Science Without Borders?

Waxing and Waning Integration in Global Scientific Research and Innovation

Preliminary Draft for Discussion

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> *"The best way to send information is to wrap it up in a person."* (J. Robert Oppenheimer)
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> *"The great scientific challenges transcend national frontiers and national prejudices. In a sense, this has always been true, for the language of science has always been universal, and perhaps scientists have been the most international of all professions in their outlook. But the contemporary revolution in transport and communications has dramatically contributed to the internationalization of science. And one consequence has been the increase in organized international cooperation."*(John F. Kennedy, Address to the National Academy of Sciences, October 22, 1963).

I. Introduction

Science has become more internationally integrated in recent decades, with increases in the rate of cross-country collaboration and flows of international students and scholars. Data from the National Science Board shows that the share of scientific publications with authors from more than one country has increased as international collaborations have expanded (see Figure 1). International knowledge diffusion as measured by citations by authors in one country to publications by authors with addresses in another country has also grown (National Science Board, 2021). Whether as a cause or consequence of this growth in collaboration, flows of international students and scholars have increased in many host countries, although the COVID crisis interrupted this trend (Figure 2).

Part of the explanation for these broad trends reflects improvements in the scientific capabilities of key countries. In recent decades, the United States has been the central node in the global network of scientific collaboration, citation and mobility (e.g. Agarwal et al 2023; Gomez, Herman and Parigi, 2022). However, there are signs that this has begun to change. In 2016, China overtook the US in number of scientific publications. In 2023, China topped the Nature Index country ranking and India was among the top 10 for the first time while Russia declined in the ranking (Woolston 2023). Meanwhile, the US's and EU's share of articles among the top 1% most-cited journal articles has begun to decline, while China's and India's has increased (National Science Board, 2023).

Do these trends reflect a rising tide that lifts all boats, with greater global integration of scientific research as large countries like China and India become increasingly strong in domestic science production? Or are there indications that key players are turning away from greater integration?

Recent disruptions, including the COVID-19 pandemic, national security–driven restrictions, geopolitical conflicts such as Russia's invasion of Ukraine, and increasingly restrictive immigration policies in the United States, suggest that countervailing forces may be pushing science toward fragmentation rather than integration. The COVID-19 pandemic introduced new barriers to mobility and collaboration, temporarily reducing international student flows and sharply curtailing in-person scientific exchange. At the same time, national security concerns have become a prominent driver of science policy, with governments increasingly seeking to exert control over the direction of research and technology development rather than promoting global diffusion (Chatterji and Murray 2025). Meanwhile, there are a growing number of armed conflicts, including Russia's invasion of Ukraine and ongoing instability in the Middle East, which have disrupted international partnerships. In the United States, restrictive immigration measures may have further reinforced this shift. Under the first and current Trump administration, such policies appear to have contributed to declining mobility and potentially international collaborations.

These shocks may help explain why the growth in scientific collaborations documented in Figure 1 gave way to a decline in the share of China's internationally coauthored publications after 2019. However, China is not the only country with relatively low rates of international collaboration. Figure 3 shows that in 2023, only 24% of Indian and 25% of Russian publications involve an international collaborator. Meanwhile, a growing share of Russia's international papers are with coauthors from China and India, while the share with a US or German authors have fallen (Van Noorden 2023). And the rates at which Indian scientists cite international articles are relatively low (except, interestingly, for articles by Iranian scientists, who also disproportionately cite Indian articles) (Table 1).

This tension between integration and decoupling poses critical questions. Will global science continue to integrate, or are we entering a new period of fragmentation? What would such a shift mean for the direction of research, the pace of innovation, and the distribution of scientific capacity across countries? And what lessons can be drawn from earlier cycles of openness and closure to help us interpret today's developments? Historical evidence shows that major conflicts, including both World War I and World War II, reshaped scientific communities and disrupted knowledge flows (e.g. Iaria et al. 2018), suggesting that today's instability could once again counteract the trend toward greater scientific integration.

If we are indeed seeing a decline in scientific integration, what are the implications for global scientific production, future economic growth and improvements in human health and well-being? What is the role of recent military conflicts, such as the war in Ukraine and in the Middle East, in these trends? What do historical studies of prior periods of integration or protectionism, such as the periods before and after the World Wars and the Cold War, suggest about the likely implications of current trends?

In this chapter, we address these questions in four parts. Section II examines the forces promoting greater international integration of science, including the mobility of students and scholars, exchange programs and funding mechanisms, and the rise of large-scale, collaborative science. Section III turns to the countervailing forces driving decoupling, including national security concerns to geopolitical concerns to restrictive immigration policies. Section IV draws lessons from historical episodes of integration and isolation, from the scientific boycotts of World War I to the post-Cold War reintegration of Soviet science. Finally, we highlight key open questions and directions for future research on the evolving international landscape of science.

II. Factors Shaping international integration of science

The past half-century has seen remarkable growth in the international integration of science. In this section, we discuss how scholar and student mobility, fellowship programs, and large-scale collaborations have created channels through for collaboration and knowledge diffusion.

A. Growth of student and scholar mobility

One of the most visible forces promoting international integration in science has been the growth of student and scholar mobility. Over the past several decades, the number of international graduate students and postdoctoral researchers has expanded dramatically, with the United States, the United Kingdom, and a small set of other advanced economies serving as central destinations (see e.g. Agarwal et al 2023). The US has been the top destination for international students and scholars in the past two decades, and although still the top destination, the US share of internationally mobile students has declined steadily over time as other countries have attracted more students, and this decline accelerated sharply during the COVID pandemic in 2020. (Ganguli and Macgarvie, forthcoming).

The United States has until recently hosted ever larger numbers of international scholars, whether as postdoctoral scholars or visiting researchers (Figure 4). The number of international scholars (researchers and postdocs, not students) coming to the US rose up to a peak before the pandemic but declined sharply and has still not fully recovered. A large part of the reason for this lack of recovery is China – there has been an extreme drop in the number of scholars coming from China (Figure 5). However, the decline is not explained by China alone. Other countries show substantial declines from 2019 to 2024. These include Canada, Europe (with large declines coming from France, Germany, Spain and Italy), and Japan. This raises questions: where are these scholars going? Are they staying at home? Or are they going to other countries? Are the Europeans staying within Europe? Is this partly explained by initiatives like Marie Curie or Thousand Talents? Or are Europeans, Australians, etc. collaborating more with people from other countries?

Several studies show that international students and postdocs contribute disproportionately to scientific productivity, innovation, and entrepreneurship in their host countries. Many continue to collaborate with colleagues in their countries of origin, contributing to global knowledge flows. Evidence shows that immigration can have positive impacts on the sending country economies, or "brain gain". Khanna and Morales (2024) show that immigration policies in the US impacted growth in the IT sector in India. They show that the US H-1B program induced Indians to switch to computer science occupations and helped drive the shift in IT production from the US to India. Other research points to diaspora ties have become important channels for sustained collaboration and citation flows, which also increases home country productivity (Kerr 2008; Agrawal et al, 2011).

Recent research also highlights how migration opportunities for highly talented youth from developing countries can significantly enhance global science. Agarwal et al. (2023) show that medalists from the International Mathematical Olympiad who migrate to the United States are up to six times more productive than equally talented peers who remain at home, suggesting that easing barriers to migration can substantially increase global scientific output.

Host-country demand for international students and scientists can be driven by productivity impacts or spillovers from immigrants. Prior work on productivity effects includes Stuen et al. (2012) which uses enrollment shocks to identify the impact of increases in foreign graduate students on the rate of production of scientific articles by US university departments. Stuen et al. (2012) find that enrolling an additional an additional international student increases productivity, but by an amount similar to the benefit of enrolling an additional domestic student. Gaule and Piacentini (2013) point to the selection effect where the "best and the brightest" may be coming to the US. They show that Chinese doctoral students in 161 US Chemistry departments are approximately 22-44% more productive in research publications than native students during the PhD. Although this group of students is highly selected, this raises questions about the impacts of declining enrolments of Chinese students in the US.

Anelli, Shih, and Williams (2017) suggest that high concentrations of international students enrolled in some majors may lead domestic students to pursue studies in other areas, but Shih (2017) finds that increases in enrollment of international students, and the higher tuition paid by these students, help subsidize enrollments of domestic students in graduate programs. Bound et al. (2021) also document that, as the number of international students at US universities has grown, they have come to play a critical role in the financing of US STEM graduate education.

