R&D

Publications Output: U.S. Trends and International Comparisons

NSB-2020-6

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This publication is part of the *Science and Engineering Indicators* suite of reports. *Indicators* is a congressionally mandated report on the state of the U.S. science and engineering enterprise. It is policy relevant and policy neutral. *Indicators* is prepared under the guidance of the National Science Board by the National Center for Science and Engineering Statistics, a federal statistical agency within the National Science Foundation. With the 2020 edition, *Indicators* is changing from a single report to a set of disaggregated and streamlined reports published on a rolling basis. Detailed data tables will continue to be available online.

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Executive Summary

Key takeaways:

- Global research output, as measured by peer-reviewed science and engineering (S&E) journal articles and conference papers, grew about 4% annually over the last 10 years.
- China's rate of research output has grown almost twice as fast as the world's annual average for the last 10 years, while the output of the United States and European Union (EU) has grown at less than half the world's annual growth rate.
- Research papers from United States and EU countries continue to have the most impact; however, China has shown a rapid increase in producing impactful publications, as measured by references to journal articles and conference papers.
- Specialization in scientific fields differs among countries, with the United States, the EU, and Japan more specialized in health sciences and China and India more specialized in engineering, as measured by journal articles and conference papers.
- International collaborations have increased over the last 10 years.

Data on articles in peer-reviewed S&E journals and conference papers reflect the rapidly expanding volume of research activity and the new knowledge it generates, the growing involvement and scientific capabilities of middle-income countries, and the expanding research ecosystem demonstrated through international collaborations. A primary method of disseminating research is through publication of articles in peer-reviewed journals and conference proceedings. This report utilizes data from the Scopus database of global S&E publications and finds that worldwide S&E publication output continues to grow on average at nearly 4% per year; from 2008 to 2018, output grew from 1.8 million to 2.6 million articles. In 2018, China (with a share of 21%) and the United States (with a share of 17%) were the largest producers. As a group, the EU countries (with a share of 24%) produced more S&E articles than China or the United States.

The international nature of research continues to grow. International collaborations increased in 2018 with slightly more than one out of five articles having coauthors from multiple countries. The collaboration base has grown as countries that were small producers of scientific publications 10 to 20 years ago have accelerated their global publication output.

Scientific impact, as measured by highly cited publications, shows the United States is among the leading countries with close to twice as many citations as would be expected given U.S. production levels. The U.S. impact in S&E publications has remained steady over the last 20 years.

The articles published from the United States and the EU countries exhibit relatively more specialization and impact in the fields of astronomy and astrophysics, biological and biomedical sciences, geosciences, health sciences, psychology, and social sciences. The EU countries also show specialization and impact in natural resources and conservation as well as mathematics and statistics. China's publications show the most specialization and impact in the fields of agricultural sciences, chemistry, computer and information sciences, engineering, materials science, natural resources and conservation, and physics.

Introduction

This report utilizes data from the Scopus database of global S&E publications, which is an abstract and citation database of peer-reviewed journal articles and conference papers.[1] The report presents the distribution of research publications across multiple dimensions, including by country, scientific field, international and interregional collaboration, specialization, and impact measures. The first section examines publication output by different regions, countries, and economies, as well as publication output growth rates by income groupings. The second section shows publication output trends and concentrations by field of science for regions, countries, or economies. The third section focuses on collaboration between researchers in the United States and other regions, countries, and economies.[2] The fourth section provides analysis of scientific impact as measured by citations in research publications. The final section combines the impact and specialization analyses.

While interpreting the data presented in this report, readers should keep in mind that counts of publications and citations mask unmeasured variables including the density of the knowledge in each article, data sets accompanying articles, and any country-specific incentives for academic publication. While publication-related data are an indicator of a nation's or economy's research output, it is not the only such measure. Other outputs from a nation's scientific and technological production, including degree awards, research workforce, innovative activities, research and development (R&D), and commercial output, are discussed in other Science and Engineering Indicators 2020 reports. These outputs can also be viewed as inputs into building a nation's science and technology capacity.

Publication Output, by Region, Country, or Economy

Publication output reached 2.6 million in 2018 (**Table 5a-1**).[3] The high-income economies (the United States, Germany, Japan, and other similar countries) produced 56% of S&E articles in 2018, upper-middle-income economies (China, Russia, Brazil, and other similar countries) produced 34%, and lower-middle-income economies (India, Indonesia, Pakistan, and other similar countries) produced 9% (**Figure 5a-1** and Table S5a-2).[4]

TABLE 5A-1

S&E articles in all fields, for 15 largest producing regions, countries, or economies: 2008 and 2018

(Number)

Rank	Region, country, or economy	2008	2018	Average annual growth rate 2008–18 (%)	2018 world total (%)	2018 cumulative total (%)
-	World	1,755,850	2,555,959	3.83	-	-
1	China	249,049	528,263	7.81	20.67	20.67
2	United States	393,979	422,808	0.71	16.54	37.21
3	India	48,998	135,788	10.73	5.31	42.52
4	Germany	91,904	104,396	1.28	4.08	46.61
5	Japan	108,241	98,793	-0.91	3.87	50.47
6	United Kingdom	91,358	97,681	0.67	3.82	54.29
7	Russia	31,798	81,579	9.88	3.19	57.49
8	Italy	56,157	71,240	2.41	2.79	60.27
9	South Korea	44,094	66,376	4.17	2.60	62.87
10	France	66,460	66,352	-0.02	2.60	65.47
11	Brazil	35,490	60,148	5.42	2.35	67.82
12	Canada	53,296	59,968	1.19	2.35	70.17
13	Spain	44,191	54,537	2.13	2.13	72.30
14	Australia	37,174	53,610	3.73	2.10	74.40
15	Iran	17,034	48,306	10.99	1.89	76.29
-	EU	528,938	622,125	1.64	24.34	-

EU = European Union.

Note(s)

The countries or economies are ranked based on the 2018 total. Article counts refer to publications from peer-reviewed journals and conference proceedings in S&E and indexed in Scopus (see **Technical Appendix** for more details). Articles are classified by their year of publication and are assigned to a region, country, or economy on the basis of the institutional address(es) of the author(s) listed in the article. Articles are credited on a fractional-count basis (i.e., for articles from multiple countries or economies, each country or economy receives fractional credit on the basis of the proportion of its participating authors). Detail may not add to total because of countries or economies that are not shown. Proportions are based on the world total excluding unclassified addresses (data not presented). Data were extracted in June 2019. Average annual change, or compound annual growth rate, is *average growth rate = (year 2 publications/year 1 publications)*$^{(1/\text{number of years})}$ *-1*. See Table S5a-1 for groupings of regions, countries, or economies. Detail and other countries are available in Table S5a-2.

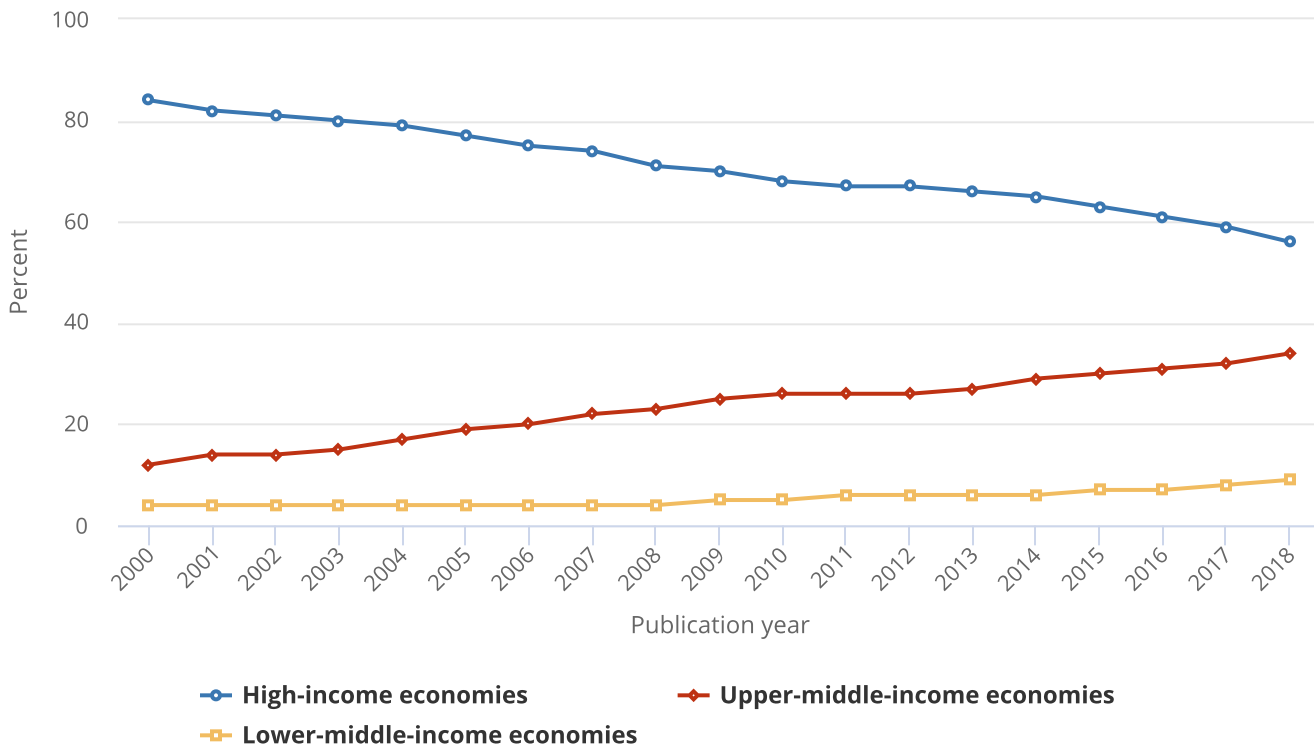
Source(s)

National Center for Science and Engineering Statistics, National Science Foundation; Science-Metrix; Elsevier, Scopus abstract and citation database, accessed June 2019.

