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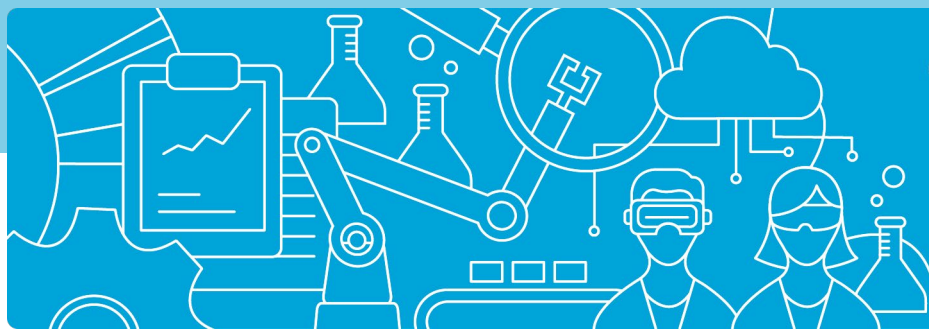

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Performance and Structures of the German Science System 2021

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Executive Summary

This study updates the annual analysis of the performance and structures of the German science system in international comparison. Bibliometric indicators are presented and discussed for the period 1995-2019, and citation-based indicators are presented for publications until 2017. Overall, all countries continued to increase their scientific productivity, with nearly constant positive growth rates between 1995 and 2019. This increase is due to increased publication output, but also reflects the increased coverage of journals by the Web of Science (WoS). Publication growth was particularly strong in China, which now holds nearly a quarter of global publications, and India, while countries with well-established science systems, such as Germany, Great Britain, France, and the USA, demonstrated less growth. China's rapidly increasing share of global publications resulted in corresponding decreases in most other countries' shares over time, with Germany holding 4% in 2019, down from 6% in 1995, as the fourth largest producer. Across fields, China's surge in publication output has led it to overtake the USA in the "hard" science fields, where it now holds a quarter of all publications in the natural sciences and a third of global engineering publications. Germany held 3-4% of global publications in each field in 2019, but in line with China's booming output, Germany's shares in all fields except the humanities and social sciences have declined over time.

Regarding the visibility and impact of scientific publications, Germany continued to publish in highly visible journals, as shown by the above average values for International Alignment and, within these journals, German publications attracted slightly above average citations. However, due to the higher expectations set by the highly visible journals, the indicator values for the Scientific Regard are slightly decreasing. Notably, China increased both its visibility and impact to above average levels for the first time in 2017, which coincided with a decrease in visibility for many European countries, including Germany. As China holds nearly a quarter of global publications, it may be that China's significant share of research is published in journals not typically amongst the core journals for many European countries, which consequently shifted which journals are most visible, resulting in a decline in visibility for many European countries that continue to publish in their traditional journal set. However, further investigation is required to confirm this hypothesis.

China has also increased its Excellence Rate to expected levels for the first time in 2017, slightly outperforming Germany, which continued a stable level of expected performance between 1995 and 2017. Most other countries were similarly stable, while the USA's performance has declined since 2003, although it continued to perform above the expected level. Germany was the fourth largest contributor of "excellent" publications to the global corpus, behind the USA, China, and Great Britain.

International collaboration continued to increase over time for all countries. Germany now collaborates on 60% of publications, up from around 50% a decade ago, a level in line with other large European countries. Switzerland retained the highest level of collaboration, and many other smaller European countries also collaborated on over two-thirds of their publications. China and the USA maintained amongst the lowest levels of international collaboration, which may reflect an aspect of autonomy granted by their large populations and the USA's well-developed science system. In examining collaboration profiles, the USA continued to be the most attractive partner for most countries, including Germany, while the USA itself collaborated most with China. Germany's strongest partnerships were with its neighbours, particularly Austria and Switzerland. Germany's collaboration levels increased in all fields, and were particularly strong in the natural sciences, and although collaboration in the humanities lagged behind the other fields, it displayed strong growth since 2006.

Examining Germany's internal performance, we see continuous growth in publication output from each of the six sectors over time, which aligns with Germany's overall increased output. Naturally given their size, the universities collectively continued to produce the largest number of publications, followed by

the Helmholtz Association (HGF) and Max Planck Society (MPG). The colleges of applied sciences and the Fraunhofer Society demonstrated the strongest growth, although their output remained the lowest of the sectors. The MPG and HGF continued to be the most impactful sectors, producing the highest numbers of publications and citations per full-time equivalent scientific staff, and also Excellence Rates well above the expected levels. All sectors have increased their levels of international collaboration over time, with between half and three-quarters of 2019 publications produced in collaborations outside of Germany.

Foreword

This report is the latest iteration in this series of bibliometric reports analysing the performance of Germany internally and within the global science system. In this report, we use a number of indicators to assess Germany's performance and compare it against 22 countries and the groups of the EU13, EU14, EU27, and OECD countries (see Appendix 1 for countries and groups). In the first section, we present 14 indicators at the country level. As indicators of the countries' scientific productivity, we present the fractional count of countries' publications, countries' fractional share of global publications, countries' growth rates of publications in 5-year intervals, and the fractional share of global publications by field for selected countries.

To examine the countries' scientific impact we present the Scientific Regard and International Alignment indicators which, respectively, show whether the countries' publications were well-cited in the journals in which they publish, and whether they publish in highly visible journals. We also present Excellence Rates, or the percentage of a country's publications that were amongst the 10% most highly cited in each discipline, and then each countries' share of the global "excellent" publications, which highlights their contribution to this corpus. We show also Germany's Excellence Rate in each discipline. Then, to show performance across the entire citation spectrum, we show the percentage of each country's publications that were cited at the median level of citations, and that remained uncited 3 years after publication.

Then we present an analysis of scientific collaboration, including the rate of countries' international collaborations, a collaboration matrix showing the collaboration profiles of each country and continent in 2019, and the rate of Germany's international collaboration in each field, to provide greater context to Germany's national performance.

In the second section, we analyse the performance of the German non-university research institutions, and collectively, the colleges of applied science (Fachhochschulen), and the universities. We include here each sector's fractional number of publications and growth rates in 5-year intervals, the number of publications and citations per full-time equivalent scientific staff to provide a more balanced comparison allowing for staffing profiles, Excellence Rates, and the percentages of publications produced nationally or with international collaboration.

This report examines articles and reviews published in journals from the Web of Science (WoS) indices, Science Citation Index Expanded (SCIE), Social Science Citation Index (SSCI), and Arts and Humanities Citation Index (A&HCI). The data is based on the KB WoS Snapshot 2020 provided by the German Competence Centre for Bibliometrics[1] as of April 2020. Fractional counting is used for all data, except when examining collaborations, when also whole counting is used. For analyses of countries, fractional counting is conducted at the level of the author and aggregated to the country-level. As such, a proportion of each publication is attributed to each author which is then aggregated into the fractional count of publications for each author's country. Similarly, where the German universities and non-university research institutions are examined, fractional counting is conducted at the level of the author and aggregated to the level of the institution, such as the Max Planck Society or the grouped universities.

We examine publications over the period 1995 to 2019. A citation window of three years is applied for citation data, as such indicators for citations include all citations of a publication which occurred within the year of its publication and the subsequent two years. Citation data are presented for the period 1995 to 2017. Self-citations have not been excluded from the data. Data for disciplines are presented using the OECD Fields of Science and Technology (FST) disciplines, which have been concorded from WoS' 'traditional' Subject Categories classification scheme. We have excluded a small proportion of items that are unclassified in

[1] http://www.bibliometrie.info

WoS and so were not able to be attributed to an FST category. See Appendix 2 for further details about the methodology used in this report.

In examining a time-series spanning more than 20 years, not only are changes in the national science systems relevant, but so too is the constantly-changing nature of the WoS database, which is regularly updated to expand its coverage of journals, both current and historical. As such, we refer readers to Section 2 of a previous report in this series [5], which provides a suite of contextual information relevant for the interpretation of the time-series for indicators presented in this report.

Section 1: Country and Region-Level Indicators

This Section presents indicators across three themes – productivity, impact, and collaboration – for 23 countries between 1995 and 2019. As indicators of productivity, we present the fractional shares of global publications and fractional publication counts, publication growth rates, and Germany and selected countries'fractional shares of global publications by field. To convey countries' impacts, we present the Scientific Regard, International Alignment, and Excellence Rate indicators, alongside the countries' fractional share of publications above the Excellence threshold, the percentage of countries' uncited publications, percentage cited more than the median, and Germany's percentage of publications cited in the 10% most cited by discipline. Finally, we present as indicators of collaboration, each countries' percentage of publications with international collaboration, a matrix of countries' collaboration partners in 2019, and the percentage of German publications involving collaboration by field. These indicators are provided with the aim of describing the performance of Germany's science system and evaluating it against the 22 countries selected for comparison (see Appendix 1).

Productivity

National shares of global publications

National publication shares are a useful indicator of a country's standing within the international science system regarding scientific output and productivity. We present in Figure 1 the fractional share of global publications held by each of the selected countries. In this figure, the width of each country's band represents its share of global publications. Further, the ordering of the bands within each group indicates the country's ranking from the largest share at the top to the smallest share at the bottom. Please note the panels have different scales on the y axis.

An immediately evident trend is China's[2] rapidly increasing share of global publications from 1.6% in 1995 to nearly a quarter of global publications in 2019, the largest share of all countries. As a result of China's rise, most other countries have recorded corresponding decreases in their own shares over time. For instance, until 2017 the USA held the largest share of global publications, however its share has steadily decreased from 32.5% in 1995 to 17.8% in 2019. Similarly, Great Britain and Germany – which currently hold the third and fourth highest shares – have lost 3.3 and 2.1 percentage points since 1995, to their current shares of just over 4% of global publications each. Japan, the current sixth largest producer, has lost half of its 7.4% share in 1995, down to 3.7% in 2019.

The only other countries that have increased their shares over this period are India (1.8% in 1995 to 3.7% in 2019, making it the fifth largest producer), Korea (0.7% to 2.9%), Brazil (0.6% to 2.3%), Poland (0.8% to 1.3%), and South Africa (0.4% to 0.5%), which may reflect the continued development of the science systems in these countries as well as the expansion of WoS to include increasingly diverse content beyond its traditional orientation toward English-language publications from North America and Europe [3].

[2] China refers to Mainland China in the Web of Science.