International students who remain in the host country may also affect the productivity and innovation performance of local businesses. Hunt and Gauthier-Loiselle (2010) find that, at the US state level, a one percentage point increase in the share of immigrant college graduates leads to an increase in the per capita rate of patenting by 9-18% (instrumenting the number of immigrants with the share of non-college educated immigrants from related countries in a state), They show that this is largely because immigrants' disproportionately holding degrees in science and engineering fields. Winters (2014) analyzes the relationship between the number of patents per capita in a metropolitan standardized area (MSA) and the stock of both native and foreign STEM graduates in the MSA as a share of total population in the MSA. Winters (2014) finds a positive and significant relationship for both, with slightly larger effects of increases in the number of native STEM graduates (though this difference is not statistically significant after instrumenting in a two-stage least squares model).

From outside of the US, there is evidence from Crown et al. (2020), who examines the 2013 change in Australia's immigration policy (the Temporary Graduate program) which allowed graduates of Australian universities to remain in the country after graduation for 18 months to 4 years. Using an instrumental variables approach that draws on variation in the location of Temporary Graduate visa holders and shows it is correlated with the lagged settlement patterns of previous immigrants in 1966, they find a positive relationship between the number of Temporary Graduate visas awarded in a particular region and the number of patent applications per capita in that region.

B. Funding and programs for cross-border mobility

Another key factor that has contributed to increased scientific integration in recent decades has been international funding and programs for collaboration and mobility. A number of studies have looked at how programs that fund international exchange and mobility affect knowledge production, collaboration and diffusion.

The U.S. Fulbright Program, created in 1961, is the flagship international academic exchange program sponsored by the US government and is designed to foster mutual understanding. Kahn and MacGarvie (2012, 2016a and 2016b) study Foreign Fulbright Fellowship recipients who came to the US on a special visa that requires return to the home country, with the goal of understanding how international mobility affects scientists' productivity, collaboration and citation patterns. Kahn and MacGarvie find that STEM PhDs who are required to return to high-income home countries are not less productive than otherwise similar peers who remained in the US. However, those who moved to a country at 50th percentile of GDP per capita subsequently produced 44% fewer publications and citations. Fulbright fellows have 57% more collaborations with researchers in their home countries. On a per article basis Fulbright scientists from "low-science" countries are cited 152% more per article at home than are controls from comparable low-science countries. Fulbrights from “high-science” countries are not cited significantly more often at home. The larger effect for low-income countries stems from the bigger impact of return requirements in these countries, while high-science countries may not need return requirements to induce return. The implication is that mobility to high-income countries can increase collaboration with no impact on productivity, but mobility-induced knowledge sharing with low-income countries comes with a tradeoff.

Other research has captured the impact of mobility not on the mobile scientists themselves, but on their peers. Fry (2022) studies the impact of the mobility of scientists funded by the National Institutes of Health Fogarty AIDS training and research program, which funds American researchers who collaborate and train African scientists who mostly return home after receiving training in the US. Fry (2022) finds that nonmigrants who are not already connected to scientists in top global institutions substantially increase research output when a Fogarty returnee joins their institution, and Fry and Ganguli (2024) further show that those non-migrants working on HIV topics receive more grant funding and publish more HIV and WHO policy documents, suggesting broader impacts of mobility on research productivity.

Perhaps intuiting these broader impacts, several countries have introduced programs designed to attract top scientists to move or return to the country. Recent papers have assessed the impacts of these programs. With a focus on the individual returnee researcher, Shi, Liu, and Wang (2022) study China’s Young Ten Thousand Talents program, which provided substantial financial incentives and start-up research funding to attract top early-career scientists to move to China (almost all scientists of Chinese origin). Examining their publication output, Shi et al. find that Thousand Talents returnees become more productive after their return to China when compared to peers who remain abroad, and that the effect appears to be due to increased access to funding and the ability to assemble larger research teams. Ash, Cai, Draca and Liu (2022) study a similar question and also find that returnees experience a large increase in productivity that offsets an initial drop (for a neutral total effect). Ash et al. also find the returnees engage in more collaboration with Chinese researchers (mostly junior researchers), while incumbent researchers see a slight decline in productivity (perhaps due to a competition effect). Focusing (like Fry 2022) on peers, Ganguli and Wang (2022), find a positive impact of Thousand Talents returnees on incumbents at lower-ranked universities, but no effect at elite schools, and a decline in international collaboration at elite schools.

Additional work on funding used to attract scientists in higher-income countries includes McHale et al (2022), which studies star scientist attraction programs in Denmark, Ireland and New Zealand. The paper finds that the arrival of a star scientist increases output of other scientists in the receiving department by 12-25% percent, with larger increases for incumbents who co-author with the star. However, there is heterogeneity in effects across countries, with most of the result driven by Denmark. Courty and Sim (2015) evaluate the Canada Research Chairs program, the main policy used by Canada to attract and retain exceptional researchers. Courty and Sim find no impact of being nominated for a Canada Research Chair on the retention of scientists.

The challenge of this type of research is identifying control scientists who are as similar as possible to the returning scientists except in their decision to return to the home country. As this decision is likely to be correlated in many unobservable ways with future scientific productivity in the receiving country, it is a challenging problem. Two recent papers that attempt to circumvent this problem evaluate European Union's Marie Skłodowska Curie Actions Individual Fellowships (MSCA-IF) using regression discontinuity designs. Quasi-experimental methods such as regression discontinuity may help with disentangling causality in a narrow range around the score cutoff but may not measure the full impact of funding (e.g. Jacob and Lefgren 2011 or Ghirelli et al. 2023)

Baruffaldi et al. (2025) make use of data on applicants, awardees and proposal scores from European Commission's COmmon Research DAta Warehouse (CORDA) matched to Scopus and find that the fellowship recipients are indeed more mobile than applicants. Fellowship recipients do not produce more publications on average than unsuccessful applicants near the funding cutoff, nor are their publications higher impact or written with more coauthors. However, there are larger differences for recipients of fellowships used to travel longer distances, where those who travel outside Europe do see an increase in productivity on average.

Another paper that uses a similar dataset (although the bibliometric data come from OpenAlex rather than Scopus) and methodology, but is focused on a different question, is Yildiz et al. (2025). The authors of this paper create a variable that captures whether an author writes on a new topic, that is publishes a paper where at least 3 out of 4 of the topics are different from the focus of prior research, and find that recipients of Marie Curie fellowships are up to 5 percentage points more likely to publish on new topics after the fellowship compared to otherwise similar applicants who just missed being awarded the fellowship.

There is a need for more research on the parameters of successful pro-mobility policies. We also need cost-benefit analysis – how much do countries benefit relative to the investment?

C. Rise of team science and large-scale, capital-intensive research

Another factor that has contributed to the growth of international collaboration and citations is the rise of team science and the increasing reliance on large-scale, capital-intensive research infrastructures. Over the past several decades, science has shifted away solo authors toward collaboration in teams. Wuchty, Jones, and Uzzi (2007) show that across almost all fields, from the natural sciences to the social sciences, research is increasingly done in teams. These papers are more frequently cited and more likely to be high-impact than research conducted by individuals.

This rise in collaborations appear to be particularly pronounced in areas that require costly and complex facilities. Particle physics at CERN, genomics initiatives like the Human Genome Project, and climate science consortia rely on shared instruments, data, and expertise that no single country or institution could manage alone. Freeman, Ganguli, and Murciano-Goroff (2015) examine international and U.S. papers among U.S. authors in 3 fields: particle physics, nanotechnology and biotechnology. They show that by 2010, almost half of the papers of US authors in particle physics were coauthored with international teams, while the majority in nanotech and biotech papers were U.S. only teams. They point to the importance of particle accelerators and other equipment that are available at only some sites in explaining the higher share of international papers in particle physics.

A similar situation exists for space exploration. While the space race symbolized geopolitical rivalry, spaceflight accomplishments were regarded not only as scientific milestones but also as demonstrations of the technological strength underpinning national security. In more recent decades, projects like the International Space Station, launched in 1993, illustrate how countries can become partners in science when the scale of investment and knowledge required is too great to tackle independently. Looking ahead, projects such as deep-space exploration, fusion energy, and large-scale artificial intelligence research are likely to further point towards larger, more international teams.

Another example is U.S. restrictions on federal funding for human embryonic stem cell (hESC) research introduced in 2001. Furman et al (2012) show that while U.S. production of hESC research initially declined by 35–40%, the decline dissipated after 2003, in part due to researchers at elite institutions and also by U.S. scientists collaborating with international partners. This shows when faced with a domestic shock to research production, international collaboration as a way to sustain research agendas.

