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A Note on Germany's Role in the Fourth Industrial Revolution

Vanessa Behrens*)
(ZEW – Leibniz-Zentrum für Europäische Wirtschaftsforschung &
World Intellectual Property Organization (WIPO))

Steffen Viete**)
(German Council of Economic Experts &
ZEW – Leibniz-Zentrum für Europäische Wirtschaftsforschung)

Working Paper 09/2020***)
December 2020

*) ZEW – Leibniz-Zentrum für Europäische Wirtschaftsforschung & World Intellectual Property Organization (WIPO),
E-Mail: vanessa.behrens@wipo.int.

**) Staff of the German Council of Economic Experts & ZEW – Leibniz-Zentrum für Europäische Wirtschaftsforschung,
E-Mail: steffen.viete@svr-wirtschaft.de, Gustav-Stresemann-Ring 11, 65189 Wiesbaden.

***) Working papers reflect the personal views of the authors and not necessarily those of the German Council of Economic Experts.

A Note on Germany‘s Role in the Fourth Industrial Revolution

By Vanessa Behrens and Steffen Viete*

This paper provides in-depth insights into patenting activities in technologies of the Fourth Industrial Revolution (4IR) in Germany and worldwide between the years 1990 and 2016. The descriptive analysis of these digital inventions at the current technological frontier yields several main findings. Germany is a leader in 4IR innovations, accounting for 12% of all 4IR patents filed wordwide. Digital inventions are predominantly filed in the ICT sector, yet compared to other 4IR leaders, Germany‘s 4IR patents are relatively more directed to the motor vehicles sector and less so to the ICT sector. This is driven by Germany‘s high R&D-intensity in this sector, rather than a larger share of 4IR inventions in the motor vehicle sector. Germany‘s leading position is driven by its high number of patent applications rather than a specialization in 4IR.

I. Introduction

One of the key technological trends of recent years is the development of physical objects that are equipped with sensors, processors and embedded software. These objects become increasingly able to act autonomously and connect and interact by means of communication protocols. The massive deployment of 'smart' objects is accompanied by advancements in software, such as artificial intelligence (AI), database technology and related hardware innovations.

The proliferation of connected devices is considered to be still at its beginning and many applications, such as AI, are still in its infancy. Yet, the recent past has already demonstrated a wide range of applications in the economy. These range from smart wearables for private consumers for entertainment or health purposes, autonomous driving, connected home applications for security or energy consumption, applications for urban mobility to machine-to-machine communication and additive manufacturing in industrial production. According to estimates by IDC (2019), there will be 41.6 billion connected devices by 2025. The compound annual growth rate of data generate by these devices is estimated to be 28.7% over the period 2018-2025. In Germany, the number of SIM cards for machine-to-machine communication grew by almost 30% to 29,7 million between 2018 and

* Behrens: ZEW – Leibniz-Zentrum für Europäische Wirtschaftsforschung, L 7, 1, 68161 Mannheim, Germany; and World Intellectural Property Organization (WIPO), United Nations, Chemin des Colombettes 34, 1202 Genève, vanessa.behrens@wipo.int. Viete: German Council of Economic Experts (GCEE) and ZEW – Leibniz-Zentrum für Europäische Wirtschaftsforschung, Sachverständigenrat zur Begutachtung der gesamtwirtschaftlichen Entwicklung, c/o Statistisches Bundesamt, 65180 Wiesbaden, Germany, steffen.viete@gcee.de. We thank Dietmar Harhoff, Monika Schnitzer and the staff of the GCEE for their valuable comments, suggestions and outstanding support. Working papers reflect the personal views of the authors and not necessarily those of the German Council of Economic Experts.

2019, which illustrates the rising demand for respective applications (Bundesnetzagentur, 2020).

These developments have been frequently attested to have the potential to trigger a *Fourth Industrial Revolution* (4IR) (Schwab, 2016). The concept characterizes current advancements in digital technology as a distinct era and successor of previous waves of technological change, such as the transition to machine production by steam power in the 18th century, the electrification and mass production in the 19th century and digitization and automation in the 20th century.

The significance of 4IR technologies is driven by their widespread applicability, which leads many of these technologies to be considered so called general purpose technologies (e.g. Goldfarb, Taska and Teodoridis, 2019). They can spread across most economic sectors and are capable of implementing ongoing technological improvements. Reinforcing this further, they can stimulate a process of co-inventions, i.e. the creation of new applications and processes, as they diffuse (Bresnahan and Trajtenberg, 1995). In Germany, the concept of the 4IR carries much weight among practitioners and policymakers. Closely related, the term *Industry 4.0* originated from a national strategic initiative by the German government (Kagermann, 2011; Bundesregierung, 2012) and refers to the computerization and diffusion of connected objects in industrial production. The initiative was considered a strategic measure to strengthen Germany as a technological leader in mechanical engineering (European Commission, 2017). High hopes for future productivity growth potentials of the 4IR in industrial production for Germany rest on the strength and the comparably large share in employment and value added of the German manufacturing sector (Elstner, Feld and Schmidt, 2016).

