

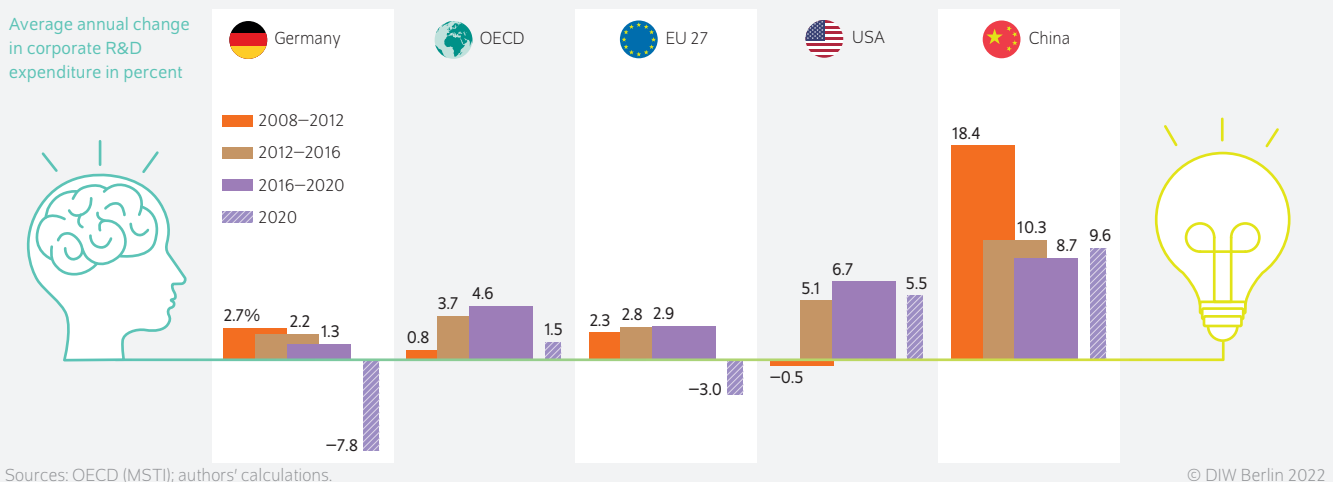
AT A GLANCE

Research and Development in German Industry: High intensity, low growth

By Heike Belitz

- Research and development (R&D) expenditure in Germany decreased by 5.3 percent in 2020, the first year of the pandemic, compared to 2019
- Decline in corporate R&D expenditure is even higher and significantly more pronounced than during the 2009 financial crisis
- R&D expenditure of German industry is not growing dynamically in an international comparison, even before 2020—R&D intensity is relatively high, but lower than in USA and Japan
- R&D is increasing worldwide in sectors that major German companies are not specialized in, such as software, hardware production, and pharmaceuticals
- Companies are increasingly dependent on research conducted in foreign countries and international collaborations—a common European research policy should be strengthened

Companies in Germany significantly reduced their R&D expenditure during 2020, the first year of the pandemic—elsewhere, the declines were smaller or there were even increases



FROM THE AUTHORS

“We have strong industrial research in Germany, but the world’s most important industrial research location is now China, followed by the USA and Japan, with Germany in fourth place. Germany has also been able to maintain its position in industrial research quite well in recent years, but it is at risk due to countries like China and the USA.”

— Heike Belitz —

MEDIA



Audio Interview with Heike Belitz (in German)
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ABSTRACT

Research and development (R&D) expenditure in Germany decreased by 5.3 percent overall in 2020 compared to 2019. While the OECD countries actually slightly increased their R&D expenditure on average for the first time in a crisis-ridden year, it declined more sharply in Germany compared to the financial crisis of 2009; German industry, and here the automotive sector, suffered particularly. The decline in R&D personnel, however, was lower. Even before 2020, German industrial research was not growing particularly dynamically in an international comparison. R&D intensity, the ratio of R&D expenditure to output, increased over the years, but still remains beneath the level of the USA and Japan. Initial data for 2021 show while top R&D-spending German companies spent more on R&D than in 2020, growth remained under the average of international competitors. Globally, R&D is growing primarily in sectors that major German companies do not specialize in, such as software and computer services, hardware production, and pharmaceuticals and biotechnology. To secure the wide variety of technologies required to transform to a digitalized and climate-neutral economy, industrial companies are becoming increasingly dependent on knowledge gained internationally, for example through their own research units abroad or through international research collaborations.

Investments in research and development (R&D) are a fundamental prerequisite for innovations. Considering the necessity of the transition to a digitalized and climate-neutral economy, R&D is becoming even more important. Measured by total corporate and public R&D expenditure, Germany is the fifth-largest research location and the most important in Europe. The USA is in first place, followed by China, Japan, and South Korea.

Decreasing momentum of R&D in Germany

Following the global financial crisis of 2009, real R&D expenditure growth in the OECD countries and EU Member States (EU 27, not including the United Kingdom) initially decreased before increasing again (Table 1). However, the average annual growth in China and South Korea remained high. Although it did fall from 2012 to 2016, it remained higher than in the OECD countries and the EU 27 countries in those years. From 2016 to 2020, the average annual growth of R&D expenditure in the OECD countries was 4.1 percent, nearly as high as the value before the financial and economic crisis. With 5.9 percent growth, the USA even had higher average growth in this period than before the crisis. The positive global trend was driven by the business sector, which achieved slightly higher growth rates than the public sector with its universities and research institutes.

In Germany, however, the situation was different: Average annual R&D growth decreased following the 2009 crisis (Figure 1). With an annual average of 1.7 percent from 2016 to 2020, it was below both the OECD countries and the EU 27 (2.8 percent). Business R&D expenditure in Germany also rose more slowly in these years by an average of 1.3 percent. While the OECD countries and the EU 27 were able to increase growth compared to 2012 to 2016, growth declined once again in Germany.