The COVID-19 pandemic may also have been expected to increase international collaboration, given the rapid adoption of virtual communication tools and cross-border data-sharing. However, analysis of publication data before and after the pandemic suggests that COVID-19 research after 2020 tended to be less international, potentially because of the geopolitical tensions which we will discuss in the next section (e.g. Zammarchi et al, 2023; Cai, Fry and Wagner, 2021).

III. Factors Shaping Scientific Decoupling

While the growth of mobility, fellowships, and large-scale collaborations points toward deeper scientific integration, countervailing forces appear to be pushing in the opposite direction. Geopolitical tensions, security concerns, and national strategies for technological self-reliance may be impacting collaboration and mobility, raising the prospect of a more fragmented global research landscape. Section III examines these forces of decoupling.

A. National security and autonomy concerns

Much of the economics of science literature has focused on the positive effects of international collaboration on knowledge diffusion and productivity. However, proponents of efforts to turn US science away from China argue that the costs in terms of industrial espionage and national security concerns outweigh the benefits of collaboration and attracting China's top scientists. The title of a recent Wall Street Journal Opinion piece summarizes the argument: "Send Harvard's Chinese Students Home: It makes no sense for the U.S. to be educating the scientific and leadership class of a future adversary" (Gallagher, 2025).

Chatterji and Murray (2025) argue that governments are increasingly seeking to control critical technologies rather than encouraging diffusion globally, and that this impacts the way innovation economists approach the innovation process. When combined with a growing emphasis on strategic autonomy, the materially complex and capital-intensive nature of deep tech production, in areas such as quantum computing, fusion energy, semiconductors, and general artificial intelligence, is prompting many nations to exert greater control over the entire innovation pipeline, from basic research to full-scale deployment.

A recent example is the CHIPS and Science Act of 2022, which links U.S. national security and economic competitiveness. Among other restrictions, CHIPS funding recipients are prohibited from expanding semiconductor manufacturing capacity in certain foreign countries of concern, and must comply with export control regimes and licensing requirements that apply both to technology transfers and to investments tied to manufacturing, joint research, or licensing (CSIS 2025).

There are many challenges associated with the cost-benefit analysis involved. One is that information on industrial espionage and national security threats is not often publicly available, and even if available, it would be difficult to quantify the economic impacts. Another is that to quantify the benefits of collaboration and attracting students, we would need better measures of the economic return on investment in science more generally, which is still a work in progress (see other chapters in this volume).

However, solving one piece of this puzzle would mean quantifying the impacts of international students on the US economy. While there are estimates of the dollar amounts spent by international students on tuition and living expenses while in host countries (see Ganguli and MacGarvie forthcoming), we still lack comprehensive assessments of the net benefit to the US of training international students. Such an assessment would have to factor in any potential crowd-out of US native students from STEM fields as well as tuition benefits to US universities (which may crowd in US students via a cross-subsidization effect), productivity impacts on US-based researchers, and innovation and productivity benefits to the US from students who remain in the country after their studies.

B. U.S.-China ties

The US and China have seen remarkable growth in scientific linkages over the past 40 years. Following the disruptions of the Cultural Revolution, very few Chinese nationals traveled to the US to study, but this changed in the 1980s as China resumed diplomatic relations with the US and sought to “jump start” Chinese science by sending large numbers of students to the US to study (Bound, Turner, and Walsh 2009, p. 20). Chinese students quickly became the largest group of international students in STEM fields, representing 12% of US PhDs in Physics, and 16.6% in Biochemistry, by 1994-2003 (Bound, Turner and Walsh, p. 51). The share of Chinese students in US STEM PhD programs continued to grow. By 2022, there were 6,029 Chinese nationals graduating from US STEM PhD programs in that year (NCSES 2024, Table 7-7). Chinese and Indian students earned 51% of STEM PhDs awarded to non-residents in 2023 (NCSES 2025).

Data from the NSF Survey of Doctorate Recipients and Survey of Earned Doctorates shows that about 90% of Chinese nationals who earned STEM PhDs from U.S. universities between 2000-2015 were still residing in the U.S. as of 2017, while intention-to-stay rates in more recent graduating cohorts have generally remained above 80% in many STEM fields (Corrigan et al. 2022; Zwetsloot et al., 2020).

At the same time, China has expanded its domestic research system, increasing R&D spending tenfold adjusting for purchasing power between 2000 and 2016 (Xie and Freeman 2019), and invested heavily in the expansion of academic science the number of domestically awarded STEM PhDs, faculty members and the number of scientific articles published by authors located in China has grown substantially. Xie and Freeman (2019) estimate that Chinese authors contributed to approximately 36% of all scientific articles published worldwide in 2016 (after adjusting counts of Chinese-language articles to make them comparable to articles published in international journals indexed by Scopus). Although they acknowledge that this is probably an overestimate, Xie and Freeman argue that the magnitude of China's scientific effort implies that "[t]he way China deploys its newly developed scientific resources will help drive the direction of science and technology into the foreseeable future."

By 2020, collaboration between U.S. and Chinese scientists peaked at 47,118 joint publications, making China the U.S.'s largest scientific partner (Xie and Freeman 2023). Such collaborations have been especially productive when involving "diaspora" Chinese in the U.S. or "returnees" in China, whose papers are more highly cited and more often placed in top journals.

However, the share of articles with a Chinese author that involve a collaboration with a US author dropped starting around 2017, ultimately declining by 5.2 percentage points by 2022. An important policy affecting U.S.-China relations was the U.S. Department of Justice's China Initiative, which began in 2018 and aimed to counter economic espionage and safeguard U.S. intellectual property. Although motivated by security concerns, the program was widely criticized for disproportionately targeting ethnically Chinese researchers and for focusing on disclosure violations rather than espionage cases. Empirical evidence suggests substantial unintended consequences. Flynn et al. (2025) find that the initiative reduced the productivity of ethnically Chinese researchers in the United States by 8–11%.

In addition to the China Initiative, Xie and Freeman attribute the fall in collaborations after 2017 to the COVID pandemic, and China's emphasis on "self-reliance and strength in science and technology" (Xie and Freeman 2023, p. 15). Jia et al. (2024) show that U.S.–China collaborations fell after 2019 even as collaborations with other countries continued to increase. They also find that US researchers with a history of collaborating with Chinese scholars experience declines in productivity and total citations relative to researchers with collaborators elsewhere. Jia et al. also incorporate qualitative evidence from interviews with scientists which suggest that the effects come from a combination of reduced access to NIH funding and students and collaborators from China, as well as productivity reductions associated with pivoting to new collaborations or different topics. Aghion et al (2023) focus on Chinese researchers and find that those with a history of collaboration with US researchers see declines in citations, publications in top journals, and H-indices relative to Chinese researchers with links to European researchers. Aghion et al. also show that negative productivity effects are largest for more productive scientists and in US-dominated fields.

In addition to the decline in collaboration, Flynn et al. (2025) document a host of impacts of the China Initiative on student flows and stay rates, citations, and productivity of ethnically Chinese researchers in the US. The latter effect is particularly striking and large (an 8-11% reduction in productivity), while China-based researchers do not exhibit similar productivity declines.

One important question that these papers raise is whether changes like the China Initiative have led China to attempt to "go it alone" and become self-sufficient in scientific production, or whether China is simply shifting its collaborations to new partner countries. Some evidence on this question can be found in Aghion et al (2023), which shows that Chinese coauthors reallocate to new, non-US coauthors in response to the initiative – however it is unclear whether the new collaborations are equally likely to be outside of China. Figure 1 documents a declining rate of international collaboration in Chinese-authored articles, but it is unclear how much of this is explained by declining collaboration with the US, and how much is a rise in the share of within-

China collaborations. Wagner and Cai (2022) document a continued increase in collaborations between Chinese and European researchers as China-US collaborations declined after 2018. Xie and Freeman (2023) show that the US share of China's international collaborations fell by 15.4 percentage points between 2015 and 2022, and 10.2 percentage points of this decline was made up for by collaborations with other Western countries, and with 5.2 points attributed to collaborations with India and middle eastern countries.