Against this background, we provide insights into 4IR innovation activities based on patent data. We focus on the regional and sectoral origin of respective patent applications in order to shed light on Germany‘s position in the worldwide innovation landscape in these digital technologies at the global technology frontier. To measure digital inventions connected to the 4IR, the European Patent Office (EPO) has brought forward a methodology to classify patents into types of 4IR technologies (Ménière, Rudyk and Valdes, 2017). Exploiting this typology, our analysis is based on European patent applications filed with the EPO for the years 1990 till 2016. Analysing the number of patent applications serves as a means to measure the innovative output of the respective innovation process (Pakes and Griliches, 1980) and reflects an important part of the knowledge based capital stock of the economy (OECD, 2013). Patents are codified technological know-how that represent an innovative step with industrial applicability. They measure innovative output rather than inputs such as R&D investments, for which it is uncertain if they result in an invention. At the same time, when interpreting our results one has to bear in mind that not every invention is patented. So far, academic research has mostly focused on single technologies, such as AI (Goldfarb, Gans and Agrawal, 2019), cloud computing (DeStefano, Kneller and Timmis, 2020), or industrial robots (Acemoglu and Restrepo, 2020). In contrast, the 4IR typology by the EPO serves as a framework to conceptualize and measure digital innovation at the technological frontier on a broader scale.

II. Data

The EPO differentiates between 16 fields of 4IR technology, which are divided into three main sectors. Inventions in core technologies form the technical basis for 4IR applications, such as cloud storage or network protocols. Enabling technologies include inventions in key technologies that can be used for various applications, such as 3D printing, machine learning, or GPS-based positioning. The third area combines technologies from the other two areas into applications, such as autonomous driving, intelligent robotics, automated production and smart wearables. Figure A1 in the appendix provides an overview of the 4IR technology fields defined by the EPO.

Our analysis is based on the EPO‘s spring 2020 version of the worldwide patent statistical database (PATSTAT). Using the EPO‘s concordance table between Cooperative Patent Classification (CPC) field ranges and 4IR technology fields, we map all 4IR patents filed in the years 1990-2016 (Ménière, Rudyk and Valdes, 2017, p. 87). In their original work, Ménière, Rudyk and Valdes (2017) additionally apply a full-text search query restricting patent documents to contain 4IR-related concepts, such as data exchange, cloud, AI, or augmented reality.[1] Since this step is not replicable with the information available, we apply a broader concept of 4IR patents similar to Benassi, Grinza and Rentocchini (2019) and only rely on the mapping by means of CPC codes.

A patent typically consists of both 4IR and non-4IR technology. We therefore apply fractional counting, by weighing each patent by the share of its CPC codes that fall into the EPO‘s 4IR criteria. We apply fractional counting in all our statistics that follow, the sum of which add up to the total absolute number of patents filed. We present all our statistics according to the earliest filing year of the patent family and according to the country of residence of the applicant.

One has to acknowledge that our patent counts will be somewhat biased towards Europe. Applicants from within Europe are more likely to target their home market by filing a patent at the EPO, compared to non-European applicants. Even though a European patent is per definition targeting an international market, as compared to filing a national patent, the differences between European and non-European applicants have to be kept in mind when interpreting the data for international comparisons. The advantage of using only data from one single regional intellectual property offices is that our analysis will not be distorted due to differences in country-specific regulations and national patent office practices (Ménière, Rudyk and Valdes, 2017).

Furthermore, we note that the analysis is still specific to the EPO‘s proprietary concept of 4IR technologies. Especially with regard to specific technologies, alternative definitions and methodologies to identify related patents have been proposed. Baruffaldi et al. (2020) compare existing patent taxonomies related to AI. They show that the definition of AI patents as used in the EPO‘s 4IR taxonomy yields similar patent counts as the alternative definition by Fujii and Managi (2018) but is stricter than the ones proposed by Cockburn, Henderson and Stern

[1]We thank the staff at the EPO for the helpful discussion on the methodology.

(2018) or OECD (2017).