Even in 2020, the first year of the coronavirus pandemic, real R&D expenditure increased slightly OECD-wide compared to 2019 (1.8 percent, Table 1). The pandemic thus had a much milder impact on research and development than the 2009 global financial crisis did, when real R&D expenditure fell by 1.2 percent. However, there was a 5.3-percent decrease in

Table 1

Average annual growth of real R&D expenditure by sector in leading countries and regions

In percent

	OECD	USA	Japan	South Korea	China	EU 27	Germany	France
2020 R&D expenditure in billions of dollars (adjusted for purchasing power)	1,648.2	720.9	174.1	112.9	582.8	442.0	143.4	74.6
Total								
2004–2008	4.5	4.6	3.4	10.0	17.0	4.2	3.9	1.3
2008–2012	1.2	0.2	–1.0	10.2	17.3	2.2	3.1	2.3
2012–2016	2.8	3.8	0.6	3.9	9.8	1.8	2.1	0.9
2016–2020	4.1	5.9	0.7	6.8	9.0	2.8	1.7	0.9
2009	–1.2	–0.8	–8.5	6.1	26.0	0.0	–1.1	4.2
2020	1.8	5.0	–2.7	3.2	9.4	–1.8	–5.3	–1.0
Business sector								
2004–2008	5.3	5.8	4.5	9.5	19.7	4.2	3.8	1.1
2008–2012	0.8	–0.5	–1.6	11.1	18.4	2.3	2.7	3.1
2012–2016	3.7	5.1	1.3	3.9	10.3	2.8	2.2	1.1
2016–2020	4.6	6.7	0.6	7.2	8.7	2.9	1.3	1.3
2009	–4.1	–3.5	–11.6	4.6	25.9	–2.3	–3.5	2.5
2020	1.5	5.5	–3.3	1.6	9.6	–3.0	–7.8	–0.6
Public sector								
2004–2008	2.9	1.8	–0.2	11.6	10.8	4.1	4.3	1.5
2008–2012	2.2	1.7	1.0	7.1	14.0	2.1	4.1	1.0
2012–2016	0.6	0.6	–1.8	4.2	8.3	0.1	2.0	0.5
2016–2020	2.8	3.7	0.8	5.1	10.1	2.6	2.6	0.1
2009	5.0	5.7	3.0	10.9	26.1	3.9	4.3	7.1
2020	2.6	3.3	–0.4	9.6	8.8	0.4	0.3	–1.7

Sources: OECD (MSTI); authors' calculations.

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Germany in 2020. German firms reduced their R&D expenditure by 7.8 percent in the first year of the coronavirus pandemic, more than companies in other large research nations, but also more than the EU 27 average (minus three percent). In contrast, corporate R&D expenditure grew in China and the USA in 2020.

The German public sector did not reduce its R&D expenditure in 2020, but the growth rate was still below the OECD and EU 27 average. From 2016 to 2020, it was equal to the EU 27 average but lower than the OECD average and significantly lower than the rates in China, South Korea, and the USA. Thus, compared with other leading research nations, Germany has displayed weak growth and, until recently, a downward trend in the development of total R&D expenditure in past years. In 2020, therefore, the share of R&D of GDP, i.e., R&D intensity, also fell slightly to 3.14 percent in Germany. R&D expenditure thus declined somewhat more sharply than output and the prospect of achieving an intensity of 3.5 percent by 2025 as planned by the German Federal Government grew fainter. Of the seven leading research nations, Germany had the third-highest R&D intensity (behind South Korea and Japan) until 2018; however, it was overtaken by the USA in 2019 (Figure 2).

Sharp slump in corporate research during the coronavirus pandemic

The decline in internal R&D expenditure and R&D personnel (measured in full-time equivalents) was greater in German

companies during the coronavirus pandemic than during the global financial crisis in 2009 (Table 2). In the manufacturing sector, however, the decline in R&D personnel was not as stark: The 2.5-percent decline in 2020 was only half as high as the decline in 2009. However, a structural effect also had an impact in 2009. Parallel to the decline in the manufacturing sector, R&D personnel was increased in information and communication services and professional, scientific, and technical activities, making the overall personnel reduction very small. The outsourcing of R&D and industrial R&D units' associated sector change likely also played a role here.

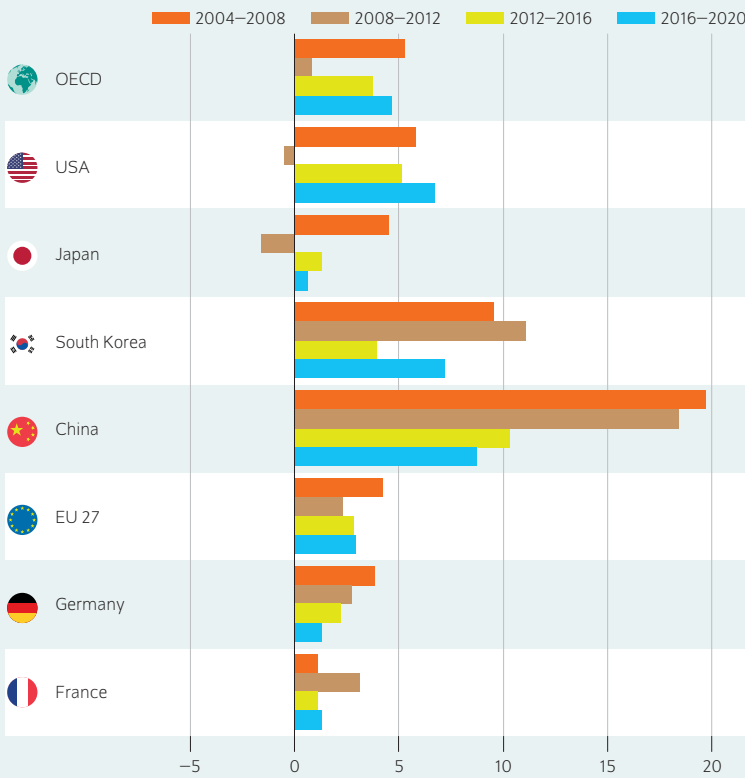
In 2020, firms' R&D personnel declined by 1.7 percent overall, significantly less than the 6.3-percent decline in internal R&D expenditure. This indicates that companies, despite decreasing R&D expenditure, attempted to keep R&D employees during the coronavirus pandemic. Short-time work, which was used by companies to a much greater extent in 2020 than in 2009, is likely to have contributed significantly to this.¹

¹ While nearly every fifth employee subject to social security was in short-time work due to economic reasons in April 2020 (18 percent), it was only every twentieth employee in May 2009 (five percent). In the manufacturing sector, too, where R&D expenditure is concentrated, the already high short-time work rates from during the global financial crisis were significantly exceeded. Cf. Statistik der Bundesagentur für Arbeit, *Grundlagen: Methodenbericht – Einführung einer Kurzarbeiterquote*. (2021) (in German).