More work is needed to understand the nature of these collaborations, what fields of study they represent, and whether these shifts in the direction of collaboration are early signs of shifts in the direction of knowledge and technology diffusion. This is important in part because Acemoglu et al. (2021) show that researchers in Chinese departments pivot their research to become more closely aligned to the research of newly appointed department heads (this is consistent with prior work by Fisman et al. 2018, which documents the influence of social ties in election to China's Academies of Science and Engineering). In his 2023 discussion at the NBER Science of Science Funding panel, Aghion argued that this suggests less Kuhnian innovation and more conformity, which China makes up for through collaborations with countries with more incentives for intellectual nonconformity. If China turns inward to "go it alone," the loss of these collaborations may lead to slower progress. However, in the same panel, Freeman presented evidence that rather than pursuing scientific self-sufficiency, China appears to be pivoting towards more collaboration with Europeans. This still has implications for global science due to the "pivot penalty" (Hill, Stein, etc.) in which research impact is reduced as researchers deviate from previous paths.

In response to the dropoff in Chinese scholars visiting the US (as seen in Figure 5), collaborations are likely to decline even further than already documented (by e.g. Aghion et al. 2023 and Jia et al. 2024), as prior work (see above) has documented a relationship between scholar mobility and collaboration.

C. Restrictive immigration policies and competition effects

The decline in U.S.–China collaboration highlights how sensitive international scientific ties are to shifts in mobility and visa policy. Restrictions that limit the ability of students and researchers to study or work in the United States not only affect bilateral linkages but also These pressures intensified with a new wave of immigration restrictions in 2025. In June 2025, the Trump administration issued a presidential proclamation barring entry for nationals of 12 countries and imposing partial restrictions—including on student and scholar visa categories (F-1, M, and J)—for seven additional countries. These measures, framed as national security protections, may deter prospective students from affected regions and beyond if it leads to perceptions of the United States as a less welcoming destination for scientific training and collaboration.

The prior Executive Order 13769 in 2017 ("the Muslim Ban") restricted visas from seven Muslim-majority countries. Ganguli and MacGarvie (2025) show for example, the number of Iranian F-1 student visas fell from 3,241 in 2015 to 1,674 in 2019, while J-1 scholar visas declined from 820 to 504 over the same period. In contrast, Canada saw an average annual growth rate of 34% in Iranian student permits between 2015 and 2019, reaching 13,495 permits by 2022, significant given Canada's smaller population.

These shifts illustrate how restrictive U.S. policies can redirect talent toward other destinations. Similar substitution patterns are visible in fields such as computer science and engineering, where declining U.S. master's enrollments among Indian students coincided with surging enrollments in Canada (from 24,498 in 2014 to 226,130 in 2022) and in the United Kingdom.

Immigration restrictions are often motivated by the competition or crowd effects on natives. Bound et al. (2021) emphasize that immigrant contributions to U.S. innovation are substantial but caution against ignoring potential crowd-out of domestic students. Borjas (2009) finds wage declines in fields with heavy inflows of foreign PhDs, while Borjas and Doran (2012) identify displacement among U.S. mathematicians after the influx of Soviet émigrés. Demirci (2019) shows that the 2008 OPT extension reduced wages and employment for recent U.S. STEM graduates in immigrant-intensive fields, though more experienced graduates benefited. Yet other work emphasizes complementarities, such as Kerr (2019) who shows how international faculty strengthen U.S. universities and expand their capacity. Bound, Khanna, and Morales (2017) estimate that while foreign-born computing workers reduced wages and employment for domestic scientists, they improved overall welfare by raising productivity and innovation.

Taken together, this evidence suggests that restrictive immigration policies reduce the U.S. ability to attract and retain top global talent, and U.S. ambitions to lead in fields like AI may be undermined by reductions in inflows of international scientific talent.[1]

C. Geopolitical Conflict: The War in Ukraine

Russia's full-scale invasion of Ukraine in 2022 has introduced another dimension of scientific decoupling. In response to the war, the European Union, United States, and other partners curtailed scientific collaboration with Russian institutions. For example, in response to the 2022 invasion of Ukraine, the European Union suspended cooperation with Russian public research bodies under Horizon 2020 and Horizon Europe, terminated payments to Russian entities, and barred new contracts with them (European Commission, 2022). The United States also issued official guidance to end federally funded collaborations with Russian government–affiliated research institutions (OSTP, 2022).

Major multinational facilities, such as CERN, suspended Russian participation. CERN formally suspended its cooperation with Russia's research institutes on November 30, 2024, following a CERN Council decision in June 2022 to end agreements in response to the full-scale invasion of Ukraine in February 2022.[2] Several international conferences that were scheduled to be held in Russia were cancelled or rescheduled in other locations. It was announced in May 2022 that the International Math Congress (ICM), which was scheduled to be held in St. Petersburg in Russia in July 2022, would be held virtually. These actions reflect the broader use of science policy as a tool of geopolitical sanction.

For Ukraine, the war has disrupted research capacity through the destruction of infrastructure, displacement of scientists, and cuts to domestic funding. At the same time, Ukrainian researchers have decoupled from Russia, as evidenced by declining coauthorships starting in 2014 following the annexation of Crimea and conflict in the eastern Donbas region. Ukraine has increased their integration with European science, supported by emergency fellowships and EU programs that enable mobility and collaboration (see e.g. De Rassenfosse et al, 2023; Ganguli and Waldinger, 2024). This decoupling of Russia's exclusion from many

[1] https://www.npr.org/2025/09/09/nx-s1-5479090/trump-wants-to-win-ai-race-but-his-immigration-policies-could-get-in-the-way

[2] See official CERN statement here: https://international-relations.web.cern.ch/stakeholder-relations/states/Russian-Federation

scientific networks, and Ukraine's partial integration into new ones, illustrates how wars can rapidly reorient international research ties.

The long-term implications remain unclear. Russia risks isolation from frontier science, potentially accelerating its reliance on domestic networks or partnerships with non-Western countries such as China and India. Russia's papers coauthored with China and India have started to increase while those with the US and EU have started to decline (Van Noorden 2023). For Ukraine, the key question is whether wartime support will translate into longer-lasting integration with European science after the conflict ends.

IV. What Can We Learn from History?

Over the past century, global science has swung between periods of openness and closure, with major wars and geopolitical rivalries disrupting existing ties and reshaping the geography of research. These historical episodes offer lessons for interpreting today's developments and for understanding likely effects on mobility, collaboration, and knowledge diffusion.

A. World War I and II

Evidence from World War I demonstrates the productivity loss associated with turning inward. Iaria et al. (2018) study the Allied boycott of Central European scientists that lasted until 1926, which restricted conference participation, journal publications, membership in scientific organizations, and cataloguing of literature. The effects were substantial: citations of Central scientists by Allied researchers declined by 40–80%, with an even sharper fall in citations flowing the other way. Productivity also fell among scientists whose work had previously depended on cross-border knowledge, indicating that the boycott hurt both sides.

Research on World War II highlights the devastating consequences of driving out a country's top scientists, and the gains for host nations able to absorb them. During the Nazi regime, Jewish scientists emigrated in large numbers, many to the United States. Waldinger (2010) documents the negative consequences for German science of this exodus. By contrast, Moser et al. (2014) show that the arrival of these émigré scientists to the U.S. contributed to large increases in patenting in chemical fields where displaced German scientists had been most active. They also show that US Chemistry departments expanded after their arrival. These findings underscore the long-term benefits of highly skilled immigration, including refugees, for host-country innovation.

B. The Postwar & Cold War Era

After 1945, international integration expanded rapidly. The Marshall Plan and initiatives such as the Fulbright Program institutionalized scientific exchange, reflecting a vision of enlightened self-interest in rebuilding and stabilizing global science. At the same time, U.S. wartime investments left a strong legacy: Gross and Sampat (2018, 2020) show that wartime R&D stimulated postwar innovation and shaped the trajectory of U.S. technological leadership. During this period, Chacua and Neffke (2025) use the American Men and Women of Science show that faculty at US universities were increasingly foreign-born scientists, growing from approximately 12% in 1950 to over 25% by 1990. Notably, these foreign-born faculty were in-with the share of foreign-born, U.S.-educated faculty around 20% by 1990.

Despite these integrative forces, the Cold War introduced new barriers. Borjas and Doran (2012) document the lack of communication and collaboration between Soviet and U.S. mathematicians, which led to divergent development of subfields. Yet rivalry also spurred investment: Kantor and Whalley (2025) estimate that U.S. space race spending boosted growth in manufacturing value added, employment, and capital accumulation in related sectors. Thus, Cold War science was characterized by both fragmentation and selective bursts of innovation induced by competition. Glitz and Meyersson (2020) show that there were positive returns to industrial esponiage during this period. They show that information provided by East German informants in the West from 1970–1989 narrowed sectoral TFP gaps between West and East Germany.

