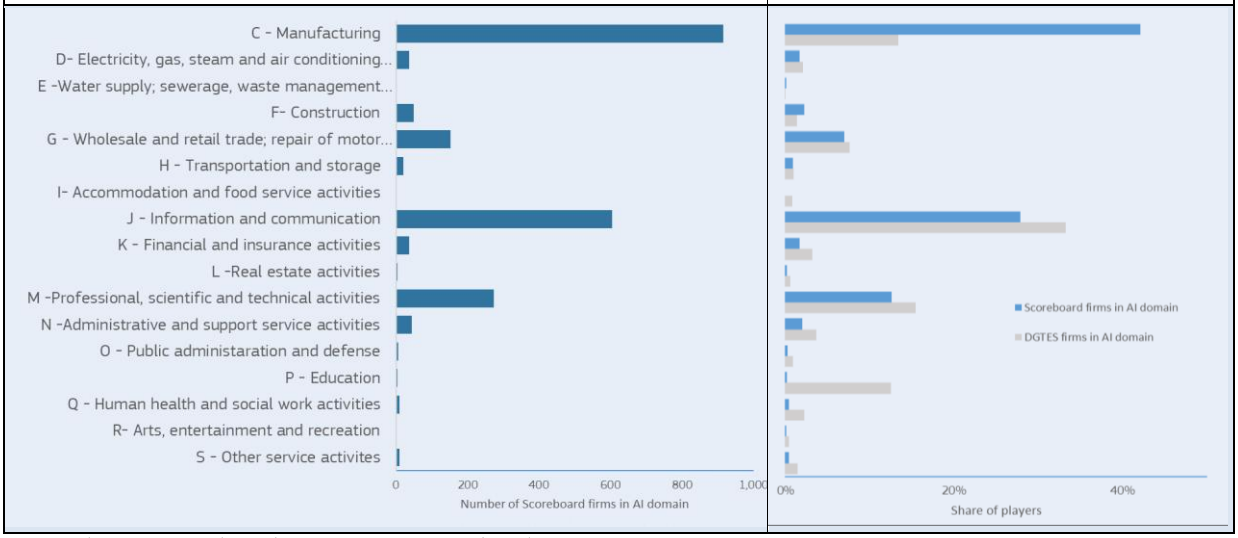
This section focuses on the subsample of firms in the AI ecosystem (that is, firms that engage in at least one innovation, research or business activity that contribute to shaping the global AI ecosystem) that also appear in the list of firms of the Scoreboard 2023. The application of the DGTES approach allows identifying 105 374 firms worldwide involved in the AI ecosystem. Out of these, 2 170 are covered by the Scoreboard 2023. These Scoreboard firms in the AI domain will be the focus of the analysis in this section.

The nature of DGTES approach allows us to consider the digital ecosystem as horizontal, overcoming the constraints of industrial classifications and potentially embracing all industrial sectors. Hence, firms in the AI ecosystem are not limited to ICT and manufacturing sectors and include players from other sectors such as education and professional activities. This horizontal approach is different to comparing the sectoral composition of the subset of firms matched with the Scoreboard and the overall AI ecosystem.

Focusing on the subset of AI firms from the Scoreboard, 42% of firms belong to the 'manufacturing' sector and 54% operate in services, of which more than half in 'information and communication' (28% of all considered firms). However, in the overall AI ecosystem it takes more sectors to cover 70% of firms, including 'professional, scientific and technical activities', 'wholesale', and 'education', which represents a large share of AI players in the global ecosystem.

Figure 101. Sectoral composition of Scoreboard firms engaging in AI activities

a) Number of Scoreboard firms in AI domain	b) Sector composition of Scoreboard in AI domain and of all firms in AI domain



Source: The 2023 EU Industrial R&D Investment Scoreboard, European Commission, JRC/DG R&I.

The information in the AI ecosystem database allows us to rank firms according to the number of activities they engage in. Figure 101 shows the top AI firms per number of patents. The top three firms have more than 7 000 AI-related patents each (over the entire period 2009-2022). The leading firm is IBM, with almost 9 000 AI-related patents. This is in line with the study of Eisfeldt, Schubert & Zhang (2023)[194] which found IBM as the firm most involved in generative AI out of the 100 largest publicly traded firms headquartered in the US. They show that the ChatGPT may have had a positive effect on the competitive pressure on firms that are more exposed to Generative AI and related Large Language Models (LLMs). Therefore, there is evidence these firms are more incentivised to innovate in AI and to engage in AI-related innovation activities.

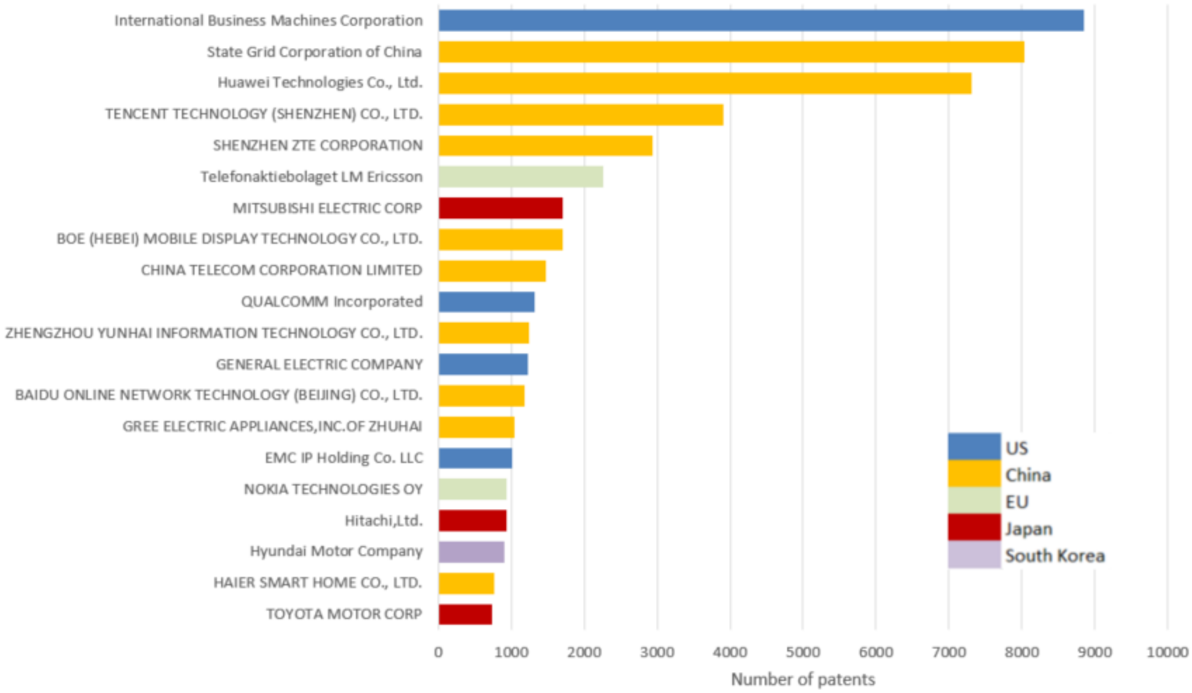
From a regional perspective, China clearly leads the ranking, with half of the top 20 AI firms registered in the country. While the innovative power of Chinese firms should not be underestimated, it is important to note that the Chinese government subsidises those firms that apply for patents. Therefore, Chinese firms are encouraged to apply for patents no matter how innovative their application is. In fact, many Chinese patents are only registered locally, without seeking protection from international competitors.

As for the EU, two firms located in Sweden and Finland make it to the top, accounting for over 3 200 patents. The leading role of the Nordic countries in AI is further supported by a recent survey indicating that more than 25% of the Nordic firms are already investing at least 20% of their R&D budget in AI projects[195].

[194] Eisfeldt, A. L., Schubert, G., & Zhang, M. B. (2023). Generative ai and firm values (No. w31222). NBER

[195] Nordic State of AI 2022 report | Silo AI Insights on Nordic artificial intelligence strategies | Computer Weekly

Figure 102. Top 2023 Scoreboard companies engaged in AI



Note: Countries refer to the geographical location of the company actually filing the patent application.
Source: The 2023 EU Industrial R&D Investment Scoreboard, European Commission, JRC/DG R&I.