Figure 1

Average change in real business expenditure on R&D from 2004 to 2020

In percent



Sources: OECD (MSTI); authors' calculations.

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Business expenditure on R&D in Germany has recently been increasing at a lower rate.

Decline primarily in the automotive sector

The decline in internal R&D in 2020 was concentrated in the manufacturing sector, which still accounts for a good 83 percent of internal R&D expenditure by all companies in Germany.² In contrast, R&D expenditure increased for information and communication services in 2020. However, its share of total private internal R&D expenditure is only 6.4 percent.

At 80 percent, the largest contribution to the decline in internal corporate R&D expenditure in Germany came from the automotive sector, which accounts for 34 percent of private R&D expenditure. It was therefore disproportionately involved in the decline in R&D during the pandemic. From 2010 to 2020, however, the share of total R&D expenditure growth accounted for by the automotive sector was slightly higher than its share in the base year. Machinery and equipment contributed around ten percent to the decline in 2020, corresponding to its share of total R&D expenditure. The

² In 2007, it was still 88 percent.

chemical and pharmaceutical industries also slightly reduced their internal R&D expenditure in 2020.³

China's industrial research trending upward

An international comparison helps to evaluate the competitiveness of German industrial research. Global R&D activities in the manufacturing sector are concentrated in seven countries: China, USA, Japan, Germany, South Korea, France, and Italy.⁴ These countries account for almost 90 percent of the industrial research capacity of the OECD countries and China combined.⁵ In Germany, China, Japan, and South Korea, between 85 and 88 percent of all companies' internal R&D expenditure was in manufacturing in 2019. This share was markedly lower in Italy (66 percent), the USA (58 percent), and France (49 percent in 2017⁶), where R&D occurs largely in the service sector.

The share of Chinese companies in the total purchasing power-adjusted R&D expenditures of the seven largest industrial research nations increased from 25 percent in 2010 to 37 percent in 2019 (Table 3). China has become the country with the largest research capacities in the manufacturing sector worldwide. Germany was able to roughly maintain its share at nearly nine percent and is the fourth largest industrial research location. The USA and Japan, who rank ahead of Germany, have lost importance over the past ten years, however. The USA's share of industrial R&D expenditure of the seven countries decreased from 36 percent to 30 percent, and Japan's share decreased from 17 to 12 percent. In the USA, however, the decline of R&D's importance in industry is more than offset by strong R&D growth in the service sector.

In 2019, 78 percent of research expenditure in the manufacturing sector of the leading nations was attributable to seven R&D-intensive sectors, each with a particularly high share of R&D expenditure in value added.⁷ These sectors include computer, electronic, and optical products as well as

³ This decline is countered, for example, by the well-known success story of BioNTech, which more than doubled its R&D expenditure from 226 million euros in 2019 to 645 million euros in 2020, cf. BioNTech, "BioNTech Announces Fourth Quarter and Full Year 2021 Financial Results and Corporate Update," press release from March 30, 2022 (available online; accessed on October 26, 2022). This applies to all other online sources in this report unless stated otherwise). The innovation survey of the Leibniz Center for European Economic Research (ZEW) even shows an expected increase in innovation expenditure by the chemical and pharmaceutical industries for 2020. Cf. ZEW, *Innovationen in der deutschen Wirtschaft: Indikatorenbericht zur Innovationserhebung 2021* (2022) (in German; available online).

⁴ R&D expenditure in the manufacturing sector in the eighth-place country, Belgium, was only half as high as in Italy (sixth place) in 2019.

⁵ The OECD has partially estimated data on R&D expenditure in manufacturing by sector for these and other countries. See OECD, *Analytical Business Enterprise Research and Development* (ANBERD) (2022).

⁶ Data are only available up to 2017 for France.

⁷ The OECD classifies pharmaceuticals and computer, electronic, and optical products as high R&D intensity industries. Other transport equipment; motor vehicles, trailers, and semi-trailers; machinery and equipment n.e.c.; chemicals and chemical products; and electrical equipment are all classified as medium-high R&D intensity industries. Not only do these sectors have especially high R&D expenditure, but they also face intense international competition. See Fernando Galindo-Rueda and Fabien Verger, *OECD Taxonomy of Economic Activities Based on R&D Intensity* (OECD Publishing: 2016) (available online).

Table 2

Change in R&D expenditure and R&D personnel in selected economic sectors in Germany compared with the respective previous year