Science and Engineering Indicators

FIGURE 5A-1

Global share of S&E articles by income group: 2000–18



Note(s)

Article counts refer to publications from a selection of peer-reviewed journals and conference proceedings in S&E fields from Scopus. Articles are classified by their year of publication and are assigned to a region, country, or economy on the basis of the institutional address(es) of the author(s) listed in the article. Articles are credited on a fractional-count basis (i.e., for articles produced by authors from different countries, each country receives fractional credit on the basis of the proportion of its participating authors). Data are not directly comparable to *Science and Engineering Indicators 2018*; see the **Technical Appendix** for information on data filters. Low-income economies are not included in this figure because of their low publication output. For more information on the 2019 World Bank Country and Lending Groups classification of income groups, see **https://datahelpdesk.worldbank.org/knowledgebase/articles/906519-world-bank-country-and-lending-groups**, accessed January 2019. Data by country and income groups are available in Table S5a-2.

Source(s)

National Center for Science and Engineering Statistics, National Science Foundation; Science-Metrix; Elsevier, Scopus abstract and citation database, accessed June 2019.

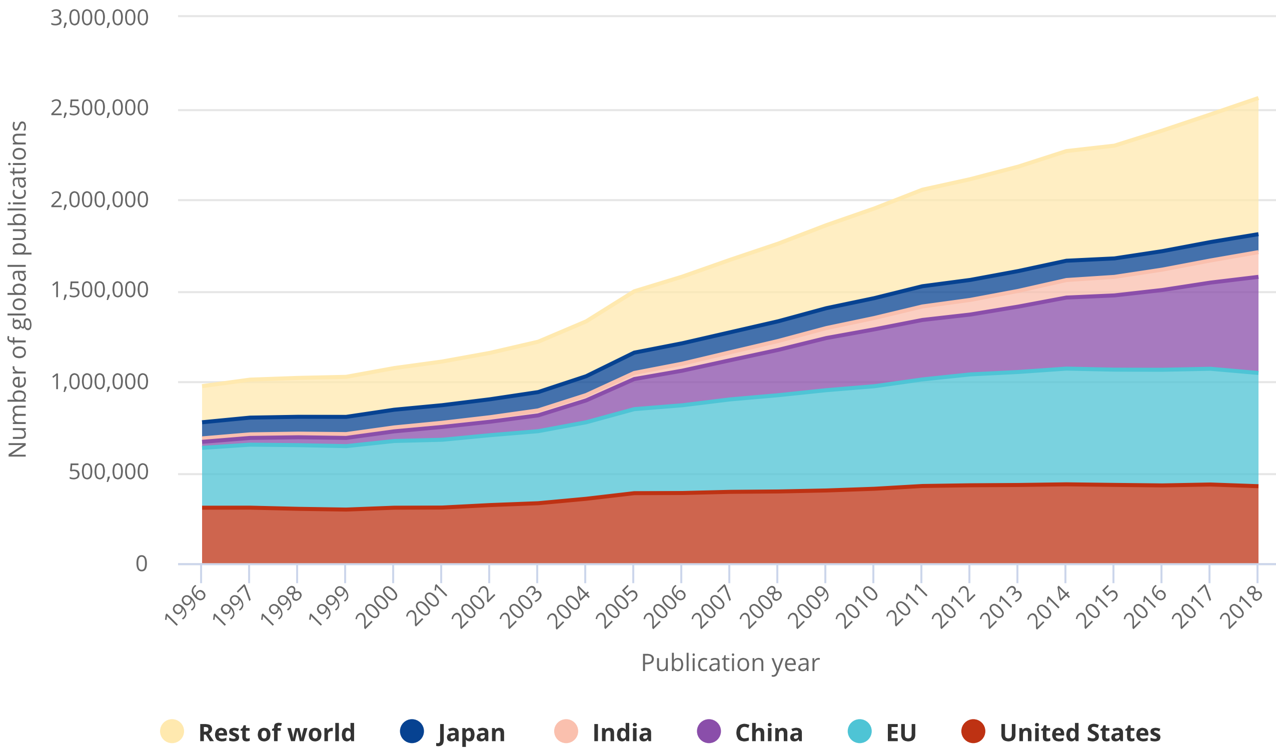
Science and Engineering Indicators

The last decade has seen a difference in the publication growth rates of middle- and high-income economies. The number of articles from upper-middle- and lower-middle-income economies combined grew 9% per year while the output of high-income countries grew 1% per year from 2008 to 2018 (Table S5a-2). The world's average annual growth rate from 2008 to 2018 slowed to 4% compared to 6% for the 2000 to 2008 period (**Table 5a-1** and Table S5a-2).[5]

The contribution to the world's increasing publication output varies across countries and economies. Viewing each country's or economy's publication output as a share of the total global output shows that the historically large producers—United States, EU countries (combined), and Japan—have declining shares of the world's increasing output since 2000 (**Figure 5a-2** and **Figure 5a-3**). Meanwhile China and India have increased their share of the growing world output. China produced 5% of global output in 2000 and grew to 21% in 2018; India's share rose from 2% to 5% during this period (**Figure 5a-3**). Among the 15 largest publication producers, countries with higher than average growth rates include South Korea (4%), Brazil (5%), China (8%), Russia (10%), India (11%), and Iran (11%) (**Table 5a-1**).

FIGURE 5A-2

S&E articles in all fields, for selected regions, countries, and economies and rest of world: 1996–2018



EU = European Union.

Note(s)

Article counts refer to publications from a selection of peer-reviewed journals and conference proceedings in S&E fields from Scopus. Articles are classified by their year of publication and are assigned to a region, country, or economy on the basis of the institutional address(es) of the author(s) listed in the article. Articles are credited on a fractional-count basis (i.e., for articles produced by authors from different countries, each country receives fractional credit on the basis of the proportion of its participating authors). Data are not directly comparable to *Science and Engineering Indicators 2018*; see **Technical Appendix** for information on data filters. For more information on the 2019 World Bank Country and Lending Groups classification of income groups, see **https://datahelpdesk.worldbank.org/knowledgebase/articles/906519-world-bank-country-and-lending-groups**, accessed January 2019. Data by country are available in Table S5a-2.

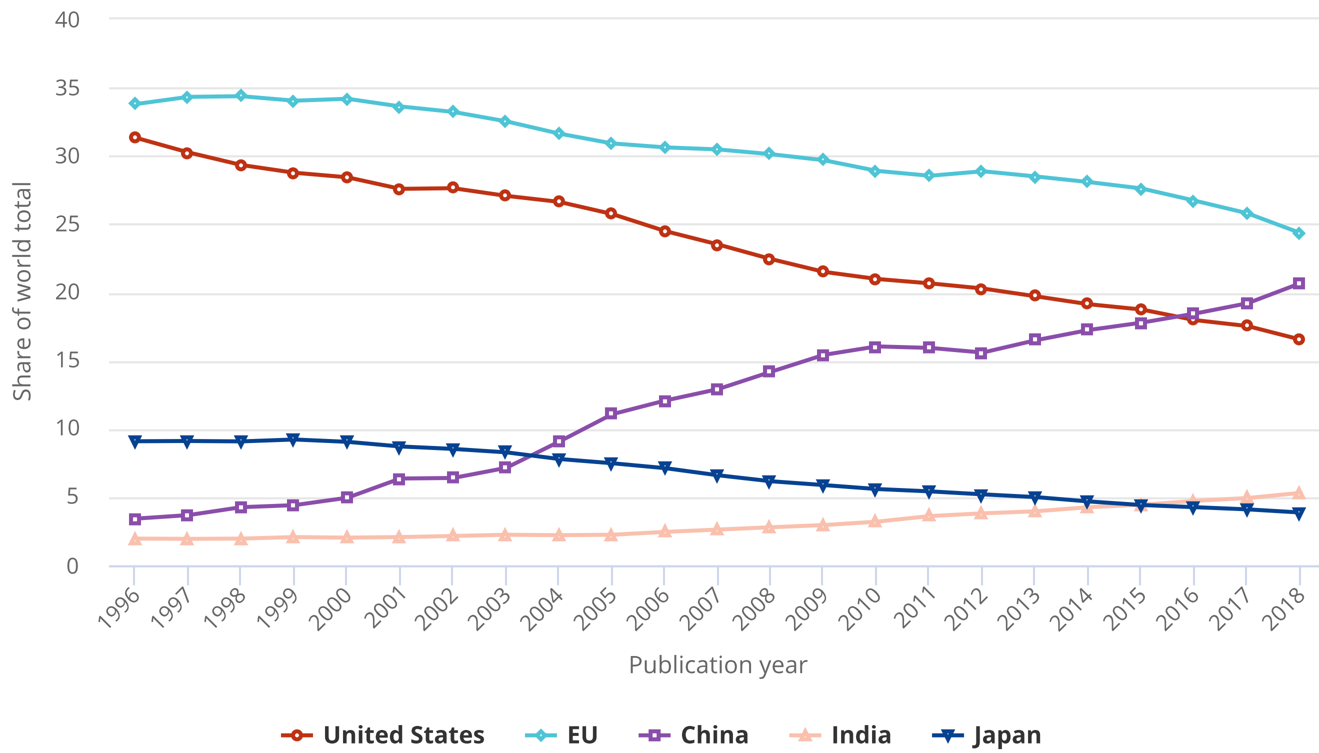
Source(s)

National Center for Science and Engineering Statistics, National Science Foundation; Science-Metrix; Elsevier, Scopus abstract and citation database, accessed June 2019.

Science and Engineering Indicators

FIGURE 5A-3

S&E articles, by global share of selected region, country, or economy: 1996–2018



EU = European Union.

Note(s)

Articles are classified by their year of publication and are assigned to a region, country, or economy on the basis of the institutional address(es) of the author(s) listed in the article. Articles are credited on a fractional-count basis (i.e., for articles produced by authors from different countries, each country receives fractional credit on the basis of the proportion of its participating authors). Data are not directly comparable to *Science and Engineering Indicators 2018*; see **Technical Appendix** for information on data filters. For more information on the 2019 World Bank Country and Lending Groups classification of income groups, see **https://datahelpdesk.worldbank.org/knowledgebase/articles/906519-world-bank-country-and-lending-groups**, accessed January 2019. Data by country are available in Table S5a-2.