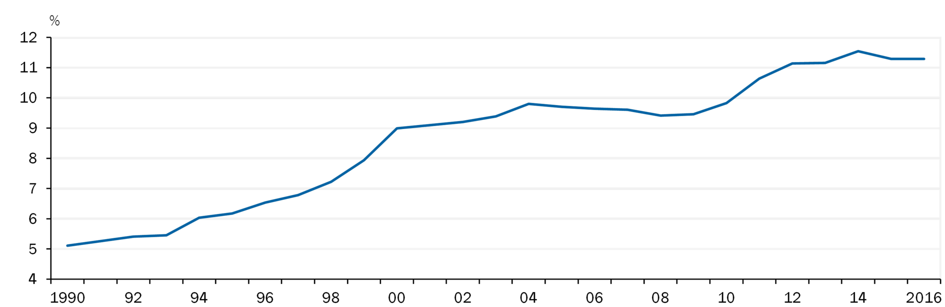
Finally, we restrict the time frame to start in 1990 with respect to the earliest filing year. Our final data set consists of around 3 million patents out of which around 9% are 4IR inventions.

III. Worldwide 4IR Inventions

The number of 4IR patent applications identified in PATSTAT has grown rapidly since the 1990s. The significance of the 4IR as an important technology trend is evident in the increase in applications; 4IR patents rose by an average of around 4% between 2010 and 2016, while only increasing by around 1% in other technology fields. In our data, the share of 4IR patents in total yearly patent applications rose from around 5% in 1990 to around 11% in 2016 (Figure 1).

FIGURE 1.

Acceleration of the Fourth Industrial Revolution
Share of 4IR[1] patents in total applications



1 – Fourth Industrial Revolution (4IR) patents are patents for connected physical objects.

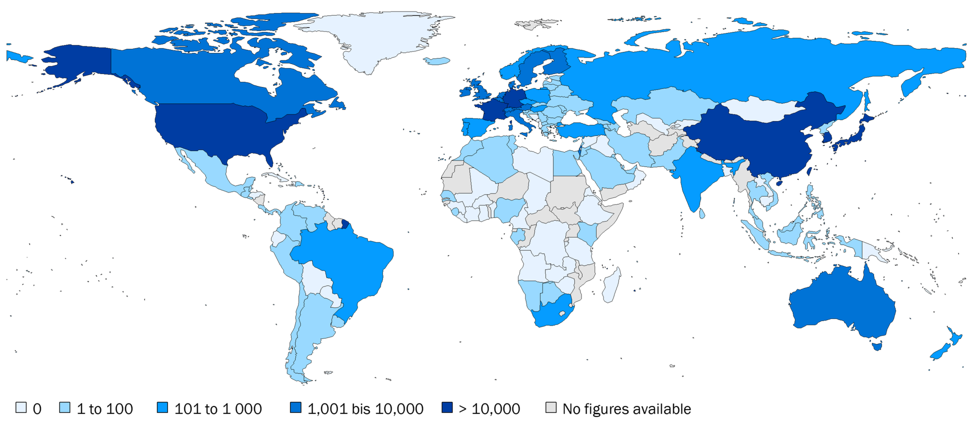
Sources: European Patent Office, own calculations

Figure 2 shows the distribution of 4IR patent applications by geographic origin. The majority of 4IR patents worldwide are held by applicants residing in the United States, accounting for around 30% of all 4IR patents. This is a similar share to that of the EU in total. Germany is the leading 4IR patent applicant in the EU, accounting for around 12% of all world-wide applications, followed by France and the United Kingdom. In addition, many 4IR patents are held by applicants from Asia, particularly Japan, South Korea and, more recently, also China. The development of 4IR patent applications over time shows that their increase worldwide, particularly in recent years, has been driven primarily by applicants from China and South Korea. These countries account for 4% and 6% of all worldwide 4IR patents in the observation period.

When normalizing the number of 4IR patent application with the number of inhabitants in Figure 3, European countries stand out. Relative to the size of the

FIGURE 2.

Number of 4IR patents[1] for the years 1990 – 2016
Highest number of 4IR patent application in Europe from Germany



1 – Fourth Industrial Revolution (4IR) patents are patents for connected physical objects.

Sources: EuroGeographics for the administrative boundaries, European Patent Office, own calculations

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economy, Switzerland, the Netherlands, Sweden and Finland in particular have filed many 4IR patent applications between 1990 and 2016.