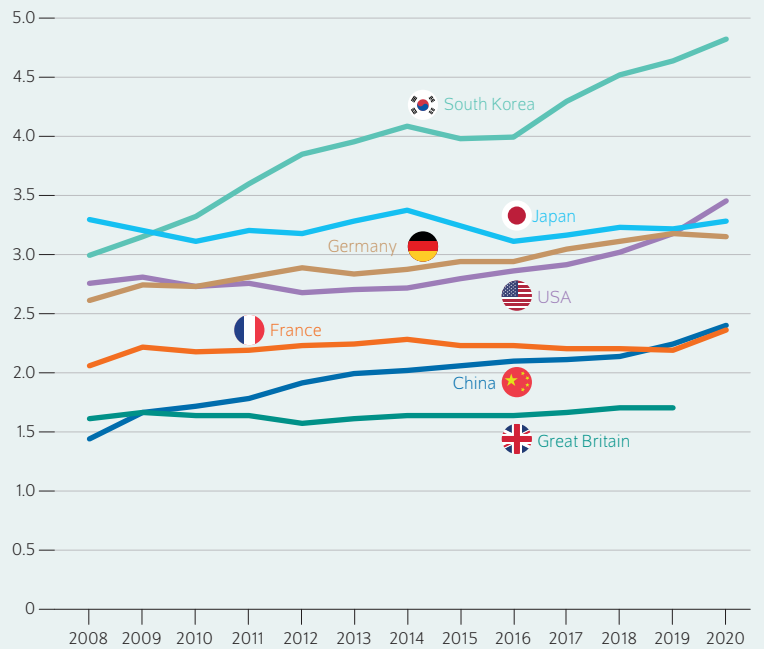
	2009	2020	2009	2020
Internal R&D expenditure				
	In millions of euros		In percent	
Total	-798	-4,798	-1.7	-6.3
Manufacturing	-2,066	-5,047	-5.1	-7.8
Automotive	-1,463	-3,836	-9.6	-13.6
Computer, electronic, optical products	-660	-64	-10.2	-0.7
Machinery and engineering	-172	-516	-3.7	-6.9
Pharmaceuticals	482	-145	14.1	-3.4
Information and communications	648	224	33.8	5.2
Professional, scientific, and technical services	510	-58	21.2	-1.0
R&D personnel				
	In full-time equivalents		In percent	
Total	-418	-8,232	-0.1	-1.7
Manufacturing	-14,596	-9,229	-5.0	-2.5
Automotive	-2,789	-5,106	-3.1	-3.7
Computer, electronic, optical products	-4,740	985	-8.7	1.6
Machinery and engineering	-2,770	-1,418	-6.8	-2.7
Pharmaceuticals	192	-643	1.0	-2.9
Information and communications	6,619	1,573	42.8	5.0
Professional, scientific, and technical services	6,605	-941	31.6	-1.7

Sources: Stifterverband Wissenschaftsstatistik, authors' calculations.

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Figure 2

R&D intensity¹ of the countries spending the most on R&D from 2008 to 2020
In percent



1 R&D expenditure to GDP ratio.

Sources: OECD (MST); authors' calculations.

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R&D intensity in Germany declined slightly in 2020.

pharmaceuticals, the sectors in which the USA has the highest R&D expenditure globally. While the USA was recently able to increase its importance in the pharmaceutical industry, its importance has decreased in computer, electronic, and optical products. China has significantly increased its significance in R&D over the past decade in computer, electronic, and optical products; chemicals and chemical products; electrical equipment; and machinery and equipment, and now even has the world's highest R&D expenditure in each of the latter three sectors. Inversely, primarily the USA and Japan lost importance in these sectors. Next to China, South Korea could also increase its share of global research capacities.

Germany accounted for the world's largest R&D expenditure (just under 26 percent) in the automotive sector, although it was closely followed by Japan and China. Germany has slightly expanded its position as a research location in this sector in recent years. In light of climate change and new international competitors such as Tesla, the automotive manufacturers that are so important for Germany as an industrial location are under great pressure to innovate. Their R&D expenditure must not only focus on climate-friendly drive systems (electric motors, fuel cells) for automobiles, but they must also link them into future mobility systems to make energy-efficient, safe, autonomous driving possible.

High R&D intensity in German industry

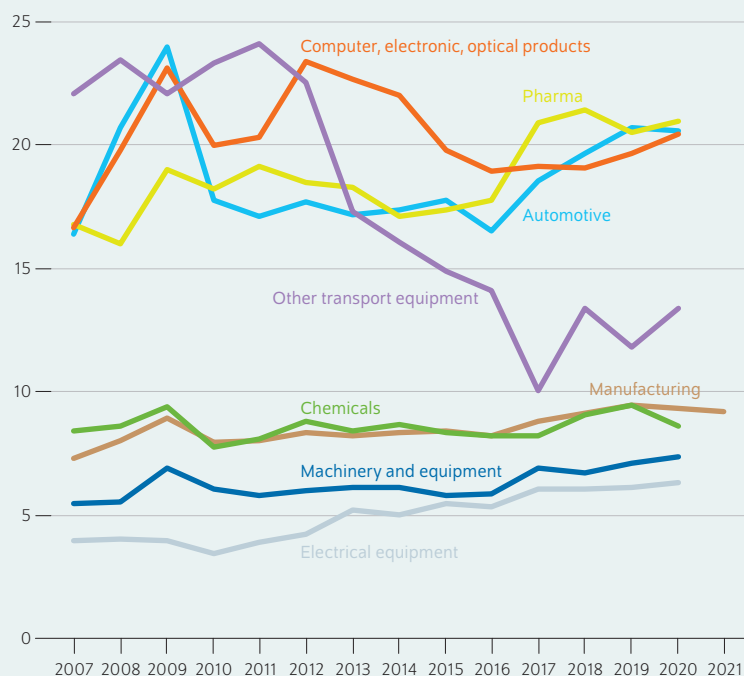
A key parameter for evaluating corporate research in an international comparison is R&D intensity, the ratio of R&D expenditure to the output generated with it. Two methods of measuring R&D intensity are used here in the analysis. In the first method, the R&D expenditures of a country's research companies are compared with the value added of all companies in an economic sector, i.e. including those not engaged in research.⁸ Only the value added generated domestically is considered, although R&D in internationally active companies is also applied in production in foreign subsidiaries and, conversely, the results of R&D conducted abroad are often implemented in domestic production. Therefore, in a second approach, the global R&D expenditure and sales of top R&D investors from various home countries are compared.

With a share of R&D expenditure of gross value added of a good 20 percent each, three sectors in Germany have an especially high R&D intensity: automotive, pharmaceutical, and computer, electronic, and optical products (Figure 3). The 10-year long sharp decline in intensity in other transport

⁸ The data on R&D and value added are taken from various firm surveys. Classifying R&D input and value-added output by industry is always fuzzy, as there are different delineations of companies and interlocking relationships, even if only data of researching companies is taken into account.

Figure 3

R&D intensity¹ of selected sectors in Germany In percent



¹ Ratio of R&D expenditure to value added.

Sources: Stifterverband Wissenschaftsstatistik, Federal Statistical Office, authors' calculations.

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Three sectors have a lead over the others, each with an R&D intensity of nearly 20 percent.

equipment (aerospace equipment, railway equipment, and ships), which was previously high intensity, has been halted. In the overall manufacturing sector, R&D intensity has been stagnating at a good nine percent.