9.6 Key points

- More than one fifth of digital players mapped by DGTES worldwide are involved at present in ca. 190 000 R&D, innovation, or commercial activities (or 16% of all activities in the global digital ecosystem).
- AI is largely R&D driven. In fact, three out of four activities are related to patenting and publishing scientific progress in journal articles. This high share suggests a higher 'R&D&I-oriented' character of AI with regard to the rest of the digital ecosystem.
- The composition of AI players also reflects the R&D strength. The share of research institutions and universities engaging in AI-related activities is twice as high as the entire digital ecosystem (8% and 3% of players, respectively).
- The relevance of AI in the entire digital ecosystem has increased from 2009 to 2022: the share of AI-related activities increased by three times between 2009 and 2022 (from 6% to 17%).
- The number of scientific journals, patents and business activities in the AI domain has risen significantly from 2009 to 2022. Particularly impressive has been the fast rate of patents, which has been increasing since 2015 due to a marked acceleration of patent filing in China, as result of government support.
- China hosts the highest number of AI players (38% of all AI players), followed by the US (20%) and the EU (11%). The EU falls down the ranking when only players with AI-related patents are considered. Here, China (63%) is first followed by the US (12%), South Korea (7%), EU (4%), Japan (4%) and India (3%).
- In terms of relative strength, Europe's revealed comparative advantage is slightly below 1, meaning that Europe's AI specialization is below the world average.
- Most players in the AI domain operate in the industrial sectors of "information and communication" (29% of all players) and "education" (18%), followed by "professional, scientific and technical activities" (15%) and "manufacturing" (12%). Looking at the Scoreboard companies active in AI, these are mostly found in the manufacturing (42%) and ICT (28%) sectors. Among the top 20 Scoreboard companies active in AI there are two European firms, namely Ericsson and Nokia.

10 Conclusions

Monitoring and analysing the state of innovation activity in Europe provides vital inputs to on-going EU policymaking in this domain[196]. Indeed, the 3% of GDP R&D investment target and promoting industrial research and innovation are central to the EU's long term agenda including alignment of national and EU policy measures to improve competitiveness and resilience in the global tech race and in coping with global uncertainties.

In this context, the EU Industrial R&D Investment Scoreboard monitors and benchmarks the performance of the EU's leading industrial R&D investors against their peers globally. Over 20 years since its first edition, the Scoreboard has been a reliable source of key insights for companies, researchers and policy-makers.

The 2023 Scoreboard lists and analyses both the world's top 2 500 companies and the top 1 000 EU-based companies by value of worldwide R&D investment in 2022. The top 2 500, with headquarters in 42 countries and over 1 million subsidiaries, each invested over EUR 53 million in R&D in 2022. The 2 500 R&D investment total amounted to EUR 1 249.4 billion - over 80% of the world's business-funded R&D. The top 50 account for around 40% of this total, as has consistently been the case over the years, constituting a significant concentration of R&D in a relatively small number of companies.

The top 2 500 includes 367 EU-based companies, accounting for 17.5% of the R&D total, 827 US companies (42.1%), 679 Chinese companies (17.8%), 229 Japanese companies (9.3%) and 398 from the rest of the world (13.2%). The RoW group comprises companies from South Korea (47), Switzerland (52), UK (95), Taiwan (77) and a further 18 countries.

Compared to the previous year (2021), companies increased R&D investments in a context of high economic uncertainty, as seen in the large inflation differential between the nominal and real R&D investment growth of 12.7% and 7.2%. The real R&D investment growth rate for EU companies of 7.8% was more than twice the 2021 value, exceeding the US (4.9%) for the first time since 2015 (13.6% and 12.7% in nominal terms for the EU and the US, respectively). Also, the Japanese companies, after a decade of moderate development, increased their R&D strongly by 10.2% (9.4% in real terms). Chinese firms continued to have the highest R&D investment growth rate at 16.4% (14.6% in real terms).

For this 20-year edition, a panel data set covering Scoreboard firms from 2003 to 2022 was analysed. The 10 and 20-year perspectives show that while the EU has continued to host prominent industrial R&D leaders, over time, proportionally fewer EU firms entered the Scoreboard in sectors combining high R&D intensities with high R&D growth (esp. ICT producers, ICT services, health). While EU strongholds such as industrials and automotive have witnessed declining R&D shares during the last 20 years, ICT services and ICT producers gained significant ground.

Four sectors (ICT producers, ICT services, health and automotive) continue to dominate more than three quarters of Scoreboard R&D. The EU leads in automotive R&D, the US in ICT services, ICT producers, and health. China, is in second place for the ICT and health sectors with an increasing number of newcomers entering the ranks.

Most large EU R&D investors are located in three countries (Germany, France, Netherlands). Brexit led to a major reshuffle in the EU 1 000 sample, whereby UK firms leaving the sample mostly resulted in additional firms from Germany, Sweden and France joining, the increase in Scoreboard firms joining from Denmark and Finland was disproportionally high, and from Spain and Italy was disproportionally low. The number of firms from EU widening countries remained stable, and there is no indication of Brexit-induced headquarter relocations in the Scoreboard sample. The majority of the EU 1 000 are outside the four top R&D sectors, indicating a broader sectoral spread of industrial R&D in the EU compared to the US.

A main finding of the 20-year Scoreboard analysis is the essential role of R&D to sustain or improve the economic performance of companies operating in key industries - automotive, health and ICT related sectors. The analysis of the effects of economic crises on Scoreboard firms shows that R&D investments by top firms

[196] September 2020 ERA Communication COM(2020) 628 final, May 2021 updated industrial strategy for Europe COM(2020) 102 final, 2030 Digital Compass COM(2021) 118 final, and European Education Area COM(2020) 625 final; The New European Innovation Agenda COM(2022)332 final, which seeks to position Europe at the forefront of the deep tech innovation, start-ups and scale-ups, improving access to finance. Green Deal Industrial Plan, COM 2023 (162), focusing on net-zero industry, critical raw materials and the transition to climate neutrality. EU long-term competitiveness strategy, which is aiming at a forward-looking, well-defined and coordinated EU framework that will foster thriving businesses, able to compete on the global market.

were more resilient than capital expenditure. Also, R&D investment by top Scoreboard companies proved vital in accelerating sales and productivity growth and enhancing environmental sustainability during times of economic turmoil. After both the financial and COVID-19 crises, capital expenditure and R&D of US firms recovered quicker than for EU companies. These recoveries were led by the ICT software, ICT hardware and health sectors – those in which the EU's competitors are comparatively stronger. In contrast, the two crises hit harder the automotive and other transport-related industries. Thus, the EU sector mix delayed the R&D recovery compared to the US and China.

Beyond monitoring and benchmarking, this edition of the Scoreboard illustrates how Scoreboard metrics can be combined with other data and methods to gain novel insights into the technological advancement of companies.

First, a patent analysis highlights the most recent trends and developments in Green and Clean Transport Technologies by Scoreboard companies, with a special focus on the automotive sector. The EU has remained the leader of high-value inventions as of 2019. Furthermore, over the period 2010 to 2019, the EU and Japan lead in patents in clean transport technologies such as internal combustion engines, electromobility, aeronautics, air transport, and hybrid vehicles.

Second, the automotive industry is analysed in a global value chain framework. The total EU value added in the global final demand for motor vehicles amounted to EUR 511.2 billion. This is more than twice the sector's gross value added and represents 4.3% of the total EU gross value added for that year. Germany alone accounts for almost half of the EU value added (both total and indirect) in the global final demand. Other significant contributors include Spain, France, Italy, Sweden and Czechia, which account for 80% of the value added in the vehicle supply chain. As the largest manufacturing sector in the EU, the automotive industry has long been a mainstay of EU's competitiveness, contributing significantly to employment, trade, and technological advancement, thus meriting specific attention.

Third, relating to the increased interest in policies aimed at leveraging European skills to harness innovation in deep technologies, patents in advanced materials of Scoreboard firms are analysed to grasp their deep tech potential relevant for a wider range of goals in the New Innovation Agenda. Between 2001 and 2020, the number of advanced materials patents rose from 8 000 to nearly 14 000, corresponding roughly to a 75% increase, in line with the global growth in patent filings with Japan in the lead, followed by EU and US.

Finally, a techno-economic ecosystem analysis is presented to understand the role played by Scoreboard companies in an emerging technology such as artificial intelligence (AI). This approach provides insight into the AI domains, players and activities, revealing that the US, China and the EU are the main geographic areas together hosting about 70% of worldwide AI players and 76% of AI activities. The EU is overall less specialised in AI than other advanced economies, but has a higher share of research institutions engaging in AI activities (11%) compared to China (9.5%) and the US (4%). The US host the largest number of Scoreboard firms involved in AI-related industrial activities (34%), followed by the EU (19%).

Following open data practices, the database underlying the Scoreboard is made publicly available on-line to allow stakeholders such as companies, policy makers and researchers to undertake their own benchmarking and monitoring exercises. In addition, for the 20-year-anniversary, we publish a novel panel data set covering the Scoreboard companies over the time period 2003-2022.