C. Chinese and Post-Soviet Reintegration

During the Cultural Revolution, China remained largely isolated, sending virtually no students abroad for graduate study. Deng Xiaoping's 1978 'Open Up' reforms, or the Open Door Policy reversed this isolation, rebuilding the domestic education system and encouraging large numbers of Chinese students to pursue doctoral training in Western universities. Borjas, Doran and Shen (2018) show that the inflow of Chinese PhD students to the U.S. after the opening increased the productivity of U.S. professors with Chinese heritage, drawing on the field of math.

The collapse of the Soviet Union in 1991 ushered in another period of scientific opening. This opening involved lifting of restrictions on mobility and access to knowledge that had been previously been inaccessible. It also led to increases in international collaboration, including large scale collaborations like the International Space Station effort, which Russian formally joined in 1993.

Many Soviet-trained scientists emigrated, particularly to the United States. Borjas and Doran (2012) show that this inflow negatively affected the productivity of incumbent U.S. mathematicians through competition, while Ganguli (2015) finds that Soviet émigrés helped diffuse knowledge by increasing citations to Soviet-era work. Agrawal et al (2016) also show that U.S. teams grew in subfields of mathematics in which the Soviets were strongest, consistent with the knowledge burden hypothesis that an increase in the knowledge frontier raises the returns to collaboration. These studies illustrate the dual nature of mobility arising from the opening: potential competition effects for incumbents, but global gains from the diffusion of new knowledge.

Western funding for scientists in the former USSR was also important for sustaining science during the economic crisis of the 1990s and for increasing international integration with western science. Ganguli (2017) shows that an "emergency" funding program funded by George Soros that provided grants to over 28,000 Soviet scientists shortly after the end of the USSR increased publications and the likelihood of staying in science for those on the margin of receiving the grant. The funding also reduced the likelihood of emigrating from scientists from the capital city of Moscow.

D. Lessons

Taken together, these episodes reveal several patterns. Periods of closure appear to have led to significant costs on both sides, reducing knowledge diffusion and scientific productivity. Migration of scientists tended to benefit receiving countries but with long-lasting declines in productivity for the sending country. These lessons suggest that today's moves toward decoupling are likely to impose significant costs on global science, even as they may lead to some gains due to shifting migration patterns.

V. Questions future research

The past half-century has seen remarkable progress in the international integration of science. Mobility of students and scholars, international funding programs, and the rise of team-based, capital-intensive projects have all created new opportunities for collaboration and knowledge diffusion. At the same time, geopolitical shocks, national security–driven restrictions, and restrictive immigration policies may slow or even reverse this trend.

The literature and evidence reviewed here underscores that international migration of scientists and students is a particularly powerful driver of knowledge creation. The productivity premium associated with migration, especially to research hubs like the United States, is large, and diaspora ties continue to link scientists across borders. At the same time, return migration and talent-attraction programs in countries like China and the EU have shown that mobility can also build scientific capacity outside of traditional hubs.

Current trends raise the possibility that fragmentation may replace integration. National security priorities and geopolitical tensions changed patterns of collaboration between the United States and China, between Ukraine and Russia, as well as Russia and other countries. New restrictions on student and scholar mobility may also change flows to the U.S. History suggests that such shocks can have long-lasting effects on science.

These patterns raise several important questions about international collaboration, knowledge diffusion and mobility, and what we should expect for the future. Many questions remain: Will the US and China decouple? Do we boycott Russian science? If so, what will be the effects? Can China "go it alone"? Or will they collaborate with other countries? What are the factors driving changes in international collaboration and mobility? How will shifts in global power dynamics affect scientific collaboration? What are the impacts of restrictions on scientific mobility? How do geopolitical conflicts shape the direction and funding of scientific research? How do emerging technologies and digital collaboration tools impact international research?

The answers to these questions will shape not only the future of global science, but also how effectively it can address pressing societal challenges that transcend borders, and how knowledge and opportunity are distributed worldwide in the decades to come.

References

Acemoglu, D., Yang, D. Y., & Zhou, J. (2022). *Power and the direction of research: Evidence from China's academia*. NBER Conference Paper. Retrieved from https://conference.nber.org/conf_papers/f173785.pdf

Agarwal, R., Ganguli, I., Gaulé, P. and Smith, G., 2023. Why US immigration matters for the global advancement of science. Research Policy, 52(1), p.104659.

Agrawal, A., Goldfarb, A. and Teodoridis, F., 2016. Understanding the changing structure of scientific inquiry. American Economic Journal: Applied Economics, 8(1), pp.100-128.

Agrawal, A., Kapur, D., McHale, J. and Oettl, A., 2011. Brain drain or brain bank? The impact of skilled emigration on poor-country innovation. Journal of Urban Economics, 69(1), pp.43-55.

Anelli, M., Shih, K. and Williams, K., 2023. Foreign students in college and the supply of STEM graduates. Journal of Labor Economics, 41(2), pp.511-563.

Baruffaldi, S., Santoleri, P., & Shevtsova, Y. (2025). *The impact of mobility grants on researchers* (Working paper).

Borjas, G. J., & Doran, K. B. (2012). The collapse of the Soviet Union and the productivity of American mathematicians. *Quarterly Journal of Economics, 127*(3), 1143–1203. https://doi.org/10.1093/qje/qjs015

Borjas, G.J., Doran, K.B. and Shen, Y., 2018. Ethnic complementarities after the opening of China: How Chinese graduate students affected the productivity of their advisors. Journal of Human Resources, 53(1), pp.1-31

Bound, J., Turner, S., & Walsh, P. (2009). Internationalization of U.S. doctorate education. *NBER Working Paper No. 14792*. Cambridge, MA: National Bureau of Economic Research. https://doi.org/10.3386/w14792

Chacua, C. and Neffke, F. (2025). A Century of Faculty Globalization and University Rise:From US-Born, Foreign-Educated to Foreign-Born, US-Educated. Mimeo.

Corrigan, J., Dunham, J. and Zwetsloot, R., 2022. The long-term stay rates of international STEM PhD graduates. Center for Security and Emerging Technology. https://cset. georgetown. edu/wp-content/uploads/CSET-The-Long-Term-Stay-Rates-of-International-STEM-PhD-Graduates. pdf.

De Rassenfosse, G., Murovana, T. and Uhlbach, W.H., 2023. The effects of war on Ukrainian research. Humanities and Social Sciences Communications, 10(1), pp.1-11.

European Commission. (2022, April). EU suspends cooperation with Russian entities in research, science and innovation. Directorate-General for Research and Innovation. Retrieved from https://research-and-innovation.ec.europa.eu/strategy/strategy-research-and-innovation/europe-world/international-cooperation/bilateral-cooperation-science-and-technology-agreements-non-eu-countries/russia_en

Fisman, R., Shi, J., Wang, Y., & Xu, R. (2018). Social ties and favoritism in Chinese science. *Journal of Political Economy, 126*(3), 1134–1171. https://doi.org/10.1086/697202

Flynn, R., Glennon, B., Murciano-Goroff, R., & Xiao, J. (2024). *Building a wall around science: The effect of US–China tensions on international scientific research* (No. w32622). National Bureau of Economic Research.

Furman, J.L., Murray, F. and Stern, S., 2012. Growing stem cells: The impact of federal funding policy on the US scientific frontier. Journal of Policy Analysis and Management, 31(3), pp.661-705.

Fry, C. and Ganguli, I., 2023. Return on Returns: Building Scientific Capacity in AIDS Endemic Countries (No. w31374). National Bureau of Economic Research.

Gallagher, M. (2025, August 20). Send Harvard's Chinese students home: It makes no sense for the U.S. to be educating the scientific and leadership class of a future adversary. *Wall Street Journal* (Opinion). Retrieved from https://www.wsj.com/opinion/send-harvards-chinese-students-home-national-security-risk-research-2e43313d

Ganguli, I. (2017). Saving Soviet science: The impact of grants when government R&D funding disappears. *American Economic Journal: Applied Economics, 9*(2), 165–201. https://doi.org/10.1257/app.20150584

Ganguli, I., & MacGarvie, M. (forthcoming). "International students' migration: immigration policy and implications for innovation" In F. Lissoni & A. Morrison (Eds.), A research agenda for migration and innovation. Edward Elgar Publishing.

Gaule, P., & Piacentini, M. (2013). Chinese graduate students and U.S. scientific productivity. Review of Economics and Statistics, 95(2), 698–701. https://doi.org/10.1162/REST_a_00260

Glitz, A. and Meyersson, E., 2020. Industrial espionage and productivity. *American Economic Review*, 110(4), pp.1055-1103.