Source(s)

National Center for Science and Engineering Statistics, National Science Foundation; Science-Metrix; Elsevier, Scopus abstract and citation database, accessed June 2019.

Science and Engineering Indicators

The U.S. annual publication growth rate of 1% fell below the world's average annual growth (4%) (**Table 5a-1**). EU countries that ranked among the world's largest 15 producers had annual growth rates below the world average from 2008 to 2018: Italy (2%), Spain (2%), Germany (1%), the UK (1%), and France (0.0%) (**Table 5a-1**). The three largest contributors to the growth in the world's publication output—from 1.8 million in 2008 to 2.6 million in 2018—were China (35%), the EU (12%), and India (11%) (**Table 5a-1**). The United States contributed 4% to the world's publication research growth from 2008 to 2018.

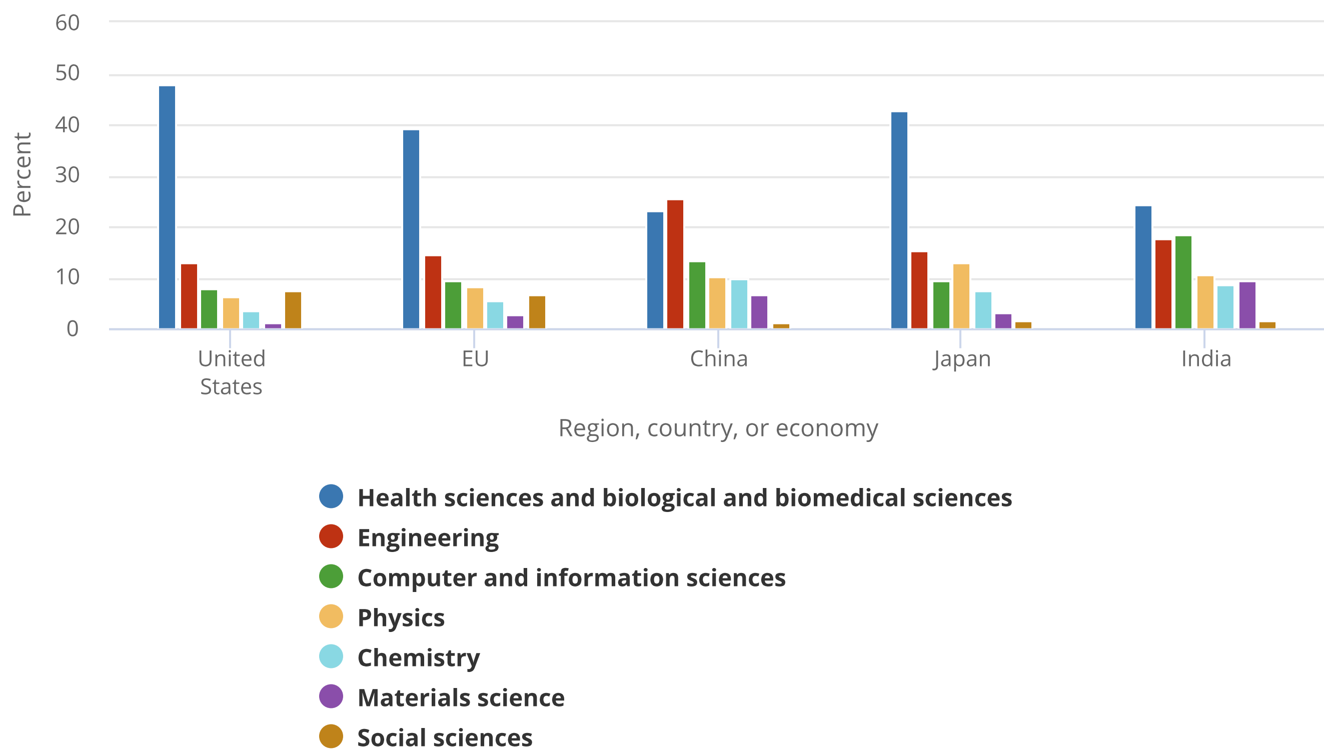
In terms of the absolute number of publications, researchers in China and the United States produced the most S&E publications, producing 528,263 (21%) and 422,808 (17%) articles, respectively, of the 2.6 million world 2018 total (**Table 5a-1**). The next closest countries by research publication count were India (135,788), Germany (104,396), Japan (98,793), and the UK (97,681) (**Table 5a-1**). Nine other countries complete the list of the largest 15 countries by output: Russia, Italy, South Korea, France, Brazil, Canada, Spain, Australia, and Iran. Together, these 15 countries produced just over 75% of the world's publication output in 2018 (**Table 5a-1**).[6] The top 15 producers of S&E articles have been stable over the last 10 years with the exception of Iran replacing Taiwan (**Table 5a-1** and Table S5a-2).

Publication Output, by Field of Science

A region's, country's, or economy's distribution of publications by field of science can indicate their research priorities and capabilities. Health-related research, which includes health sciences plus biological and biomedical sciences, is the largest global field of science (36% of publications) (Table S5a-17). In the United States and EU, health-related research and engineering are the largest scientific fields. In China, the largest research area is engineering (25%) followed closely by health-related research (23%); computer and information sciences (13%) is a distant third (**Figure 5a-4**). Japan has a portfolio with health-related research (43%) at the top followed by engineering (15%) and physics (13%) (**Figure 5a-4**).

FIGURE 5A-4

S&E research portfolios by seven largest fields of science by selected region, country, or economy: 2018



EU = European Union.

Note(s)

Articles refer to publications from a selection of peer-reviewed journals and conference proceedings in S&E fields from Scopus. Articles are classified by their year of publication and are assigned to a region, country, or economy on the basis of the institutional address(es) of the author(s) listed in the article. Articles are credited on a fractional-count basis (i.e., for articles from multiple countries, each country receives fractional credit on the basis of the proportion of its participating authors). Data are not directly comparable to *Science and Engineering Indicators 2018*; see **Technical Appendix** section on data filters. See Table S5a-1 for countries included in the EU. See Table S5a-17 for all fields of science. See Table S5a-2 through Table S5a-16 for source data.

Source(s)

National Center for Science and Engineering Statistics, National Science Foundation; Science-Metrix; Elsevier, Scopus abstract and citation database, accessed June 2019.

Science and Engineering Indicators

Scientific Field Concentrations Across Regions, Countries, and Economies

The specialization index allows for the comparison of research concentration or focus areas among regions, countries, and economies. The specialization index normalizes a country's share of output in a field of science with the total global share of output in that field (Science-Metrix, 2018). For example, astronomy and astrophysics articles comprised 0.8% of the U.S. S&E publication output (Table S5a-17). Normalizing the 0.8% by the world average of 0.5% in that field shows the U.S. specialization index for astronomy and astrophysics is 1.6, which is above the world average of 1.0 (Table S5a-17 and Table S5a-19). The specialization index also permits comparison across countries, revealing that the U.S. concentration is on par with several other countries but below that of Chile (5.5) (Table S5a-19), which houses many of the world's leading observatories.

Figure 5a-5 shows fields (blue) where the region, country, or economy has a concentration above the world average. The figure reveals that the United States has above-average concentrations in psychology (2.0), astronomy and astrophysics (1.6), social sciences (1.6), health sciences (1.4), biological and biomedical sciences (1.2), and geosciences (1.2). The EU has similar focus areas as well as mathematics and statistics (1.1) and natural resources and conservation (1.0). The concentration areas for China show more focus in chemistry (1.6), materials sciences (1.6), engineering (1.5), natural resources and conservation (1.3), computer and information sciences (1.2), physics (1.1), and agricultural sciences (1.1). Researchers find that G7 countries[7] emphasize the life sciences while BRIC countries[8] focus on physics, chemistry, mathematics, and engineering (Yang et al. 2012).

FIGURE 5A-5

Specialization of S&E articles by field by region, country, or economy: 2018

Field	United States	EU	China	Japan	India
Agricultural sciences	0.56	0.88	1.10	0.48	1.12
Astronomy and astrophysics	1.56	1.59	0.36	1.02	0.55
Biological and biomedical sciences	1.17	1.01	0.82	1.01	0.87
Chemistry	0.57	0.86	1.55	1.19	1.36
Computer and information sciences	0.72	0.90	1.24	0.87	1.72
Engineering	0.76	0.85	1.50	0.89	1.04
Geosciences	1.15	1.03	0.95	0.76	0.49
Health sciences	1.43	1.14	0.55	1.29	0.59
Materials sciences	0.31	0.61	1.55	0.76	2.22
Mathematics and statistics	0.85	1.06	0.87	0.70	1.44
Natural resources and conservation	0.61	1.01	1.32	0.60	0.75
Physics	0.71	0.92	1.10	1.41	1.16
Psychology	2.00	1.49	0.20	0.57	0.15
Social sciences	1.55	1.45	0.22	0.31	0.31

EU = European Union.

Note(s)

World index value is 1.00 for all fields. Articles are classified by their year of publication and are assigned to a region, country, or economy on the basis of the institutional address(es) of the author(s) listed in the article. The specialization index (SI) is calculated as follows: SI = $(Fe/Te)/(Fw/Tw)$, where Fe is the fractional count of a given region, country, or economy's output in a given field (F) divided by the total output for the region, country, or economy (Te); this is divided by the total output of the world in a given field (Fw) divided by the total output across all fields at the world level (Tw). The English-language bias of the Scopus database may impact the SI for psychology and social sciences (see **Technical Appendix** for more information). Geosciences includes geosciences, atmospheric sciences, and ocean sciences. See Table S5a-18 through Table S5a-31 for data about other countries and from 2000–18. See Table S5a-1 for countries included in the EU.

