U.S. R&D and Innovation in a Global Context: The 2023 Data Update

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BOTTOM LINE: The U.S.'s public R&D investments continue to stagnate, while others invest heavily. The U.S. is still tentatively the biggest R&D spender in the world, but 13th in public R&D intensity, 5th in private spending intensity and 10th in basic research intensity.

For the first time, the U.S. does not produce the largest share of publications, with China claiming the number one spot as well as keeping its position as the largest share of patents granted.

In terms of the research workforce, the U.S. has the 3rd largest workforce but is 18th in researchers as a share of the total workforce.

Investment in research and development (R&D) – activities to generate new knowledge and create new technology – is a cornerstone input for innovation. This report provides an update of major global trends in R&D and related innovation metrics, considering continuing Congressional interest in U.S. competitiveness.

This report relies primarily on new data from the Organisation of Economic Cooperation and Development (OECD), released in late March 2023.[1] For certain topics, the OECD data is supplemented with data from other sources.

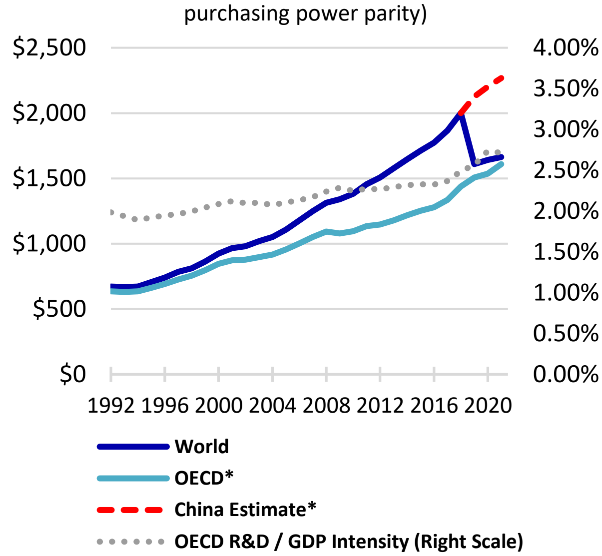
1. Aggregate Trends

Adjusted for inflation and cross-economy price differences, global R&D investment has tripled over the past 20 years, from $672 billion in 1992 to over $2.2 trillion as of 2021, when correcting for the lack of investment reporting out of China. (Figure 1.1). COVID-19 appeared to slow this spending growth somewhat, with the year over year increases in R&D investments across the (reporting) world decreasing to under 2% in 2020 and 2021. This compares to the previous decade, whose lowest year over year increase was 3.6%.

In last year's report, it was noted that OECD countries, which make up 38 of the world's most wealthy and robust economies, are no longer the sole drivers of R&D globally. This trend continues, though with the gap in reporting from China it becomes evident that the country is leading a significant chunk of the non-OECD investments.

This gap comes from the fact that China's self-reported R&D indicators for 2019-2021 have been removed for review by the OECD. There were some questions as to its coherence to the values to the Frascati Manual, guidelines that dictate reporting standards.

Figure 1.1: Total World R&D Since 1992
(Billions of constant dollars adjusted for purchasing power parity)



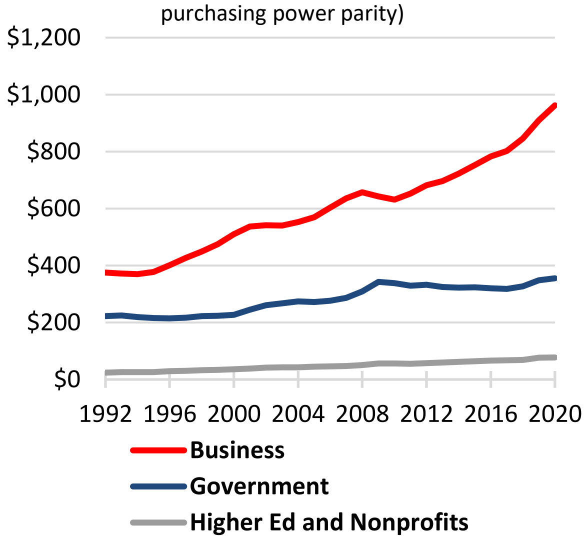
*The OECD has put China's 2019-2021 numbers under review and not published them. The estimate models for continued growth as compared to prior levels and should not be treated as fact.
Includes public and private sectors.
Data from OECD Main S&T Indicators, April 2023 | AAAS

In 2018, the last year for which China's reported values are available, it accounted for 82% of non-OECD countries' R&D investments. Here we estimate, using calculations based on prior year's growth, in an attempt to map what the world total might look like with the inclusion of Chinese R&D. This estimate is not to be treated as fact, as it does not generate an accurate portrayal of Chinese funding.

OECD countries are also growing, with their cumulative R&D investments as a fraction of GDP is indicated on the right-side axis of the figure, and now sit at 2.71% in 2021, up 2.56% pre-pandemic. The business sector, as seen in Figure 1.2, is by far the largest funder of R&D in OECD economies, providing over $960 billion and accounting for 64% of OECD R&D in 2020. That year, government financing – which refers almost entirely to national government in most cases – accounted for 24% of R&D, and the remainder was composed of universities, nonprofits, and foreign sources.

Figure 1.2: R&D By Funding Sector, OECD Countries

(Billions of constant dollars adjusted for purchasing power parity)



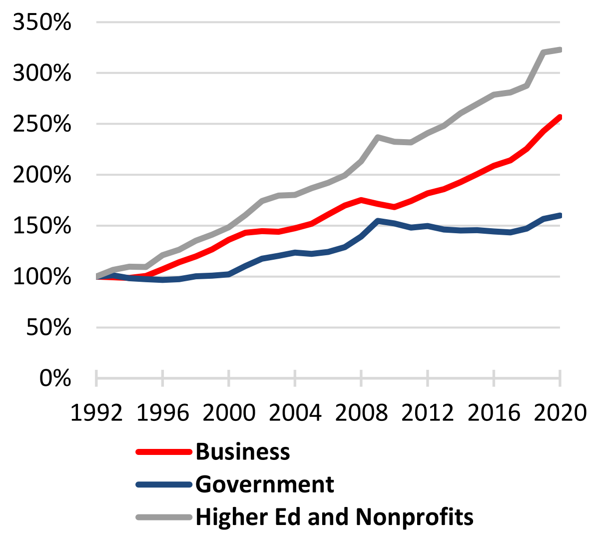
AAAS calculation based on OECD Main S&T Indicators, April 2023 | AAAS

However, since 1992, relative funding growth has looked somewhat different (Figure 1.3). Over that time, R&D funding from higher education and other nonprofit institutions more than tripled in real term (223% increase over 28 years), while industrial R&D financing has more than doubled (157% increase), and government R&D has only increased by 60%.