Gomez, C.J., Herman, A.C. and Parigi, P., 2022. Leading countries in global science increasingly receive more citations than other countries doing similar research. Nature Human Behaviour, 6(7), pp.919-929.

Gross, D. P., & Sampat, B. N. (2018). Inventing the endless frontier: The effects of the World War II research effort on postwar innovation. *NBER Working Paper No. 25093*. https://doi.org/10.3386/w25093

Gross, D. P., & Sampat, B. N. (2020). The legacy of wartime R&D: Evidence from the Apollo Program. *NBER Working Paper No. 27067*. https://doi.org/10.3386/w27067

Hill, R., Yin, Y., Stein, C., Wang, X., Wang, D., Jones, B. F. (2025). The pivot penalty in research. *Nature, 642*(7902), 999-1006. https://doi.org/10.1038/s41586-025-09048-1

Hunt, J., & Gauthier-Loiselle, M. (2010). How much does immigration boost innovation? American Economic Journal: Macroeconomics, 2(2), 31–56. https://doi.org/10.1257/mac.2.2.31

Iaria, A., Schwarz, C., & Waldinger, F. (2018). Frontier knowledge and scientific production: Evidence from the collapse of international science. *Quarterly Journal of Economics, 133*(2), 927–991. https://doi.org/10.1093/qje/qjx046

Institute of International Education (2024). International Scholars Total by Places of Origin 2000/01 – 2023/04. *Open Doors Report on International Exchange.* Retrieved from https://opendoorsdata.org in August 2025.

Jacob, B., & Lefgren, L. (2011). The impact of NIH postdoctoral training grants on scientific productivity. Research Policy, 40(6), 864–874. https://doi.org/10.1016/j.respol.2011.04.003

Jia, R., Roberts, M. E., Wang, Y., & Yang, E. (2024). The impact of US–China tensions on US science: Evidence from the NIH investigations. *Proceedings of the National Academy of Sciences, 121*(19), e2301436121. https://doi.org/10.1073/pnas.2301436121

Kantor, S., & Whalley, A. (2025). Moonshot: Public R&D and growth. *American Economic Review, 115*(9), 2891–2925. https://doi.org/10.1257/aer.20210928

Kerr, W.R., 2008. Ethnic scientific communities and international technology diffusion. The Review of Economics and Statistics, 90(3), pp.518-537.

Khanna, G. and Morales, N., 2025. The IT boom and other unintended consequences of chasing the American dream. Working Paper.

Moser, P., Voena, A., & Waldinger, F. (2014). German Jewish émigrés and U.S. invention. *American Economic Review, 104*(10), 3222–3255. https://doi.org/10.1257/aer.104.10.3222

National Center for Science and Engineering Statistics (NCSES). (2024). *Doctorate recipients from U.S. universities: 2023 data tables* (NSF 24-336). Alexandria, VA: U.S. National Science Foundation. Retrieved from https://ncses.nsf.gov/surveys/earned-doctorates

National Center for Science and Engineering Statistics (NCSES). (2025). *Nearly half of 2023 U.S. doctorate recipients with temporary visas were from China or India* (NSF 25-336). Alexandria, VA: U.S. National Science Foundation. Retrieved from https://ncses.nsf.gov/pubs/nsf25336

National Science Board, National Science Foundation. 2023. Publications Output: U.S. Trends and International Comparisons. Science and Engineering Indicators 2024. NSB-2023-33. Alexandria, VA. Available at https://ncses.nsf.gov/pubs/nsb202333/.

National Science Board, National Science Foundation. 2021. Publications Output: U.S. and International Comparisons. *Science and Engineering Indicators 2022*. NSB-2021-4. Alexandria, VA. Available at https://ncses.nsf.gov/pubs/nsb20214/.

OECD (2024), *Education at a Glance 2024: OECD Indicators*, OECD Publishing, Paris, https://doi.org/10.1787/c00cad36-en.

Office of Science and Technology Policy (OSTP), The White House. (2022, June 11). Guidance on scientific and technological cooperation with the Russian Federation for U.S. government and U.S. government-affiliated organizations. Retrieved from https://bidenwhitehouse.archives.gov/ostp/news-updates/2022/06/11/guidance-on-scientific-and-technological-cooperation-with-the-russian-federation-for-u-s-government-and-u-s-government-affiliated-organizations/

Shih, K., 2017. Do international students crowd-out or cross-subsidize Americans in higher education?. Journal of Public Economics, 156, pp.170-184.

Stuen, E. T., Mobarak, A. M., & Maskus, K. E. (2012). Skilled immigration and innovation: Evidence from enrollment fluctuations in U.S. doctoral programs. Economic Journal, 122(565), 1143–1176. https://doi.org/10.1111/j.1468-0297.2012.02543.x

Van Noorden, R., 2023. Data hint at Russia's shifting science collaborations. Nature, 615, p.199.

Wagner, C. S., & Cai, X. (2022). Changes in co-publication patterns among China, the European Union (28), and the United States of America, 2016–2021. SSRN. https://ssrn.com/abstract=4035897

Waldinger, F. (2010). Quality matters: The expulsion of professors and the consequences for PhD student outcomes in Nazi Germany. *Journal of Political Economy, 118*(4), 787–831. https://doi.org/10.1086/655975

Ganguli, I. and Waldinger, F., 2024. War and science in Ukraine. Entrepreneurship and Innovation Policy and the Economy, 3(1), pp.165-188.

Woolston, C. (2023, June 15). Nature Index Annual Tables 2023: China tops natural-science table. *Nature*. https://doi.org/10.1038/d41586-023-01868-3

Xie, Q., & Freeman, R. B. (2019). Bigger than you thought: China's contribution to scientific publications and its impact on the global economy. *China & World Economy, 27*(1), 1–27. https://doi.org/10.1111/cwe.12265

Yıldız, Y., Chavarro, D., Visentin, F., & Ciarli, T. (2025). *Expanding horizons: The impact of post-doctoral mobility grants on research diversification* (Working paper).

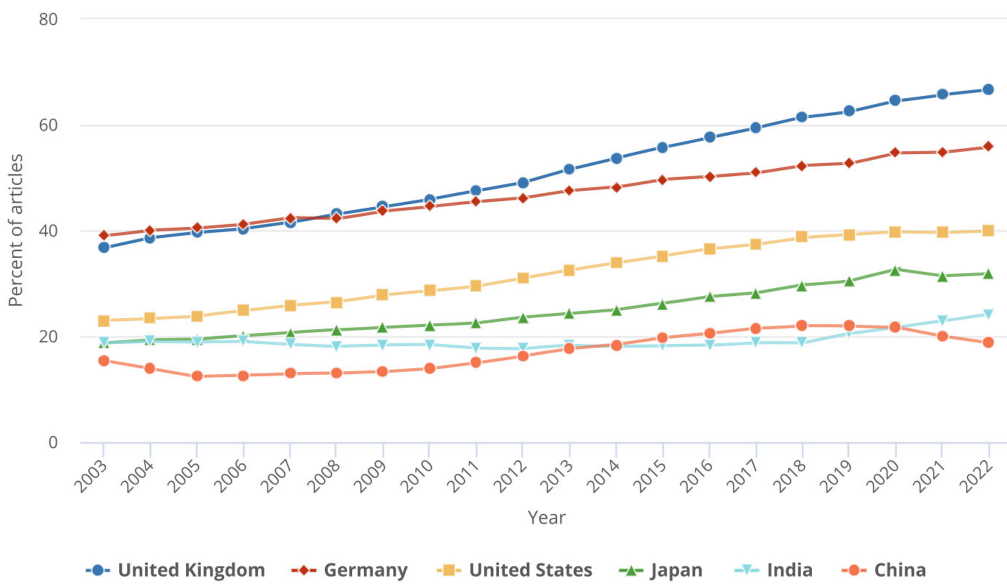
Zwetsloot, R., Feldgoise, J. and Dunham, J., 2020. Trends in US intention-to-stay rates of international Ph. D. graduates across nationality and STEM fields. Center for Security and Emerging Technology. https://cset. georgetown. edu/publication/trends-in-us-intention-to-stay-rates-of-international-ph-d-graduates-across-nationality-and-stem-fields/#:~: text= They% 20are% 20highest% E2, 80.