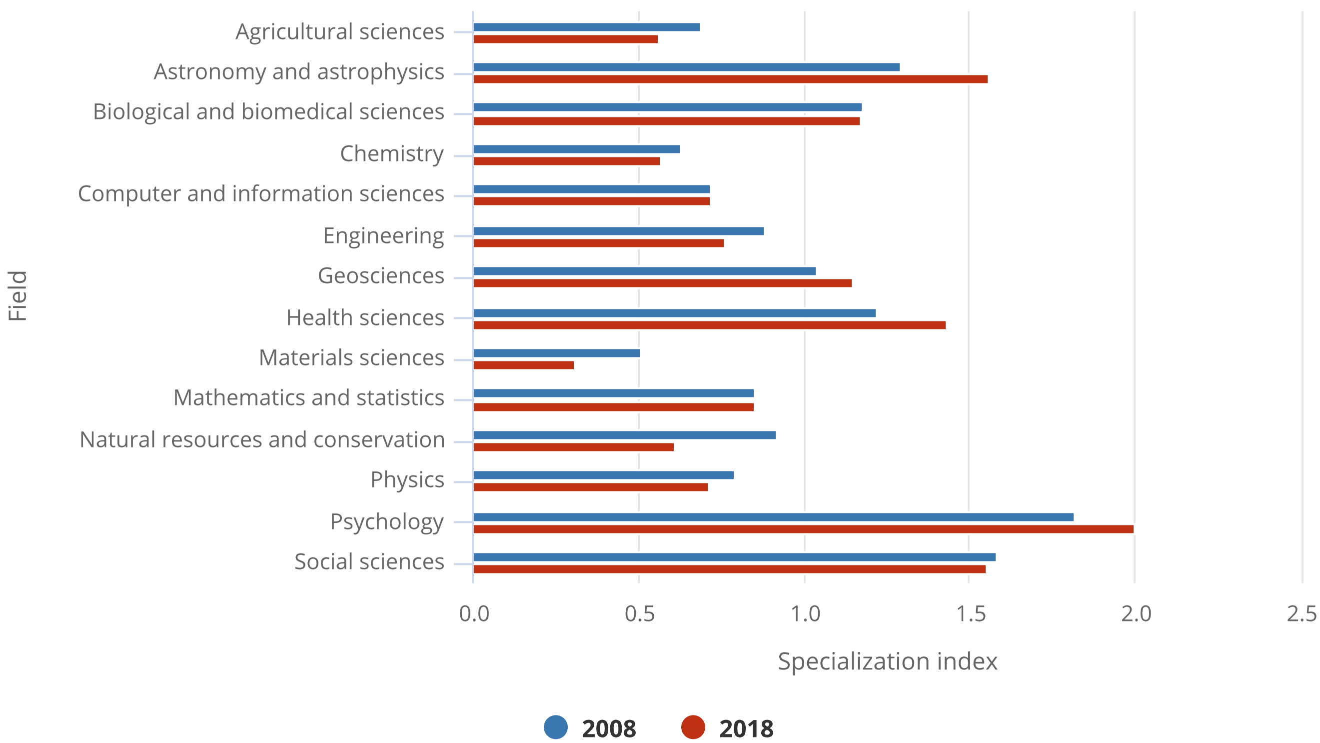
Source(s)

National Center for Science and Engineering Statistics, National Science Foundation; Science-Metrix; Elsevier, Scopus abstract and citation database, accessed July 2019.

The U.S. specialization index scores have increased from 2008 to 2018 for astronomy and astrophysics, geosciences, health sciences, and psychology (**Figure 5a-6**). The 18% increase in the health sciences index from 2008 to 2018 demonstrates the increasing concentration of the United States in health sciences and aligns with federal spending patterns in life sciences (see Figure 4-11 "Federal obligations for research, by agency and major S&E field: FY2017" in the forthcoming Indicators 2020 report Research and Development: U.S. Trends and International Comparisons).

FIGURE 5A-6

U.S. specialization of S&E articles, by field: 2008 and 2018



Note(s)

Articles are classified by their year of publication and are assigned to a region, country, or economy on the basis of the institutional address(es) of the author(s) listed in the article. The specialization index (SI) is calculated as follows: SI = (*Fe*/*Te*)/(*Fw*/*Tw*), where *Fe* is the fractional count of a given region, country, or economy's output in a given field (*F*) divided by the total output for the entity (*Te*); this is divided by the total ouput of the world in a given field (*Fw*) divided by the total output across all fields at the world level (*Tw*). Geosciences includes geosciences, atmospheric sciences, and ocean sciences. Data for additional years are available in Table S5a-18 through Table S5a-31.

Source(s)

National Center for Science and Engineering Statistics, National Science Foundation; Science-Metrix; Elsevier, Scopus abstract and citation database, accessed June 2019.

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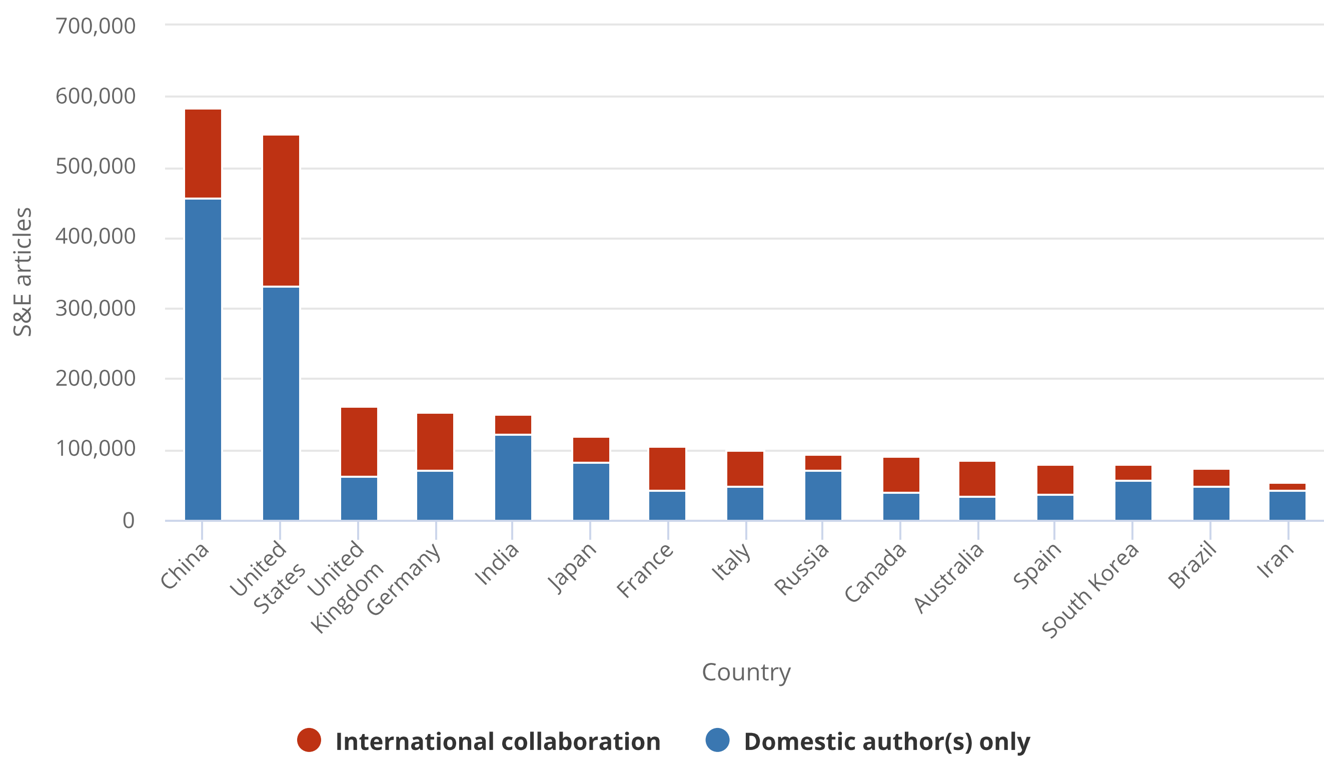
International Collaboration

The percentage of worldwide S&E articles produced with international collaboration—that is, by authors from universities and research institutions in at least two countries—rose from 17% to 23% between 2008 and 2018[9] (Table S5a-32). International connections among researchers indicate the expanding research capabilities around the world. Researchers collaborate for a number of reasons including access to a desirable collaborator; access to costly or shared equipment; or conditions attached to research funding that require international collaboration (Wagner 2018). S&E research has steadily become more global over the past decade, which can be measured by examining coauthorships on peer-reviewed articles (Glänzel and Schubert 2005; Royal Society 2011). International collaborations have been shown to increase the impact of research, as measured by citations (Sugimoto et al. 2017). Domestic collaboration, between academic, government, and industry, also receive higher citation rates (see forthcoming *Indicators 2020* report "Invention, Knowledge Transfer, and Innovation," section Business Collaboration in Peer-Reviewed Publications).

Among the 15 largest producers of S&E scholarly articles in 2018, most have high rates of international collaboration: the UK (62%), Australia (60%), France (59%), Canada (56%), Germany (53%), Spain (53%), and Italy (50%) (**Figure 5a-7**).[10] The United States has a collaboration rate of 39%, slightly below the average collaboration rate for the largest 15 producers (41%).[11]

FIGURE 5A-7

International coauthorship of S&E articles, for the 15 largest producing countries of S&E articles by country: 2018



Note(s)

Articles refer to publications from a selection of journals and conference proceedings in S&E from Scopus. Articles are classified by their year of publication and are assigned to a region, country, or economy on the basis of the institutional address(es) of the author(s) listed in the article. Articles are credited on a whole-count basis (i.e., each collaborating country or economy is credited with one count). Articles without international coauthorship are counts of articles with one or more institutional addresses all within a single region, country, or economy, which include single-author articles and articles coauthored under the same institutional address. International articles are articles with institutional addresses from more than one country or economy. The numbers of articles from the "international collaboration" and "domestic author(s) only" categories may not sum to the total article number because some coauthored publications having incomplete address information in the Scopus database. Those often cannot be reliably identified as international or domestic collaborations. For this reason, they are not included in either subcategory but are still counted towards the total number of articles. For more detail see Table S5a-32.

Source(s)

National Center for Science and Engineering Statistics, National Science Foundation; Science-Metrix; Elsevier, Scopus abstract and citation database, accessed June 2019.