OECD economies have largely stagnant R&D investments from federal sources since the 2009 financial crisis, though it appears to have increased marginally in recent years - with a nearly 10% increase jump between 2018 and 2019.

Figure 1.3: OECD R&D Growth By Funding Sector

Indexed to 1992 levels



AAAS calculation based on OECD Main S&T Indicators, April 2023

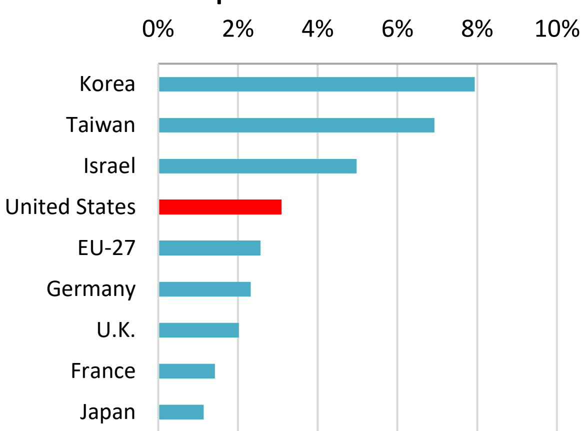
This data also shows the first of the pandemic years, which was expected to have significant increases in government funding. However, between 2019 and 2020 there was only a 3% increase in federal funding for R&D, about on par with previous year-over-year increases.

The graphs cover through the first year of the pandemic, showing an increase in funding growth in all sectors as countries encountered the research-heavy challenge. Despite early estimates that research would return to "normal" levels[2], early reporting shows that the elevated increases continued into 2021 for many countries.[3] For more, see country-level breakdowns in the next section.

2. R&D Investments by Country:

Last year we reported that China was showing the greatest growth in the last twenty years, and that is still likely the case. The Chinese data, however, is currently being reviewed and has been removed from the dataset, so we will wait for its re-inclusion to speculate too heavily on its growth.

Figure 2.1: Annual Growth in R&D Expenditures Since 2000



Including public and private sources.
Analysis based on OECD S&T Indicators data, April 2023. | AAAS

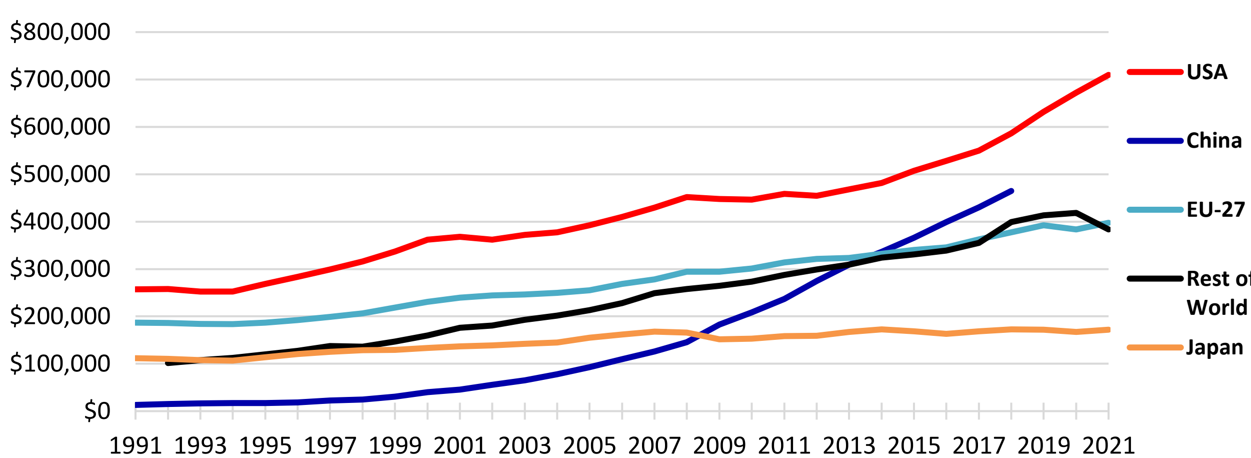
In the meantime, Korea, Taiwan, and Israel continue to rank highly in terms for R&D growth, as can be seen in Figure 2.1, so all three small economies that punch well above their weight in terms for STEM investments. The U.S. comes next, with a 3.1% annual growth, outpacing the EU.

As can be seen in Figure 2.2, the U.S. is still, in theory, the largest spender on R&D in the world, with China not reporting and the EU and Japan staying steady. The rest of the world actually saw a decrease in R&D spending during the pandemic.

This included South Korea, which continued to maintain a gradual increase despite the pandemic, and France and Germany, which started to plateau instead. The U.K. is also in that group; the country recalculated how it measures R&D investment, especially business investments in R&D. This puts the UK in a slightly higher position than previously, but it is still looking at a plateauing R&D investment at large.

R&D Intensity: R&D intensity – or R&D as a share of gross domestic product – indicates the relative share of resources devoted to R&D in an economy, providing an indicator of its innovative capacity. For instance, Israel and Korea, the two countries with the most R&D-intensive economies, spend far less on R&D than the United States or China in absolute dollars, but

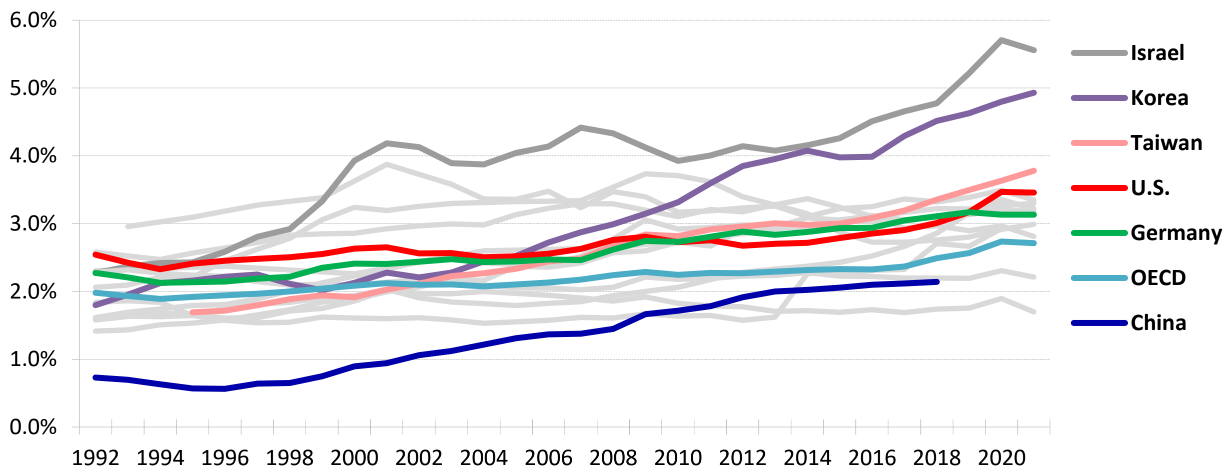
Figure 2.2: World R&D by Country / Region
(millions of constant dollars adjusted for purchasing power parity)



Source: OECD Main S&T Indicators, April 2023 | AAAS

Figure 2.3 National R&D Intensity

Gross R&D investment as a percent of GDP



Source: OECD Main S&T Indicators, April 2023 | AAAS

those dollars account for a much larger share of their respective economies, indicating stronger relative focus on science and innovation.