IV. Patents in 4IR Technologies by Industrial Sector

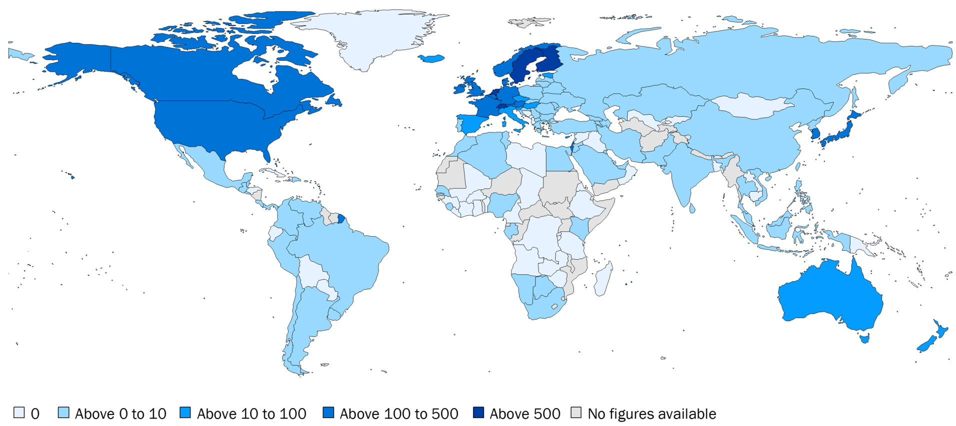
Patents are assigned to industrial sectors by means of their International Patent Classification (IPC) codes.[2] A breakdown of the sectoral distribution of 4IR applications by country shows that three sectors are responsible for the majority of 4IR innovations in the countries with the most patent applications (Figure 4). The most important industry sector as regards to 4IR patent applications in many countries is ICT hardware manufacturing (computer, electronic and optical equipment). In Germany, by contrast, ICT hardware manufacturers account for a comparatively small share of 4IR patent applications (45%). This sector is most predominant in 4IR applications filed by Chinese (82%), South Korean (74%) and US applicants (59%). The relatively lower share of the ICT hardware industry in 4IR patent applications for Germany reflects its relatively lower economic importance. While the ICT sector overall (including ICT services) accounted for 3.7% of gross value added in 2017 in Germany, a significantly higher share in value added accrues to the ICT sector in countries like Japan (5.7%), the US (5.9%) or South Korea (9.2%). Hence, at 9%, the proportion of R&D spending by German companies in the ICT sector is far below the share in South Korea (52%) and the United States (30%), and also below the EU average of around 15% (Mas et al., 2020).

The proportion of 4IR patent applications from the manufacturers of machinery

[2]Mapping IPC to NACE codes relies on the concordance table provided by EUROSTAT in co-operation with KU Leven.

FIGURE 3.

Number of 4IR Patents[1] per million Inhabitants for the years 1990 – 2016



1 – Fourth Industrial Revolution (4IR) patents are patents for connected physical objects.

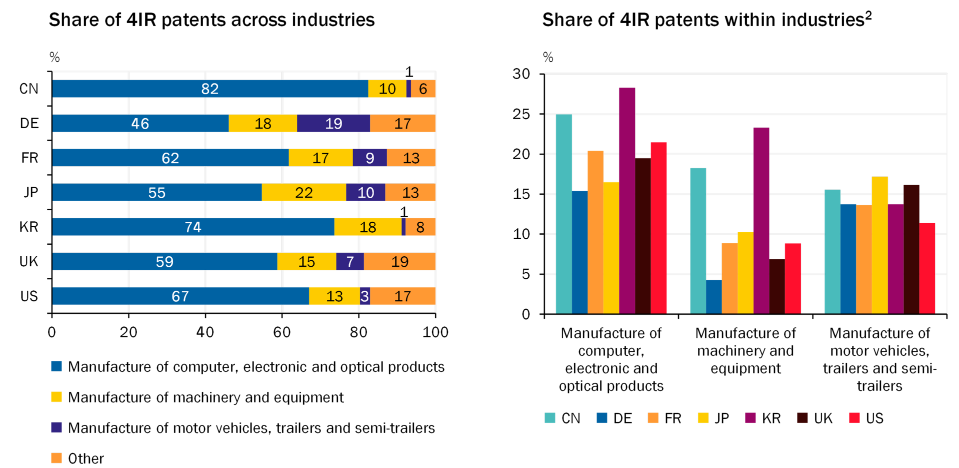
Sources: EuroGeographics for the administrative boundaries, European Patent Office, own calculations

and equipment in Germany is comparable to that of France and South Korea, but smaller than Japan. Germany's automotive industry accounts for a comparatively significant share of 4IR patent applications (19%). The relatively large number of 4IR patents in the German automotive industry is primarily due the high general level of innovation activity in the sector. The automotive industry has the largest share of German R&D expenditure, accounting for 37% of spending on research and development which compares to 26% in Japan, 14% in South Korea, and 6% in France and the US, respectively (Mas et al., 2020).

However, if we look at the share of 4IR patent applications within different sectors of the economy, we can see that the German automotive sector, along with ICT hardware manufacturing and manufacturers of machinery and equipment, is not pushing 4IR innovation any harder than the equivalent sectors in other countries. In fact, the share of 4IR patents within the German ICT hardware industry is the smallest among the top seven countries holding the most 4IR patents. In Germany, 15% of the patents filed by the ICT hardware manufacturers are 4IR patents, whereas this share amounts to 25% in China and 28% in the South Korea. Similarly, the German manufacturers of machinery and equipment exhibit the lowest share of 4IR patents (4%). Again, respective industries in China (18%) and Korea (23%) stand out in international comparison. Differences between countries in the automotive industry are less pronounced. This is the first piece of evidence that the high absolute number in 4IR patent applications in Germany is due to the relatively high overall innovation performance rather than a technological specialization of certain German industries in these technologies.