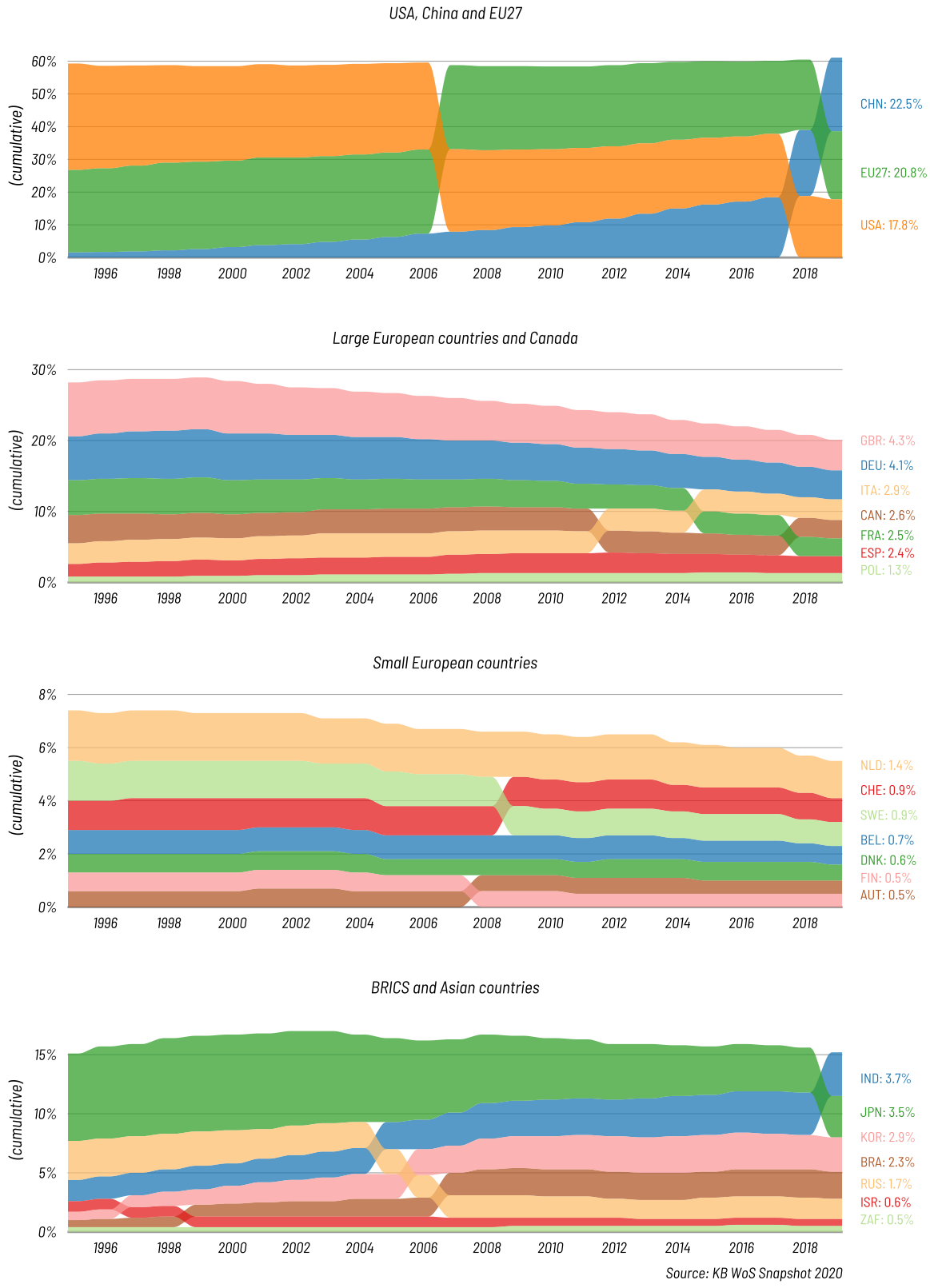

Figure 1: Countries' fractional shares of world publications, 1995-2019. Shares are presented cumulatively. The width of each country's band represents its fractional share of publications, and the ordering of the bands shows the country's ranking within its group with larger shares at the top.

Fractional counts of national publications

In addition to shares of global publications, we also present in Figure 2 the fractional counts of publications as an indicator of the country's contribution. In conjunction with the share of global publications, the fractional count of national publications shows the countries' level of scientific output. Here we see that China and the USA are by far the most productive countries, contributing 431,249 and 340,378 publications in 2019, respectively, followed by Great Britain and Germany with around 80,000 publications each in 2019. India's scientific output has grown rapidly over time to make it the fifth largest producer, overtaking Japan in 2018 and only slightly behind Germany and Great Britain. Notably, Japan's level of productivity has been relatively stable since the late 1990s, while most other countries increased their output.

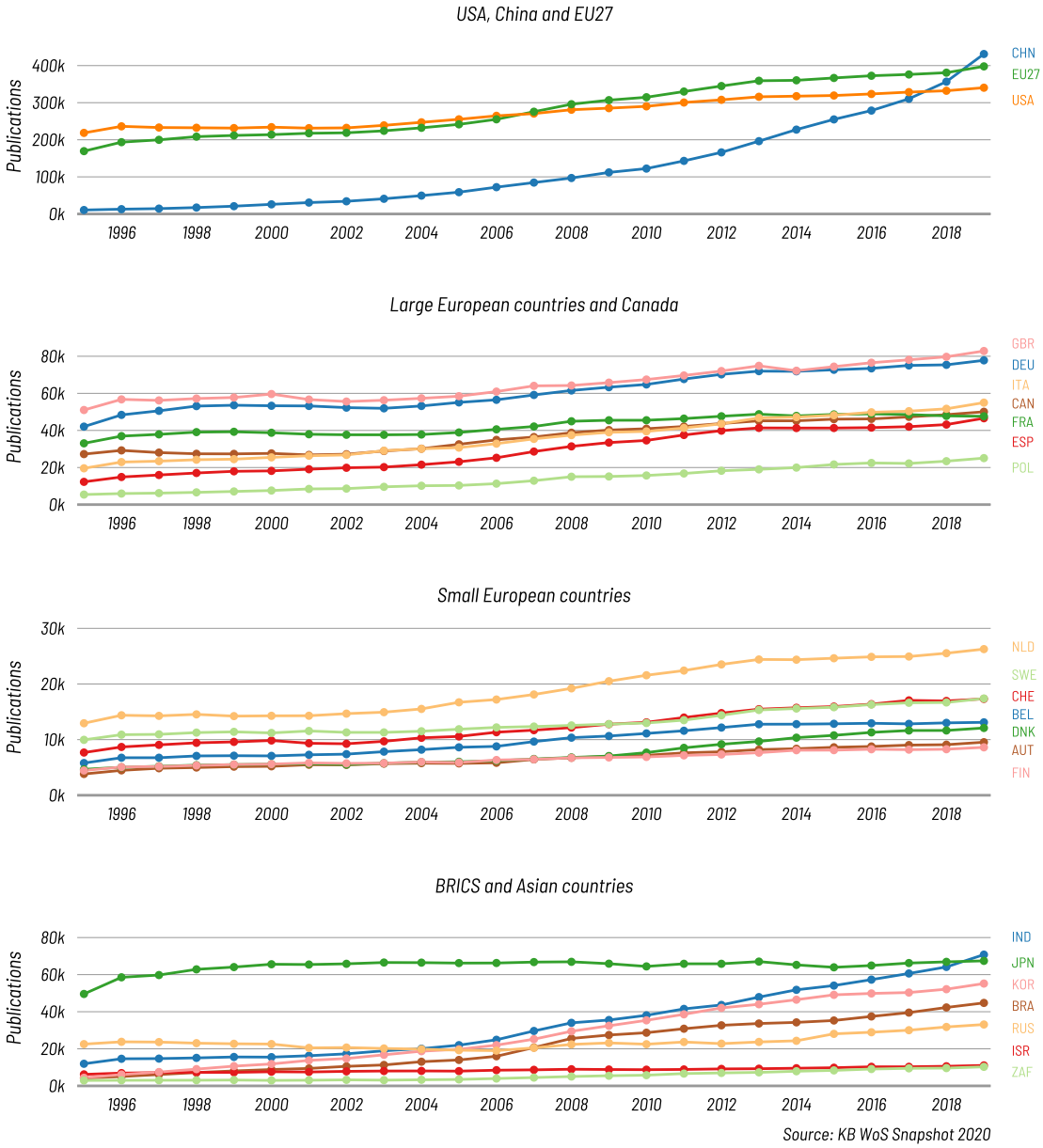

Figure 2: Fractional counts of national publications, 1995-2019.

Growth rates of national publications

Despite most countries losing ground in their share of publications, nearly all countries continuously increased the number of publications they produced over the time-series. To quantify this growth in publications, we show in Figure 3 the compound annual growth rate of countries' publications, which represent the smoothed percentage of annual growth, and the corresponding year-on-year growth rate. Only Russia, Great Britain, France, and Japan experienced periods of small reductions in productivity. Conversely, Brazil, India, Korea, Poland, and in particular China, demonstrated strong growth throughout this time-series. China, for instance, increased its productivity by more than 16% annually. Most other countries grew by less than 5% annually, with countries such as the USA and Japan recording particularly low growth rates. Germany displayed a notable trend of declining growth over time, although growth remained positive except for the 2000-2004 period when it was zero.

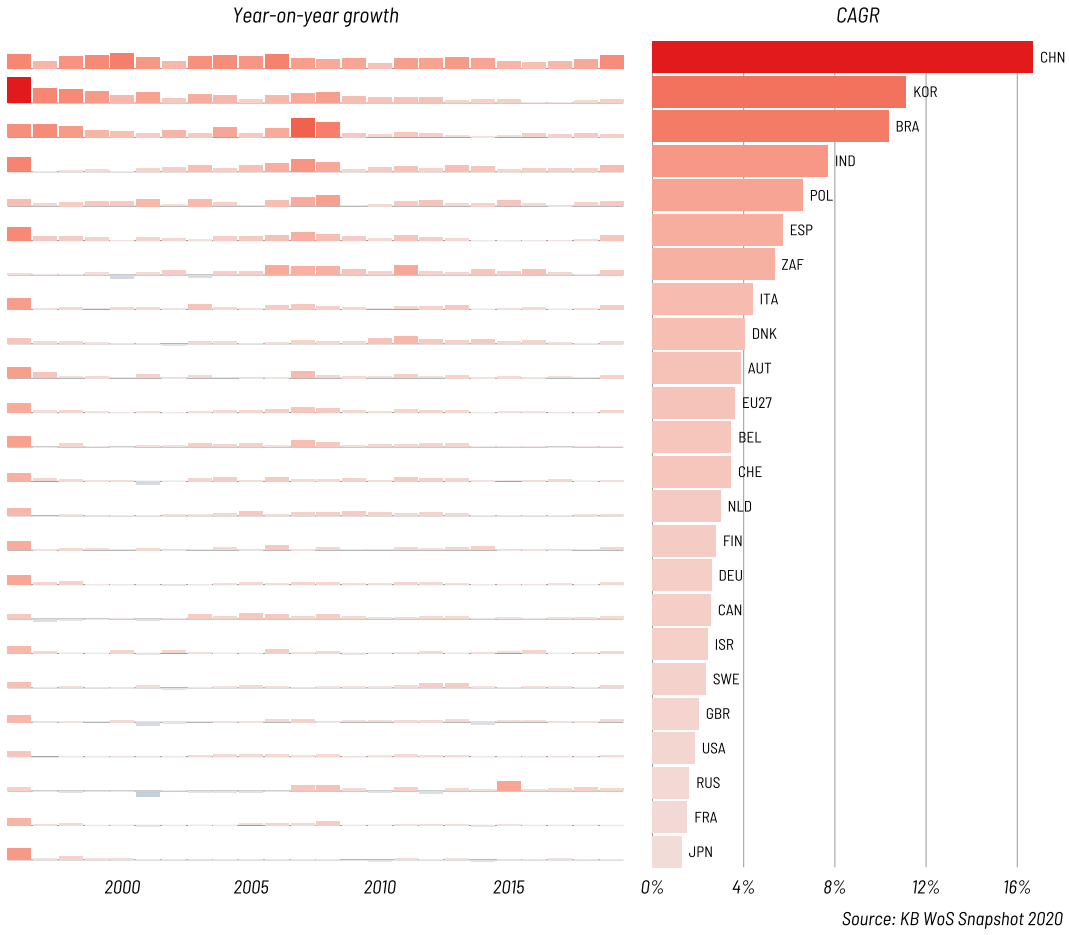

Figure 3: Year-on-year growth (left panel) and compound annual growth rates (right panel) of countries' fractional publications, 1995-2019.

National shares in 10% most cited publications

In addition to the productivity measures described above, we show in Figure 4 each country's share of the global 10% most highly cited publications between 1995 and 2017, which reflects the country's relative contribution to the corpus of excellent publications. This indicator can be considered in combination with the related Excellence Rates (ERs) in the Impact section, which normalises a country's number of highly cited papers against its total publication output and provides an indicator of the share of the country's publications which could be considered excellent.