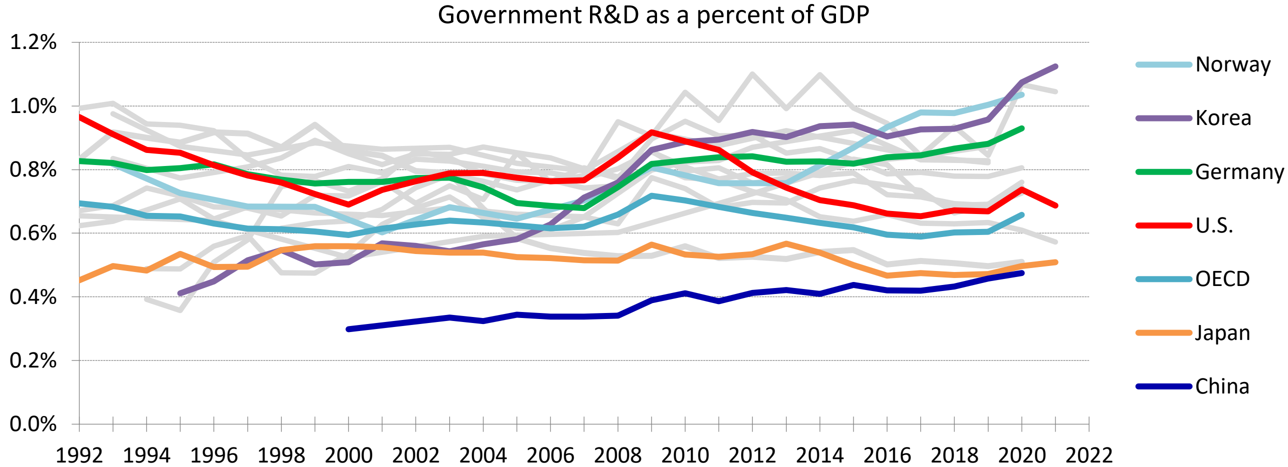
The U.S. is now climbing its way back up the rankings after dropping out of the top 5 in the mid-1990s. As of 2021, the U.S. is 4th in R&D intensity. Israel, Korea, and Taiwan remain at the top, while the U.S. crept back ahead of Germany in 2019, and more recently outpaced Japan and Sweden (Figure 2.3). China was expected to continue its dramatic rise upwards, with a goal towards 3% of GDP, but it remains to be seen if it has been reached.

Public and Private R&D Intensity. Not every economy portions out its research the same way, with some countries favoring government or private sector investments in R&D.

Focusing first on public R&D intensity in Figure 2.4, the U.S. has fallen in the leadership ranks since the 1990s, placing 13th as of 2019, the last year all countries reported data. The U.S. federal contribution only increased marginally from that

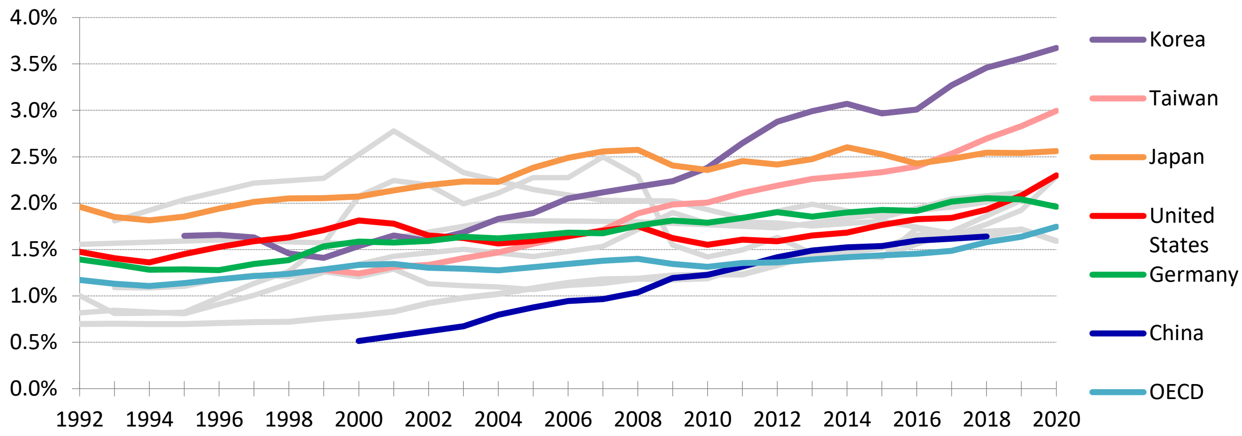
Figure 2.4 Public R&D Intensity

Government R&D as a percent of GDP



Source: OECD Main S&T Indicators, April 2023 | AAAS

Figure 2.5 Private R&D Intensity
Business-funded R&D as a percent of GDP



Source: OECD Main S&T Indicators, April 2023 | AAAS

value through 2021, so an even lower ranking could be expected.

The U.S. decline appears to be a product of the extended federal R&D slowdown after the financial crisis and the enactment of the Budget Control Act of 2011,[4] though federal R&D spiked in 2020 in response to COVID-19 before normalizing again in 2021.

Global leaders in this category include Norway, Korea, Germany, and Switzerland who overtook Austria for 4th place in 2019. In 2020 Korea increased its federal investments in R&D significantly, likely as a result of the pandemic, but its increases continued through 2021, and it will likely rank in first place once the rest of the world reports their figures as well.

Most countries that have so far reported values saw an increase in public funding during 2020, though those that have reported values for 2021 are split nearly 50-50 and now rank between Korea's continued increase and the U.S.'s return to normal spending.

While the pandemic creates a sharp rise in public R&D spending, that did not negate increases in private spending in more countries. Figure 2.5 shows that even through the beginning of the pandemic, private funding continued to rise in most cases, excluding Japan whose private R&D ecosystem has been plateauing for some time, and Germany, which saw a decrease.