The R&D intensity of German industry is lower than that of the USA, Japan, and South Korea (Figure 2).⁹ When comparing the R&D intensities of manufacturing on an international scale, the influence of the respective shares of various R&D intensive sectors must be considered. To do so, structure-adjusted R&D intensities of the manufacturing sector are calculated here by

- weighting the branch intensities in the respective countries with the US branch structure, the country with the highest R&D intensity
- weighting the branch intensities in the USA with the respective branch structures in the reference country

If German industry had the same branch structure as US industry, R&D intensity in 2019 would have been somewhat lower than the actual (Figure 4). Thus, German industry benefits from its research-intensive structure. By applying a

⁹ There is no information on the value added of the Chinese manufacturing industry, making it impossible to calculate its R&D intensity.

uniform industry structure, in this case that of the USA, the differences in industrial R&D intensity between Germany, France, and South Korea disappear. However, a clear gap remains between German intensity and that of the USA and Japan.

If German sectors had had the R&D intensity of the US sectors in 2019, total intensity would have been 11 percent, significantly higher than the actual intensity. Thus, compared to the USA, German industry has a deficit, which is mainly due to lower R&D intensities in the respective sectors. In two branches, however, automotive and chemicals, R&D intensity is higher than in the USA.

Using data from the annual reports of the top R&D-performing companies worldwide, which are published annually in the EU Industrial R&D Scoreboard,¹⁰ the R&D sales intensity of the largest German companies can be compared on an international level.¹¹ The 96 top R&D-investing German companies had total global R&D expenditure of 83.1 billion euros in 2020.¹² In 2019, the year before the coronavirus pandemic, their R&D revenue intensity was 5.2 percent, significantly higher than that of a comparison group of 1,578 top R&D-performing companies worldwide, with 4.5 percent.¹³ The German firms also had a higher R&D intensity than the 205 companies from the other 26 EU Member States included in the analysis (an average of 3.5 percent). The 467 US companies, however, had a significantly higher R&D intensity of seven percent. Surprisingly, the German firms in the most research-intensive sectors even had higher intensities than the US firms (Figure 5).¹⁴ The R&D intensities of the US companies are only greater in the pharmaceutical and biotechnology and the less research-intensive sectors. Thus, R&D-strong German companies are not lagging behind their competitors in the same industries in terms of intensity. However, the branch structure of US companies, of which more companies are active in research-intensive

¹⁰ See European Commission, *EU Industrial R&D Investment Scoreboard* (available online).

¹¹ Global R&D expenditure is not allocated to the individual research locations, but a large share is generally accounted for by the companies' respective home locations. Cf. Heike Belitz, Anna Lejpras, and Maximilian Priem, "Research and Development Abroad: German Companies Focus on Strengths Similar to Those at Home," *DIW Weekly Report*, no. 35/36 (2019) (available online). However, the data on global R&D expenditure published in companies' annual reports in accordance with accounting guidelines are not always based on the criteria of the OECD's Frascati Manual for statistical recording of R&D expenditure. Cf. OECD, *Frascati Manual 2015 – Guidelines for Collecting and Reporting Data on Research and Experimental Development, The Measurement of Scientific, Technological and Innovation Activities* (2015) (available online). For example, since the IFRS 15 accounting guideline came into force in the 2018 financial year, the total amount of internal R&D cannot be discerned from annual reports in many cases because contract research conducted by a company for other companies is not reported as R&D. This explains a large part of Continental's reduction in R&D expenditure in 2021. See Nicola Grassano and Hector Hernández Guevara, "Top R&D investors recovering fast from the Covid-19 crisis: Preliminary insight to the 2022 Industrial R&D Investment Scoreboard," *Science for Policy Brief – Industrial Innovation & Dynamics Series*, no. JRC130014 (2022).

¹² To compare: In Germany, internal R&D expenditure of all companies in this year totaled 71 billion euros. See Barbara Grave, *Forschung und Entwicklung in der Wirtschaft 2020: facts – Zahlen und Fakten aus der Wissenschaftsstatistik* (SV Wissenschaftsstatistik: 2022) (in German).

¹³ For these companies, data on global R&D expenditure and sales from the EU Industrial R&D Scoreboard are available for 2015 to 2020.

¹⁴ The sectors of the principal activities of the companies in the EU Industrial R&D Scoreboard are based on the Industry Classification Benchmark (available online).

Table 3

Industrial R&D expenditure in the seven leading countries in 2019 by sector

	China	Germany	France ¹	Italy	Japan	South Korea	USA	All 7 countries together	
Breakdown by country and industry in percent									
Manufacturing	37.0	8.9	2.2	1.7	12.4	7.5	30.3	100	100.0
Chemicals	44.1	10.4	2.3	1.4	16.2	7.7	17.9	100	5.9
Pharmaceuticals	11.4	5.7	0.8	0.8	10.1	1.6	69.6	100	13.3
Computer, electronic, optical products	26.9	4.9	2.1	0.7	10.8	17.8	36.9	100	24.6
Electric equipment	65.1	7.0	2.1	2.0	8.0	4.9	10.9	100	5.3
Machinery and equipment	44.6	11.7	1.7	3.5	15.2	5.1	18.2	100	8.9
Automotive	21.1	25.9	2.1	1.7	25.5	6.7	17.0	100	15.1
Other transport equipment	24.0	6.2	8.9	5.2	2.5	2.3	51.0	100	4.4
Other sectors	64.7	3.4	1.9	1.9	7.6	2.9	17.5	100	22.5
Change in the share of countries by industry in 2019 compared with 2010 in percentage points									
Manufacturing	12.1	-0.3	-1.7	-0.1	-5.0	1.2	-6.2	0	-
Chemicals	10.8	-0.8	-1.5	0	-3.1	1.8	-7.1	0	-
Pharmaceuticals	4.6	-0.7	-0.6	-0.2	-5.5	0.4	2.1	0	-
Computer, electronic, optical products	22.9	-1.1	-1.8	-0.7	-10.2	2.1	-11.1	0	-
Electric equipment	7.3	0.6	-2.0	-0.1	-5.0	1.1	-1.8	0	-
Machinery and equipment	6.9	-0.1	-1.3	0.6	-4.5	0.6	-2.3	0	-
Automotive	0.3	2.0	-1.9	-0.1	-4.6	0.5	3.8	0	-
Other transport equipment	5.4	0.2	1.6	2.4	1.6	1.0	-12.2	0	-
Other sectors	13.1	-1.6	-2.1	0	-4.8	0	-4.6	0	-

1 Data is from 2017, as no more current data are available.

Sources: OECD (ANBERD), authors' calculations and estimates.