Science and Engineering Indicators

Beyond the 15 largest producers, in 2018 collaboration rates vary widely: Saudi Arabia (75%), Switzerland (72%), and Belgium (71%) have relatively high collaboration rates whereas those with relatively low rates include India (18%), China (22%), and Russia (23%) (Table S5a-32). U.S. authors collaborated with at least one international peer on 39% of articles in 2018 compared to 27% in 2008 (Table S5a-32). Countries in the EU show high collaboration rates by virtue of their size, geographic proximity, and political support for cross-country collaboration (Wagner 2018). Germany, France, and the UK collaborate on over half of their articles; collaborations for these three countries increased from around 40% of their publications involving international collaboration in 2008 to over 50% in 2018 (**Figure 5a-7** and Table S5a-32).

In 2018, U.S. authors collaborated most frequently with authors from China. In 1996, the United States' largest collaboration country was the United Kingdom (13%) (Table S5a-33). In comparison, researchers in China collaborated on about 26% of U.S. internationally coauthored articles in 2018 (**Table 5a-2**). China's rapidly growing scientific and technological capabilities, such as rising R&D spending and university degree awards, likely contributed to this high rate of collaboration. Another possible factor may be the educational ties between the two countries: China is the largest foreign country of origin for international U.S. S&E doctorate recipients (Figure 2-17). U.S. authors also had substantial collaboration with authors from the UK (13%), Germany (11%), and Canada (10%) (**Table 5a-2**). Authors from China (44%), South Korea (44%), and Canada (43%) have notably high collaboration rates with U.S. authors as indicated by the share of these countries' international articles with a U.S. author (**Table 5a-2**).

TABLE 5A-2

International coauthorship of S&E articles with the United States, by world and selected country: 2018

(Percent)

Country	Share of country's international articles with U.S. coauthor	Share of U.S. international articles with coauthor from the country or economy
World	37.40	na
China	43.65	25.71
United Kingdom	28.64	13.29
Germany	28.77	10.96
Canada	42.83	10.20
France	25.32	7.16
Italy	27.47	6.41
Japan	31.99	5.35
Australia	27.56	6.47
South Korea	43.53	4.53
Spain	24.29	4.75
Netherlands	29.61	4.64
Switzerland	31.90	4.37

TABLE 5A-2

International coauthorship of S&E articles with the United States, by world and selected country: 2018

(Percent)

Country	Share of country's international articles with U.S. coauthor	Share of U.S. international articles with coauthor from the country or economy
Brazil	35.23	4.03
India	30.20	3.74
Sweden	28.43	3.27

na = not applicable.

Note(s)

Articles refer to publications from a selection of journals and conference proceedings in S&E from Scopus. Articles are classified by their year of publication and are assigned to a region, country, or economy on the basis of the institutional address(es) of the author(s) listed in the article. Articles are credited on a whole-count basis (i.e., each collaborating country or economy is credited with one count). Articles with international institutions are counts of articles with institutional addresses from more than one country or economy. See Table S5a-33.

Source(s)

National Center for Science and Engineering Statistics, National Science Foundation; Science-Metrix; Elsevier, Scopus abstract and citation database, accessed June 2019.

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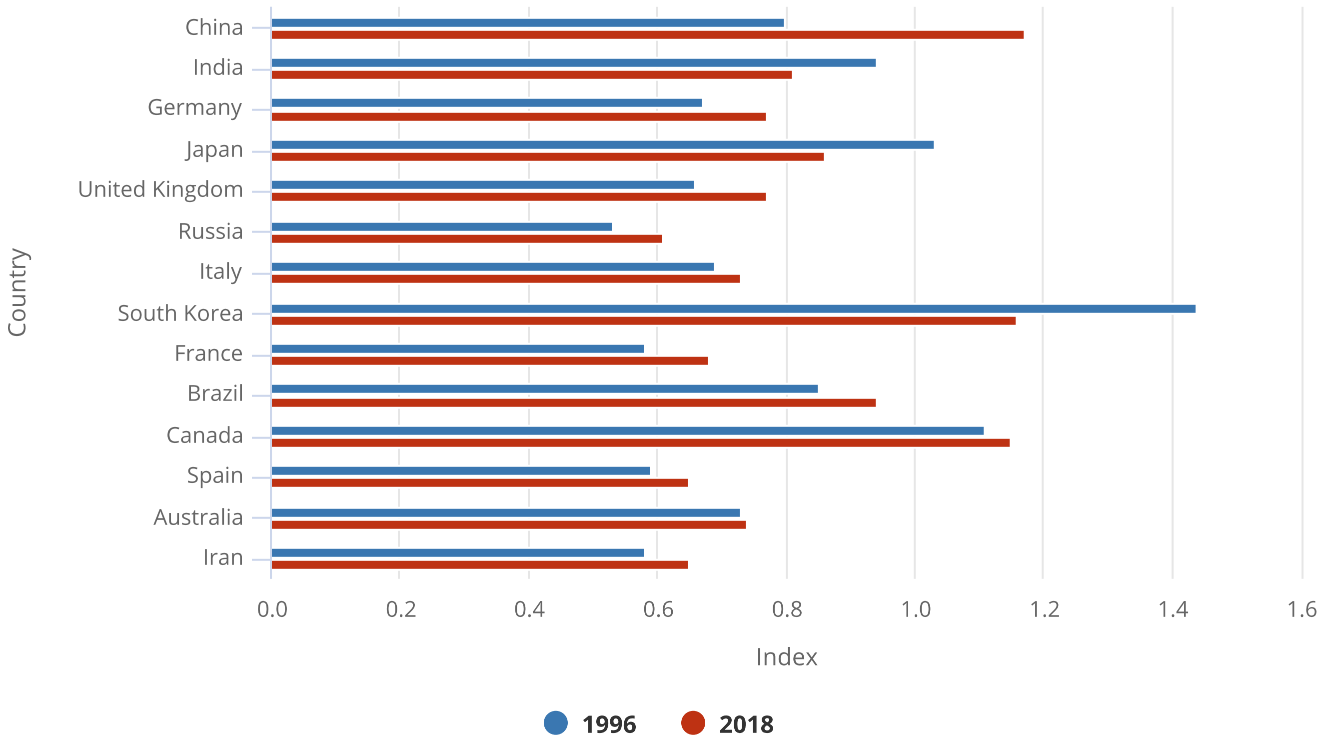
International collaboration can also be compared using an index. This provides another method for comparing across countries and time, while reducing the effects of country size (He 2009). The index is obtained by dividing a country's share of collaboration with another country by its overall share of international collaborations with all countries. The index measures the relative strength of collaborative ties between two countries. An index of 1.0 occurs when coauthorship between two countries is exactly proportional to their overall shares of international collaborations. Index values above 1.0 indicate stronger ties, while scores below 1.0 indicate weaker collaborative ties. The index of internationally coauthored S&E publications increased between the United States and most other major research countries from 1996 to 2018,[12] with the exceptions of South Korea (1.4 to 1.2), Japan (1.0 to 0.9), and India (0.9 to 0.8) (**Figure 5a-8**). The international collaboration index can also be used to understand the strength of partnerships between countries and regions (NSB ***Indicators 2018***: **Coauthorship and Collaboration in S&E Literature**).

FIGURE 5A-8

U.S. indexes of internationally coauthored S&E publications with other large-producing countries: 1996 and 2018



Note(s)

Article counts for computing the index refer to publications from a selection of journals and conference proceedings in S&E from Scopus. Articles are classified by their year of publication and are assigned to a region, country, or economy on the basis of the institutional address(es) of the author(s) listed in the article. Articles are credited on a whole-count basis (i.e., each collaborating region, country, or economy is credited with one count). Regions, countries, or economies that have contributed to less than 1% of all internationally coauthored articles in 2018 are omitted. The index of collaboration is calculated as follows: *ICxy* = (*Cxy*/*Cx*)/(*Cy*/*Cw*), where *ICxy* is the index of collaboration between country *x* and country *y*, *Cxy* is the number of papers coauthored between country *x* and country *y*, *Cx* is the total number of international coauthorships by country *x*, *Cy* is the total number of international coauthorships by country *y*, and *Cw* is the total number of international coauthorships in the database. For additional countries see Table S5a-34.

Source(s)

National Center for Science and Engineering Statistics, National Science Foundation; Science-Metrix; Elsevier, Scopus abstract and citation database, accessed June 2019.

Science and Engineering Indicators

Impact of Published Research

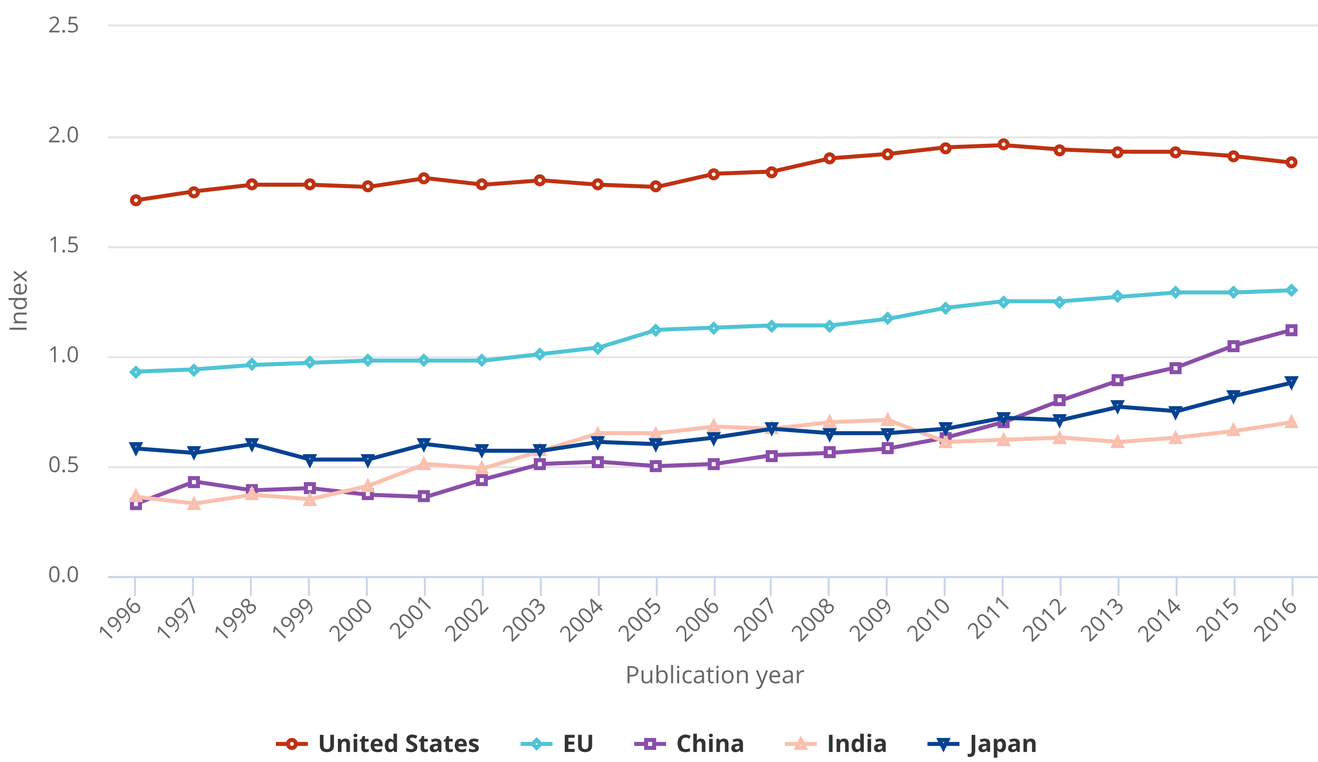
The global scientific publication enterprise cannot simply be categorized by its volume of production, the degree of article use matters as well. This is measured by the patterns and flows of citations. Data from citations provides a window into the impact of specific articles and authors, as well as the return on a country's scientific investment (Narin and Hamilton 1996). Publications are also used in patenting technologies, which will be covered in the forthcoming *Indicators 2020* report "Invention, Knowledge Transfer, and Innovation."