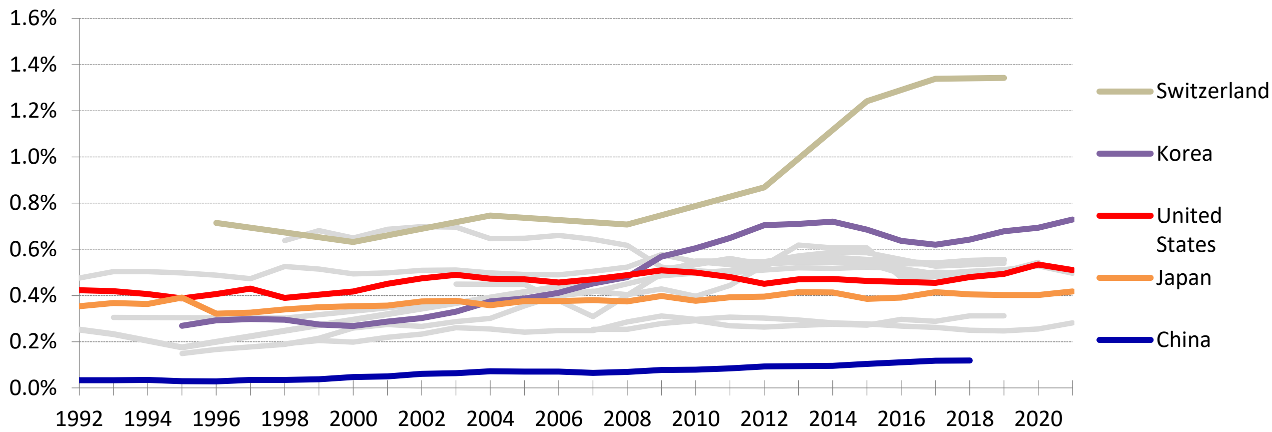
Many of the countries that are seeing private R&D funding increases are doing so through tax reforms that attract innovation-heavy industries, Korea expensing tax benefits in 2016, or through foreign direct investments as is the case of Taiwan.

The U.S. is now 4th in private R&D intensity in 2020, jumping up one spot since the previous year. The U.S. is also poised to continue this increase with the passage of several bills in 2022, most notably the Inflation Reduction Act, which contain tax incentives for private R&D efforts.

Basic Science Intensity. In the same way that different economies feature differing mixes of funding sources, they can also exhibit a tendency toward short-term investment by focusing on development spending or longer-term investment through basic science. Basic science is inherently uncertain with unpredictable results, and the gap between initial investment and economic impact can amount to several years, if ever.[5] The tangible benefits from knowledge gains can also be difficult for individual investors to recoup due to knowledge spillovers. Yet the knowledge generated from basic science can also open the door to new commercial capabilities

Figure 2.6: Basic Research Intensity

Reported basic research as a percent of GDP



Source: OECD Main S&T Indicators, April 2023 | AAAS

that are unavailable to short-term R&D funders, with social returns far larger than private returns. For this reason, basic science has historically been more closely associated with public investment, while industrial R&D has historically focused more on applied science and development.

In 2019, the last year with full data available, the U.S. ranked 10th in the world in basic science intensity, and that ranking has likely not changed for 2020. This leaves the U.S. behind Switzerland, the global leader in basic research, Korea, the United Kingdom, and Denmark, as well as several others.

Switzerland's status is not at risk quite yet, but its basic research funding has been plateauing for some time. This has been suggested to be because Switzerland's R&D ecosystem is dominated by the pharmaceutical industry, where advances in preclinical research have made the process cheaper[6].

3. Research Workforce: Small Economies Surge Forward

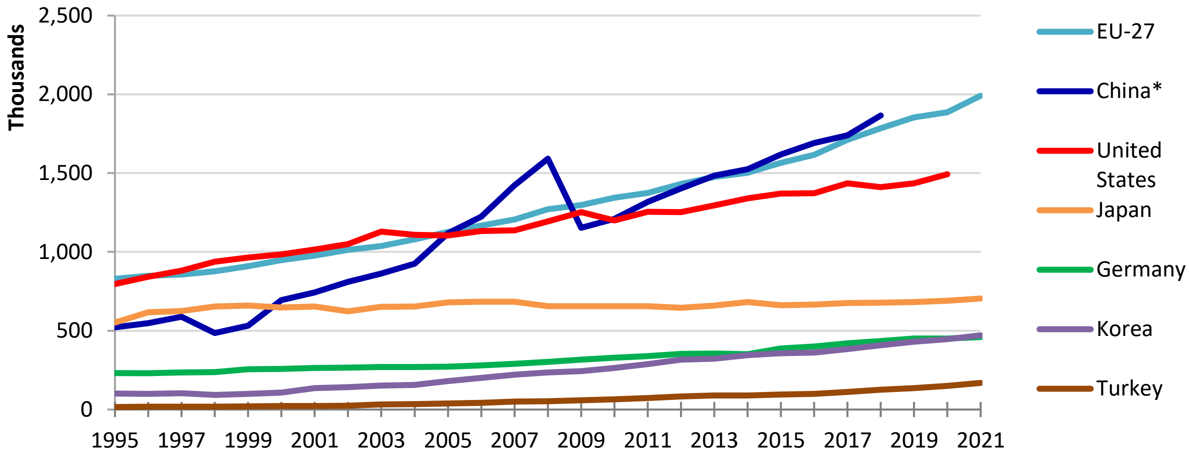
An innovative economy requires not just investment in R&D, but a workforce capable of performing that R&D and exploiting the knowledge produced by it.

In 2013, China had overtaken the EU as the largest generator of researchers in the world, as seen in Figure 3.1, and was poised to make the gap even greater in 2019, but the redaction of the data leaves its success in that endeavor under question. Instead, we saw most countries continue to have moderate increases in their training of researchers, except for Japan who seems to have plateaued.