Figure 1

National Center for Science and Engineering Statistics | NSB-2023-33

Figure PBS-13

Selected leading region, countries, or economies with publications with international coauthors: 2003–22



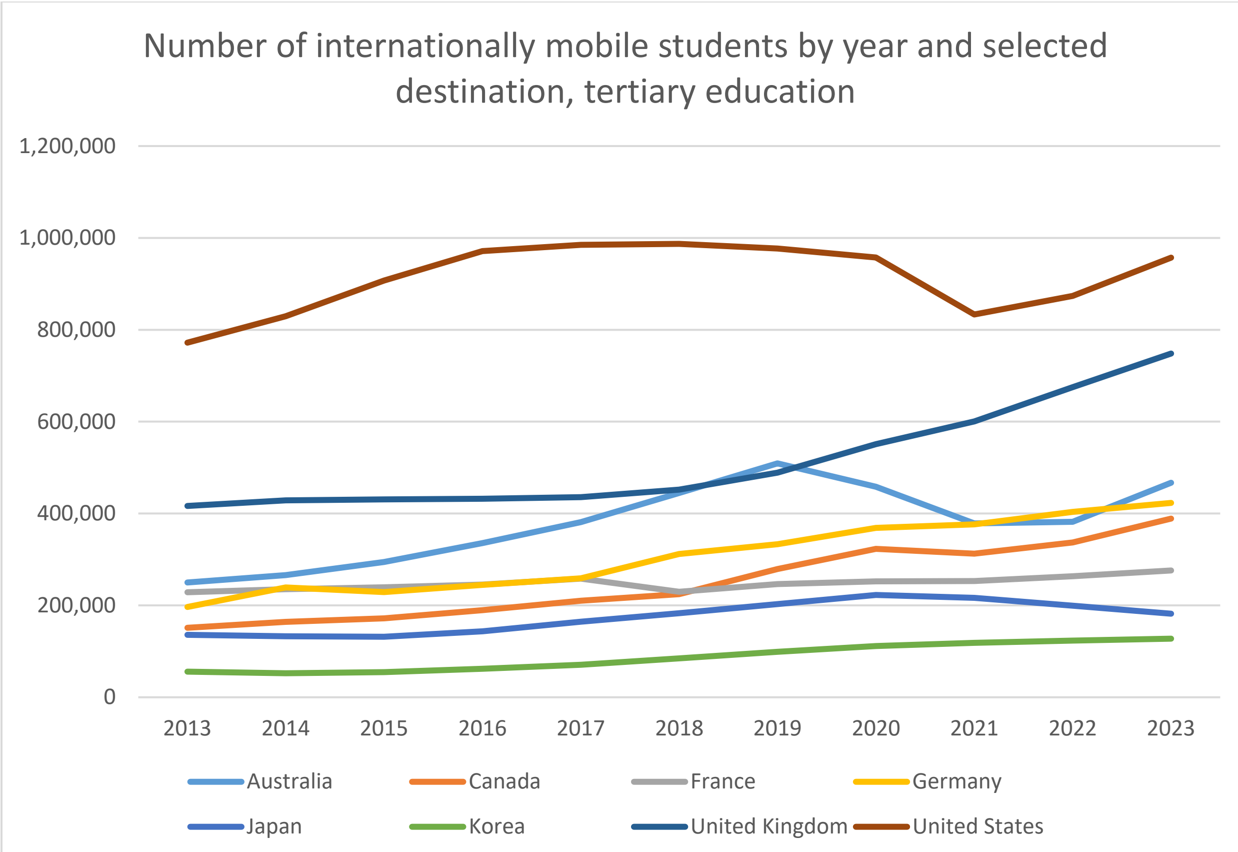
Note(s):
Articles refer to publications from a selection of journals and conference proceedings in S&E from Scopus. Articles are classified by their year of publication and are assigned to a region, country, or economy on the basis of the institutional address(es) of the author(s) listed in the article.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

Source(s):
National Center for Science and Engineering Statistics; Science-Metrix; Elsevier, Scopus abstract and citation database, accessed April 2023.

Science and Engineering Indicators

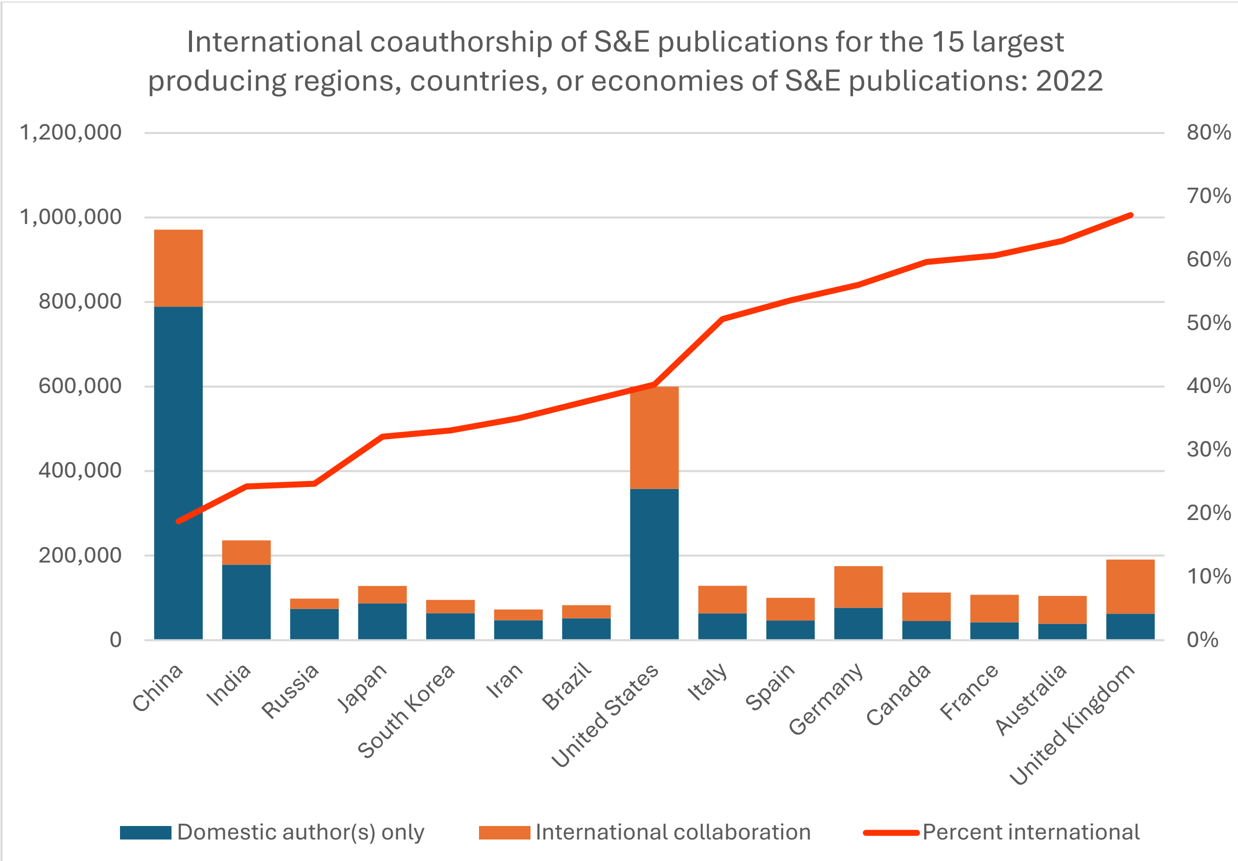
From the National Science Board's *Science and Engineering Indicators* 2023.