Citation data provide indications of scientific impact or influence by counting how frequently other journal articles or conference papers reference an article. Publications with more citations are said to have more impact on a particular scientific discipline (Waltman, Van Eck, and Wouters 2013). A small subset within the count of cited articles are categorized as highly cited articles (HCA), or the publications most frequently cited in other researchers' articles and conference papers. This report presents data on the top 1% of most-cited publications.[13] The index of a country's number of highly cited articles relative to the world's highly cited articles creates a comparable cross-country measure.[14]

The United States contributed nearly twice the expected volume of HCA in 2016 (HCA score of 1.9) (**Figure 5a-9**). China's HCA score is just above its expected share (HCA score of 1.1). Not all major article-producing countries were above the world average HCA—Japan and India each had below their expected level of articles in the top 1% in 2016 (HCA scores of 0.9 and 0.7, respectively) (**Figure 5a-9**). This report provides data for 2016 because HCA scores require the passage of time following publication for other researchers to read, analyze, and cite the articles (Wang 2012).

FIGURE 5A-9

S&E publication output in the top 1% of cited publications, by selected country or economy: 1996–2016



EU = European Union.

Note(s)

Articles are classified by their year of publication and are assigned to a region, country, or economy on the basis of the institutional address(es) of the author(s) listed in the article. Citation data are based on all citations made to articles in their publication year and all following years and are normalized by subfield and publication year to allow for comparisons across subfields and over time, resulting in the world-level standing at 1 for each subfield and year. A minimum 2-year citation window is needed for a relative citation (RC) score to be computed. This results in scores regarding highly cited articles not being computed after 2016 because the citation window for more recent years is not yet complete. The share of articles in the top 1% is computed as follows: $Sx = HCPx/Px$, where Sx is the share of output from country x in the top 1% most-cited articles; $HCPx$ is the number of articles from country x that are among the top 1% of most-cited articles (using full counting, with the exception of papers at the limit of the top 1%, which are fractioned so the world average can stand at 1%); and Px is the total number of papers from country x with an RC score, which excludes articles released after 2016 and unclassified publications. The world average stands at 1.00 for each year. See Table S5a-35 for source data. See Table S5a-1 for countries included in the EU.

Source(s)

National Center for Science and Engineering Statistics, National Science Foundation; Science-Metrix; Elsevier, Scopus abstract and citation database, accessed June 2019.

Science and Engineering Indicators

In addition to cross-country comparisons, the HCA score provides an opportunity to understand changes in a country's representation within the most highly cited articles. From 2006 to 2016, the impact of Chinese researchers grew faster than the impact of researchers in the United States and other countries (Conte et al. 2017; Xie and Freeman 2018). The HCA score of the United States increased slightly from 1.8 in 2006 to 1.9 in 2016 (**Figure 5a-9**). Over the same decade, the share of Chinese articles among the top 1% most-cited articles doubled (with HCA scores of 0.5 in 2006 and 1.1 in 2016) (**Figure 5a-9**). In 2006, publications from India had slightly more impact compared to China, although India's HCA score has remained relatively flat fluctuating around 0.7 over the 2006 to 2016 period (**Figure 5a-9**). HCA scores for Japan have increased from 0.6 in 2006 to 0.9 in 2016 (**Figure 5a-9**). The HCA score for China roughly equaled Japan's score in 2011; however, China's percentage of articles in the top 1% has surpassed Japan's since 2012 (**Figure 5a-9**).

The EU's HCA score increased from 1.1 in 2006 to 1.3 in 2016, driven by the growth of highly cited research from several member countries, such as the UK (which increased from 1.7 in 2006 to 2.4 in 2016), Germany (which increased from 1.3 in 2006 to 1.8 in 2016), and France (which increased from 1.3 in 2006 to 1.7 in 2016) (Table S5a-35).

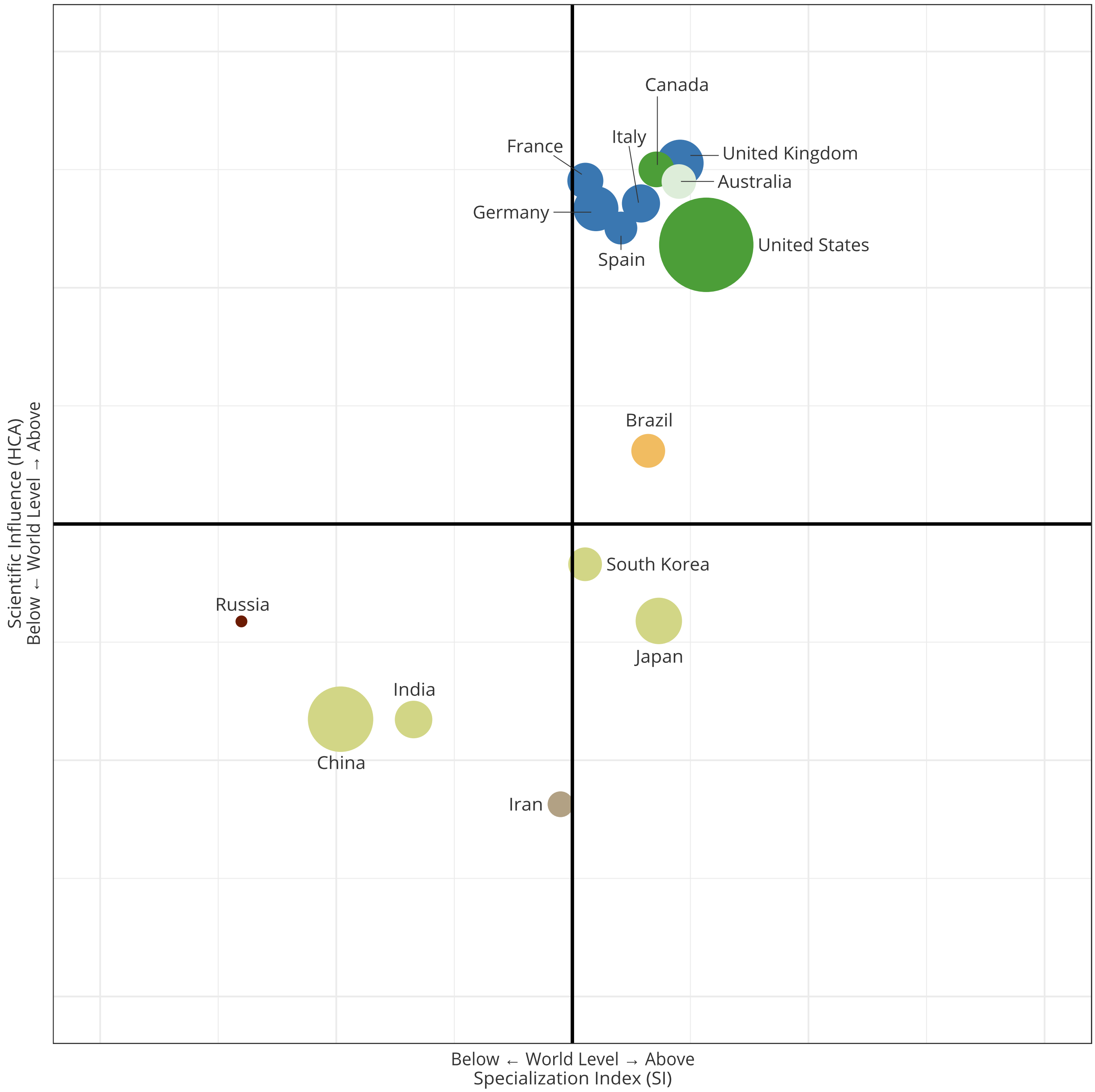
Specialization and Impact Analysis Combined

Combining the specialization index and HCA reveals scientific fields where countries are above the world average for both volume (specialization index) and impact (HCA). The positional analysis uses a bubble chart where countries to the right of the vertical axis produce a greater than average number of publications in the field. Countries above the horizontal axis have a higher HCA and therefore have more impact in the scientific field. The size of the bubble corresponds to the volume of output. Therefore, countries in the upper right quadrant of the graph are above the world average in both production and impact.