Turkey is included as well due to a sharp increase in its reported researcher count, in part due to new incentives to reverse brain drain that were launched in 2018.[7]

In terms of researchers as a portion of the labor force, Korea dominates the graph in Figure 3.2, with its long-term concerted effort to increase its scientific enterprise. Their latest workforce initiative is BrainKorea21 Four, a program that aims to revitalize graduate education in a country where over 80% of the R&D is performed by individuals at major companies (see Figure 3.3) Japan, facing a similar problem with dwindling interest in academia by younger researchers, set

Figure 3.1: Total Researchers (FTE) per Region



*Headcount methodology updated in 2009.
Source: OECD S&T Indicators, April 2022 | AAAS

out a goal to establish a major fund for university research.[8]

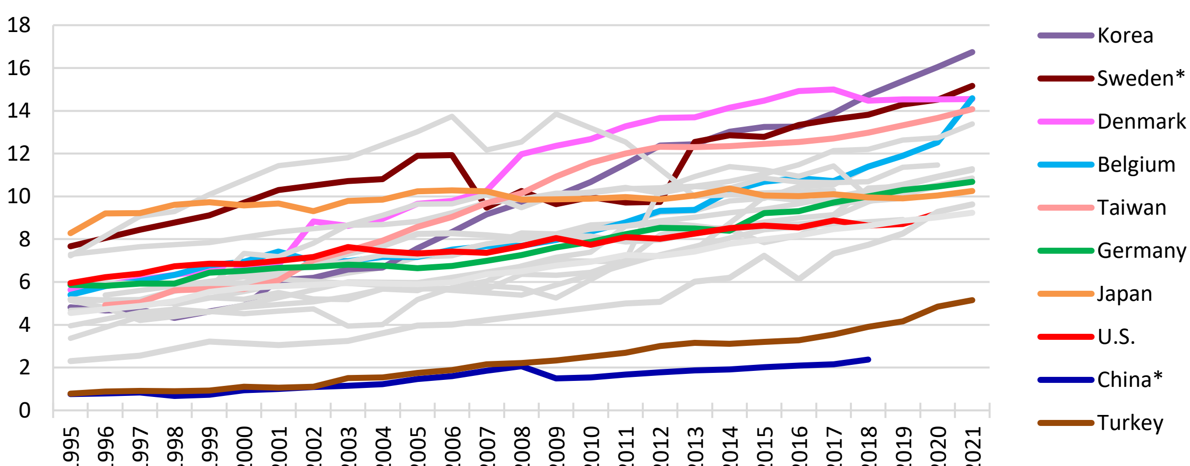
Sweden, Denmark, and a stunning surge by Belgium are the next highest proportion of researchers per population, Belgium's rise is due in part to a series of tax reforms aimed at incentivizing innovation in the country.

Turkey is once again visible at the bottom of Figure 3.2, surging upwards primarily through increases in the business sector which saw a 16% increase in researcher counts for 2019-2020 and 2020-2021.

The U.S. has increased to approximately 10 researchers per thousand in 2020, the figures for 2021 not yet available. This puts the U.S. at 18th in the world in terms of researchers per thousand.

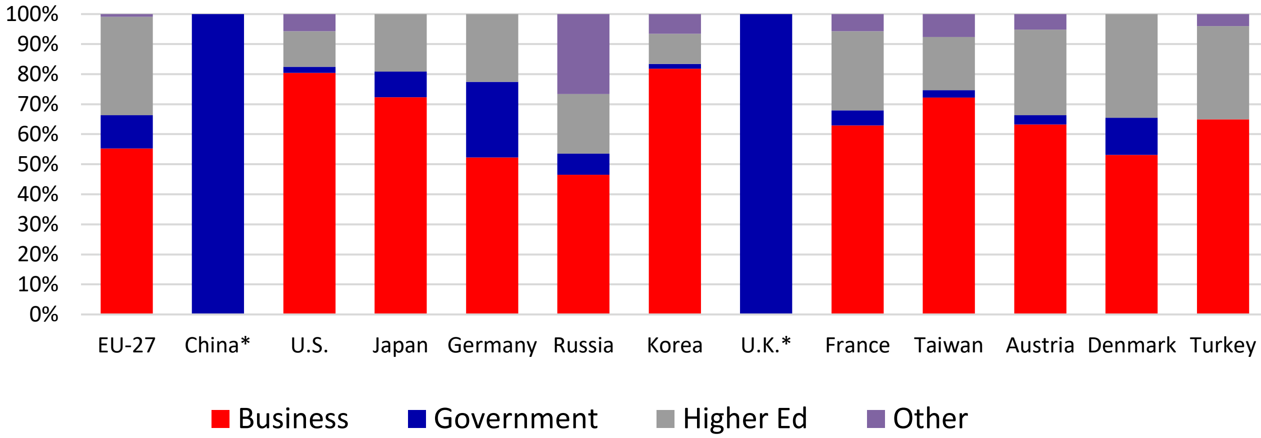
The U.S. also continues to be one of the countries with the most researchers operating within the

Figure 3.2: Researchers per 1,000 in the Labor Force



*Includes changes in researcher headcount methodology in prior years.
Source: OECD Main S&T Indicators, April 2023 | AAAS

Figure 3.3: Researchers by Sector
Calculated from 2020 FTE Equivalents



* - China and the UK only reported government researcher numbers for 2020
Source: OECD Main S&T Indicators, April 2023 | AAAS

business sector with 80% of researcher full time employees allocated there.

Germany has the highest proportion of government researchers, however, as increasing researchers at federal institutions is a continuing priority under the new Prime Minister. Europe at large is also proportionally higher in researchers located in higher education institutions. This is despite several years of attempts at creating a robust innovation ecosystem in Europe that has met several challenges, including varied innovation capacities of member states and bridging siloed university and industry partners[9]. Despite the initial challenges, the policies continue to be implemented[10] and more researchers were proportionally added recently to the business sector than any other in 2021.

These distinctions are important when one considers the roles that each sector typically plays in the innovation lifecycle. For instance, while government and higher education researchers have historically partaken in a varied research portfolio including basic and applied research and development, business researchers tend to stay closer to developmental work, though there has been a recent increase in industrial basic science, as mentioned earlier. The sector mix might also suggest varying national capacity to generate new breakthroughs, to share and disseminate knowledge through norms of open science, or to translate new discoveries into societal application via commercial products, clinical treatments, and the like.