FIGURE 4.

High concentration of 4IR patents in few industrial sectors[1]



1 – Fourth Industrial Revolution (4IR) patents are patents for connected physical objects. Countries with the most 4IR patent applications. CN-China, DE-Germany, FR-France, JP-Japan, KR-Republic of Korea, UK-United Kingdom, US-USA. 2 – Industrial sectors with the most 4IR patent applications worldwide.

Sources: European Patent Office, own calculations

V. Firm Concentration of 4IR Patents

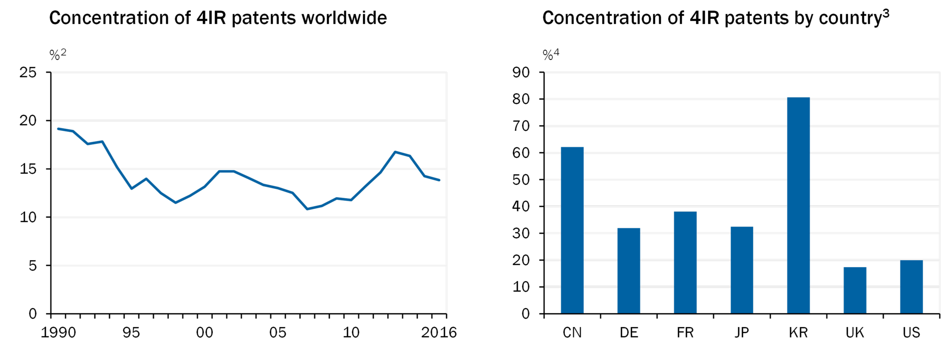
Not only are 4IR patents highly concentrated in a few selected industries worldwide, but they are also highly concentrated in a small number of companies. Around a quarter of the 4IR patents filed with the EPO between 2006 and 2016 are concentrated in 20 companies around the world. Figure 5 provides insights into the firm concentration of 4IR patents by plotting the share of 4IR patent applications that accrue to the top 5 patentees. We find that the concentration of 4IR patent applications was by and large stable over time worldwide. Between 1990 and 2016 it only sightly declined. In 1990, around 19% of patenting activity was carried out by the top 5 applicants whereas in 2016 this share declined to 14% (left panel). However, there are pronounced differences in the concentration of 4IR patents between countries (right panel). South Korea and China exhibit a high concentration with 81% and 62% of all applications between 1990 and 2016 stemming from the top 5 applicants in these countries. In contrast, in the US and the UK the concentration is considerably lower with 20% and 17%, respectively. Germany exhibits a medium level of concentration of 4IR patenting acitivity. Similar to Japan, the top 5 patentees account for only 32% of all 4IR patent applications.

VI. Quality adjusted 4IR Inventions

The quality of patented innovations varies widely over firms, industries and countries (Scherer, 1965; Böing and Mueller, 2016). For instance, innovation policy in the form of patent subsidies, as implemented in China in the past, do not only

FIGURE 5.

Medium concentration of 4IR[1] patentees in Germany



1 – Fourth Industrial Revolution (4IR) patents are patents for connected physical objects. 2 – Share of top 5 patentees in all applications by year 1990 – 2016. 3 – Countries with the most 4IR patent applications. CN-China, DE-Germany, FR-France, JP-Japan, KR-Republic of Korea, UK-United Kingdom, US-USA. 4 – Share of top 5 patentees in all applications within a country 1990 – 2016.

Sources: European Patent Office, own calculations

support financially constrained firms in protecting intellectual property, but also provide incentives for excessive filing of low-quality patents (Böing, 2020). Moreover, the information and communication sector exhibits an increasing propensity of patenting, in particular with regards to digital communication technologies (Fink, Khan and Zhou, 2016). As 4IR technologies in general are characterized by a high degree of technological complexity and the convergence of different technological domains, these technologies have a higher likelihood for the emergence of patent thickets (Shapiro, 2000), i.e. high numbers of patents with overlapping claims (Von Graevenitz, Wagner and Harhoff, 2011). Consequently, the number of patents might not merely reflect the technological value created, but also strategic considerations by applicants.