Using bubble charts, the fields of health sciences and computer and information sciences display markedly different clustering among the 15 largest-producing countries. The western countries show greater scientific impact and concentration in the health sciences (**Figure 5a-10**), while China shows greater impact and concentration in computer and information sciences (**Figure 5a-11**). In health sciences, the United States is 34% more specialized than the world average and nearly twice as impactful compared to the world average (**Figure 5a-10**). In computer and information sciences, articles produced by authors from U.S. institutions are more than twice as likely to be in the top 1% most-cited articles (2.2), but concentration in the field (0.7) is less than the world average (**Figure 5a-11**). Meanwhile articles produced by authors from Chinese institutions are above the world average for highly cited papers (1.7) and above the world average level of concentration (1.1) (**Figure 5a-11**).

FIGURE 5A-10

S&E articles-based positional analysis in health sciences for the 15 largest producing countries: 2016



Note(s)

Articles are classified by their year of publication and are assigned to a region, country, or economy on the basis of the institutional address(es) of the author(s) listed in the article. The specialization index (SI) is calculated as follows: SI = (*Fe*/*Te*)/(*Fw*/*Tw*) where *Fe* is the fractional paper count of a given region, country, or economy's output in a given field (*F*), *Te* is the total (*T*) output for the entity, *Fw* is the total ouput of the world in the same field, and *Tw* is the total output across all fields at the world level. The 15 largest publication-producing countries of S&E in 2018 were selected (see **Table 5a-1**). Countries are colored according to their main region (see Table S5a-1 for a definition of the regions). The axes are log-normalized to facilitate the display of the data. Citation data are based on all citations made to articles in their publication year and all following years and are normalized by subfield and publication year to allow for comparisons across subfields and over time, resulting in the world-level standing at 1.0 for each subfield and year. A minimum 2-year citation window is needed for a relative citation (RC) score to be computed. This results in scores regarding highly cited articles not being computed after 2016 because the citation window for more recent years is not yet complete. The share of articles in the top 1% is computed as follows: $Sx = HCAx/Ax$, where Sx is the share of output from country x in the top 1% most-cited articles; $HCAx$ is the number of articles from country x that are among the top 1% of most-cited articles (using full counting, with the exception of papers at the limit of the top 1%, which are fractioned so the world average can stand at 1%); and Ax is the total number of articles from country x with an RC score, which excludes articles released after 2016 and unclassified publications. The raw data (not transformed) are available in Table S5a-10, Table S5a-25, and Table S5a-43.

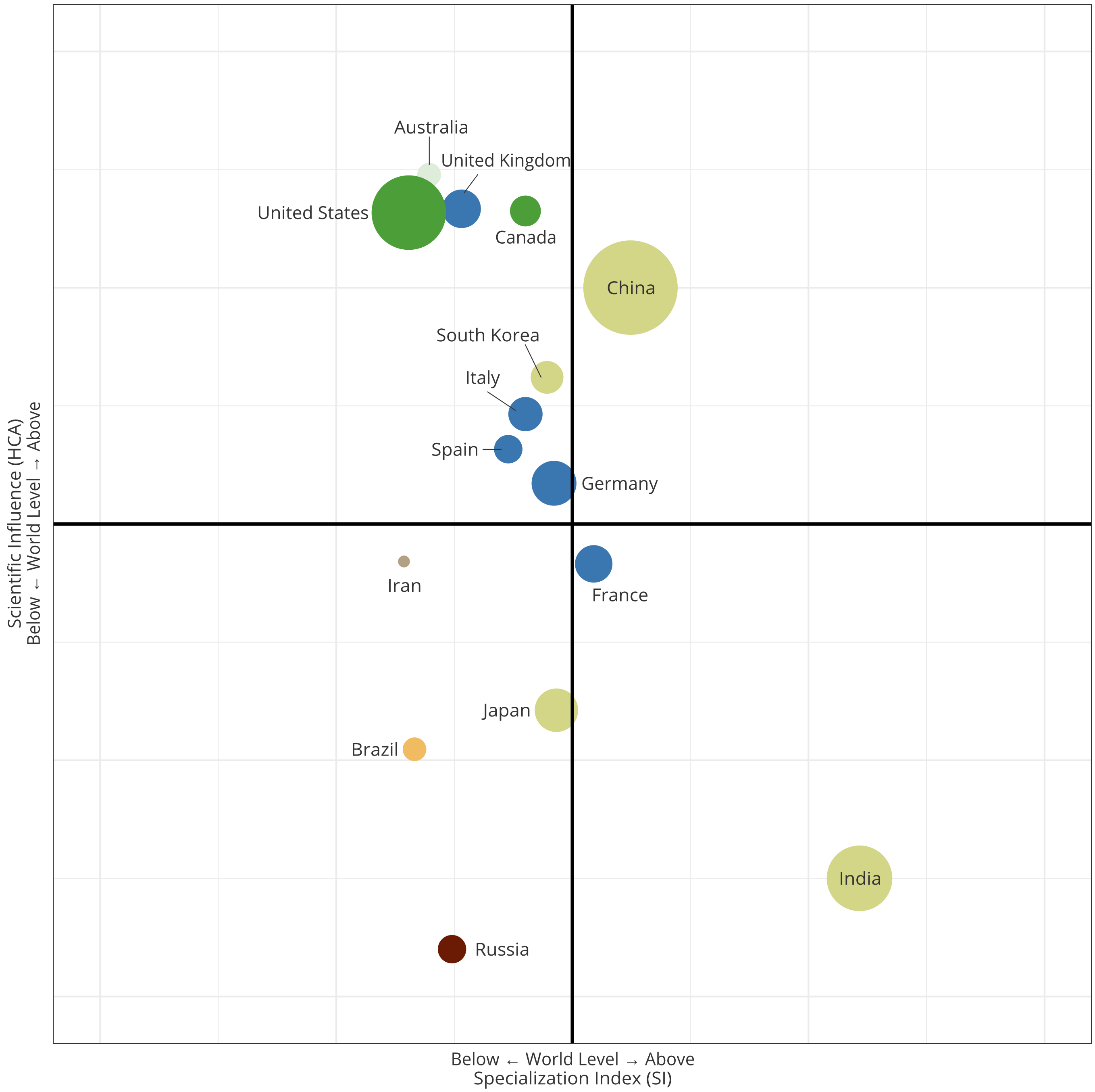
Source(s)

National Center for Science and Engineering Statistics, National Science Foundation; Science-Metrix; Elsevier, Scopus abstract and citation database, accessed June 2019.

Science and Engineering Indicators

FIGURE 5A-11

S&E articles-based positional analysis in computer and information sciences for the 15 largest producing countries: 2016



Note(s)

Articles are classified by their year of publication and are assigned to a region, country, or economy on the basis of the institutional address(es) of the author(s) listed in the article. The specialization index (SI) is calculated as follows: SI = (*Fe*/*Te*)/(*Fw*/*Tw*) where *Fe* is the fractional paper count of a given region, country, or economy's output in a given field (*F*), *Te* is the total (*T*) output for the entity, *Fw* is the total ouput of the world in the same field, and *Tw* is the total output across all fields at the world level. The 15 largest publication-publishing countries of S&E in 2018 were selected (see **Table 5a-1**). Countries are colored according to their main region (see Table S5a-1 for a definition of the regions). The axes are log-normalized to facilitate the display of the data. Citation data are based on all citations made to articles in their publication year and all following years and are normalized by subfield and publication year to allow for comparisons across subfields and over time, resulting in the world-level standing at 1.0 for each subfield and year. A minimum 2-year citation window is needed for a relative citation (RC) score to be computed. This results in scores regarding highly cited articles not being computed after 2016 because the citation window for more recent years is not yet complete. The share of articles in the top 1% is computed as follows: *Sx* = *HCAx*/*Ax*, where *Sx* is the share of output from country *x* in the top 1% most-cited articles; *HCAx* is the number of articles from country *x* that are among the top 1% of most-cited articles (using full counting, with the exception of papers at the limit of the top 1%, which are fractioned so the world average can stand at 1%); and *Ax* is the total number of articles from country *x* with an RC score, which excludes articles released after 2016 and unclassified publications. The raw data (not transformed) are available in Table S5a-7, Table S5a-22, and Table S5a-40.

Source(s)

National Center for Science and Engineering Statistics, National Science Foundation; Science-Metrix; Elsevier, Scopus abstract and citation database, accessed June 2019.

Science and Engineering Indicators

More broadly, the western economies demonstrate more specialization and impact in astronomy and astrophysics, biological and biomedical sciences, geosciences, health sciences, psychology, and social sciences (Table S5a-19, Table S5a-20, Table S5a-24, Table S5a-25, Table S5a-30, Table S5a-31, Table S5a-37, Table S5a-38, Table S5a-42, Table S5a-43, Table S5a-48, and Table S5a-49). Eastern economies demonstrate more specialization and impact in chemistry, computer and information sciences, engineering, and material sciences (Table S5a-21, Table S5a-22, Table S5a-23, Table S5a-26, Table S5a-39, Table S5a-40, Table S5a-41, and Table S5a-44).

Conclusion

Overall, the United States remains a highly influential nation in its contribution to S&E publications, based on the overall size of the U.S. contribution and its relative impact, as measured by citations in S&E publications. In terms of S&E publication quantity, China's output has grown rapidly and is now comparable to the United States. In terms of impact among S&E publications, China has increased rapidly in the last decade from a small base; however, it still lags the United States and EU countries. The high-income economies (including the United States, the EU, and Japan) have grown more slowly in S&E publications, while lower-, middle-, and upper-middle-income economies have increased production, collaboration, and impact at a much faster rate.

International research collaboration is increasing, reflecting traditional cross-country ties and new relationships that stem from growing capabilities in the middle-income economies. This international collaboration indicates that S&E knowledge is flowing with increasing ease across the world.

Glossary

Definitions

Article Counts: The number of peer-reviewed articles and conference papers indexed in the Scopus database that are produced by a given region, country, economy, or institutional sector. Articles coauthored by multiple countries or institutional sectors are counted in two ways: fractional or whole (see definitions in glossary).

BRIC: A grouping acronym referring to the countries of Brazil, Russia, India, and China.

Citations: Citations, generally at the end of each article, provide researchers with the list of the prior research relied upon for the article. Citations of S&E publications by other S&E publications provide an indication of the impact of publications and of the flow of knowledge or linkage between sectors or geographic locations.