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Annex 1. General Information on the Scoreboard

Investment in research and innovation is at the core of the EU policy agenda. The Europe 2020 growth strategy includes the Innovation Union flagship initiative[197] with a 3 % headline target for intensity of research and development (R&D)[198]. R&D investment from the private sector plays also a key role for other relevant European initiatives such as the Industrial Policy[199], Digital Agenda and New Skills for New Jobs flagship initiatives.

The project "Global Industrial Research & Innovation Analyses" (GLORIA)[200] supports policymakers in these initiatives. The Scoreboard, as part of the GLORIA project, aims to improve the understanding of trends in R&D investment by the private sector and the factors affecting it. The Scoreboard identifies main industrial players in key industrial sectors, analyse their R&D investment and economic performance and benchmark EU companies against their global counterparts.

This report describes and analyses the Scoreboard data and provides additional information on the positioning of Scoreboard companies in relation to other key indicators of relevance for industrial innovation policy and industrial R&D positioning. The annual publication of the Scoreboard intends to raise awareness of the importance of R&D for businesses and to encourage firms to disclose information about their R&D investments and other intangible assets.

The data for the Scoreboard are taken from companies' publicly available audited accounts. As in more than 99% of cases these accounts do not include information on the place where R&D is actually performed, the company's whole R&D investment in the Scoreboard is attributed to the country in which it has its registered office (headquarter). This should be borne in mind when interpreting the Scoreboard's country classifications and analyses.

The Scoreboard's approach is, therefore, fundamentally different from that of statistical offices or the OECD when preparing business enterprise expenditure on R&D data, which are specific to a given territory. The R&D financed by business sector in a given territorial unit (BES-R&D) includes R&D performed by all sectors in that territorial unit[201]. **Therefore, the Scoreboard R&D figures are comparable to BES-R&D data only at the global level.**

The Scoreboard data are primarily of interest to those concerned with private sector R&D investments and positioning and benchmarking company commitments and performance (e.g. companies, investors and policymakers). BES-R&D data are primarily used by economists, governments and international organisations interested in the R&D performance of territorial units defined by political boundaries. The two approaches are therefore complementary. The methodological approach of the Scoreboard, its scope and limitations are further detailed in Annex 2 below.

Scope and target audience

The Scoreboard is a benchmarking tool which provides reliable up-to-date information on R&D investment and other economic and financial data, with a unique EU-focus. The 2 500 companies listed in this year's Scoreboard account for 80% to than 90% of worldwide R&D funded by the business enterprise sector and the Scoreboard data refer to a more recent period than the latest available official statistics. Furthermore, the dataset is extended to cover the top 1 000 R&D investing companies in the EU.

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197 The Innovation Union flagship initiative aims to strengthen knowledge and innovation as drivers of future growth by refocusing R&D and innovation policies for the main challenges society faces.

198 This target refers to the EU's overall (public and private) R&D investment approaching 3 % of GDP (http://ec.europa.eu/europe2020/pdf/targets_en.pdf).

199 The Industrial Policy for the Globalisation Era flagship initiative aims to improve the business environment, notably for small and medium-sized enterprises, and support the development of a strong and sustainable industrial foundation for global competition.

200 GLORIA builds on the IRIMA project (Industrial Research and Innovation Monitoring and Analysis). See: http://iri.jrc.ec.europa.eu/home_/. The activity is undertaken jointly by the Directorate General for Research (DG R&I A; see: http://ec.europa.eu/research/index.cfm?lg=en) and the Joint Research Centre, Directorate Growth and Innovation (JRC-Seville; see: https://ec.europa.eu/jrc/en/science-area/innovation-and-growth).

201 The Scoreboard refers to all R&D financed by a company from its own funds, regardless of where the R&D is performed. BES-R&D refers to all R&D activities funded by businesses and performed by all sectors within a particular territory, regardless of the location of the business's headquarters. The sources of data also differ: the Scoreboard collects data from audited financial accounts and reports whereas BES-R&D typically takes a stratified sample, covering all large companies and a representative sample of smaller companies. Additional differences concern the definition of R&D intensity (BES-R&D uses the percentage of R&D in value added, while the Scoreboard considers the R&D/Sales ratio).

The data in the Scoreboard, published since 2004, allow long-term trend analyses, for instance, to examine links between R&D and business performance.

The Scoreboard is aimed at three main audiences.

— **Policymakers, government and business organisations** can use R&D investment information as an input to industry and R&D assessment, policy formulation or other R&D-related actions such as R&D tax incentives.

— **Companies** can use the Scoreboard to benchmark their R&D investments and so find where they stand in the EU and in the global industrial R&D landscape. This information could be of value in shaping business or R&D strategy and in considering potential mergers and acquisitions.

— **Researchers, investors, and financial analysts** can use the Scoreboard to assess investment opportunities and risks, as well as analyse investment trends.

Furthermore, the Scoreboard dataset has been made freely accessible to encourage further economic and financial analyses and research by any interested parties. See https://iri.jrc.ec.europa.eu/data

Annex 2. Methodological notes

The data for the 2023 Scoreboard have been collected from companies' annual reports and accounts by Bureau van Dijk – A Moody's Analytics Company (BvD). The source documents, annual reports & accounts, are public domain documents and so the Scoreboard is capable of independent replication. In order to ensure consistency with our previous Scoreboards, BvD data for the years prior to 2022 have been checked with the corresponding data of the previous Scoreboards adjusted for the corresponding exchange rates of the annual reports.

Main characteristics of the data

The data correspond to companies' latest published accounts, intended to be their 2022 fiscal year accounts, although due to different accounting practices throughout the world, they also include accounts ending on a range of dates between late 2021 and mid-2023. Furthermore, the accounts of some companies are publicly available more promptly than others. Therefore, the current set represents a heterogeneous set of timed data. However, around 70% of companies closed their accounts in December 2022.

In order to maximise completeness and avoid double counting, the consolidated group accounts of the ultimate parent company are used. Companies which are subsidiaries of another company are not listed separately. Where consolidated group accounts of the ultimate parent company are not available, subsidiaries are included.

In the case of a demerger, the full history of the continuing entity is included. The history of the demerged company can only go back as far as the date of the demerger to avoid double counting of figures.

In case of an acquisition or merger, pro forma figures for the year of acquisition are used along with pro-forma comparative figures if available.

The R&D investment included in the Scoreboard is the cash investment which is funded by the companies themselves. It excludes R&D undertaken under contract for customers such as governments or other companies. It also excludes the companies' share of any associated company or joint venture R&D investment when disclosed. However, it includes research contracted out to other companies or public research organisations, such as universities.

Where part or all of R&D costs have been capitalised, the additions to the appropriate intangible assets are included to calculate the cash investment and any amortisation eliminated.

Companies are allocated to the country of their registered office. In some cases this is different from the operational or R&D headquarters. This means that the results are independent of the actual location of the R&D activity.

Companies are assigned to industry sectors according to the NACE Rev. 2[202] and the ICB (Industry Classification Benchmark). In the Scoreboard report we use different levels of sector aggregation, according to the distribution of companies' R&D and depending on the issues to be illustrated.

Limitations

Users of the Scoreboard data should take into account the methodological limitations, especially when performing comparative analyses (see Box A2 below)

The Scoreboard relies on disclosure of R&D investment in published annual reports and accounts. Companies which do not disclose figures for R&D investment or only figures which are not material enough are not included in the Scoreboard. Due to different national accounting standards and disclosure practices, companies of some countries are less likely than others to disclose R&D investment consistently. There is a legal requirement to disclose R&D in company annual reports in some countries.

In some countries, R&D costs are very often integrated with other operational costs and can therefore not be identified separately. For example, companies from many Southern European countries or the new Member States are under-represented in the Scoreboard. On the other side, UK companies could be over-represented in the Scoreboard. For listed companies, country representation improves with IFRS adoption.

The R&D investment disclosed in some companies' accounts follows the US practice of including engineering costs relating to product improvement. Where these engineering costs have been disclosed separately, they are excluded from the *Scoreboard*. However, the incidence of non-disclosure is uncertain and the impact of this practice is a possible overstatement of some overseas R&D investment figures in comparison with the EU. Indeed, for US companies, the GAAP accounting standards are always used because they are the official, audited ones, however non-GAAP results may give a more realistic view of true R&D investments.

Where R&D income can be clearly identified as a result of customer contracts it is deducted from the R&D expense stated in the annual report, so that the R&D investment included in the *Scoreboard* excludes R&D undertaken under contract for customers such as governments or other companies. However, the disclosure practise differs and R&D income from customer contracts cannot always be clearly identified. This means a possible overstatement of some R&D investment figures in the *Scoreboard* for companies with directly R&D related income where this is not disclosed in the annual report.