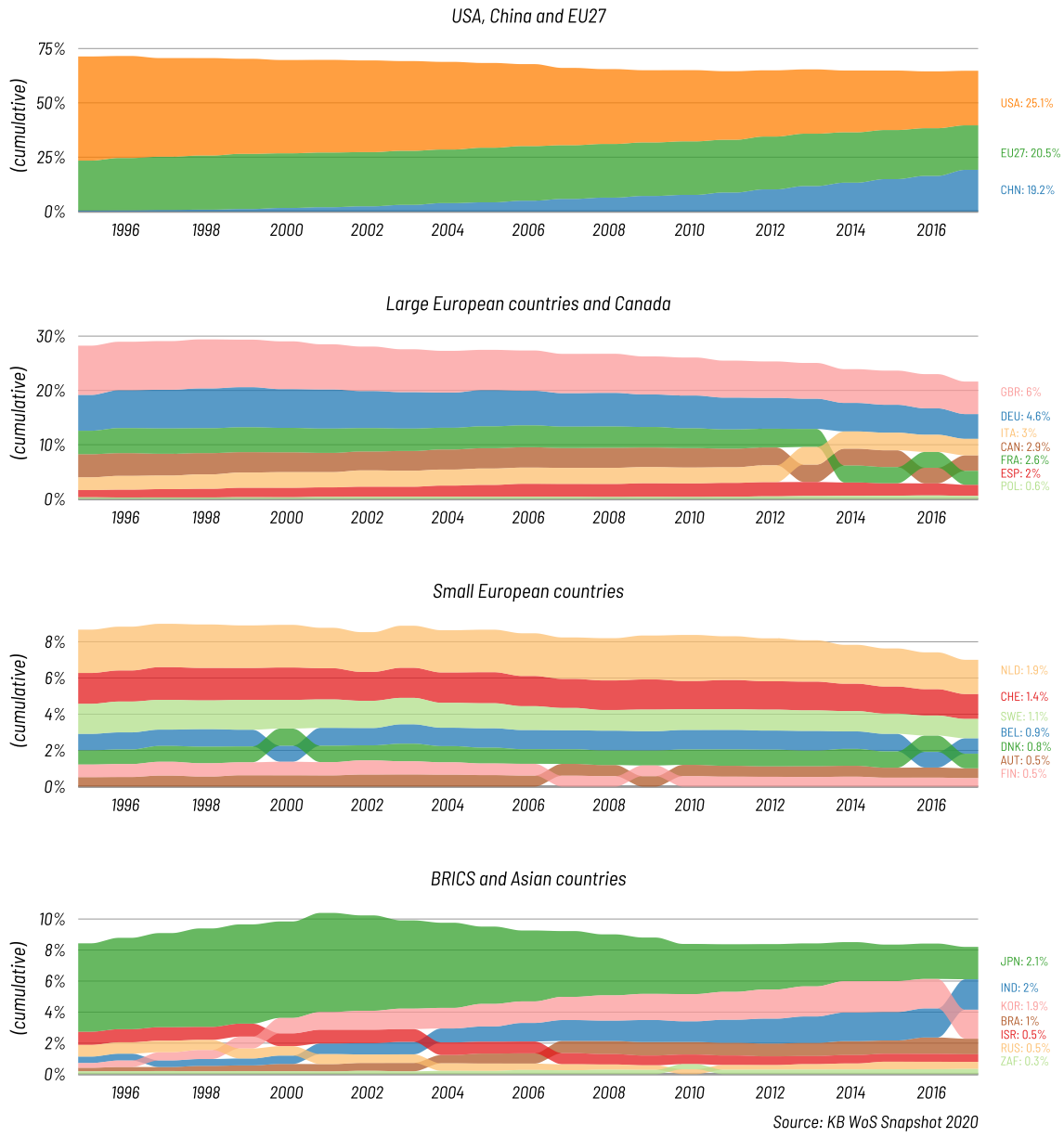

Figure 4: Fractional share of global publications in 10% most cited per discipline by country group, 1995-2017. Shares are presented cumulatively. The width of each country's band represents its fractional share of publications, and the ordering of the bands shows the country's ranking within each group with larger shares at the top.

We see that the countries' shares of excellent publications in 2017 broadly aligned with their levels of overall scientific productivity in the same year, with the USA producing the highest share of excellent publications (25.1%), followed by China (19.2%), Great Britain (6.0%), and Germany (4.6%). These rankings can be compared to the ERs presented in the next section, where we see differences between the two indicators. While Switzerland, Great Britain, the USA, the Netherlands, and Denmark had the highest ERs – indicating these countries had the largest percentages of their national corpora that were excellent publications – the USA, China, Great Britain, and Germany contributed the highest shares of excellent publications to the global corpus. Notably, Germany moved from 9th place contributor based on ERs to 4th place in overall share, indicating that it contributes a larger share of excellent publications than, for instance, the Netherlands (1.9%), Sweden (1.1%), Belgium (0.9%), and Denmark (0.8%), although these countries have higher ERs. Similar changes in ranking are observed for Italy, Canada and Spain due to the large corpora of these countries. In contrast, Switzerland – which had the highest ER – was ranked 13th by overall contribution (1.4%) due to its small corpus, and while Japan and India produced approximately 4% of global publications each, they produced only 2% of excellent publications each, which aligns with their ERs of around 5%.

Publication shares by field

To examine the disciplinary composition of selected countries' publications, we present in Figures 5 and 6 the fractional share of global publications held by Germany, China, the USA, Great Britain, and France in each OECD field over time. These countries are the most productive or countries against which Germany is often compared.

The increase in Chinese publications over time is evident, particularly in the natural sciences and engineering fields. Historically the USA held the largest share of all fields, with half of all social science publications and more than 25% of publications in the other five fields in 1996. However, China's surge in publication output has led it to overtake the USA in the "hard" science fields, where it now holds a quarter of all publications in the natural sciences and a third of global engineering publications. The USA's shares in both fields accordingly dropped to 13.4% and 9.1% respectively. China's growth was not as strong in the social sciences and humanities, where the USA and Great Britain continued to be the largest producers. Although the USA held around 25% of publications in these fields in 2019, this is still only around half of what it held in the social sciences in 1996, highlighting the growing diversity of producers of social science publications and indexation in WoS.

Germany held approximately 4% of global publications in natural, medical, and social sciences and humanities, with slightly lower shares of around 3% of global agricultural science and engineering publications. In line with China's booming publication shares, Germany's shares in all fields except humanities have declined over time by 35-57%.

Figure 5: National fractional shares of global publications from selected countries in each field, 1995-2019. Shares are presented cumulatively. The width of each country's band represents its fractional share of publications, and the ordering of the bands shows the country's ranking within each field with larger shares at the top.

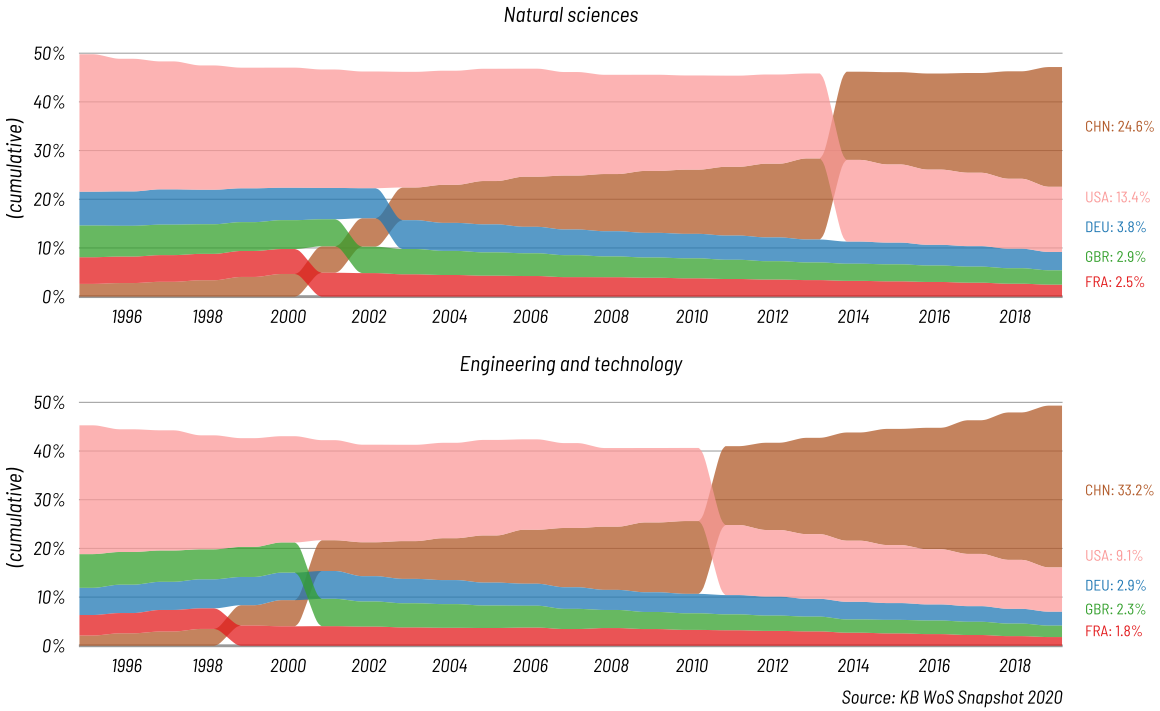

Figure 6: National fractional shares of global publications from selected countries in each field, 1995-2019. Shares are presented cumulatively. The width of each country's band represents its fractional share of publications, and the ordering of the bands shows the country's ranking within each field with larger shares at the top.

Impact

Excellence Rates

While productivity indicators demonstrate a country's level of output, indicators of impact can provide insight into the reception of those publications by the scientific community and their impact as measured by citations. One such indicator is Excellence Rates (ER), which are the percentage of publications that are in the 10% most highly cited publications per discipline. The expected percentage is 10% so any higher percentage reflects performance that is better than expected. We show in Figure 7 the ERs for the country groups and individual countries up to 2017 to allow a 3-year citation window.

In 2017, several countries exceeded the expected level of performance, including Switzerland, Great Britain, the USA, the Netherlands, and Denmark. Germany ranked 9th, performing as expected with a rate of 10.3%. Conversely, countries such as Korea, Japan, Poland, and the BRICS countries, except China, performed well below the expected level with ERs lower than 6.5%.

Patterns in ERs were largely stable over time for most countries with fluctuations of around 1 percentage point. Two exceptions are the USA, which began a downward trend in 2002 from 15.0% to 12.9% by 2017 – although it still retained a high ER – and Japan, which declined from around 7% in the late 1990s to 5.3% in 2017. Conversely, China, India, and South Africa improved over time. China's ER steadily rose from 2.9% in 1995 to 10.4% in 2017, crossing the expected threshold for the first time and slightly out-performing Germany. India too demonstrated steady improvement, doubling its ER from 2.4% to 5.5% over the time-series, while South Africa's ER increased from 4.2% to 6.0%.

Figure 7: Excellence Rates by country, based on fractional counting, 1995-2017

Percentage of publications in 50% most cited

To complement Excellence Rates, which examine performance toward the top of the citation distribution, we also show in Figure 8 the percentage of each country and country group's publications that were cited more than the median. As before, a country could expect half of its publications to be above this threshold and a higher percentage indicates higher performance. Once again, the Netherlands (59.5%), Switzerland (58.7%), Denmark (57.7%), and Great Britain (57.2%) held the highest percentages, and Russia (26.0%), Brazil (37.3%), Poland (38.6%), India (40.2%), and Japan (40.4%) the lowest. These trends are also quite stable, although the USA declined by 4 percentage points over the time-series and Japan by 7 points. China increased its percentage from 30.2% to now expected levels at 49.9%, while India also improved from 28.7% but remained below expectations at 40.2%, and Italy crossed the threshold from 47.9% in 1995 to 55.0% in 2017. Germany maintained a stable performance over time of between 52.4% and 54.3%.

The notable decline in Poland's performance circa 2008 before returning to a normal trend – which, as Poland is the largest producer of scientific publications amongst the EU13 countries, also influences the indicators for this broader group – has been observed both in previous versions of this report and those from other institutions, such as the French Science and Technology Observatory [4], and may be related to changes in national science policy around this period [2].