Coauthorship: Coauthorship is when there is more than one author listed on a publication. Coauthorship measures collaboration across regions, countries, economies, and institutional sectors. Publication counts of coauthorship use whole counting, resulting in a full count assignment for each country or institutional sector contributing to the article. An article is considered an international coauthorship when there are institutional addresses for authors from two or more different countries. Table S5a-32 shows international coauthorship from 1996 to 2018.

European Union (EU): The EU is comprised of 28 member nations: Austria, Belgium, Bulgaria, Croatia, Cyprus, Czechia, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Ireland, Italy, Latvia, Lithuania, Luxembourg, Malta, the Netherlands, Poland, Portugal, Romania, Slovakia, Slovenia, Spain, Sweden, and the UK. Unless otherwise noted, Organisation for Economic Co-operation and Development data on the EU include all 28 nations. Bulgaria and Romania joined the EU in 2007 and Croatia joined in 2013—they are included in the EU grouping for all years analyzed in this report.

Fractional counting: Method of counting S&E publications in which credit for coauthored publications is divided among the collaborating institutions or countries based on the proportion of their participating authors. Fractional counting allocates the publication count by the proportion of each of the countries or institutional coauthors named on the article. Fractional counting enables the counts to sum up to the number of total articles. For example, if a paper was authored by two researchers from the University of Oslo, one from the University College London, and one from the University of Washington, half of the paper would be attributed to Norway and one quarter each to the UK and the United States when the fractions are calculated at the level of researchers. For this report, fractions were calculated at the level of researchers.

G7 countries: The Group of Seven (G7) is an international intergovernmental economic organization consisting of the seven largest International Monetary Fund members: Canada, France, Germany, Italy, Japan, the United Kingdom, and the United States.

Highly cited articles (HCA): An HCA score is not a perfect measure of influence, but it provides a rough indication of scientific impact (Waltman, Van Eck, and Wouters 2013). The first step is to create a dataset of the top 1% most-cited publications in each field and for each year. The HCA score for a country is the share of authors with institutional addresses within that country who have articles that are among the top 1% of the world's highly cited articles, relative to all the articles ascribed to that country. The HCA score is indexed to 1, so that a country's authors producing highly cited articles at the expected (i.e., global average) rate has an HCA score of 1—that is, 1% of the country's articles are among the top 1% of the world's highly cited articles. Countries with authors producing highly cited articles at greater than the expected rate have HCA scores greater than 1, and countries with authors producing influential articles at lower than the expected rate have HCA scores less than 1. For example, assume a world of two countries produced an output of 10,000 articles, with country *x* with authors producing 7,000 articles and country *y* with authors producing 3,000 articles. If both countries had the same influence in the citation records, then country *x* would have 70 highly cited articles and country *y* would have 30 highly cited articles in the top 100 most-cited articles in the world. Each country would have an HCA score of 1. The scores would be different if authors in one of the countries produced a higher proportion of the highly cited articles. For example, if authors in country *y* produced 50 of the most highly cited articles, then their HCA score would be 1.7, indicating that 1.7% of the articles of country *y*'s authors (50 out of 3,000) are among the top 1% of the world's highly cited articles. For country *x*, the HCA score would be 0.7 (50 out of 7,000). The top 5% or 10% of highly cited articles can be analyzed in a similar fashion (Table S5a-35).

International collaboration index: The collaboration index is calculated as follows: $ICxy = (Cxy/Cx)/(Cy/Cw)$, where $ICxy$ is the index of collaboration between country *x* and country *y*, Cxy is the number of papers coauthored between country *x* and country *y*, Cx is the total number of international coauthorships by country *x*, Cy is the total number of international coauthorships by country *y*, and Cw is the total number of international coauthorships in the database. An index greater than 1.0 means that a country-country pair has a stronger-than-expected tendency to collaborate; an index less than 1.0 indicates a weaker-than-expected tendency to collaborate (Table S5a-34).

Specialization index: For any given scientific field, the specialization index indicates the extent to which a country focuses in that area. The index assesses the share of a country's articles produced in a field of science relative to the world's output in that field. The indicator is computed by comparing a country to the global average. In 2018, for instance, the United States produced about 143,000 of its 423,000 articles in health sciences (Table S5a-2 and Table S5a-10). By comparison, at the world level, only about 604,000 of 2,556,000 total articles were in health sciences (Table S5a-2 and Table S5a-10). Thus, the United States produces more articles in this area than expected, based on its total output and the world proportions. This indicator is indexed to 1.0, which represents the world level, meaning that a score above 1.0 shows that a country produced more of its publication output in the given scientific field than the global proportion, whereas a score below 1.0 shows that a country produced fewer articles in this field than the global average. When a country's share of articles increases in one area, its share must decrease proportionately in other areas.

Whole counting: This measure (also called *full* or *integer* counting) assigns one count to each country or institutional sector involved in coauthoring the article, irrespective of their proportionate involvement in authorship. Whereas fractional counting aims to assess the proportionate contributions of countries or sectors, whole counting aims instead to assess the participation of countries or sectors. One result of this difference is that the sum of articles from countries or institutional sectors will exceed the total number of articles when whole counting is used. For the United States in 2018, there were 423,000 publications in the Scopus database as measured on a fractional-count basis and 549,000 as measured on a whole-count basis (Table S5a-2). In the full counting method, each paper is counted once for each entity listed in the address field. For example, if a paper was authored by two researchers from the University of Oslo, one from the University College London, and one from the University of Washington, the paper would be counted once for the University of Oslo, once for the University College London and once for the University of Washington. It would also be counted once for Norway, once for the UK, and once for the United States. When it comes to aggregating groups of institutions (e.g., research consortia) or groups of countries (e.g., the EU), double counting is avoided. This means that if authors from Croatia and France copublished a paper, this paper would be credited only once when counting papers for the EU, even though each country had been credited with one publication count.

Key to Acronyms and Abbreviations

BRIC: Brazil, Russia, India, and China

EU: European Union

G7: Group of Seven

HCA: highly cited articles

NSF: National Science Foundation

R&D: research and development

S&E: science and engineering

UK: United Kingdom

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Notes

1 More information on the selection of documents for analysis can be found in the **Technical Appendix** for this report.

2 Data can also be examined for institutional collaboration (NSB ***Indicators 2018***: **Coauthorship and Collaboration in S&E Literature**).

3 Publication output only includes those indexed in the Scopus database. The publication output discussion uses fractional counting, which credits coauthored publications according to the collaborating institutions or countries, based on the proportion of their participating authors. Country assignments refer to the institutional address of authors, with partial credit given for each international coauthorship. As part of our data analysis, we employ filters on the raw Scopus S&E publication data to remove publications with questionable quality, which appear in what are sometimes called “predatory” journals (NSB ***Indicators 2018***: **Bibliometric Data Filters sidebar**).

4 This report uses the World Bank’s country income classifications issued on July 1, 2018. The World Bank updates the classifications each year on July 1. The World Bank income classifications are assigned using the gross national income per capita as measured in current U.S. dollars. This report uses the rankings. More information is available at **https://datahelpdesk.worldbank.org/knowledgebase/articles/906519-world-bank-country-and-lending-groups**.

5 Year-to-year comparisons across *Indicators* reports are not possible because the bibliometric database constantly updates as new articles enter the database and additional information becomes available. The publication output trends and year-to-year comparisons are valid within all the *2020 Indicators* reports because they all rely upon the June 2019 Scopus database download.

6 The trends are consistent whether using fractional counting as in **Figure 5a-3** and **Table 5a-1** or whole counting as in Table S5a-2. There is a slight difference between the United States and China when looking at the whole counting total production numbers. Using whole counting for 2018, the United States had 548,847 articles while China had 584,407. A whole counting measure allocates one full count to each country with an author contributing to the paper, rather than fractional counting where each country only receives a fraction. For example, if an article had four authors with two from the United States, one from China, and one from Brazil, the fractional scores would be 2/4 for the United States, 1/4 for China, and 1/4 for Brazil. The difference between whole and fractional counting indicates that the United States has more authors working with Chinese authors than China has working with U.S. authors.

7 The Group of Seven (G7) is an international intergovernmental economic organization consisting of the seven largest International Monetary Fund members: Canada, France, Germany, Italy, Japan, the United Kingdom, and the United States.

8 A grouping acronym referring to the countries of Brazil, Russia, India, and China.

9 The worldwide international collaboration rates should not be used as benchmarks against which to compare the share of international co-publications of individual countries. Due to the multi-lateral nature of co-publications, the world's share based on full counting of co-publications and publications is not directly comparable to the country scores. Individual country scores also use whole counting where each country, with an institutional address on the paper, receives one point. Therefore the basis count for individual countries will be larger than the number of papers that have authors with institutional addresses from 2 or more countries, which is the basis for the worldwide collaboration computation.

10 **Figure 5a-7** uses whole counting: each collaborating country or economy is credited with one count. The United States has a larger number of articles on a whole-count basis because the United States is more collaborative than China. Accurate cross-country comparisons for article production uses fractional counting as shown in **Figure 5a-3**.

11 The United States serves in a leadership position in international collaboration as determined by the number of times that an author from a U.S. institution is listed first among an article's authors. See Chinchilla-Rodríguez Z, Sugimoto CR, Larivière V. 2019. Follow the Leader: On the Relationship between Leadership and Scholarly Impact in International Collaborations. *PLOS ONE* 14(6):e0218309. Available at **https://journals.plos.org/plosone/article?id=10.1371/journal.pone.0218309** Accessed 18 September 2019.

12 The difference between 2018 and 1996 index values are rounded to show trends; some index values are slightly negative due to year-to-year fluctuations. A 22-year time span is used because international collaboration is a slow-moving trend.

13 Table S5a-35 presents data on the top 1%, 5%, and 10% HCA.

14 The share of S&E articles in the top 1% of cited articles is computed by field because different fields of science have different rates of citation.

Errata

May 2020

The labels for Canada and the UK were reversed in the image of **Figure 5a-11** and have been corrected in all viewing and downloading options. The Excel data download was not affected.

Percentages for Japan and India have been corrected in table S5a-17 and **figure 5a-4**. Text referencing **figure 5a-4**, located in the section **Publication Output, by Field of Science**, were also corrected.

Acknowledgments and Citation

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