In implementing the definition of R&D, companies exhibit variability arising from a number of sources: i) different interpretations of the R&D definition; ii) different companies' information systems for measuring the costs associated with R&D; iii) different countries' fiscal treatment of costs. Some companies view a process as an R&D process while other companies may view the same process as an engineering or other process.

Interpretation

There are some fundamental aspects of the Scoreboard which affects the interpretation of the data. The focus on R&D investment as reported in group accounts means that the results do not indicate the location of the R&D activity. The Scoreboard indicates rather the level of R&D funded by companies, not all of which is carried out in the country in which the company is registered. This enables inputs such as R&D and capex investment to be related to outputs such as sales, profits, productivity ratios and market capitalisation only at the group and the at global level.

The data used for the Scoreboard are different from data provided by statistical offices, e.g., the R&D expenditures funded by the business enterprise sector and performed by all sectors within a given territorial unit (BES-R&D). The Scoreboard refers to all R&D financed by a particular company from its own funds, regardless of where that R&D activity is performed. In contrast, BES-R&D refers to all R&D activities funded by businesses and performed within a particular territory, regardless of the location of the business's headquarters. Therefore, the Scoreboard R&D figures are directly comparable to BES-R&D data only at the global level, i.e. the aggregate of the 2500 companies R&D investment can be compared with the global total BES-R&D.

The Scoreboard collects data from audited financial accounts and reports. In contrast, BES-R&D typically takes a stratified sample, covering all large companies and a representative sample of smaller companies. An

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[202] NACE is the acronyme for "Nomenclature statistique des activités économiques dans la Communauté européenne".

additional difference concerns the definition of R&D intensity, BES-R&D uses the percentage of value added, while the Scoreboard measures it as the R&D/Sales ratio as value added data is not available at a micro-level

Sudden changes in R&D figures may arise because a change in company accounting standards. For example, the first time adoption of IFRS[203], may lead to information discontinuities due to the different treatment of R&D, i.e. R&D capitalisation criteria are stricter and, where the criteria are met, the amounts must be capitalised.

For many highly diversified companies, the R&D investment disclosed in their accounts relates only to part of their activities, whereas sales and profits are in respect of all their activities. Unless such groups disclose their R&D investment additional to the other information in segmental analyses, it is not possible to relate the R&D more closely to the results of the individual activities which give rise to it. The impact of this is that some statistics for these groups, e.g. R&D as a percentage of sales, are possibly underestimated and so comparisons with non-diversified groups are limited. By allocating all companies to a single sector, the R&D of diversified companies is allocated to one sector only leading to overstatement of R&D in that sector and under-statement of it in other sectors.

For companies outside the Euro area, all currency amounts have been translated at the Euro exchange rates ruling at *31 December 2022* as shown in Table A2.1[204]. The exchange rate conversion also applies to the historical data. The result is that over time the Scoreboard reflects the domestic currency results of the companies rather than economic estimates of current purchasing parity results. The original domestic currency data can be derived simply by reversing the translations at the rates above. Users can then apply their own preferred current purchasing parity transformation models.

Glossary

1. **Research and Development (R&D) investment** in the Scoreboard is the cash investment funded by the companies themselves. It excludes R&D undertaken under contract for customers such as governments or other companies. It also excludes the companies' share of any associated company or joint venture R&D investment. However, it includes research contracted out to other companies or public research organisations, such as universities. Being that disclosed in the annual report and accounts, it is subject to the accounting definitions of R&D. For example, a definition is set out in International Accounting Standard (IAS) 38 “Intangible assets” and is based on the OECD Frascati manual. **Research** is defined as original and planned investigation undertaken with the prospect of gaining new scientific or technical knowledge and understanding. Expenditure on research is recognised as an expense when it is incurred. **Development** is the application of research findings or other knowledge to a plan or design for the production of new or substantially improved materials, devices, products, processes, systems or services before the start of commercial production or use. Development costs are capitalised when they meet certain criteria and when it can be demonstrated that the asset will generate probable future economic benefits. Where part or all of R&D costs have been capitalised, the additions to the appropriate intangible assets are included to calculate the cash investment and any amortisation eliminated.
2. R&D expenditures funded by the business enterprise sector (**BES-R&D**), provided by official statistics, refer to the total R&D performed within a territorial unit that has been funded by the business enterprise sector (private or public companies).
3. **Net sales** follow the usual accounting definition of sales, excluding sales taxes and shares of sales of joint ventures & associates. For banks, sales are defined as the “Total (operating) income” plus any insurance income. For insurance companies, sales are defined as “Gross premiums written” plus any banking income.
4. **R&D intensity** is the ratio between R&D investment and net sales of a given company or group of companies. At the aggregate level, R&D intensity is calculated only by those companies for which data exist for both R&D and net sales in the specified year. The calculation of R&D intensity in the *Scoreboard* is different from that in official statistics, e.g. BES-R&D, where R&D intensity is based on value added instead of net sales.

[203] Since 2005, the European Union requires all listed companies in the EU to prepare their consolidated financial statements according to IFRS (International Financial Reporting Standards, see: http://www.iasb.org/).

[204] Companies from some countries report their data in US dollars, e.g. in this edition, most companies based in Israel present their results in US dollars.

5. **Operating profit** is calculated as profit (or loss) before taxation, plus net interest cost (or minus net interest income) minus government grants, less gains (or plus losses) arising from the sale/disposal of businesses or fixed assets.
6. **One-year growth** is simple growth over the previous year, expressed as a percentage: 1 yr growth = 100*((C/B)-1); where C = current year amount and B = previous year amount. 1yr growth is calculated only if data exist for both the current and previous year.
7. **Capital expenditure (capex)** is expenditure used by a company to acquire or upgrade physical assets such as equipment, property, industrial buildings. In accounts capital expenditure is added to an asset account (i.e. capitalised), thus increasing the asset's base. It is disclosed in accounts as additions to tangible fixed assets.
8. **Number of employees** is the total consolidated average employees or year-end employees if average not stated.

Box A2. Methodological caveats

Users of Scoreboard data should take into account the methodological limitations summarised here, especially when performing comparative analyses:

A typical problem arises when comparing data from different currency areas. The Scoreboard data are nominal and expressed in Euros with all foreign currencies converted at the exchange rate of the year-end closing date (31.12.2022). The variation in the exchange rates from the previous year directly affects the ranking of companies, favouring those based in countries whose currency has appreciated with respect to the other currencies. In this reporting period, the exchange rate of the Euro depreciated by 5.8% against the US dollar, appreciated by 7.8% against the Japanese Yen and by 5.5% against the Pound Sterling, respectively. However, ratios such as R&D intensity or profitability (profit as % sales) are based on the ratio of two quantities taken from a company report where they are both expressed in the same currency and are therefore not affected by currency changes.

The growth rate of the different indicators for companies operating in markets with different currencies is affected in a different manner. In fact, companies' consolidated accounts have to include the benefits and/or losses due to the appreciation and/or depreciation of their investments abroad. The result is an 'apparent' rate of growth of the given indicator that understates or overstates the actual rate of change. For example, this year the R&D growth rate of companies based in the Euro area with R&D investments in the US is partly overstated because the 'gains' of their overseas investments due to the appreciation of the US dollar against the Euro (from USD 1.13 to USD 1.06). Conversely, the R&D growth rate of US companies is partly understated due to the 'losses' of their investments in the Euro area. Similar effects of understating or overstating figures would happen for the growth rates of other indicators, such as net sales.

When analysing data aggregated by country or sector, in many cases, the aggregate indicator depends on the figures of a few firms. This is due, either to the country's or sector's small number of firms in the Scoreboard or to the indicator dominated by a few large firms.

In most cases, companies' accounts do not include information on the place where R&D is actually performed; consequently the approach in the Scoreboard is to attribute each company's total R&D investment to the country in which the company has its registered office or shows its main economic activity. This should be borne in mind when interpreting the Scoreboard's country classification and analyses. In some cases where company are headquartered in countries for fiscal reasons with little R&D or other activity in that country, a misleading impression may be received.

Growth in R&D can either be organic, the outcome of acquisitions or a combination of the two. Consequently, mergers and acquisitions (or de-mergers) may sometimes underlie sudden changes in specific companies' R&D and sales growth rates and/or positions in the rankings.

Other important factors to take into account include the difference in the various' countries' (or sectors') business cycles, which may have a significant impact on companies' investment decisions, and the initial adoption or stricter application of the International Financial Reporting Standard (IFRS) [205]..