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sectors, results in their R&D intensity being higher overall than that of German companies.

Increasing concentration in R&D-intensive industrial research

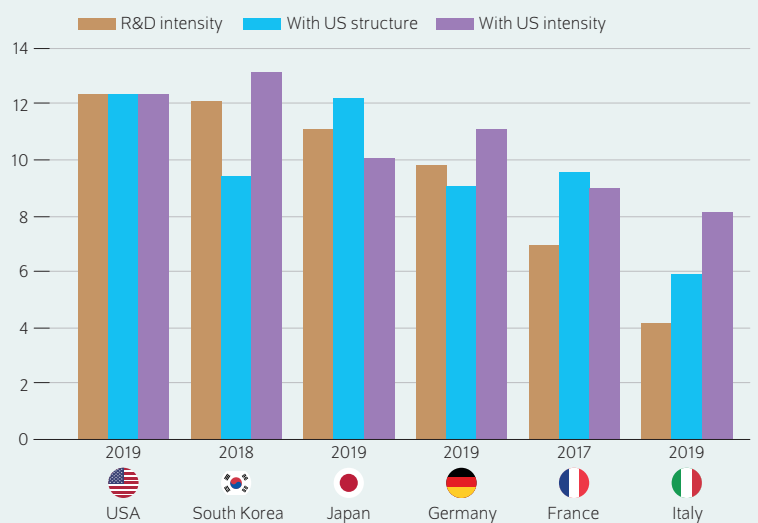
The revealed technology advantage (RTA, Box) index is employed to conduct an international comparison of German industrial research's particular specialization in individual sectors. In the comparison, the country-specific share of R&D expenditure of a respective sector is compared with the corresponding share in the seven countries with the highest private research expenditure combined. In an international comparison, Germany's industrial research specializes in the automotive sector in particular, but also on machinery and equipment as well as chemicals (Figure 6). Japanese industry has similar R&D specializations. The USA, in contrast, has significant advantages in pharmaceuticals; other transport equipment; and computer, electronic, and optical products. South Korea's industrial research specializes in computer, electronic, and optical products in particular. Compared to its international competitors, China has advantages due to its specialization in electrical equipment, machinery and equipment, and chemicals. Unlike the other major research countries, much of Chinese research is focused on the non-R&D-intensive sectors.

The share of R&D-intensive sectors of R&D expenditure in the manufacturing sector was highest in Germany and South

Figure 4

Actual and adjusted R&D intensity¹ of manufacturing in selected countries

In percent; most recent year available



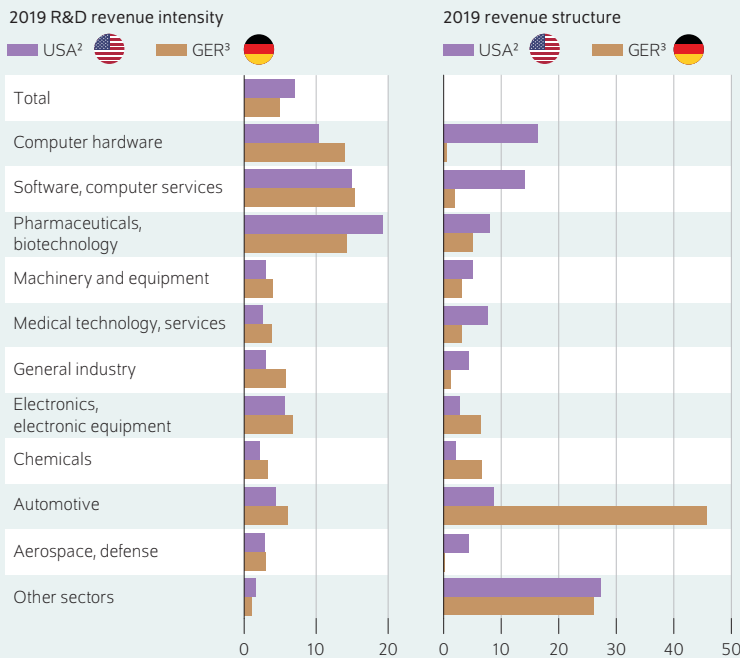
1 R&D expenditure to value added ratio.

Sources: OECD (STAN, ANBERD), authors' calculations.

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If German industry had the sector intensities of US industry, total German R&D intensity would have been somewhat higher in 2019.

Figure 5
Global R&D intensity¹ and sales structure of top R&D investors in Germany and the USA
 In percent



1 Ratio of R&D expenditure to sales generated by companies.
 2 The 467 top R&D investing companies were considered.
 3 The 96 top R&D investing companies were considered.

Sources: EU Industrial R&D Scoreboard (2020), authors' calculations.

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In most research-intensive sectors, German companies have higher intensities than US companies.

Korea and was lowest in China in 2019 (Table 4). This share has actually decreased in China and Italy in recent years, while it remained roughly the same in other leading industrial countries. The concentration of R&D activities within the R&D-intensive manufacturing sector, which is measured using the Herfindahl-Hirschmann index (HHI, see Box), was highest in South Korea. Germany, the USA, and Japan lagged behind considerably. Italy, China, and France have relatively low concentrations. In particularly R&D-intensive countries, research is more strongly concentrated in individual sectors.

The concentration of R&D in individual sectors, as measured by the HHI of R&D expenditure and the number of companies by sector, increased slightly among the 2,000 top R&D-performing companies as well from 2011 to 2020.¹⁵ This also applies to the sector-related R&D of the 40 companies with the most research in the USA, France, Switzerland, and Japan (Table 5). In Germany and the United Kingdom, this group's R&D sector concentration remained unchanged, while it declined slightly in China and Taiwan. In South Korea, there was a sharp decline in the HHI of sector-related R&D expenditure, although it was still relatively high recently. Swiss and Taiwanese companies have the highest R&D sector concentration, followed by German and South Korean companies.