Hence, in the following we look into the patenting activity in 4IR technologies accounting for the quality of the inventions. We try to more closely approach the national technological capacity (quality adjusted patent counts) in 4IR technologies. There are numerous ways to measure the technological and economic value of patented inventions (Squicciarini, Dernis and Criscuolo, 2013). We resort to commonly used patent-based indicators as proxies for the quality of inventions. In particular, for each 4IR patent we compute the number of forward citations, i.e. the number of family-cleaned citations received from subsequent EP patents. Prior research has shown that the number of citation received by a certain patent reflects the invention‘s technological importance and its social and private economic value (Harhoff, Scherer and Vopel, 2003; Trajtenberg, 1990). We count the forward citations over a period of five years after the filing date. We can therefore investigate quality adjusted measures for patents filed up to the year 2011.

In particular, we measure the number of forward citations CIT for patent application i filed in year P_i as:

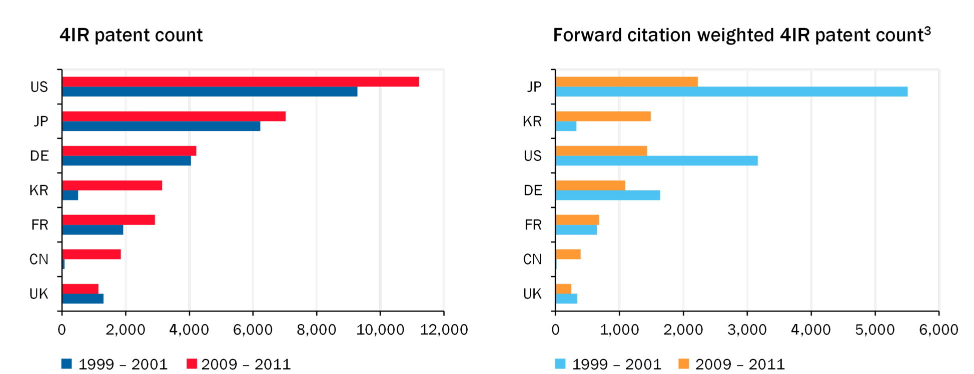
$$CIT_i = \sum_{t=P_i}^{P_i+5} \sum_{j \in J_t} C_{ji} \tag{1}$$

where C_{ji} is an indicator equal to 1 if the patent document j cites patent document i and 0 otherwise. J_t is the set of all patent applications filed in year t.

Figure 6 compares the simple counts of 4IR patents by country with the respective quality adjusted patent counts for the years 1999-2001 and 2009-2011, respectively. The general decrease in the quality adjusted measure in most countries in the right panel reflects a commonly observed downward trend in citations over time (Squicciarini, Dernis and Criscuolo, 2013). The left panel shows that, according to an unadjusted patent count, the US, Japan and Germany are the countries with the most 4IR patent filings in both observed time periods. Noteworthy is that South Korea and China have been catching up, having increased their registrations sixfold and twenty-fourfold over the period, respectively. Looking at the right hand side of the figure, we see that South Korea considerably moves up the ranks once quality is adjusted for. Between 2009 and 2011 South Korea ranks second following Japan, which scores highest in terms of forward citation weighted 4IR patents. Germany decreases its rank from third to fourth adjusting for patent quality and the US from first to third.

FIGURE 6.

National technological capacity in the 4IR[1]
Quality-adjusted 4IR[2] patent counts



1 – CN-China, DE-Germany, FR-France, JP-Japan, KR-Republic of Korea, UK-United Kingdom, US-USA. 2 – Fourth Industrial Revolution (4IR) patents are patents for connected physical objects. 3 – Weighted by forward citations over five years after the filing date.

Sources: European Patent Office, own calculations

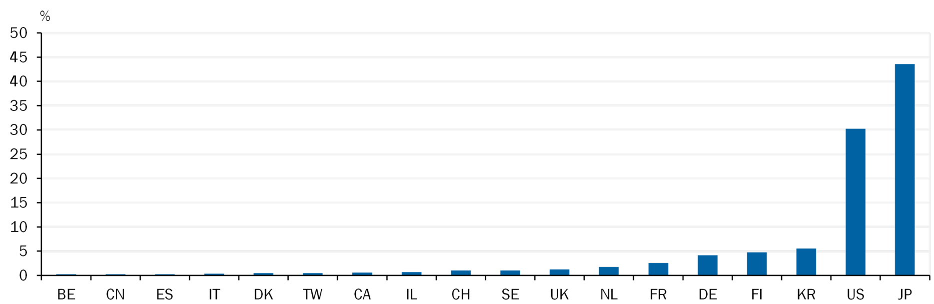
In addition to a citation weighted patent count, we try to identify 4IR inventions with a particular high impact. Such ”breakthrough” inventions generate great improvements over existing technology rather than incremental innovations. They serve extensively as prior art for further innovations (Tushman and Anderson, 1986; Kerr, 2010) and are strongly related to firms' entrepreneurial and competitive strategies (Ahuja and Morris Lampert, 2001). Building on the count of forward citations within a five year time window, we identify breakthrough patented inventions as the top 1% of cited patents similar to Ahuja and Morris Lampert (2001).