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

Table A1 1. Euro exchange rates

Country	As of 31 Dec 2021	As of 31 Dec 2022
Australia	$ 1.56	$ 1.56
Brazil	6.32 Brazilian Real	5.63 Brazilian Real
Canada	$ 1.43	$ 1.44
China	7.19 Yuan Renminbi	7.35 Yuan Renminbi
Czechia	24.86 Koruna	24.12 Koruna
Denmark	7.43 Danish Krone	7.43 Danish Krone
Hungary	369.19 Forint	400.87 Forint
Hong Kong	8.83 HKD	8.81 HKD
Indonesia	16100.42 Indonesian Rupiah	16519.82 Indonesian Rupiah
India	84.29 Indian Rupee	84.17 Indian Rupee
Israel	3.51 New Shekel	3.75 New Shekel
Japan	130.38 Yen	140.66 Yen
Malaysia	4.71 Ringgit	4.69 Ringgit
New Zealand	1.66 NZD	1.68 NZD
Norway	9.99 Norwegian Kronor	10.51 Norwegian Kronor
Poland	4.59 Zloty	4.68 Zloty
Singapore	1.52 SGD	1.43 SGD
South Korea	1344.09 Won	1346.38 Won
Sweden	10.25 Swedish Kronor	11.12 Swedish Kronor
Switzerland	1.03 Swiss Franc	0.98 Swiss Franc
Taiwan	$ 31.32 New dollar	$ 32.72 New dollar
Türkiye	15.23 Turkish lira	19.96 Turkish lira
UK	£0.84	£0.88
US	$ 1.13	$ 1.06
United Arab Emirates	4.16 Dirham	3.91 Dirham
Vietnam	25968.82 Dong	25279.90 Dong

Source: The 2023 EU Industrial R&D Investment Scoreboard, European Commission, JRC/DG R&I.

Annex 3. The new Scoreboard panel data set 2003-2022

Since the inception of the Scoreboard in 2004, each year's ranking and the underlying data are published on the website for the Scoreboard[206]. Since then, a change in the data provider (until 2011 data was sourced from 'Company Reporting') and the continuous expansion of the Scoreboard sample from initially 500 EU companies and 500 non-EU companies to the global top 2500 and the top EU1000 caused a structural break in the time series. For a general description of Scoreboard data (in particular the adjustment of R&D investment in line with the Frascati Manual) and its specificities please see Annex 1 and Annex 2.

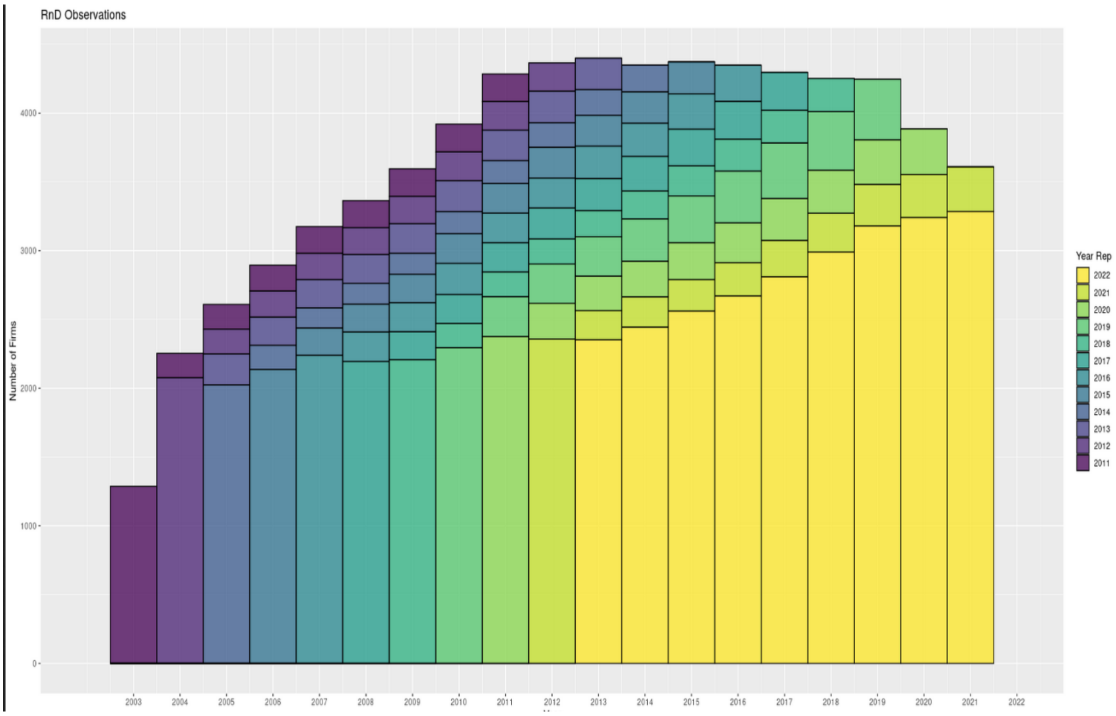
Since the switch to Bureau van Dijk – A Moody's Analytics Company (BvD) Orbis database in 2012, the data for each company contain observations of the key financial indicators up to nine years preceding each "Scoreboard year" or "vintage" (e.g., the Scoreboard 2023 refers to data from the financial year 2022, see also Annex 1 and Annex 2 on general information and methodology). Thus, each year we received data on approximately 3 300 companies for a time span of up to 10 years.

Another structural break relates to the Brexit: as discussed in Chapter 4.2., the exit of the UK from the EU caused a major reshuffle in the EU 1 000 sample. While until 2019 we also have data on UK companies beyond the global top 2 500 ranking (i.e., the extended EU sample), from 2020 onwards the EU 1 000 sample is constructed without additional UK companies. Thus, the number of UK companies drops sharply in 2020, including only the top companies.

[206] https://iri.jrc.ec.europa.eu/data

In an attempt to collect the maximum number of observations for the maximum number of years we combined each single Scoreboard vintage between 2012-2022 to one data set. This allows to provide information for a company even in years when the company was not included in the ranking of a specific year (e.g., due to a temporary delisting, too little R&D to cross the specific threshold, etc.) and to close gaps due to missing data. Given that with each vintage we include data on the (up to) nine financial years preceding the current reporting year, we generate a large number of duplicates. If for a specific firm an observation was missing in a certain Scoreboard vintage we can recover the data with a more recent or even an older Scoreboard vintage. If there are several observations for a firm-year-pair from different vintages we keep the observation from the most recent Scoreboard vintage. With this strategy we are able to construct a data set reaching back to 2003 and covering a larger number of companies as in the initial Scoreboard report.

Figure 103. Scoreboard Panel – Observations per reporting year, 2003-2022

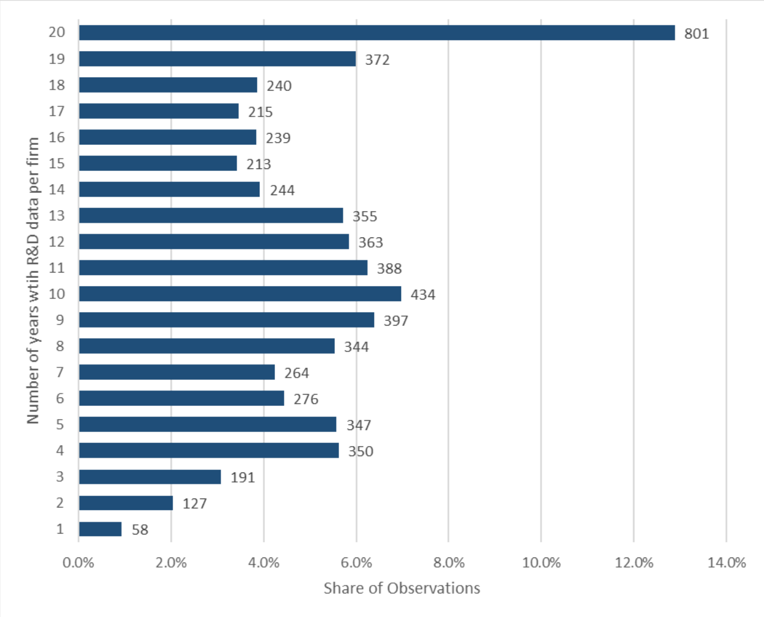


Source: Authors based on Scoreboards 2012-2023.

Figure 103 shows how many observations we have per year and from which reporting year (Scoreboard vintage) the data originates. The colours indicate from which Scoreboard vintage the data for a specific year were taken from (year reporting).