Percentage of uncited publications

To complete the picture of performance across the spectrum of citations, we show in Figure 9 the percentage of each country and country group's publications that were uncited 3 years after publication, quantifying the percentage of a country's publications that were poorly received by the academic community. In 2017, the countries with the lowest percentage of uncited publications were the Netherlands (9.8%), Denmark (10.0%), Sweden (10.8%), Switzerland (11.4%), and Italy (11.6%). Germany was ranked equal tenth with Great Britain with 14.2% of their publications uncited. Russia, South Africa, Brazil, and Poland had the highest percentage of uncited publications, at 20% or more of their corpuses. However, these countries demonstrated large improvements over time. Indeed, we see a declining trend in uncited publications for all countries, which is likely in part due to the continuous indexing of additional content in the WoS. This occurs because, as the corpus from which citations are drawn continues to expand, the likelihood increases that any publication will be cited by the indexed items. China improved the most, decreasing its uncited publications by 75.4% from 56.0% to 13.8% in 2017, followed by India (68.4% decrease), and Korea and Italy (63% decrease each). Comparatively, most countries' percentage of uncited publications – including Germany's – declined by around 54% over the time-series.

Figure 8: National fractional percentage of publications cited more frequently than the median, 1995-2017.

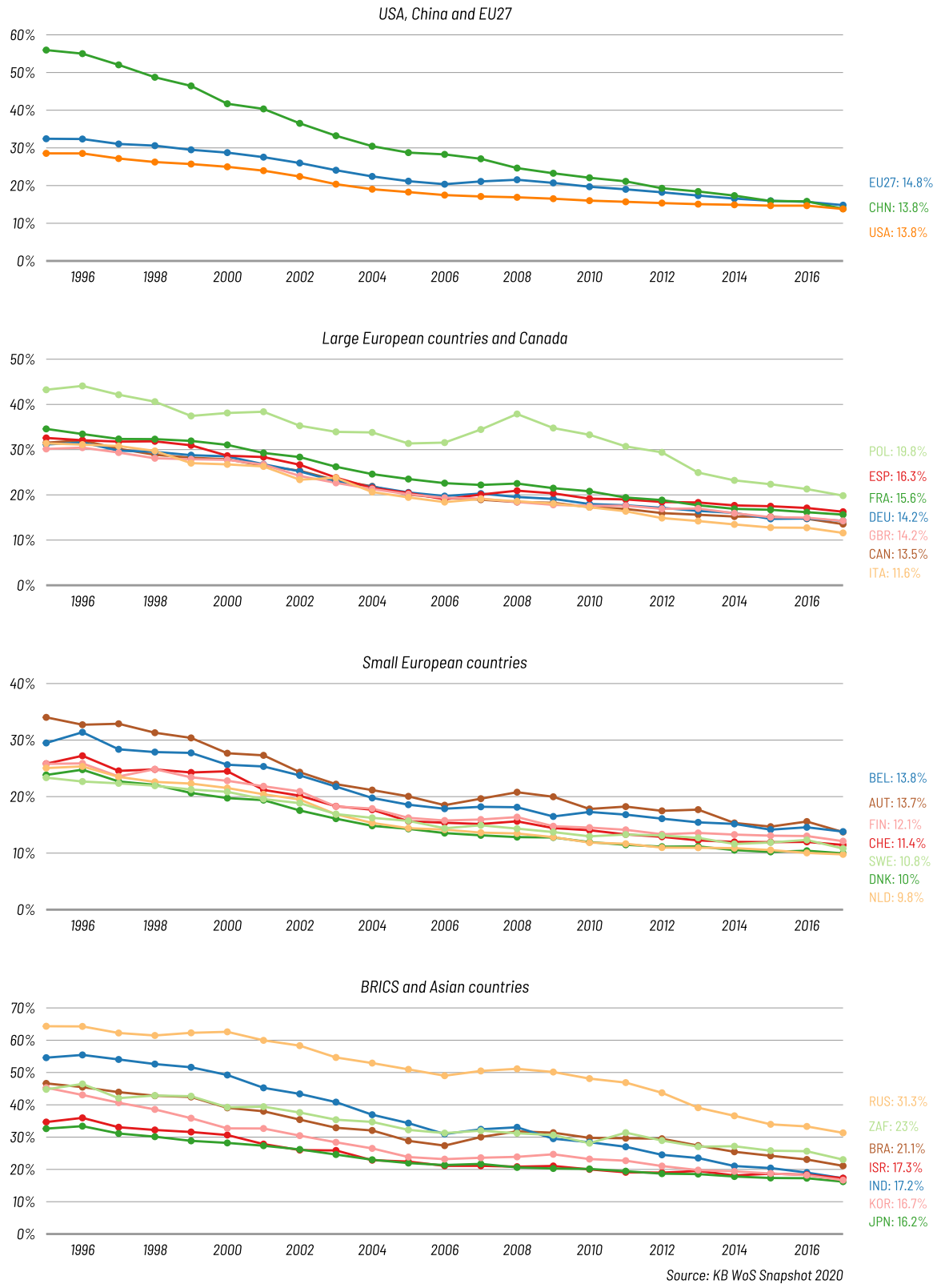

Figure 9: National fractional percentage of publications that were uncited 3 years after publication, 1995-2017

Scientific Regard and International Alignment

Scientific Regard (SR) is an indicator of how well cited a country's publications are compared to other publications in the same journals. SR is centred on zero and so positive values indicate the country's publications were cited more often than average for the journals in which they were published, and negative values indicate the converse. International Alignment (IA) complements SR as, while SR measures the citedness of publications in a journal, IA measures the citedness of the journals in which the country published compared to the average of all journals. IA too is centred on zero and as such, higher IA values reflect greater visibility and impact compared to the global average. We present in Figures 10 and 11 the SR and IA values for each country and country group. SR and IA are based on citations within 3 years of publication and so are presented up to 2017.

In examining SR and IA, and also the other indicators presented in this report, one should consider the influence of the variance in disciplinary coverage in the WoS on these indicators. We have previously observed the WoS to have good coverage of the natural and medical sciences and engineering and technology disciplines, but less complete coverage of the social sciences and humanities [5]. Poor coverage of a discipline results in under-representation of a country's citation counts, producing lower values in citation-based indicators. As such, countries with disciplinary profiles that align with the WoS' coverage have an advantage over countries with misaligned profiles.

Taking the complementary indicators together in 2017, we observed three groups of countries. First, the countries that had positive values for both, indicating they received higher than average citations in highly visible journals. These countries are Germany, Great Britain, the USA, Austria, Belgium, Switzerland,

	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
ITA	-4	-3	-5	-3	-4	-3	-5	-1	-4	-4	-3	-3	-1	-2	-1	0	1	6	8	8	10	9	10
CHE	14	14	16	14	15	14	14	12	14	13	16	13	13	14	14	12	12	10	10	9	9	9	7
GBR	8	8	8	8	7	6	6	7	6	5	5	4	4	5	6	6	4	4	4	5	6	7	6
NLD	9	10	10	10	8	8	8	6	10	8	8	7	7	8	7	8	9	8	7	5	6	6	5
CHN	-23	-21	-16	-15	-9	-7	-6	-4	-1	1	0	-2	-1	0	0	0	1	2	1	2	2	3	5
BEL	7	6	8	7	4	6	5	8	9	3	7	8	9	10	10	9	12	8	9	8	7	2	4
DNK	12	11	13	14	10	14	12	10	15	12	13	11	10	12	12	12	12	12	8	9	8	7	3
USA	6	6	7	7	7	8	8	8	7	7	6	6	5	5	5	4	4	3	4	3	3	2	2
DEU	11	13	11	10	11	10	10	9	9	9	9	9	9	9	7	7	6	7	6	4	4	3	2
EU14	5	6	5	4	4	4	3	3	3	2	3	3	4	3	3	3	3	4	3	3	3	2	1
EU27	3	4	3	3	3	2	2	2	2	1	2	2	3	2	2	2	3	3	3	2	2	1	0
SWE	13	12	12	10	11	9	7	8	6	4	4	4	1	1	4	4	3	2	3	1	2	0	0
AUT	6	8	4	2	4	5	5	6	9	8	8	6	8	4	5	5	4	5	1	4	2	3	0
OECD	4	4	4	4	4	4	3	3	3	3	2	2	2	2	2	2	1	1	1	1	1	0	-1
IND	-28	-26	-25	-23	-23	-19	-17	-16	-13	-12	-11	-8	-7	-7	-6	-6	-6	-5	-3	-3	-2	-2	-1
FIN	11	11	9	7	9	5	7	6	5	2	0	2	1	0	2	2	2	2	1	0	-2	0	-2
CAN	2	0	0	2	2	1	2	0	2	3	1	0	1	1	-1	-1	-1	-1	-2	-2	-2	-2	-2
ZAF	-9	-12	-6	-10	-9	-7	-10	-11	-8	-7	-5	-1	-4	0	-1	1	-2	-5	0	-3	-3	-2	-4
RUS	-2	-1	-3	-5	-2	-3	-6	-4	-4	-6	-6	-5	-6	-6	-7	-5	-5	-5	-3	-1	-2	-1	-4
POL	-12	-15	-15	-15	-10	-13	-10	-10	-8	-11	-12	-9	-10	-11	-11	-10	-6	-1	1	1	0	-1	-4
EU13	-12	-13	-13	-9	-10	-10	-8	-8	-8	-9	-8	-5	-4	-5	-3	-4	-2	-1	0	-1	-2	-3	-5
ESP	-9	-9	-10	-11	-9	-5	-9	-7	-7	-3	-2	-1	-1	-1	0	-1	-1	-1	-2	-2	-3	-4	-5
FRA	2	3	3	2	1	0	1	-1	-1	-1	-1	0	2	0	0	0	0	-1	-2	-2	-4	-4	-7
BRA	-19	-22	-20	-17	-21	-16	-19	-18	-16	-17	-14	-14	-9	-7	-6	-7	-7	-10	-10	-11	-9	-9	-11
KOR	-20	-18	-15	-15	-13	-11	-12	-9	-11	-10	-8	-9	-8	-8	-8	-8	-9	-9	-9	-10	-12	-13	-14
JPN	-5	-6	-5	-5	-5	-6	-5	-6	-8	-7	-8	-8	-9	-9	-11	-11	-12	-12	-13	-13	-14	-14	-15
ISR	-10	-12	-11	-13	-12	-9	-7	-8	-12	-9	-12	-10	-11	-13	-13	-15	-13	-15	-17	-14	-15	-17	-16

Source: KB WoS Snapshot 2020

Figure 10: Scientific Regard by country and group, based on fractional counting, 1995-2017.

Denmark, Italy, the Netherlands, Sweden, and China, which through consistent improvement over time entered this group for the first time in 2017. In contrast, Brazil, India, Japan, Korea, Poland, Russia, and South Africa received below average citations and published in less visible journals, shown by their dual negative values. The third group, consisting of Canada, France, Finland, Israel, and Spain, received below average citations for their publications but their publications appeared in well-cited journals. In particular, France had concurrent trends of decreasing SR and increasing IA, indicating that French publications increasingly appeared in well-cited journals where there was greater difficulty in exceeding the journal's average citations, producing a decreasing SR. German too demonstrated this trend, as its SR fell from 10.9 to 1.5 while its IA climbed from 1.1 to 10.1 over the same period. As such, Germany's declining SR is likely a result of its publishing in increasingly visible journals rather than a decline in impact.

Of note is the decline in IA values for many European countries in 2017. Simultaneously, China improved its IA by 5 points, publishing in highly visible journals for the first time in 2017. As shown in Figure 1, China now holds nearly a quarter of global publications. As such, it may be that China's significant share of research and citations are directed toward journals not typically amongst the core journals for many European countries. This may have shifted the set of journals that are most highly cited, resulting in a decline in IA values for many European countries which continue to publish in their traditional journal set. Changes such as these that results from China's rise have broad implications for the global science system and warrant further investigation.