4. Scientific Publications: U.S. Remains Dominant in Life Sciences, Surpassed in Physical Sciences

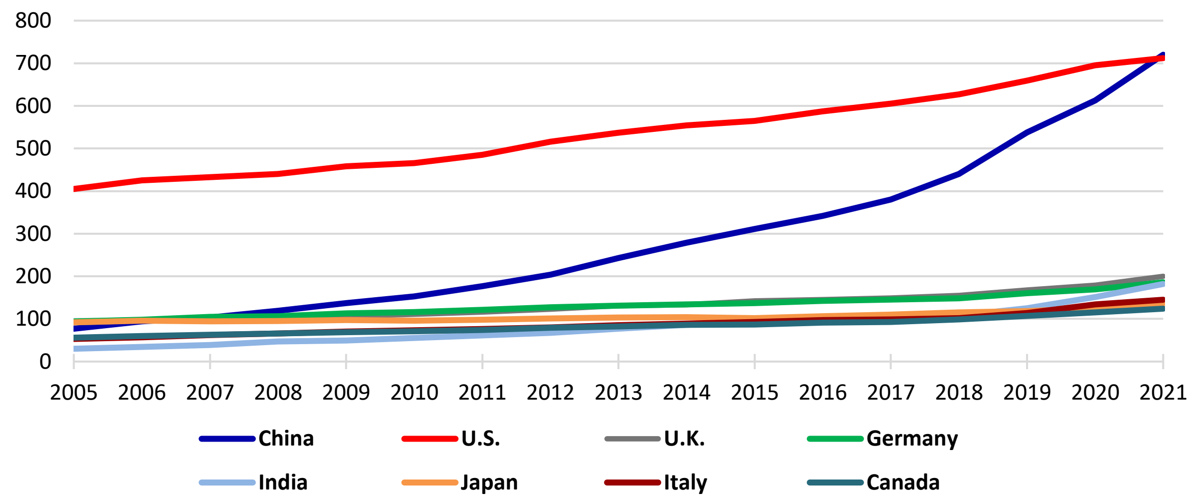
One common measure of scientific output and performance is the publication of original peer-reviewed research articles in scientific journals. Such articles are the most common form of sharing new theories or experimental discoveries.

Total Publications. Figure 4.1 shows total publications by country, as pulled from the Web of Science (WoS) core collection. While the WoS database does include social sciences and arts and humanities work, those comprise about 8% of the whole dataset, with science and engineering publications taking up the remaining 92%.

China's publication output has been increasing sharply, more than quadruppling in the last decade and surpassing the U.S. publication output in 2021. This is in part due to steep jumps in output during the course of the pandemic, 14%

Figure 4.1: Total Publications

Top 8 as of 2021, total articles in thousands



Source: Web of Science, April 2023. | AAAS

and 17% in 2020 and 2021 respectively, while the U.S. maintained a steady publication rate.

The U.K. comes in third place, though barely edging out Germany and the rest of the pack. India continues to punch above its weight, ranking 5th and in the middle of a group of developed nations that have strong economies and established research ecosystems.

Influential Publications. Publications do not write themselves, and highly cited work is tied to influencial researchers in their fields. Every year Clarivate identifies the 0.1% most cited researchers in their fields.[11]

Despite being surpassed in terms of raw publications, the 2022 list of highly cited researchers still had the largest number of highly cited researchers from the U.S., with 2764 researchers, or 38.3% of the list. This is, however, a decrease in the number of highly cited researchers from the U.S. over the last few years. China came in second with 1169 researchers, followed by the U.K. with 579.

Institutions are also ranked in this report, with 3 American institutions, Havard, Stanford, and the National Institutes of Health, ranking in the top 5. Harvard, with 233 highly cited researchers, has been the top institution for some time now. Second in the ranking is the Chinese Academy of Sciences with 228 highly cited researchers.

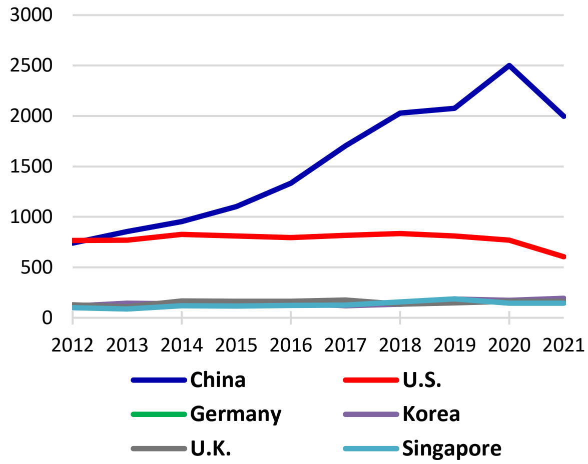
Field Specialization. Not every country tries to dominate each field of science, and a breakdown of a representative physical science (chemistry), formal (math) and life science (biology) shows that the U.S. is dominant in the latter, and decreasing in prominance in the others.

To demonstrated this, highly cited publications, that the top 1% of publications in the field, are used to demonstrate production of the most impactul work.

Publication in chemistry, Figure 4.2, are trending downward in the U.S., and while China's dominance in publishing novel work in this field is not at risk, it is also declining. It is worth noting that the field-specific data was accessed in April of the previous year, so there might be some fuzziness to the 2021 numbers.

Figure 4.2: Highly-Cited Chemistry Publications

Global top 6 by publication year

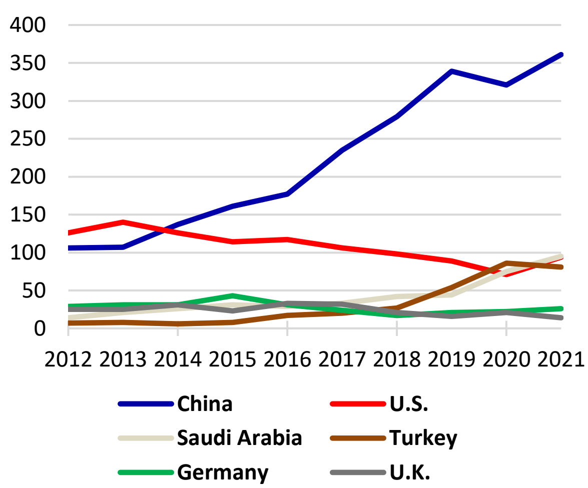


Based on Web of Science data, accessed April 2023| AAAS

Mathematics, Figure 4.3, is looking much the same, with a strong dominance by China but a potential decline in highly-cited publications. Interestingly, the U.S. ranks 3rd in the global pack, with several other nations closing in that could push it lower.

Figure 4.3: Highly-Cited Mathematics Publications

Global top 6 by publication year

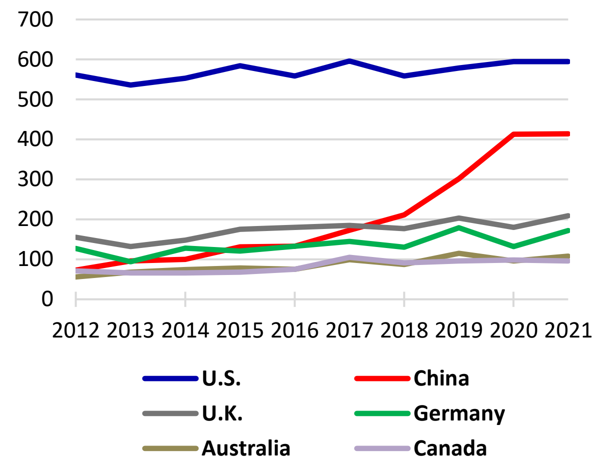


Based on Web of Science data, accessed April 2023 | AAAS

In the life sciences, a representative of which is shown in Figure 4.4, the U.S. still dominates, with an increase in highly-cited publications continuing through the pandemic. China has been increasing dramatially though, as it has in nearly every field, so the U.S. monopoly in this field of research is not assured in the future.