This strong R&D concentration in Germany, especially in the automotive sector, is sometimes viewed critically. Greater diversification of research efforts is required to mitigate risks from technological upheaval and to strengthen the resilience of the innovation system.¹⁶ This contrasts with the fact that there has been an increasing concentration of research in individual R&D-intensive sectors at all major leading industrial research locations (Table 4) and among the world's top R&D investors (Table 5) until recently. The process could stop, however, if the current trends toward deglobalization and strengthening national resilience continue.

Outlook: Global corporations markedly increasing R&D expenditure in 2021

Although internationally comparable R&D data for the leading research locations are not yet available for 2021, data from the previously published annual reports of large firms can be used to estimate the development trends of R&D activities. Data on 678 top R&D investors indicate R&D expenditure is experiencing strong growth in 2021.¹⁷ While R&D expenditure of all companies increased by 12.7 percent in nominal terms and in euro terms, it increased in companies in the EU 27 countries and in Germany by only a good eight percent (Table 6). Thus, R&D expenditure will pick up speed again after stagnating in 2020. This is also the case for the largest German automobile manufacturers, who reduced

Table 4
Concentration of R&D-intensive industrial research in selected countries

	Share of R&D-intensive branches of industrial research		HHI ¹ in R&D-intensive sectors ²	
	2010	2019	2010	2019
	In percent			
Germany	89.7	91.5	0.236	0.285
USA	88.4	87.0	0.244	0.263
China	75.0	60.6	0.168	0.183
France ³	80.4	80.2	0.189	0.193
Italy	79.3	74.4	0.169	0.173
Japan	86.2	86.2	0.229	0.233
South Korea	91.1	91.2	0.431	0.438

1 HHI stands for the Herfindahl-Hirschmann index, which measures the concentration of R&D activities within an R&D-intensive sector. The larger the value between 0 and 1, the greater the concentration (see the Box for more).
 2 Calculated for seven R&D-intensive sectors.
 3 The data for France is for 2017 instead of 2019, as no more current data is available.

Sources: OECD (ANBERD), authors' calculations and estimates.

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¹⁵ The observation period begins in 2011, as this is the year the sector definitions in the Industry Classification Benchmark, which are used in the EU Industrial R&D Scoreboard, were changed.

¹⁶ Cf. Holger Bornemann, Jan-Philipp Kramer, and Matthias Woiwode von Gilardi, *Zukunft der EU-Strukturpolitik in Deutschland ab 2021* (DLR Projektträger, Prognos: 2018) (in German).

¹⁷ Grassano and Hernández Guevara, "Top R&D investors recovering fast."

Box

Measuring R&D specialization and concentration

To measure the various sector specializations of industrial research, a relative technological specialization index, the revealed technology advantage (RTA), is used. The RTA measures the relative concentration of R&D activities of the selected firms in specific industries compared to a population of companies, in this case in the seven most research-intensive countries (G7), and is defined as follows:

$$RTA_{il} = 100 \times \text{TANHYP} \left(\text{LN} \left(\frac{f_{il}}{\sum f_l} \right) - \text{LN} \left(\frac{f_{iG7}}{\sum f_{G7}} \right) \right)$$

The RTA indicates whether a country (l) invests a higher share (positive value) or a lower share (negative value) of its industrial R&D expenditure (f) in sector (i) than the average of the group of the seven countries spending most industrial R&D (G7). By transforming with the hyperbolic tangent and logarithmizing, the RTA becomes a symmetrical measure with values between -100 and +100.

The concentration of companies' R&D activities in sector j is measured using the Herfindahl-Hirschmann index (HHI). It is defined as the sum of the squares of all industry shares f_j of total R&D expenditure or the shares of the number of research companies in an industry of all companies:

$$HHI = \sum_{j=1}^J f_j^2$$

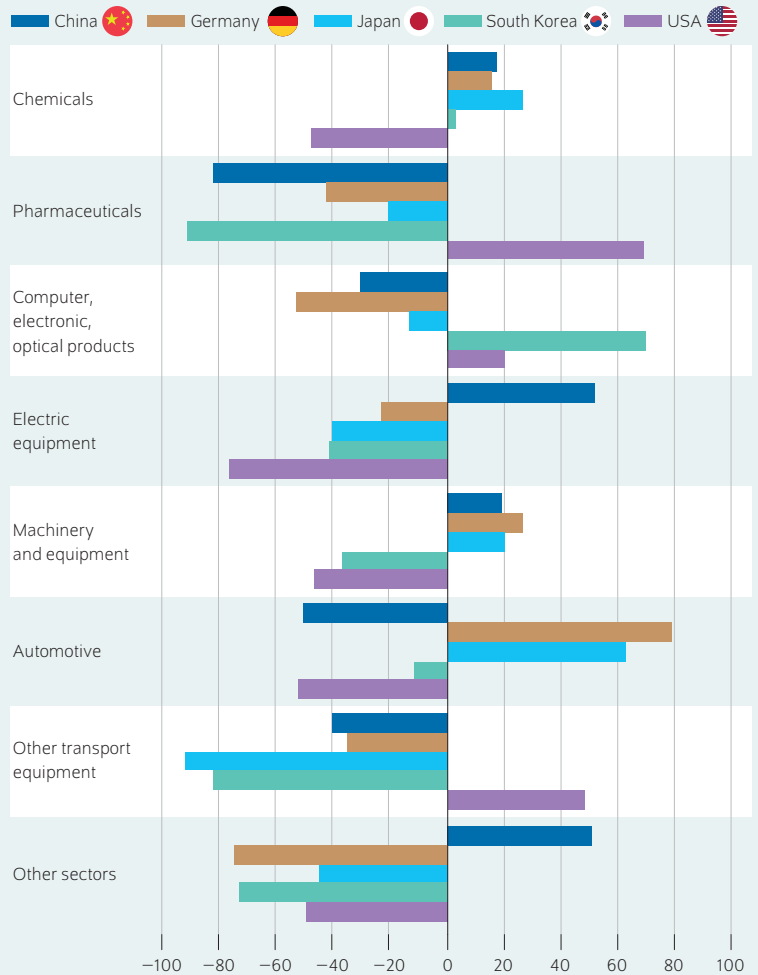
The HHI approaches 0 when the R&D expenditure or the researching companies are evenly distributed across all sectors and reaches its maximum of 1 if R&D only occurs in one sector.