	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
CHE	30	29	30	28	27	26	29	27	26	27	26	25	26	28	29	28	29	30	30	28	29	28	25
USA	31	32	31	31	30	30	30	30	29	28	27	26	28	29	28	27	27	26	25	23	22	20	18
NLD	16	12	16	15	18	20	18	19	21	21	22	23	24	25	25	27	26	24	23	21	20	19	17
GBR	7	7	8	10	9	10	11	14	13	13	14	14	16	19	18	18	17	17	16	16	16	15	13
DNK	8	8	9	10	13	14	13	12	16	15	15	15	17	19	19	19	17	17	17	17	15	15	13
SWE	7	9	9	7	8	10	10	10	10	10	11	10	14	14	14	15	13	11	12	13	12	12	10
DEU	1	1	2	1	3	4	4	5	7	6	8	9	10	13	14	15	16	15	15	14	14	14	10
FRA	-3	0	0	-1	-1	1	2	1	2	2	3	3	6	7	8	10	11	11	12	12	11	11	9
OECD	13	13	12	12	12	12	12	12	12	11	11	11	12	12	12	12	12	11	10	10	9	8	7
EU14	0	1	1	1	3	4	3	4	5	5	6	6	7	8	9	10	10	10	9	9	8	9	7
BEL	1	-3	1	-1	3	3	2	1	4	4	6	7	7	7	12	8	10	10	9	10	7	9	7
CAN	1	5	6	6	7	7	8	8	8	7	7	8	10	11	11	10	11	10	9	8	8	8	6
ISR	8	4	6	6	8	6	8	8	8	9	10	9	11	13	12	14	15	14	11	11	8	9	5
AUT	-8	-5	-2	-4	1	2	-2	3	2	4	5	6	7	6	4	7	7	5	6	7	5	5	5
CHN	-61	-60	-58	-58	-56	-50	-51	-46	-42	-40	-37	-35	-30	-26	-23	-19	-16	-12	-9	-7	-3	-1	4
EU27	-4	-3	-3	-3	-1	0	-1	-1	0	0	2	2	2	2	2	4	4	3	3	4	3	3	2
ITA	-1	2	2	2	6	5	3	5	4	5	7	6	5	7	6	6	5	4	3	3	2	2	1
FIN	3	1	6	2	5	8	4	5	5	3	5	4	5	6	6	7	6	5	6	4	3	0	1
ESP	-9	-7	-9	-9	-8	-7	-8	-8	-6	-4	-3	-1	-2	-3	-2	0	1	1	0	2	0	1	1
KOR	-43	-39	-40	-38	-33	-26	-28	-26	-25	-24	-19	-20	-21	-21	-21	-19	-16	-13	-11	-9	-6	-5	-3
JPN	-6	-7	-4	-4	-3	-3	-3	-4	-3	-2	-3	-4	-2	0	2	0	2	1	0	-2	-3	-4	-7
IND	-59	-59	-59	-60	-58	-56	-53	-52	-52	-46	-44	-39	-40	-41	-37	-38	-34	-30	-29	-24	-23	-20	-19
POL	-48	-45	-47	-47	-45	-44	-48	-43	-42	-44	-40	-41	-45	-52	-49	-48	-47	-48	-42	-39	-36	-33	-31
ZAF	-50	-51	-47	-49	-47	-44	-43	-45	-42	-40	-37	-37	-38	-37	-38	-33	-40	-37	-34	-35	-34	-36	-32
EU13	-52	-50	-49	-50	-47	-46	-46	-44	-42	-42	-40	-39	-46	-50	-49	-47	-47	-45	-42	-39	-37	-34	-33
BRA	-37	-36	-38	-41	-40	-36	-38	-36	-36	-37	-35	-35	-42	-47	-48	-48	-47	-46	-43	-40	-39	-35	-34
RUS	-78	-78	-77	-78	-78	-78	-76	-76	-74	-74	-73	-72	-73	-75	-76	-75	-74	-70	-66	-64	-61	-60	-59

Source: KB WoS Snapshot 2020

Figure 11: International Alignment by country and group, based on fractional counting, 1995-2017.

Percentage of publications in 10% most cited by discipline

To provide further context to Germany's performance with regard to highly-cited publications, we examine in Figure 12 the share of highly cited publications by OECD discipline over time, allowing us to identify the areas in which German publications are most or least impactful within the academic community.

Twelve disciplines exceeded the 10% threshold in 2017 (right panel). Four of these 12 were in the natural sciences, and two of the three medical disciplines were also above 10%, suggesting Germany was particularly strong in these fields. Most of these disciplines have historically been strong (left panel), with positive deviations from the expected thresholds since the 1990s, except for Media and communications, which has only recently begun performing above expectations. Other social science disciplines also demonstrated improvements over time, including Political science, Educational sciences, and Social and economic geography, although these disciplines are still marginally below the 10% threshold. Conversely, Chemical sciences, Mathematics, Electronic and electrical engineering, Environmental Biotechnology, and particularly Environmental engineering were historically high-performing disciplines that have fallen below the 10% threshold in recent years.

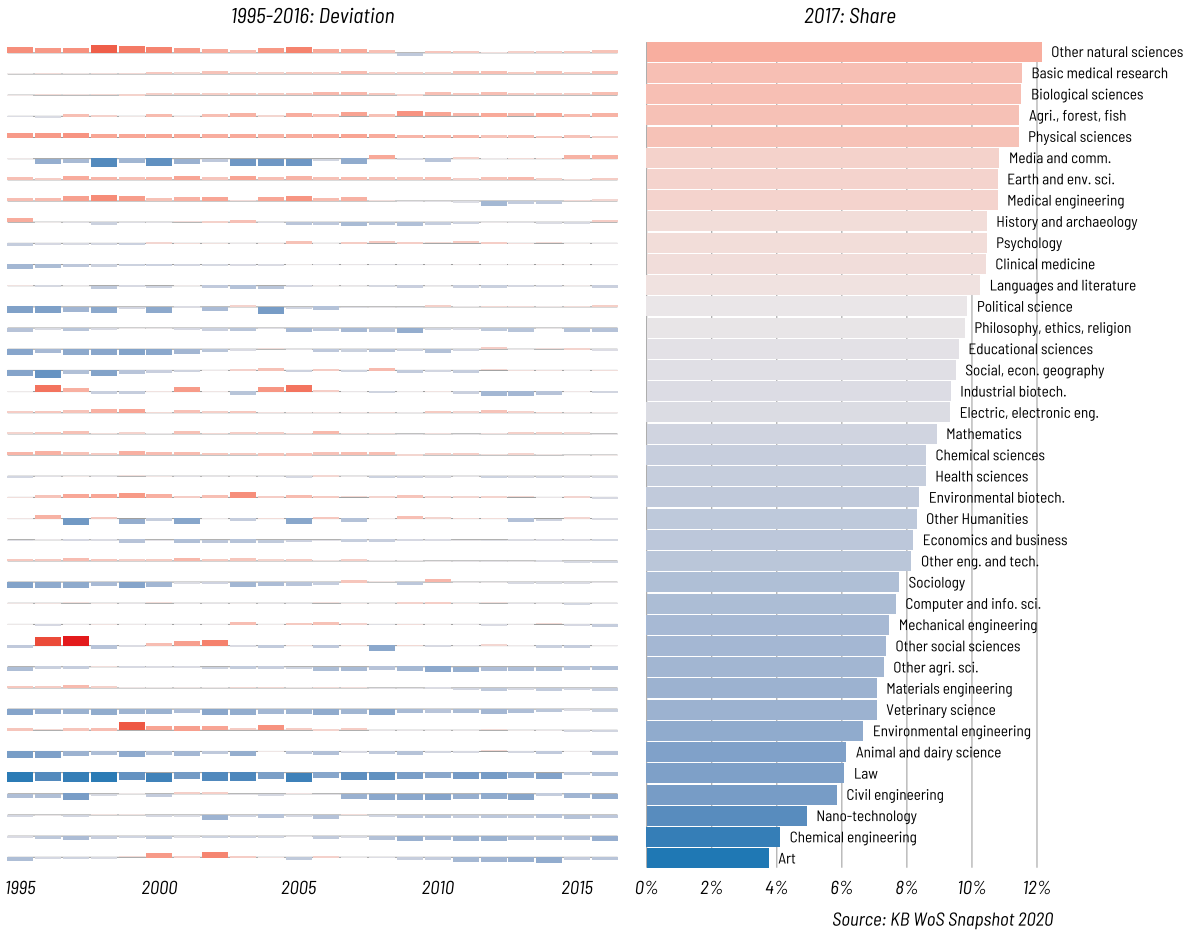

Figure 12: Percentage of Germany's 2017 fractional publications that are in the 10% most cited publications (right panel) and positive (red), respectively negative (blue) deviation from expected 10% share between 1995 and 2016 (left panel) by OECD discipline.

Collaboration

Percentage of publications with international collaboration

Scientific research is an increasingly international endeavour, with international collaboration in studies now the norm in many fields. We show in Figure 13 the percentage of publications by country and group that involved international collaboration. These data are based on whole counts of publications. There was a common trend across most countries for increasing levels of international collaboration over time.

Several European countries now collaborate on over two-thirds of their publications, including the Netherlands, Finland, Denmark, Sweden, Belgium, Austria, and Switzerland, which produces 75.9% of its publications in collaborations. This may reflect the relatively small size of these countries, which encourages collaboration for sharing of resources and field diversity. Germany collaborated internationally on 60% of its publications in 2019, a similar rate to other large European countries such as Great Britain, France, and Spain, as well as Canada.

Notably, despite it's rapid development in both productivity and impact, China maintained one of the lowest levels of international collaboration over the time-series with only 26.7% of publications produced in collaboration in 2019, up slightly from 22.3% in 1995. The USA too maintained a comparatively low level of international collaboration, which like China, may reflect an aspect of autonomy granted by its large population and well-developed science system.

	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
CHE	44	44	46	49	51	51	53	56	57	58	58	60	62	63	64	66	67	68	69	70	71	74	74	76	76
AUT	38	40	40	42	45	46	48	49	50	52	55	56	57	59	60	63	63	65	66	67	68	71	71	73	74
BEL	41	41	44	46	49	50	50	53	53	53	55	56	56	57	59	60	62	62	64	66	68	69	71	73	73
SWE	35	37	38	41	42	44	46	47	48	49	49	51	53	54	56	58	59	60	60	62	65	67	68	69	70
DNK	39	41	44	47	47	49	49	50	50	51	53	55	56	57	58	59	59	60	61	62	64	66	67	69	70
FIN	32	32	36	38	40	42	42	43	45	44	46	47	49	50	51	54	54	57	58	60	62	64	66	67	69
NLD	32	34	36	39	41	43	44	45	47	48	47	49	50	51	52	54	55	58	59	60	62	64	66	67	68
GBR	25	26	28	31	32	33	36	38	39	41	42	43	45	46	48	49	51	52	54	57	59	61	63	64	65
FRA	30	31	33	35	36	38	40	41	43	45	46	47	48	48	50	51	53	54	55	57	58	61	62	63	65
ZAF	22	25	28	31	34	36	38	39	43	44	45	45	45	45	46	48	48	50	53	54	55	57	58	60	61
DEU	29	30	31	34	35	37	39	41	42	44	44	45	47	47	48	50	51	51	53	54	55	58	58	59	60
CAN	27	28	31	34	35	36	38	40	40	42	42	42	44	45	46	47	48	49	50	52	53	56	57	58	60
ESP	28	29	29	32	32	34	35	36	37	38	39	40	40	41	41	44	45	46	47	50	52	55	56	56	56
ITA	31	31	32	34	36	36	37	38	37	38	40	39	41	42	42	44	45	46	47	48	50	52	53	55	55
ISR	34	35	35	37	38	38	40	40	40	40	41	41	41	42	43	46	48	47	49	49	51	52	52	53	54
EU14	26	27	28	30	31	33	34	35	36	37	38	38	39	40	41	42	43	44	45	47	48	51	52	53	54
EU27	25	26	28	30	31	32	33	34	35	36	36	37	37	37	38	39	40	41	42	44	45	48	49	50	51
EU13	38	38	40	41	42	41	42	42	43	44	43	43	39	36	37	37	38	38	40	41	42	44	45	46	47
USA	15	16	17	19	20	21	23	24	24	25	26	26	28	29	30	31	32	34	35	36	38	40	41	42	43
POL	40	40	39	40	40	40	39	39	39	40	39	39	35	32	33	33	33	33	34	35	35	37	39	39	40
BRA	35	35	34	34	33	34	33	33	31	31	30	30	27	25	25	26	27	28	30	33	35	38	38	39	40
RUS	21	22	25	27	29	30	33	34	34	35	36	36	34	32	31	31	31	33	34	35	35	35	38	37	39
OECD	14	14	15	17	18	19	20	21	21	22	22	23	24	25	25	27	28	28	30	31	33	35	36	37	38
JPN	14	14	15	17	17	18	19	20	21	22	22	24	24	25	26	27	28	29	29	30	31	33	34	35	36
KOR	27	24	24	24	24	23	25	26	27	27	28	28	27	27	26	27	28	28	29	29	29	31	32	32	33
IND	12	12	12	15	15	17	18	19	19	19	19	20	19	19	20	21	22	22	22	23	24	26	26	27	28
CHN	22	23	24	25	24	24	23	24	23	23	22	22	22	23	23	24	24	24	24	24	25	26	27	27	27

Source: KB WoS Snapshot 2020

Figure 13: Percentage of each country's publications that involved international collaboration, based on whole counting, 1995-2019.