Overall, the data set contains observations for 6,215 firms over the period 2003-2022, resulting in 72,899 firm-year-observations. As Figure 104 below shows, for 801 firms we have data for the entire 20 year period, for 372 firms for 19 years, etc. Per definition, the firms that were observed for the entire period were among those with the highest R&D investment over this period, and as a result these companies account for 66.4% of the total R&D investment (measured at 2022 exchange rates). 62.1% of the firms are observed for at least 10 years and they cover more than 94% of the R&D investment.

Figure 104. Length of observation per firm, 2003-2022



Source: Authors based on Scoreboards 2012-2023.

The variables included in the dataset are the company name (*company*), the country of headquarter (*country_sb*), sector (ICB3/ICB4 classification, NACE Rev 2.), the ranking positing (world rank, EU rank, 2012-2022), the currency, and the exchange rate (measured at end of year). The indicators per company are R&D investment (*rnd*) (adjusted as describe in Annex 2, Box A2), net sales (*netsales*), operating profit (*profit*), capital expenditures (*capex*), market capitalisation (*mcap*) and employment (*emp*).

Due to legal reasons we cannot publish the company identifier, but instead the companies need to be identified via the company name. As name changes occur, the company name is harmonised to the last name with which a company was registered in the Scoreboard (*company*) and the variable *company_name* captures the changes in the company name. The unique identifier in the panel is thus the variable *company*.

Each monetary variable is measured in EUR million and is reported in three different ways: i) in the original currency value for each year (e.g. *rnd_org*), ii) in euro measured with the (end-of-year) exchange rate for each year (e.g. *rnd_euro*), and iii) at 2022 (end-of-year) exchange rates to euro (e.g. *rnd_22*) (with the 22-variables the figures of the Scoreboard 2023 are calculated). By adding specific deflators and PPP conversion factors the users can transform the data to the formats and base years required for specific analyses.

The sector classification in the Scoreboard needs to be taken with caution. For consistency over the years, Moody's utilizes the ICB3 sector classification which was last updated in 2019. This classification, along with its ICB4 disaggregation, is maintained in the Scoreboard. We aggregate the ICB3/ICB4 levels into 'icb3_short', an 11-group classification detailed in Table 5. Approximately 13% of companies underwent a sector reclassification during panel construction, based on manual internet searches. While 4-digit NACE sectors are included, they have not undergone manual checks. It is crucial to recognize that assigning large multinational firms to a single sector is a simplification, requiring caution. The update and refinement of the sector classification are areas for future research efforts.

This Scoreboard panel dataset is unique in the respect that it covers R&D investment from a firm-level perspective, in contrast to official statistics that report national/regional aggregates. It collects information on the largest R&D investing firms in the world that meet specific reporting and auditing standards and are publicly listed. Furthermore, the R&D investment data is adjusted such that it (ideally) only reflects privately funded R&D by the companies themselves. The dataset has certain omissions (compare the case of Amazon, see Section 3) that mostly result from the quality requirements set by the data provider. Deviations from official company reports may arise due to the aggregation of subsidiaries to mother companies. Errors may happen, and if discovered, please report to the Scoreboard Team.

Annex 4. Annex Section 2.2

Table A4 1. Top 50 companies worldwide by R&D investment

	company	Sector	R&D 2022	Growth, yoy	Net profit 22	Growth, yoy	Net sales 2022	Growth, yoy	Capex 2022	Growth, yoy
1	ALPHABET	ICT services	37,034	25.2%	70,169	-4.9%	265,175	9.8%	29,519	27.8%
2	META	ICT services	31,520	36.4%	31,460	-28.2%	109,328	-1.1%	29,468	69.3%
3	MICROSOFT	ICT services	25,497	10.9%	84,065	7.7%	198,683	6.9%	26,352	17.7%
4	APPLE	ICT producers	24,612	19.8%	111,979	9.6%	369,706	7.8%	10,039	-3.4%
5	HUAWEI INVESTMENT & HOLDING	ICT producers	20,925	10.6%	n.a.	missing	n.a.	missing	4,726	3.0%
6	VOLKSWAGEN	Automobiles & Parts	18,908	21.3%	21,230	15.3%	279,232	11.6%	12,948	21.5%
7	SAMSUNG ELECTRONICS	ICT producers	18,435	10.3%	32,090	-16.0%	223,593	8.1%	39,304	6.6%
8	INTEL	ICT producers	16,434	15.4%	2,049	-90.1%	59,117	-20.2%	23,486	23.2%
9	ROCHE	Health industries	14,268	2.5%	17,747	-3.7%	64,262	0.8%	3,502	-6.6%
10	JOHNSON & JOHNSON	Health industries	13,691	-0.8%	24,339	5.7%	89,015	1.2%	3,759	9.8%
11	MERCK US	Health industries	11,080	14.2%	17,449	21.7%	55,581	21.7%	4,114	-1.3%
12	PFIZER	Health industries	10,713	-1.5%	34,884	35.5%	94,065	23.4%	3,034	19.4%
13	GENERAL MOTORS	Automobiles & Parts	9,188	24.1%	10,150	-22.2%	146,948	23.4%	19,864	-4.2%
14	ASTRAZENECA	Health industries	8,943	18.5%	3,320	outlier*	41,582	18.5%	1,023	0.0%
15	BRISTOL-MYERS SQUIBB	Health industries	8,823	-10.5%	10,583	11.6%	43,277	-0.5%	1,048	14.9%
16	TOYOTA MOTOR	Automobiles & Parts	8,776	10.4%	19,260	-9.0%	262,603	18.4%	23,731	-3.6%
17	NOVARTIS	Health industries	8,521	0.5%	8,623	-21.3%	48,592	-2.0%	1,123	-13.1%
18	MERCEDES-BENZ	Automobiles & Parts	8,509	-5.2%	19,485	-31.9%	150,017	-10.7%	3,481	-24.0%
19	TENCENT	ICT services	8,240	18.4%	36,153	14.7%	74,424	-1.0%	3,044	-22.6%
20	ORACLE	ICT services	8,085	19.4%	12,913	-13.0%	46,835	17.7%	8,152	92.8%
21	QUALCOMM	ICT producers	7,682	14.2%	13,833	51.2%	41,440	31.7%	2,121	19.8%
22	ALIBABA GROUP HOLDING	ICT services	7,681	3.2%	13,468	44.1%	116,582	1.8%	n.a.	missing
23	ROBERT BOSCH	Automobiles & Parts	7,483	18.3%	3,474	23.4%	88,201	12.0%	n.a.	missing
24	FORD MOTOR	Automobiles & Parts	7,313	2.6%	5,884	38.8%	148,188	15.9%	6,437	10.3%
25	BMW	Automobiles & Parts	7,178	4.5%	14,028	4.2%	142,610	28.2%	9,050	36.7%
26	NVIDIA	ICT producers	6,881	39.3%	5,882	-41.3%	25,290	0.2%	1,719	87.8%
27	ELI LILLY	Health industries	6,742	2.3%	6,704	12.2%	26,759	0.8%	1,739	41.6%
28	STELLANTIS	Automobiles & Parts	6,720	14.1%	19,940	31.5%	179,592	20.2%	8,615	79.6%
29	SANOFI	Health industries	6,705	17.9%	10,001	29.7%	42,997	13.9%	2,201	7.7%
30	CHINA STATE CONSTRUCTION ENGINEERING	Construction & Materials	6,670	25.0%	14,800	-5.5%	273,125	8.7%	3,482	-16.6%
31	BAYER	Health industries	6,630	20.2%	5,820	83.2%	50,739	15.1%	2,949	12.9%
32	CISCO SYSTEMS	ICT producers	6,337	3.2%	13,149	2.1%	48,338	3.5%	447	-31.1%
33	HONDA MOTOR	Automobiles & Parts	6,221	6.8%	5,518	-10.4%	119,502	16.2%	3,358	77.2%
34	SAP	ICT services	6,139	18.8%	4,670	0.3%	30,871	10.9%	874	9.3%
35	ABBVIE	Health industries	6,082	-7.1%	17,491	0.8%	54,429	3.3%	652	-11.7%
36	NTT	ICT services	5,721	9.2%	12,996	1.8%	92,846	8.1%	13,089	5.3%
37	IBM	ICT services	5,646	1.3%	7,111	24.2%	56,750	5.5%	1,262	-34.7%
38	SIEMENS	ICT producers	5,591	8.9%	9,158	42.6%	71,977	15.6%	2,084	20.5%
39	GSK	Health industries	5,480	4.4%	9,536	26.4%	39,493	2.3%	1,293	20.3%
40	SONY	Others	5,340	19.2%	8,370	-1.5%	81,563	16.3%	4,337	39.1%
41	BOEHRINGER SOHN	Health industries	5,047	22.3%	4,770	1.4%	24,149	17.1%	1,021	5.5%
42	TAIWAN SEMICONDUCTOR	ICT producers	4,985	30.9%	34,274	72.4%	69,120	42.6%	33,056	29.0%
43	SALESFORCE	ICT services	4,739	13.2%	1,282	148.1%	29,394	18.3%	748	11.3%
44	ADVANCED MICRO DEVICES	ICT producers	4,692	75.9%	1,089	-68.0%	22,127	43.6%	422	49.5%
45	GILEAD SCIENCES	Health industries	4,666	-7.2%	6,872	-26.1%	25,578	-0.1%	683	25.7%
46	BROADCOM	ICT producers	4,612	1.3%	13,395	64.8%	31,130	21.0%	398	-4.3%
47	NOKIA	ICT producers	4,513	9.0%	2,597	26.6%	24,911	12.2%	601	7.3%
48	TAKEDA PHARMACEUTICAL	Health industries	4,476	20.4%	3,452	7.6%	28,466	12.8%	994	14.1%
49	ERICSSON	ICT producers	4,254	14.2%	2,407	-13.2%	24,416	16.9%	403	22.2%
50	AMGEN	Health industries	4,157	-8.0%	9,500	32.6%	24,679	1.3%	878	6.4%