Figure 4.4: Highly-Cited Biological Sciences Publications

Top 6, total articles



Based on Web of Science data, accessed April 2023 | AAAS

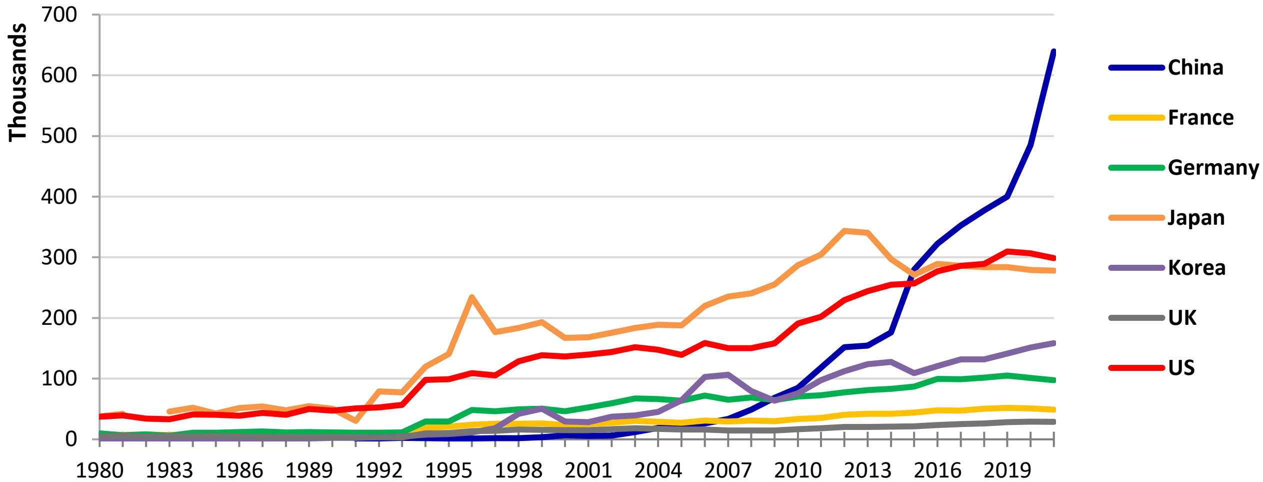
5. Patenting: China Rises to the Top in Total Patent Applications

After the announcement of novel research to the world through publication comes the implementation step, best monitored through patents. Just like publications, patents are not a flawless metric – not every patent results in products – but it is the closest one can get to tracking the implementation of innovations.

The data presented in this section is pulled from the World Intellectual Property Organization (WIPO) dataset of Patent Cooperation Treaty (PCT) approved patents. This is a special class of patents that are filed once and can be applied to all 150 nation states of the treaty, enacting patent protections internationally.

The most recent PCT patent data runs through 2021, as shown in Figure 5.1. Since 2015, China has been outperforming other countries in terms of total PCT patents granted, coinciding with a decrease in patent output by Japan, the previous world leader in patent submissions. In 2019, the U.S. recaptured its spot in second place,

Figure 5.1: Total Patent Grants by Origin



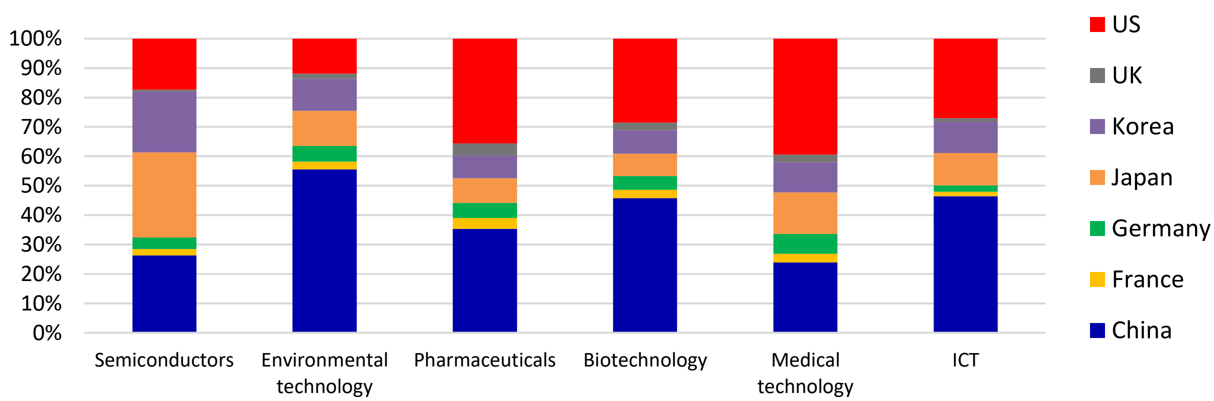
Refers to total patent applications to the Patent Cooperation Treaty system.
Source: WIPO IP Statistics Data Center, 2023| AAAS

managing to generate slightly more patents than Japan's flatlining rate.

The R&D topics these countries submit patents in are not all the same, with certain countries specializing in different patent fields. Figure 5.2 highlights the relative submissions for the highlighted countries in each field. ICT, or Information and Communication Technologies, is represented here as an aggregate of several WIPO fields: 3- telecommunications, 4- digital communications, 5- basic communication processes, 6- computer technology, and 7- IT methods for management. All other topics listed are a single, self-named, WIPO patent field.

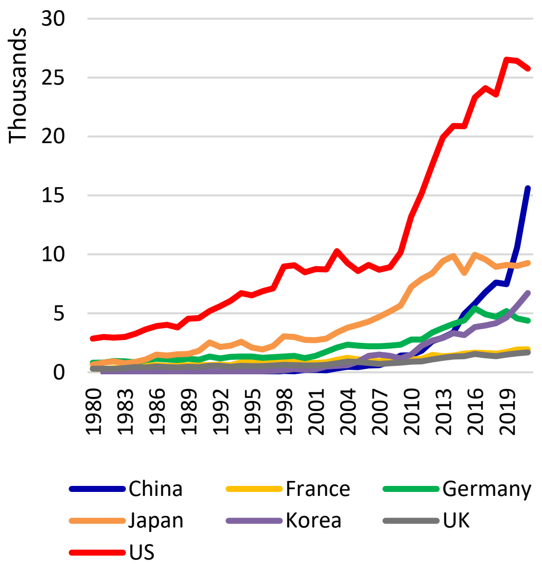
The dataset covers the first two years of the pandemic, and as such one can observe some trends in relevant fields. Figure, 5.3 demonstrates the total number of patents granted in the medical technology field, which saw a sudden spike in patenting for both China and Korea as the pandemic unfurled. Interestingly, the U.S. saw a decrease in patenting throughout the pandemic, though it did not lose its overall dominance in the Medical Technology field because of it.