Collaboration matrix

To examine broad patterns of collaboration, we examine in Figure 14 the percentage of each country's 2019 fractional publications that were produced in collaboration with one another for the 23 selected countries. The matrix is read as the entity on top (Focus Country) produced the noted percentage of co-publications with the entity on the left. For instance, 5.5% of Great Britain's publications in 2019 were co-authored with China, while 0.9% of China's publications were produced with Great Britain. Darker shades of blue highlight greater collaboration and Figure 14 is ordered by the weight given to the focus country by the other countries, with more common collaboration partners at the top of the matrix. The figures shown in shades of red on the diagonal in Figure 14 denote the fractional share of each country's publications that are produced without international collaboration.

Then examining collaboration between countries, the USA was the key collaboration partner for most countries, co-producing between 3.0% and 11.6% of each country's publications, although the USA maintained one of the highest levels of national publications, independently producing nearly three-quarters of its publications. Germany was another common collaboration partner for many countries, particularly those regionally proximate such as Austria (10.5%), Switzerland (8.2%), the Netherlands (4.9%), Sweden (3.9%), and Belgium (3.8%), ranking it second after the USA. Germany itself produced most of its publications with the USA (6.2%), Great Britain (3.1%), China (3.0%), and France and Italy (each 2.0%). China was also a common collaborator for many countries, such as the USA, Canada, and Great Britain, although it produced nearly 90% of its publications independently.

Focus Country

in co-authorship with	USA	DEU	CHN	GBR	ITA	FRA	ESP	NLD	CAN	CHE	SWE	JPN	BEL	IND	BRA	RUS	DNK	AUT	POL	FIN	KOR	ZAF	ISR
USA	74.4	6.2	4.0	7.0	5.0	5.9	4.6	6.9	11.6	8.5	6.6	4.5	6.0	3.0	4.9	3.2	7.1	6.1	3.1	5.4	5.6	6.8	11.6
DEU	1.5	62.6	0.5	2.9	2.6	3.2	2.4	4.9	1.6	8.2	3.9	1.2	3.8	0.7	1.1	2.9	4.2	10.5	2.5	3.5	0.6	1.9	3.1
CHN	6.8	3.0	88.4	5.5	1.3	2.6	1.2	2.9	6.2	1.9	3.9	4.1	2.7	1.2	0.5	2.0	3.8	1.8	1.1	3.4	2.8	1.9	2.0
GBR	1.8	3.1	0.9	57.3	3.2	3.1	3.1	4.9	2.4	4.5	4.3	1.1	4.2	1.0	1.4	1.2	4.5	3.5	1.7	3.7	0.6	4.2	2.2
ITA	0.9	2.0	0.2	2.3	67.6	2.9	3.0	2.4	1.0	3.9	2.2	0.5	3.1	0.4	1.1	1.2	2.1	3.2	1.7	1.9	0.3	1.1	1.9
FRA	0.9	2.0	0.3	1.8	2.4	58.6	2.2	2.0	1.7	4.0	1.9	0.8	4.7	0.4	1.2	1.4	1.6	1.9	1.2	1.7	0.3	1.2	1.4
ESP	0.7	1.4	0.1	1.7	2.3	2.1	66.1	1.8	0.7	1.8	1.7	0.4	2.2	0.2	1.3	0.6	1.7	1.7	1.1	1.5	0.2	1.0	1.0
NLD	0.6	1.7	0.2	1.7	1.1	1.1	0.9	55.3	0.7	1.9	1.7	0.3	4.5	0.2	0.4	0.4	2.0	1.5	0.6	1.6	0.1	1.5	0.8
CAN	1.6	0.9	0.6	1.4	0.7	1.5	0.7	1.2	61.2	1.4	1.2	0.6	1.1	0.4	1.0	0.4	1.2	1.1	0.6	1.0	0.4	1.0	1.5
CHE	0.5	1.8	0.1	1.0	1.2	1.4	0.7	1.4	0.7	48.0	1.1	0.3	1.4	0.2	0.3	0.4	1.0	2.1	0.6	1.0	0.2	0.7	0.7
SWE	0.3	0.8	0.2	0.9	0.6	0.6	0.6	1.1	0.4	0.9	52.0	0.2	0.9	0.2	0.2	0.4	3.0	1.1	0.6	3.3	0.1	0.8	0.4
JPN	0.8	0.8	0.5	0.7	0.5	0.9	0.4	0.5	0.6	0.8	0.7	78.2	0.6	0.5	0.2	0.7	0.5	0.8	0.5	0.8	1.1	0.5	0.5
BEL	0.2	0.7	0.1	0.7	0.7	1.2	0.6	2.3	0.3	1.0	0.8	0.2	50.6	0.1	0.2	0.2	0.7	0.8	0.4	0.8	0.1	0.9	0.3
IND	0.6	0.5	0.2	0.7	0.4	0.5	0.4	0.4	0.6	0.5	0.6	0.6	0.4	84.6	0.3	0.6	0.5	0.5	0.6	0.6	1.3	1.7	0.9
BRA	0.7	0.6	0.0	0.8	0.7	1.0	1.2	0.6	1.0	0.6	0.6	0.2	0.7	0.2	79.2	0.3	0.8	0.5	0.3	0.7	0.1	0.6	0.2
RUS	0.3	1.0	0.1	0.4	0.4	0.9	0.4	0.4	0.2	0.5	0.6	0.4	0.5	0.3	0.3	75.8	0.4	0.8	0.7	1.6	0.2	0.5	0.8
DNK	0.3	0.6	0.1	0.7	0.4	0.4	0.4	0.8	0.3	0.7	2.1	0.1	0.6	0.1	0.2	0.1	52.7	0.6	0.3	1.2	0.1	0.3	0.2
AUT	0.2	1.2	0.0	0.4	0.5	0.4	0.4	0.5	0.2	1.1	0.6	0.1	0.6	0.1	0.1	0.3	0.5	49.9	0.4	0.6	0.1	0.2	0.3
POL	0.2	0.6	0.0	0.4	0.5	0.5	0.5	0.4	0.2	0.5	0.6	0.2	0.6	0.2	0.1	0.5	0.5	0.7	74.5	0.7	0.1	0.4	0.4
FIN	0.2	0.4	0.1	0.4	0.3	0.3	0.3	0.5	0.2	0.4	2.0	0.1	0.4	0.1	0.1	0.5	0.8	0.6	0.4	54.7	0.1	0.3	0.2
KOR	0.8	0.4	0.3	0.3	0.2	0.3	0.2	0.2	0.4	0.3	0.3	0.9	0.3	0.9	0.1	0.3	0.4	0.3	0.2	0.4	81.6	0.2	0.3
ZAF	0.2	0.2	0.0	0.5	0.2	0.2	0.2	0.4	0.2	0.4	0.4	0.1	0.4	0.2	0.1	0.1	0.2	0.2	0.2	0.3	0.0	59.1	0.2
ISR	0.3	0.4	0.0	0.2	0.3	0.2	0.2	0.3	0.3	0.3	0.2	0.1	0.2	0.1	0.1	0.3	0.2	0.2	0.2	0.2	0.1	0.2	64.8

Source: KB WoS Snapshot 2020

Figure 14: Percentage of each country's 2019 publications (column) that involved international co-authorship with another country (row), based on fractional counting.

Percentage of German publications with international collaboration by field

We show in Figure 15 the percentage of German publications, based on whole counting, that involved international collaboration by OECD field over time. International collaboration was highest in the natural sciences in 2019 (68.3%), followed by engineering (56.2%), agricultural sciences (55.2%), medical sciences (54.6%), and the social sciences (49.3%), and was lowest in the humanities (19.4%). This aligns with the focus of the "hard" sciences – and the natural sciences in particular – on globally relevant research questions and the sharing of physical resources among large research teams compared to the often local focus and tendency toward sole authorship of the humanities. All fields showed an degree of international collaboration above the OECD member countries's average over time, with a particular large positive deviation in collaboration in the humanities. This growth, while influenced by the indexation processes of the WoS, may also reflect changes within the field with regard to collaborative practices and the expanding scope of studies beyond local boundaries. Contrary to the above average deviation for Engineering & Technology and Natural Sciences decreases over time and German collaborations converge towards the OECD member's average in these fields.

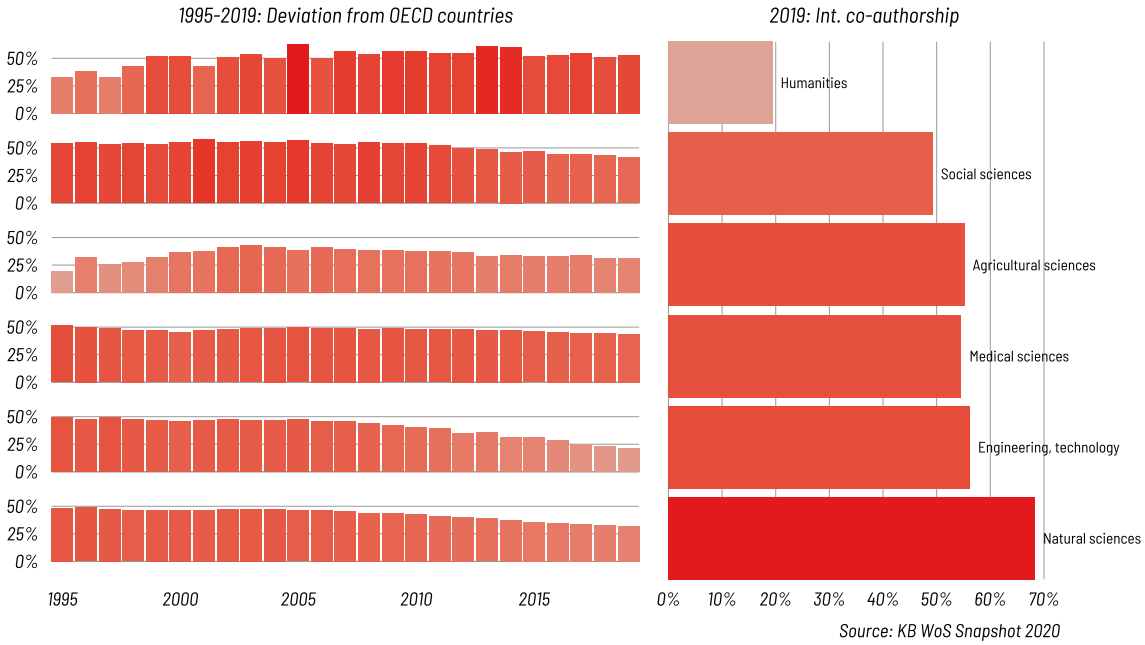

Figure 15: Percentage of German publications that involved international collaboration (right panel) and percentage deviation from OECD member country average (left panel) by OECD field , based on whole counting, 1995-2019.