Over our observation period 1990 till 2011, there was a high regional concentration of breakthrough patent registrations, with over 40% from Japanese applicants, and almost 30% from the United States (Figure 7). Germany accounts for just over 4% of this type of patent, making it one of the leading holders of 4IR breakthrough patents in the EU, which holds a total of 15% of these patents. South Korea held around 7% of such patents during the period observed, and China less than 1%.

4IR breakthrough inventions are highly concentrated in many countries among a few firms. For instance, in Finland, the country with the fourth most 4IR breakthrough inventions amounting to 4% of the world total, Nokia is the single company responsible for all breakthrough inventions in our data.

FIGURE 7.

High regional concentration of 4IR breakthrough inventions[1]
Share of worldwide 4IR[2] breakthrough inventions[3] by country



1 – BE-Belgium, CN-China, ES-Spain, IT-Italy, DK-Denmark, TW-Taiwan, CA-Canada, IL-Israel, CH-Switzerland, SE-Sweden, UK-United Kingdom, NL-Netherlands, FR-France, DE-Germany, FI-Finland, KR-Republic of Korea, US-USA, JP-Japan. 2 – Fourth Industrial Revolution (4IR) patents are patents for connected physical objects. 3 – Breakthrough inventions are top 1 % cited patents measured by citations during the first 5 years after filing.

Sources: European Patent Office, own calculations

VII. Relative Specialization in 4IR Technologies

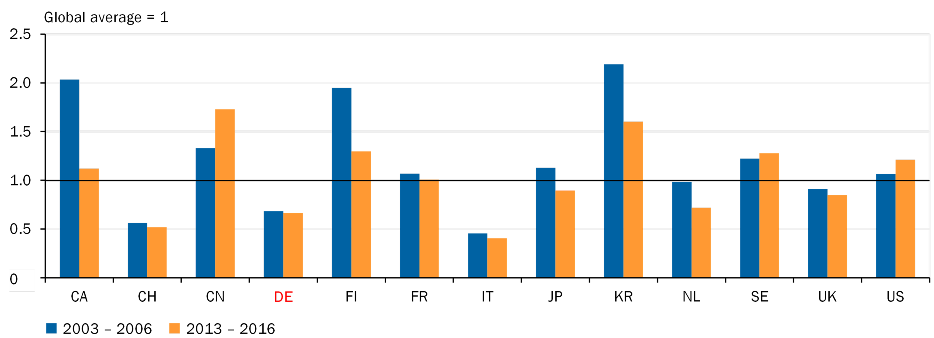
Finally, we consider a country's relative specialization in 4IR technologies. The Revealed Technological Advantage (RTA) index is a measure of an economy's specialization in a certain technology field. We compute the RTA index as the share of patents in a technology field in an economy relative to the global share of patents in that field (Dernis et al., 2019, p.29). Formally, the RTA index is defined as

(2)
$$RTA_{it} = \frac{ps_{it} / \sum_t ps_{it}}{\sum_i ps_{it} / \sum_i \sum_t ps_{it}}$$

where ps_{it} is the number of patents in an economy i in a technology field t. The index is zero when a company holds no patents in a technology field. Values above one indicate positive specialization, whereas values equal to one indicate no specialization and below one relative despecialization. By definition, the world average for the RTA index is equal to one.

FIGURE 8.

Little specialisation in 4IR technologies for Germany in international comparison[1]
RTA index of patent applications[2]



1 – Fourth Industrial Revolution (4IR) patents are patents for connected physical objects. 2 – The RTA index (Revealed Technology Advantage index) is defined as the share of patents in a certain technoloy field in one country compared with the worldwide share of patents in the same field. Countries illustrated are those with the most 4IR patent applications filed between 1990 and 2016. CA-Canada, CH-Switzerland, CN-China, DE-Germany, FI-Finland, FR-France, IT-Italy, JP-Japan, KR-Republic of Korea, NL-Netherlands, SE-Sweden, UK-United Kingdom, US-USA.

Sources: European Patent Office, own calculations

Figure 8 shows the RTA index for selected countries for the years 2004-2006 and 2014-2016, respectively. Germany accounts for a comparatively high number of 4IR patents in absolute terms. However, if we look at the level of technological specialization, the German economy has been consistently despecialized in 4IR technologies since 2004. Although the 4IR is a major topic of public and political debate in Germany, the level of technological specialisation does not reflect the significance of these technologies overall. In the observation period, the relative specialization in 4IR technologies even decreased slightly in Germany. Between 2004 and 2016, China in particular has increased its relative specialization in the development of 4IR inventions and has the highest value of the RTA index by 2016. Sweden and the USA have manged to sustain a positive specialization in 4IR technologies and even increase their relative specialization in these technologies over the observation period.