Figure 5.2: Total Patents by Topic
based on 2021 data



Refers to total patent applications to the Patent Cooperation Treaty system.
Source: WIPO IP Statistics Data Center, 2023 | AAAS

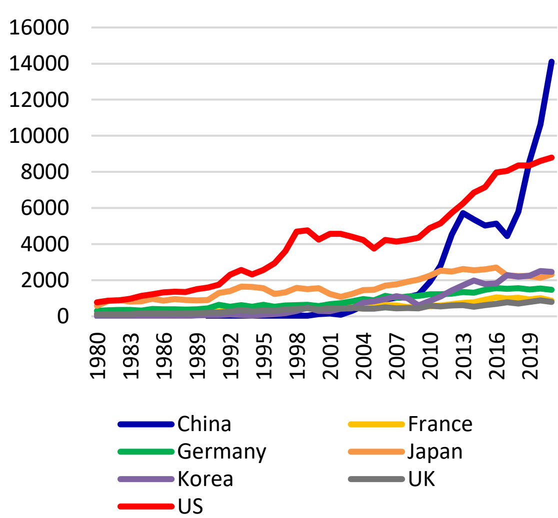
Figure 5.3: Total Medical Technology Patents



Refers to total patent applications to the Patent Cooperation Treaty system.
Source: WIPO IP Statistics Data Center, 2023| AAAS

Biotechnology patents, shown in Figure 5.4, did not have a new spike, with patents keeping previously established trend of sharp increases throughout the pandemic.

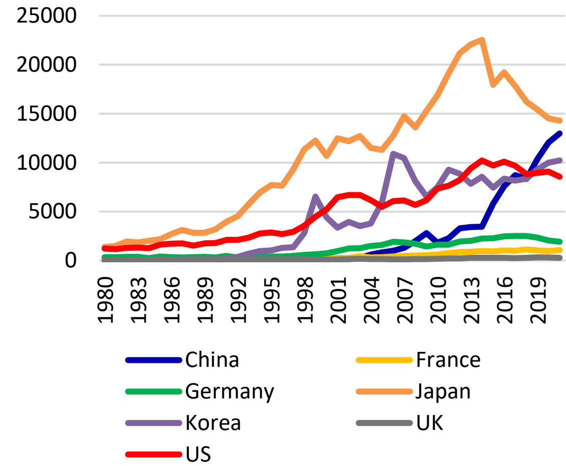
Figure 5.4: Total Biotech Patents



Refers to total patent applications to the Patent Cooperation Treaty system.
Source: WIPO IP Statistics Data Center, 2023| AAAS

Moving away from the biomed space, China is very close to overcoming Japan in semiconductor patents, as can be seen in Figure 5.5.

Figure 5.5: Total Semiconductor Patents



Refers to total patent applications to the Patent Cooperation Treaty system.
Source: WIPO IP Statistics Data Center, 2023| AAAS

6. Conclusion

The U.S. continues to remain dominant in terms of expenditure, but the auditing of Chinese figures allows for a risk that the dominance is not as assured as one might think. In all other metrics, the production of researchers, publications, and patents, the U.S. has fallen to second or third place.

When adjusting for scale, the U.S. is even worse off, currently 4th in R&D intensity in 2021, 10th in basic science intensity in 2019 (the last complete dataset), and 14th in researchers relative to the overall labor force in 2020. Two of those values are improvements over prior years – climbing up from 6th in R&D intensity in 2020 and 17th in researchers relative to the labor force in 2019.

Other countries are not standing still. While China's funding number are not known, the country surpassed the U.S. in total publications this year, and continue to increase the speed at which it receives patents in multiple fields. Other economies continue to invest as well, with Korea, Taiwan, and others achieving high rankings in R&D and researcher intensity.

Ultimately, the U.S. is not in a poor position – far from it. But if U.S. science and technology leadership is to be maintained, policymakers must take a proactive approach to investment policy.

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[1] Main Science and Technology Indicators. (2023, April). OECD. https://www.oecd.org/sti/msti.htm

[2] "OECD Main Science and Technology Indicators. R&D Highlights in the March 2022 Publication", OECD Directorate for Science, Technology and Innovation. http://www.oecd.org/sti/msti2022.pdf

[3] "Science, Technology and Innovation outlooks 2023", OECD https://www.oecd.org/sti/science-technology-innovation-outlook/

[4] Hourihan, M. (2021, January 19). "The Budget Control Act May Have Cost Over $200 Billion in Federal R&D." American Association for the Advancement of Science. https://www.aaas.org/news/budget-control-act-may-have-cost-over-200-billion-federal-rd

[5] For instance, Ahmadpoor and Jones (2017) found that the impact lag can reach two decades for more abstract fields of knowledge like pure mathematics. See Ahmadpoor, M., & Jones, B. F. (2017). The dual frontier: Patented inventions and prior scientific advance. *Science*, *357*(6351), 583–587. https://doi.org/10.1126/science.aam9527

[6] "Research and Development (RD) in the Business Enterprise Sector", Federal Statistical Office, Swiss Confederation. https://www.bfs.admin.ch/news/en/2022-0526

[7] (2021, March 17) "Turkey seeks to reverse brain drain with generous research grants." Daily Sabah https://www.dailysabah.com/turkey/education/turkey-seeks-to-reverse-brain-drain-with-generous-research-grants

[8] Kajimoto, T. (2021, November 8). "Japan unveils $88 bln university fund in growth strategy." Reuters. https://www.reuters.com/world/asia-pacific/japan-panel-urges-govt-launch-88-bln-university-fund-2021-11-08/

[9] Benedetti Fasil, C. et all (2017, November) "JRC Science for Policy Report: Current challenges fostering the European innovation system" European Commission https://publications.jrc.ec.europa.eu/repository/bitstream/JRC108368/jrc108368_current_challenges_in_fostering_the_european_innovation_ecosystem_final.pdf

[10] "Innovation Policy" Fact Sheets for the European Union. https://www.europarl.europa.eu/factsheets/en/sheet/67/innovation-policy

[11] Price, G. (2022, November 15) "Clarivate Releases Highly Cited Researchers 2022 List" Info Docket https://www.infodocket.com/2022/11/15/clarivate-releases-highly-cited-researchers-2022-list/