Section 2: Sector-Level Indicators

This Section presents indicators of productivity, impact, and collaboration for six sectors of the German science system – universities, colleges of applied science (Fachhochschulen), and four key non-university research associations: the Fraunhofer Society (FHG), the Helmholtz Association (HGF), the Max Planck Society (MPG), and the Leibniz Association (WGL). Each sector has a particular focus: the universities conduct teaching and research across all fields; the Fachhochschulen focus on technical application of the sciences; WGL conducts both basic and applied research in the social sciences and humanities, natural and environmental sciences, and engineering; the HGF focuses on health, energy, and earth and physical sciences research, often on a large scale; the MPG undertakes basic research in the natural and life sciences and humanities; and the FHG is an applied research organisation.

For each of these sectors, we present the fractional count of publications, publication growth rates, the number of publications and citations per full-time equivalent scientific staff member, Excellence Rates, and the percentage of publications involving international collaboration, between 1995 and 2019. Each sector's performance on these indicators should be considered within the context of the purpose and focus of the sector.

Productivity

Fractional count of publications and growth rates

As an overall indicator of scientific output, we show in Figure 16 the annual fractional count of publications produced by each sector, and the corresponding compound annual growth rates in Figure 17. These growth rates represent the smoothed percentage of annual growth in publications in each period and is accompanied by the year-on-year growth rates.

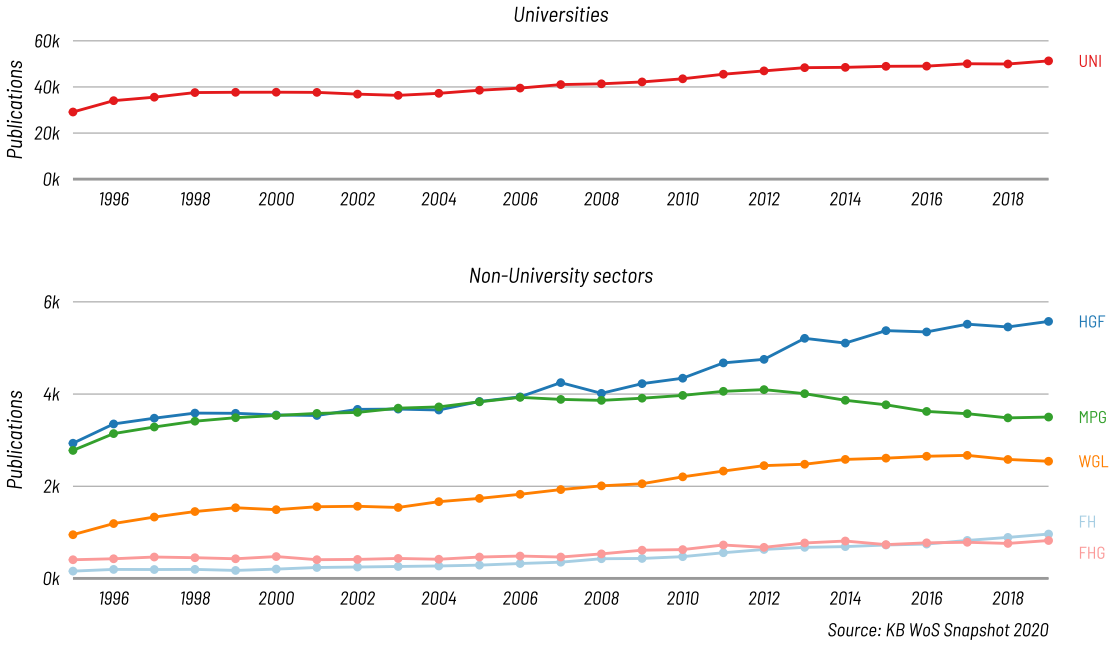

Figure 16: Fractional count of German sectors' publications, 1995-2019.

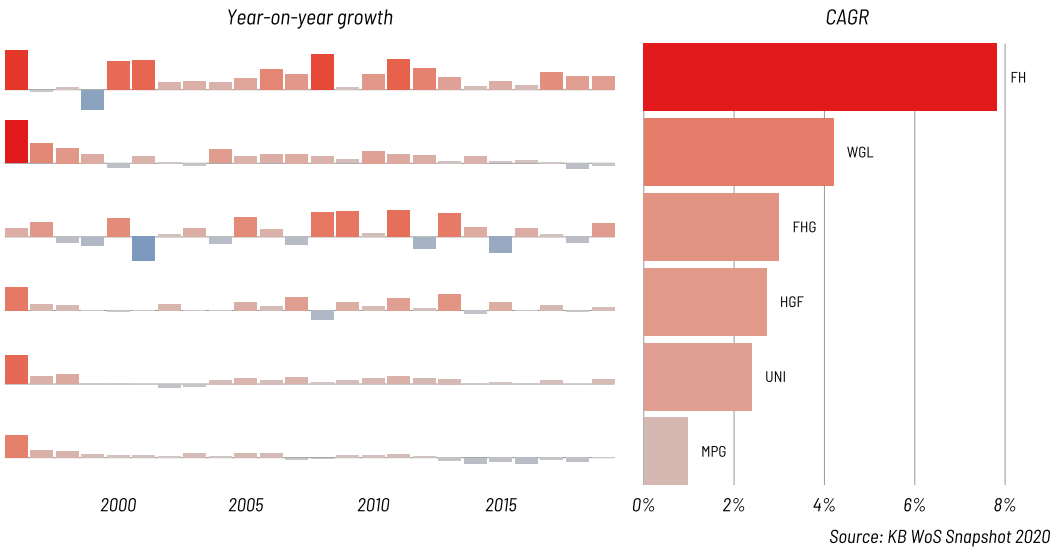

Figure 17: Year-on-year growth (left panel) and compound annual growth rates (right panel) of sectors' fractional publications, 1995-2019.

Naturally, given its much larger size, the universities constituted the most productive sector, with over 51,000 publications in 2019. This was followed by the HGF, which, after producing similar numbers of publications as the MPG since the mid-1990s, has been the most productive non-university research association since 2007. The Fachhochschulen and FHG performed similarly with the least numbers of publications, however, when considering the growth rates, the Fachhochschulen and FHG demonstrated the strongest growth, except for a period of reduced productivity for the FHG in 2000-2004. We observe similar profiles for the HGF, WGL, and universities, with smaller increases in productivity, or small losses, after initial rapid growth in 1995-1999, while the MPG has declined in productivity. The overall trends of publication output and the associated growth rates indicates that all sectors but the MPG demonstrated nearly continuous growth over the last 24 years.

Impact

Excellence Rates

Excellence Rates are the percentage of a sector's publications that were amongst the 10% most cited publications per discipline. The expected Excellence Rate for a sector is thus 10%, with higher rates indicating better than expected performance. We show in Figure 18 the Excellence Rates per sector between 1995 and 2017, allowing for a 3-year citation window.

The MPG, HGF, and WGL show relatively stable patterns of high performance. The MPG consistently produced approximately twice the expected rate of highly cited publications – between 17.8% and 21.8% – over the time-series, followed by the HGF with between 13.1% and 14.9%, and the WGL with fluctuations between 11.2% and 13.6%. The Excellence Rate of the university sector showed nearly continuous improvement from around 10% in the late 1990s to around 11% by the mid-2010s, before declining slightly in the most recent years. Due to smaller publication numbers, the trends for the FHG and Fachhochschulen are more unstable. The trend for the FHG suggests a decline from above 10% to around 8% in recent years, while the Fachhochschulen consistently produced fewer than the 10% expected rate of publications, although

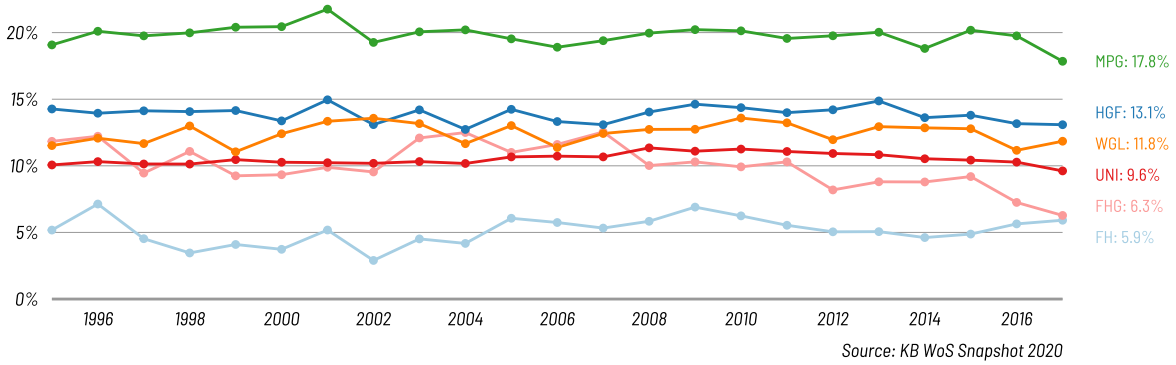

Figure 18: Excellence Rates of German sectors, based on fractional counting, 1995-2017.

there appears to be a trend of gradual improvement. Overall, the university sector, MPG, HGF and WGL perform comfortably above the expected threshold, while the FHG generally performs as expected, and the Fachhochschulen below the expected level, but with an upward trend to its performance.

Number of publications and citations per full-time equivalent

To account for differences in the staffing structures of the sectors, we show in Figure 19 the annual fractional count of publications and citations per full-time equivalent (FTE) scientific staff member. We obtained the numbers of FTE scientific staff in each sector via a request to the German Statistics Office (Statistisches Bundesamt). Based on the availability of the FTE data, we provide the number of publications per FTE between 2006 and 2018, and citations per FTE up to 2017 to allow a 3-year window for citations to accrue to a representative level.

Notably, after accounting for staffing, the universities fell in productivity from first to fourth rank with 0.27 publications per FTE staff member. This potentially reflects that scientific staff at universities, and also Fachhochschulen, likely have a higher teaching component than staff in the other sectors. The MPG, WGL and HGF had high levels of both productivity and impact, with more than 0.3 publications and upward of 3 citations per FTE. The universities, FHG and Fachhochschulen were stable over time in both their publications and citations per FTE, while the WGL and HGF gradually improved in both measures. The MPG was more variable, with relative stability between 2006 and 2013, before peaking in 2014 and slowly declining in the years thereafter. This pattern likely reflects staffing changes, as MPG's staff grew slowly from 5,700 in 2006 to 7,400 in 2013, dropped to 6,300 in 2014 before climbing steeply to 9,100 in 2018.

Figure 19: Number of fractional publications (top) and citations (bottom) per full-time equivalent scientific staff in each German sector.

Collaboration

Percentage of publications involving international collaboration

As we saw at the country level, international collaboration is a growing component of the global science system, with nearly two-thirds of Germany's output co-published with other countries in recent years. We show now in Figure 20 the percentage of each sector's publications, based on whole counting, that were produced either by authors affiliated with only German institutions within the sector or that involved international collaboration. We exclude from these percentages a small number of publications from single authors who held affiliations with multiple countries, although these are included in the total count of publications. As such, the percentages do not always sum to 100%.

In all six sectors there was an increasing trend of international collaboration. The MPG was the most collaborative, with 78.0% of its publications in 2019 involving authors outside of Germany. This aligns with the MPG's focus on basic research in the natural sciences, which lends itself to collaboration on globally relevant research questions. The HGF and WGL collaborated internationally on two-thirds of their publications in 2019 – 67.9% and 66.6%, respectively – while 56.3% of the universities' publications were international collaborations. Just under half (46%) of the FHG and Fachhochschulen's publications involved international authors, reflecting their stronger focus on local and applied research.