Source: The 2023 EU Industrial R&D Investment Scoreboard, European Commission, JRC/DG R&I

Table A4 2. Entry/exit dynamics in the quintiles per region, number of companies

	EU		US		China		Japan		ROW	
	Entry	Exit	Entry	Exit	Entry	Exit	Entry	Exit	Entry	Exit
Q1	1	1	2	5	2	1	0	0	0	1
Q2	0	0	3	14	4	3	2	0	3	6
Q4	2	1	4	16	5	3	0	1	2	4
Q4	2	2	26	23	17	9	0	0	6	5
Q5	17	14	61	34	50	59	5	10	24	26
Total	22	18	96	92	78	75	7	11	35	42

Source: The 2023 EU Industrial R&D Investment Scoreboard, European Commission, JRC/DG R&I

Annex 5. Annex Section 5.2

This appendix presents the regression results for a selected set of key findings discussed in the main text. As outlined in the technical section containing the main methodological details, the results of the regressions are depicted graphically to facilitate interpretation. Here, we provide a comprehensive presentation of the regression analysis results, encompassing the effects of both crises on capex, R&D, carbon intensity scores, the carbon intensity elasticity of R&D, as well as social and governance indicators.

Table A5 1: Capex after the financial crisis, by region

	(1) Capex - Overall	(2) Capex - EU	(3) Capex - US
2009	-0.277**	-0.265**	-0.265**
	[0.012]	[0.023]	[0.020]
2010	-0.168**	-0.221**	-0.106**
	[0.014]	[0.026]	[0.023]
2011	-0.025+	-0.104**	0.048*
	[0.014]	[0.025]	[0.025]
2012	0.000	-0.112**	0.112**
	[0.016]	[0.031]	[0.028]
2013	-0.028	-0.152**	0.120**
	[0.017]	[0.035]	[0.029]
Net sales	0.000**	0.000**	0.000**
	[0.000]	[0.000]	[0.000]
Constant	4.242**	4.586**	3.552**
	[0.027]	[0.029]	[0.039]
Company fixed effects	Yes	Yes	Yes
Joint F test	113.093	31.809	47.493
R sq	0.946	0.963	0.937
N (companies X year)	17150	3155	6022
N (companies)	2003	392	690

Notes: The year 2008 is excluded as it serves as the reference period. Years 2005-2007 are included in the analysis but not reported for the sake of readability. In all columns, the dependent variable is the logarithm of Capex. R&D and Capex series are in 2015 US PPP$, while net sales in 2015 US$. The samples used consist of all firms with R&D data for at least two observations before and two observations after the financial crisis (column 1); a similar sample with EU companies only (column 2); and US companies only (column 3). Standard errors, clustered at the company level, are presented in parentheses. Significance levels: + p<0.1, * p<0.05, ** p<0.01.

Table A5 2: Capex after the COVID-19 crisis, by region

	(1) Capex - Overall	(2) Capex - EU	(3) Capex - US	(4) Capex - China
2020	-0.036**	-0.102**	-0.068**	0.099**
	[0.012]	[0.023]	[0.024]	[0.026]
2021	0.037*	-0.080**	-0.013	0.230**
	[0.015]	[0.026]	[0.031]	[0.038]
Net sales	0.000**	0.000**	0.000**	0.000*
	[0.000]	[0.000]	[0.000]	[0.000]
Constant	4.605**	4.834**	3.811**	4.902**
	[0.032]	[0.044]	[0.036]	[0.071]
Company fixed effects	Yes	Yes	Yes	Yes
Joint F test	61.468	13.258	16.214	30.492
R sq	0.940	0.964	0.949	0.865
N (companies X year)	10966	2131	2886	2898
N (companies)	2236	440	591	584

Notes: The year 2019 is excluded as it serves as the reference period. Years 2017-2018 are included in the analysis but not reported for the sake of readability. In all columns, the dependent variable is the logarithm of Capex. R&D and Capex series are in 2015 US PPP$, while net sales in 2015 US$. The samples used consist of all firms with R&D data for at least two observations before and one observation after the COVID-19 crisis (column 1); a similar sample with EU companies only (column 2); US companies only (column 3) and Chinese companies only (column 4). Standard errors, clustered at the company level, are presented in parentheses. Significance levels: + p<0.1, * p<0.05, ** p<0.01.

Table A5 3: R&D after the financial crisis, by region

	(1) R&D - Overall	(2) R&D - EU	(3) R&D - US
2009	0.017*	0.047**	-0.038*
	[0.009]	[0.017]	[0.016]
2010	0.067**	0.069**	0.014
	[0.011]	[0.020]	[0.022]
2011	0.163**	0.139**	0.146**
	[0.012]	[0.022]	[0.020]
2012	0.221**	0.166**	0.229**
	[0.013]	[0.027]	[0.024]
2013	0.266**	0.151**	0.313**
	[0.014]	[0.028]	[0.024]
Net sales	0.000**	0.000**	0.000**
	[0.000]	[0.000]	[0.000]
Constant	4.131**	4.155**	4.242**

	[0.028]	[0.044]	[0.026]
Company fixed effects	Yes	Yes	Yes
Joint F test	114.203	21.265	52.262
R sq	0.909	0.923	0.906
N (companies X year)	18607	3854	6184
N (companies)	2096	433	699

Notes: The year 2008 is excluded as it serves as the reference period. Years 2005-2007 are included in the analysis but not reported for the sake of readability. In all columns, the dependent variable is the logarithm of R&D. R&D and Capex series are in 2015 US PPP$, while net sales in 2015 US$. The samples used consist of all firms with R&D data for at least two observations before and two observations after the financial crisis (column 1); a similar sample with EU companies only (column 2); and US companies only (column 3). Standard errors, clustered at the company level, are presented in parentheses. Significance levels: + p<0.1, * p<0.05, ** p<0.01.

Table A5 4: R&D after the COVID-19 crisis, by region

	(1)	(2)	(3)	(4)
	R&D - Overall	R&D - EU	R&D - US	R&D - China
2020	0.067**	-0.018	0.073**	0.170**
	[0.006]	[0.013]	[0.012]	[0.015]
2021	0.169**	-0.003	0.199**	0.380**
	[0.009]	[0.017]	[0.018]	[0.024]
Net sales	0.000**	0.000*	0.000*	0.000**
	[0.000]	[0.000]	[0.000]	[0.000]
Constant	4.914**	4.850**	5.067**	4.815**
	[0.031]	[0.066]	[0.026]	[0.048]
Company fixed effects	Yes	Yes	Yes	Yes
Joint F test	189.625	12.682	63.053	154.535
R sq	0.930	0.964	0.947	0.876
N (companies X year)	11140	2203	2908	2917
N (companies)	2247	444	594	584

Notes: The year 2019 is excluded as it serves as the reference period. Years 2017-2018 are included in the analysis but not reported for the sake of readability. In all columns, the dependent variable is the logarithm of R&D. R&D and Capex series are in 2015 US PPP$, while net sales in 2015 US$. The samples used consist of all firms with R&D data for at least two observations before and one observation after the COVID-19 crisis (column 1); a similar sample with EU companies only (column 2); US companies only (column 3) and Chinese companies only (column 4). Standard errors, clustered at the company level, are presented in parentheses. Significance levels: + p<0.1, * p<0.05, ** p<0.01.