their R&D expenditure in 2020. Annual R&D growth in the 678 research-strong companies was higher in 2021 than the average growth of a larger group of 1,578 companies from 2015 to 2020. The German companies, however, had lower growth rates than all other companies, especially those from China and the USA. This is likely to be mainly due to the fact that the growth hierarchy of the sectors remains as it has been in past years: The largest increases in R&D worldwide will continue to be in software and computer services, pharmaceuticals and biotechnology, and hardware production.¹⁸ As few German companies belong to these sectors, German companies' R&D expenditure growth was also below the average of the most research-strong companies worldwide in 2021.

¹⁸ Grassano and Hernández Guevara, "Top R&D investors recovering fast."

Figure 6

Technological specialization (RTA¹) of industrial research in selected countries in 2019



¹ Relative technological specialization index (see Box).

Sources: OECD, authors' calculations and estimates.

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In an international comparison, Germany's industrial research specializes in the automotive, machinery and equipment, and chemical sectors in particular.

Preliminary trend data on internal R&D expenditure of German companies for 2021 show nearly six percent growth compared to 2020.¹⁹ However, this value is still far below the 2019 value, including in the manufacturing sector, where R&D intensity declined slightly in 2021. This decline has still not been compensated for in the automotive, machinery and equipment, and other transport equipment sectors. However, other R&D-intensive sectors (chemicals, pharmaceuticals, computers and electronics, electrical engineering) already reported higher internal R&D expenditure than in 2019. Furthermore, corporate R&D personnel increased by

¹⁹ The data are from the *Wissenschaftsstatistik* of the *Stiftverband*. Press release 18.11.2022 (in German; available online).

Table 5

Sector concentration of R&D of the 40 top R&D-performing companies of selected home countries, 2011 and 2020
Herfindahl-Hirschmann index¹

Home country	R&D expenditure		Number of companies	
	2011	2020	2011	2020
Worldwide ²	0.102	0.118	0.062	0.081
Germany	0.336	0.336	0.138	0.114
USA	0.188	0.281	0.146	0.235
China	0.184	0.171	0.128	0.105
South Korea	0.493	0.314	0.089	0.098
France	0.130	0.177	0.068	0.064
United Kingdom	0.216	0.216	0.056	0.069
Switzerland	0.465	0.489	0.098	0.136
Japan	0.168	0.207	0.128	0.158
Taiwan	0.457	0.444	0.400	0.389

1 The Herfindahl-Hirschmann index is a measure of concentration. The larger the value between 0 and 1, the greater the concentration (see the Box for more).

2 The 2,000 top R&D-performing companies were considered.

Sources: EU Industrial R&D Scoreboard, authors' calculations.

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Table 6

Growth of R&D expenditure of top R&D-investing companies of selected home countries until 2021

Home country	Companies	Average annual growth		Companies	Annual average growth
		2020	2015-2020		
	Number	In percent		Number	In percent
Total	1,578	-0.26	6.0	678	12.7
Germany	96	-0.47	4.4	not available	8.1
USA	467	-1.52	7.1	198	13.1
China	265	14.50	19.5	112	21.1
EU 27	302	-2.04	4.0	274	8.1

Sources: EU Industrial R&D Scoreboard (various years); Nicola Grassano and Hector Hernández Guevara, "Top R&D investors recovering fast from the Covid-19 crisis: Preliminary insight to the 2022 EU Industrial R&D Investment Scoreboard," *Science for Policy Brief – Industrial Innovation & Dynamics Series*, no. JRC130014 (2022); European Commission; authors' calculations.

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a good two percent in 2021, reaching a new high of just over 477,000 employees.

Conclusion: Powerful German industrial research increasingly under pressure

In recent years, Germany has had relatively low and even declining growth in private R&D expenditure. In an international comparison, it decreased particularly starkly in 2020, the first year of the coronavirus pandemic. While large German companies are again showing considerable growth in their global R&D expenditure in 2021, it continues to be below the average of international competitors. Globally, R&D is growing much faster in those sectors in which large German companies do not specialize, such as software and computer services, hardware production, and pharmaceuticals and biotechnology. This is likely to lead to rather moderate R&D growth in Germany in the near future.

The R&D intensity of industrial companies in Germany is high in an international comparison, but lower than in the USA and Japan when adjusted for structural factors. Compared to their international competitors, the most R&D spending German companies have high sector-specific R&D revenue intensities and thus no disadvantages in R&D investments.

The transition to climate-neutral, digitalized production processes also poses major technological challenges for the "traditional" sectors: automotive, chemicals, and machinery and equipment, sectors in which German industrial research is particularly strong. R&D at other leading industrial research locations is also heavily concentrated in a few research-intensive sectors, and the trend is increasing. To secure the wide variety of technologies needed for industry's transition, companies are dependent on knowledge gained internationally, for example through their own research units abroad and on international research collaborations. Thus, globalization of R&D in research-strong companies remains an important prerequisite for the ability to innovate. Disadvantages of the small national innovation systems in Europe compared to the USA and China must also be overcome with a common European research policy. As many core issues involving the digital and ecological transformation can only be solved together with other countries, the OECD calls on Germany to take a leading role in the governance and development of key technologies at the EU level and beyond in its current report on innovation policy.²⁰ Due to its special industrial structure, research and technology policy in Germany must also go its own way in the European network; it can only be based on these policies in the USA and Japan, who have different structures, to a limited extent.

²⁰ Cf. OECD, *OECD-Berichte zur Innovationspolitik: Deutschland 2022. Agile Ansätze für erfolgreiche Transformationen* (2022) (in German; available online).

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