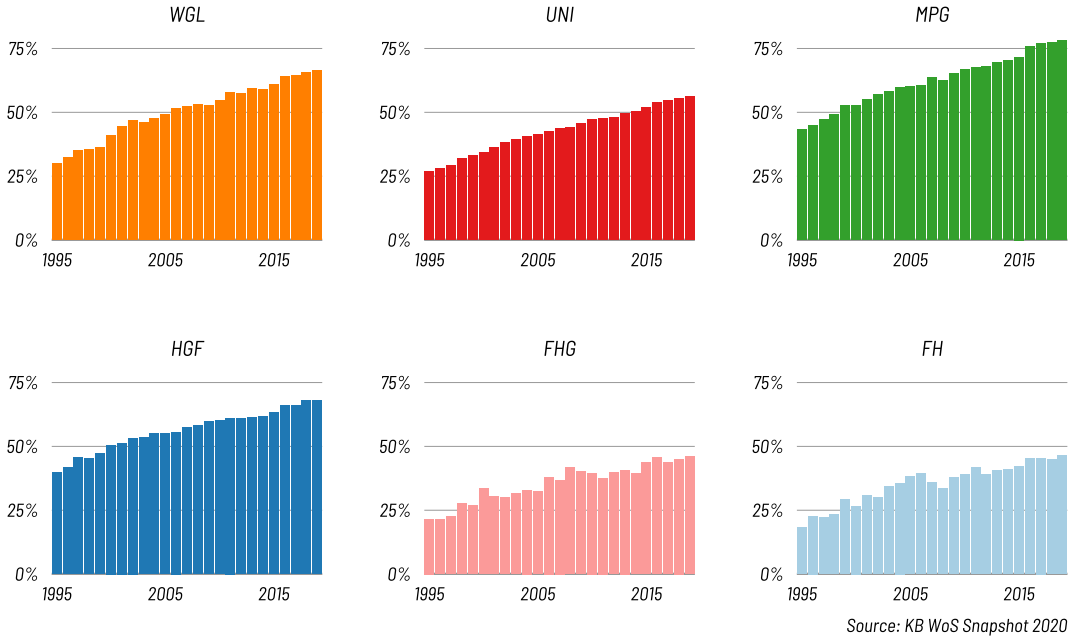

Figure 20: Percentage of German sectors' publications produced with international collaboration, based on whole counting, 1995-2019

Appendix 1: Country code list

Table 1: Names and codes of countries in this report and the groups in which they are included.

Country	Code	EU13	EU14	EU27	OECD
Australia	AUS	-	-	-	Yes
Austria	AUT	-	Yes	Yes	Yes
Belgium	BEL	-	Yes	Yes	Yes
Brazil	BRA	-	-	-	-
Bulgaria	BGR	Yes	-	Yes	-
Canada	CAN	-	-	-	Yes
Chile	CHL	-	-	-	Yes
China	CHN	-	-	-	-
Colombia	COL	-	-	-	Yes
Croatia	HRV	Yes	-	Yes	-
Cyprus	CYP	Yes	-	Yes	-
Czech Republic	CZE	Yes	-	Yes	Yes
Denmark	DNK	-	Yes	Yes	Yes
Estonia	EST	Yes	-	Yes	Yes
Finland	FIN	-	Yes	Yes	Yes
France	FRA	-	Yes	Yes	Yes
Germany	DEU	-	Yes	Yes	Yes
Greece	GRC	-	Yes	Yes	Yes
Hungary	HUN	Yes	-	Yes	Yes
Iceland	ISL	-	-	-	Yes
India	IND	-	-	-	-
Ireland	IRL	-	Yes	Yes	Yes
Israel	ISR	-	-	-	Yes
Italy	ITA	-	Yes	Yes	Yes
Japan	JPN	-	-	-	Yes
Latvia	LVA	Yes	-	Yes	Yes
Lithuania	LTU	Yes	-	Yes	Yes
Luxembourg	LUX	-	Yes	Yes	Yes
Malta	MLT	Yes	-	Yes	-
Mexico	MEX	-	-	-	Yes
New Zealand	NZL	-	-	-	Yes
Norway	NOR	-	-	-	Yes
Poland	POL	Yes	-	Yes	Yes
Portugal	PRT	-	Yes	Yes	Yes
Romania	ROU	Yes	-	Yes	-
Russia	RUS	-	-	-	-
Slovak Republic	SVK	Yes	-	Yes	Yes
Slovenia	SVN	Yes	-	Yes	Yes
South Africa	ZAF	-	-	-	-

Country	Code	EU13	EU14	EU27	OECD
South Korea	KOR	-	-	-	Yes
Spain	ESP	-	Yes	Yes	Yes
Sweden	SWE	-	Yes	Yes	Yes
Switzerland	CHE	-	-	-	Yes
The Netherlands	NLD	-	Yes	Yes	Yes
Turkey	TUR	-	-	-	Yes
United Kingdom	GBR	-	-	-	Yes
United States	USA	-	-	-	Yes

Appendix 2: Methodological details

This appendix discusses key methodological details to be considered in the interpretation of data from this report. This report is predominantly based on document types 'articles' and 'reviews' from the publication type 'journal'. Data are extracted from the Science Citation Index Expanded (SCIE), Social Science Citation Index (SSCI), and Arts and Humanities Citation Index (A&HCI) from the Web of Science (WoS). Fractional counting is used for all data disaggregated by country or discipline, except for collaboration indicators when whole counting is used. Publications are examined for the period 1995 to 2019, in accordance with the availability of data to the German Competence Centre of Bibliometrics. Citation data are examined for the period 1995 to 2017 based on a 3-year citation window. The following sections describe key features of the methodology used in compiling this report and which should be considered when interpreting these data.

Whole versus fractional counting

There are two methods for counting publications that have more than one author – whole counting or fractional counting. Whole counting assigns a whole count of the paper to each author so one paper is considered as one contribution from each author and the country with which they are affiliated. Consider, for example, one paper with an author from Germany and an author from France. Using whole counting the paper would count as one paper each for Germany and France, for a total count of two papers. Evidently this method of counting inflates the overall number of publications. One method of remedying this inflation is to award each author a proportion of the paper, known as fractional counting. In this example, equal proportions of the paper would each be attributed to Germany and France and the total number of publications remains at one. Fractional counting can however disadvantage countries that regularly collaborate internationally as they lose a proportion of these papers from their totals, and this should be considered in interpreting the data here.

This report primarily uses fractional counting for all data disaggregated by country. For the latter part of the WoS time-series, fractionalisation was applied at the level of the author. That is, a proportion of the paper was attributed to each of the author's affiliated institutions and these proportions are summed across the corpus of relevant papers for each country. This approach sufficiently captures the multiple international affiliations authors may have and provides the most accurate counts of each country's publications. However, the quality of the data linking authors with affiliations prior to 2008 in WoS was inadequate to support author-level fractional counting. As such, for years prior to 2008, fractional counting has been applied at the level of the organisation rather than the author. This would produce somewhat different counts than if author-level counting was applied throughout the time-series. For instance, Table 2 shows an example of a publication's authorship with four authors from 3 organisations in 2 countries. When fractional counting is applied to the authors, each author receives 0.25 of the publication which aggregates to 0.75 for country 1 and 0.25 for country 2. When the fractional counting is applied at the organisational level, each organisation receives 0.33 of the publication which aggregates to 0.66 for country 1 and 0.33 for country 2. In this way, fractional counts of countries' publications will differ between 2008 and later years. For further information, Waltman and Eck [6] provides a useful discussion on counting methods and their impacts on field-normalised indicators.

Table 2: An example of a publication's authorship

Author	Organisation	Country
Author 1	Organisation 1	Country 1
Author 2	Organisation 1	Country 1
Author 3	Organisation 2	Country 1
Author 4	Organisation 3	Country 2

Fractional counting is also applied to data that are disaggregated by discipline. For example, a paper may be published in a journal that Clarivate Analytics – owners of WoS – have assigned to more than one discipline within their databases' native classifications. We have then applied fractional counting to attribute the proportions of the paper to the relevant disciplines of the native classifications, before summing these fractional counts to the Fields or Disciplines of the OECD's Fields of Science and Technology Classification, as described below.

The analysis of international collaboration in this report uses whole counting instead of fractional counting. International co-publications are items on which two or more authors from two or more countries collaborated. Counts of publications are calculated using the whole counting method, such that each paper counts as one co-publication per co-authoring country.

Disciplines classification

Data disaggregated by scientific disciplines are presented using the OECD's Fields of Science and Technology (FOS) classification. Clarivate Analytics provided a concordance mapping its 'traditional' Subject Categories classification scheme to the FOS structure that was used in this report. However, the WoS concordance does not map any native category to the FOS disciplines 'health biotechnology', 'agricultural biotechnology' and 'other medical sciences' and so these categories are not presented in this report. Also, a small proportion of items not classified to any category in WoS have been excluded here as these items were not able to be attributed to any FOS discipline.

In WoS, publications can be classified to more than one discipline. As such, the publications counts have also been fractionalised based on the number of classifications they were assigned to within their native structure and then aggregated to the FOS categories. The field-normalisation of indicators occurs on the classifications assigned in WoS, and data is then presented by FOS discipline.

Citation window

While counts of publications can be reliably calculated as early as the following year, a period of time must elapse during which publications are disseminated, read and accumulated citations before counts of the publications' citations can be calculated. As such, it is typical in bibliometric studies to analyse citations in a window of 3 to 5 years after the publishing year. Wang [8] determined that 3 years is required for most publications to reach their maximum number of citations per year, after which point the number of citations are likely representative of the publication's long-term impact. For this reason this report uses a 3 year citation window, which also ensures the relevancy of the data better than the longer 5 year window. As such, any data and indicators pertaining to citations include all citations received within the year the paper was published and the subsequent two years. Consequently, items published at the end of a year have a slight disadvantage in that they have slightly shorter window in which to accrue citations.

Self-citations

Self-citations can either be included or excluded from citations counts. Self-citations have been retained in the data for this report on the basis that, first, self-citation is a standard means of scientific communication and of building upon one's own previous body of work, and secondly that the patterns of self-citation are likely to be similar with fields so will not present an advantage or disadvantage due to differing citation practices after field normalisation [1].

Excellence Rate

The Excellence Rate identifies the percentage of a country's publications that were in the 10% most highly cited publications from each discipline and that could be considered of excellent quality on this basis. In this report, we employed the method described by Waltman and Schreiber [7] to calculate the 10% most frequently cited publications. Following this method, we identified the publications with citations above the 90th percentile, however there may be a number of publications with citations on the threshold of the 10th percentile which, if included, would exceed the 10% required. As a secondary step then, we proportionally assigned the publications on the 90th percentile threshold to achieve exactly the top 10%. When interpreting Excellence Rates, the expected rate is 10%. Values higher than 10% then indicate the country had a higher than expected percentage of publications in the subset of 'excellent' publications and thus better performance.

Scientific Regard

The Scientific Regard (SR) indicator shows whether a country's publications are cited more or less than average compared to other publications from the same journals. SR is calculated by comparing the observed number of citations for a country's corpus of papers to the number of citations those papers could have been expected to receive, i.e. the average citations of papers in the journals the country published in, and then the scale is transformed to range between -100 and 100. As such, an SR of 0 indicates the countries were cited at the average of the journals they published in, while values over 0 indicate the country's publications are cited more frequently than average, and values below 0 indicate a lower than average citation rate compared to other publications from the same journals. The SR value for a country is calculated as:

$$SR_k = 100\, tanh\, ln\, (OBS_k / EXP_k)$$

where OBS_k is the observed rate of citations of country k's publications, and EXP_k is the expected citation rate based on the average citation rate of the journals in which country k published.

International Alignment

International Alignment (IA) is a measure of the international visibility of the journals in which a country publishes, based on citations. The IA value for a country is calculated as:

$$IA_k = 100\, tanh\, ln\, (EXP_k / OBS_w)$$

where OBS_w is the observed number of citations of all publications in the world, and EXP_k is the expected number of citations for country k based on the number of citations received by the journals

country k published in. As such, positive IA values indicate the country's papers were published in journals that were cited more frequently than average, and so reflect higher visibility and impact. Conversely, negative IA values indicate the country published in journals that were cited less frequently than the world average.

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