VIII. Conclusion

Recent advancements in digital technology and the convergence of the physical and digital worlds have been subsumed under the concept of the Fourth Industrial Revolution (4IR). This note sheds light on Germany‘s position in the global innovation system in 4IR technologies. It provides a comprehensive description of patenting activity in respective technologies in Germany and worldwide between the years 1990 and 2016. Based on this analysis several main findings emerge.

The global surge in 4IR patenting activity relative to other technology fields illustrates the importance of this technological trend. The prominence of respective technology fields, such as AI, autonomous driving, e-health or smart manufacturing suggests that the growth trend in patent applications in 4IR technologies will continue in the future.

Germany has been one of the most important innovators in 4IR technologies and is the leading applicant in Europe. Only the US and Japan hold more 4IR patents. Much of the dynamics in 4IR patenting in more recent years was driven by applicants from South Korea and China. Especially South Korea showed notable improvement in its 4IR performance, in particular once quality of inventions was adjusted for, overtaking Germany in 2011.

International differences in 4IR innovation documented here are on the one hand the results of preexisting technological structures. Especially in relatively new technologies, where established innovators can build on comparably little preexisting knowledge, countries such as China and South Korea have become 4IR-specialized competitors. On the other hand, cross-country differences are also the results of a strategic decision towards specialization in 4IR technologies. In the EU and in Germany in particular, the manufacturing sector comprises a large share of the economy. Hence, industrial applications of the 4IR are particularly valuable. This is reflected in multiple European and German policies directed towards industrial applications of 4IR technologies. At the EU level, the Digitising European Industry (DEI) initiative aims at triggering public and private investments and establishing framework conditions for the 4IR in industrial production. In Germany, the Platform Industrie 4.0, Mittelstand 4.0 and regional initiatives at the sub-national level are directed towards innovation and diffusion of respective technologies. Similarly, the strategic policy plan China 2025 strives to develop China‘s industrial capabilities through means of 4IR technology (Morisson, 2019). Korea has been prominently pursuing an ambitious national strategy for the roll-out of the 5G infrastructure (Forge and Vu, 2020).

Overall, the analysis points to the strong dependence on a handful of enterprises for 4IR innovations, especially in China and South Korea. While innovation in general rests a lot on large firms in Germany, 4IR inventions are considerably less concentrated than in China and South Korea. In the US or the UK, however, the concentration of 4IR inventions is even lower.

Finally, the technological specialization of the German economy does not reflect the prominence the 4IR has in the political and public debate. It‘s level of specialization in 4IR technologies has been consistently below that of leading Asian economies (China, Japan and South Korea), the US, but also other European countries, such as France, the Netherlands, Sweden, Finland, or the UK. China, in particular, has become more specialized in 4IR technologies and was the most specialized economy by 2016. In contrast to Germany, the US, for instance, maintained and even extended their positive specialization in 4IR technologies despite the increased patenting activity form Asian economies.

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Appendix

Figure A1.

4IR technology fields by sector

Technology field	Definition	Example
Core technology fields		
Hardware	Basic hardware technology	Sensors, advanced memories, processors, adaptive displays
Software	Basic software technology	Intelligent cloud storage and computing structures, adaptive databases, mobile operating systems, virtualisation
Connectivity	Basic connectivity systems	Network protocols for massively connected devices, adaptive wireless data systems
Enabling technology fields		
Analytics	Enabling the interpretation of information	Diagnostic systems für Big Data
Security	Enabling the security of data or physical objects	Adaptive security systems, intelligent safety systems
Artificial intelligence	Enabling machine understanding	Machine learning, neural networks
Position determination	Enabling the determination of the position of objects	Enhanced GPS, device to device relative and absolute positioning
Power supply	Enabling intelligent power handling	Situation-aware charging systems
Three-dimensional support systems	Ernabling the realisation of physical or simulated 3D systems	3D printers and scanners for parts manufacture, automated 3D design and simulation
User interfaces	Enabling the display and input of information	Virtual reality, information display in eyewear
Application domains		
Home	Applications for the home environment	Alarm systems, intelligent lighting and heating
Personal	Applications pertaining to the individual	Personal health monitoring devices, smart wearables, entertainment devices
Enterprises	Applications for business enterprises	Intelligent retail and healthcare systems, autonomous office systems
Manufacture	Applications for industrial manufacture	Smart factories, intelligent robotics
Infrastructure	Applications for infrastructure	Intelligent energy distribution and transport net-works, intelligent lighting and heating systems
Vehicles	Applications for moving vehicles	Autonomous driving, vehicle fleet navigation devices

Sources: European Patent Office, own presentation