Table A5 5: Carbon intensity scores after the financial crisis:

	(1)	(2)	(3)
	Carbon intensity	Carbon energy intensity	Energy intensity
2009	0.065**	-0.029	0.093**
	[0.018]	[0.026]	[0.024]
2010	-0.028	-0.102**	0.074+
	[0.029]	[0.035]	[0.038]
2011	-0.059*	-0.096*	0.038
	[0.026]	[0.041]	[0.040]
2012	-0.103**	-0.079+	-0.024
	[0.029]	[0.042]	[0.040]
2013	-0.111**	-0.096*	-0.015
	[0.028]	[0.045]	[0.044]
Constant	-2.591**	-2.304**	-0.287**
	[0.016]	[0.024]	[0.023]
Company fixed effects	Yes	Yes	Yes
Joint F test	8.344	2.428	4.420
R sq	0.947	0.659	0.866
N (companies X year)	3282	3282	3282
N (companies)	455	455	455

Notes: The year 2008 is excluded as it serves as the reference period. Years 2005-2007 are included in the analysis but not reported for the sake of readability. Dependent variables are the logarithm of: carbon intensity in column 1, carbon energy intensity in column 2 and energy intensity in column 3. Net sales are in 2015 US$. The sample in all columns consists of all firms with carbon intensity data for at least two observations before and two observations after the financial crisis. Standard errors, clustered at the company level, are presented in parentheses. Significance levels: + p<0.1, * p<0.05, ** p<0.01.

Table A5 6: Carbon intensity scores after the COVID-19 crisis

	(1)	(2)	(3)
	Carbon intensity	Carbon energy intensity	Energy intensity
2020	-0.004	-0.046**	0.042*
	[0.015]	[0.016]	[0.016]
2021	-0.150**	-0.113**	-0.037*
	[0.016]	[0.017]	[0.016]

Constant	-3.065**	-2.413**	-0.652**
	[0.008]	[0.010]	[0.010]
Company fixed effects	Yes	Yes	Yes
Joint F test	46.042	14.441	7.486
R sq	0.954	0.744	0.940
N (companies X year)	4564	4565	4564
N (companies)	996	996	996

Notes: The year 2019 is excluded as it serves as the reference period. Years 2017-2018 are included in the analysis but not reported for the sake of readability. Dependent variables are the logarithm of: carbon intensity in column 1, carbon energy intensity in column 2 and energy intensity in column 3. Net sales are in 2015 US$. The sample in all columns consists of all firms with carbon intensity data for at least two observations before and one observation after the COVID-19 crisis. Standard errors, clustered at the company level, are presented in parentheses. Significance levels: + p<0.1, * p<0.05, ** p<0.01.

Table A5 7: Carbon intensity scores elasticities of R&D after the financial crisis

	(1)	(2)	(3)
	Carbon intensity	Carbon energy intensity	Energy intensity
R&D x 2009	-0.015	0.039*	-0.050**
	[0.014]	[0.019]	[0.018]
R&D x 2010	-0.023	0.046+	-0.068*
	[0.016]	[0.025]	[0.028]
R&D x 2011	-0.038*	0.032	-0.064*
	[0.018]	[0.025]	[0.029]
R&D x 2012	-0.035	0.063*	-0.072*
	[0.022]	[0.030]	[0.032]
R&D x 2013	-0.051*	0.028	-0.063+
	[0.024]	[0.030]	[0.032]
Capex	0.331**	0.085*	0.240**
	[0.046]	[0.036]	[0.055]
Constant	-3.483**	-2.371**	-0.817**
	[0.226]	[0.210]	[0.264]
Company fixed effects	Yes	Yes	Yes
Joint F test	8.171	1.450	4.509
R sq	0.700	0.399	0.586
N (companies X year)	3637	3080	3136
N (companies)	468	452	453

Notes: The year 2008 is excluded as it serves as the reference period. All years (2005-2013), R&D and R&D x pre-crisis years (2005-2007) are included in the analysis but not reported for the sake of readability. Dependent variables are the logarithm of: carbon intensity in column 1, carbon energy intensity in column 2 and energy intensity in column 3. Net sales are in 2015 US$. Capex is in 2015 US PPP$. The sample in all columns consists of all firms with carbon intensity data for at least two observations before and two observations after the financial crisis. Standard errors, clustered at the company level, are presented in parentheses. Significance levels: + p<0.1, * p<0.05, ** p<0.01.

Table A5 8: Carbon intensity scores elasticities of R&D after the COVID-19 crisis

	(1)	(2)	(3)
	Carbon intensity	Carbon energy intensity	Energy intensity
R&D x 2020	-0.021*	0.003	-0.022*
	[0.009]	[0.010]	[0.011]
R&D x 2021	-0.026+	0.016	-0.053**
	[0.015]	[0.013]	[0.016]
Capex	0.493**	0.030	0.466**
	[0.036]	[0.022]	[0.034]
Constant	-3.813**	-2.352**	-1.428**
	[0.159]	[0.126]	[0.156]
Company fixed effects	Yes	Yes	Yes
Joint F test	30.608	5.139	23.291
R sq	0.607	0.246	0.604
N (companies X year)	4914	4513	4541
N (companies)	1052	1006	1007

Notes: The year 2019 is excluded as it serves as the reference period. All years (2017-2021), R&D and R&D x pre-crisis years (2017-2018) are included in the analysis but not reported for the sake of readability. Dependent variables are the logarithm of: carbon intensity in column 1, carbon energy intensity in column 2 and energy intensity in column 3. Net sales are in 2015 US$. Capex is in 2015 US PPP$. The sample in all columns consists of all firms with carbon intensity data for at least two observations before and two observations after the COVID-19 crisis. Standard errors, clustered at the company level, are presented in parentheses. Significance levels: + p<0.1, * p<0.05, ** p<0.01.

Table A5 9: Social (S) and governance (G) indicators after the financial crisis

	(1)	(2)	(3)
	Share of non-exec (G)	Injuries per hour worked (S)	Share of women managers (S)
2009	0.005	-0.066**	0.004+

	[0.003]	[0.024]	[0.002]
2010	0.011**	-0.112**	0.009**
	[0.004]	[0.024]	[0.003]
2011	0.016**	-0.173**	0.014**
	[0.004]	[0.027]	[0.003]
2012	0.022**	-0.250**	0.020**
	[0.004]	[0.030]	[0.003]
2013	0.026**	-0.308**	0.021**
	[0.004]	[0.033]	[0.004]
Net sales	0.000	0.000	0.000
	[0.000]	[0.000]	[0.000]
Constant	0.481**	1.654**	0.178**
	[0.006]	[0.054]	[0.008]
Company fixed effects	Yes	Yes	Yes
Joint F test	7.215	14.786	12.623
R sq	0.935	0.895	0.917
N (companies X year)	3391	1694	1664
N (companies)	477	271	274

Notes: The year 2008 is excluded as it serves as the reference period. Years 2005-2007 are included in the analysis but not reported for the sake of readability. Dependent variables are the logarithm of: share of non-executive board members in column 1, number of injuries per hour worked in column 2 and share of women managers in column 3. Net sales are in 2015 US$. The sample in all columns consists of all firms with social and governance data for at least two observations before and two observations after the financial crisis. Standard errors, clustered at the company level, are presented in parentheses. Significance levels: + p<0.1, * p<0.05, ** p<0.01.

Table A5 10: Social (S) and governance (G) indicators after the COVID-19 crisis

	(1)	(2)	(3)
	Share of non-exec (G)	Injuries per hour worked (S)	Share of women managers (S)
2020	0.007**	-0.105**	0.007**
	[0.001]	[0.010]	[0.001]
2021	0.014**	-0.134**	0.013**
	[0.002]	[0.014]	[0.001]
Net sales	-0.000*	0.000**	-0.000
	[0.000]	[0.000]	[0.000]
Constant	0.551**	1.244**	0.196**
	[0.003]	[0.014]	[0.002]
Company fixed effects			
Joint F test	30.322	34.416	43.387
R sq	0.934	0.919	0.952
N (companies X year)	5095	3001	3169
N (companies)	1054	687	742

Notes: The year 2019 is excluded as it serves as the reference period. Years 2017-2018 are included in the analysis but not reported for the sake of readability. Dependent variables are the logarithm of: share of non-executive board members in column 1, number of injuries per hour worked in column 2 and share of women managers in column 3. Net sales are in 2015 US$. The sample in all columns consists of all firms with social and governance data for at least two observations before and two observations after the COVID-19 crisis. Standard errors, clustered at the company level, are presented in parentheses. Significance levels: + p<0.1, * p<0.05, ** p<0.01.

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