Figure 2



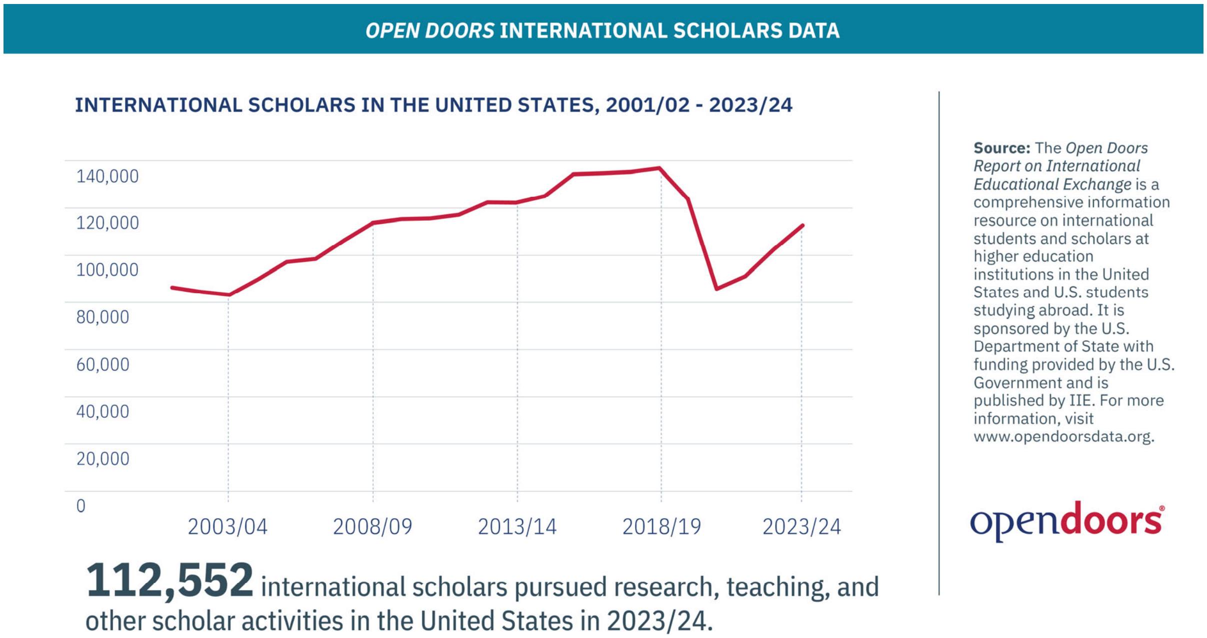
Source: Number of mobile students enrolled and graduated by country of origin (OECD *Education at a Glance* 2024).

Figure 3



Source(s): National Center for Science and Engineering Statistics; Science-Metrix; Elsevier, Scopus abstract and citation database, accessed April 2023, and authors' calculations.

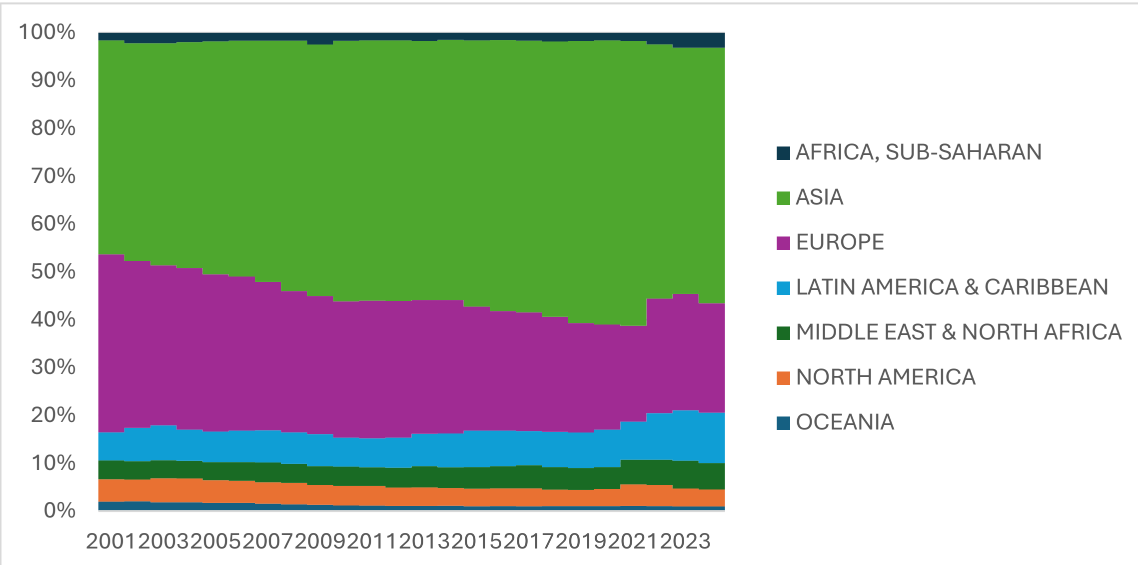
Figure 4



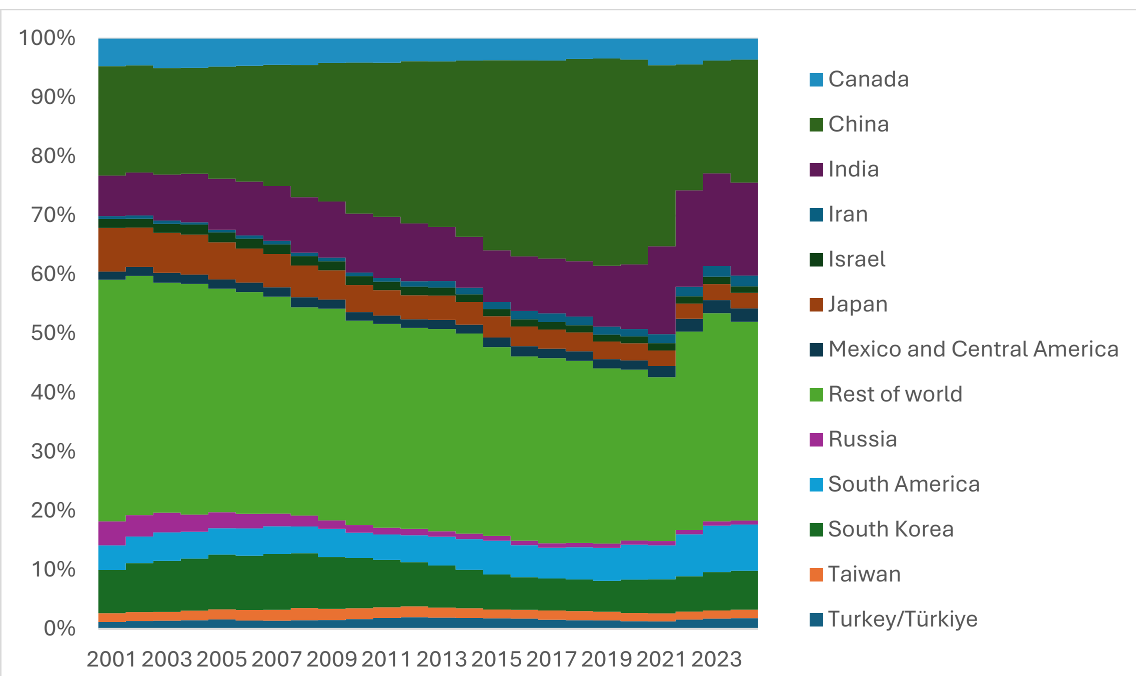
Source: Institute of International Education (IIE) Open Doors database, accessed August 2025. https://opendoorsdata.org/infographic/international-scholars-in-the-united-states-2001-02-2023-24/

Figure 5

Distribution of scholar counts by region of origin

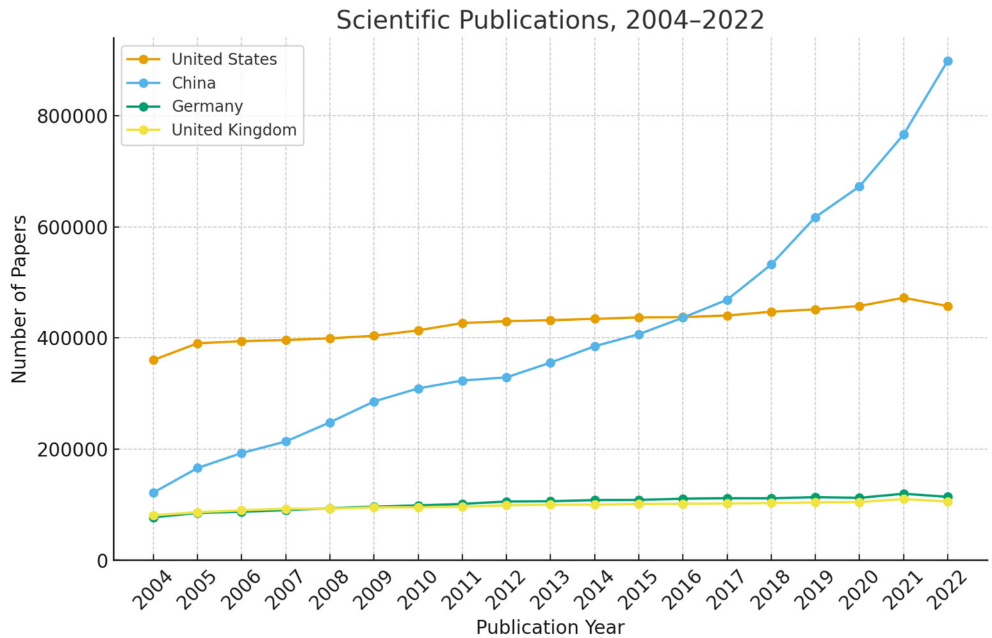


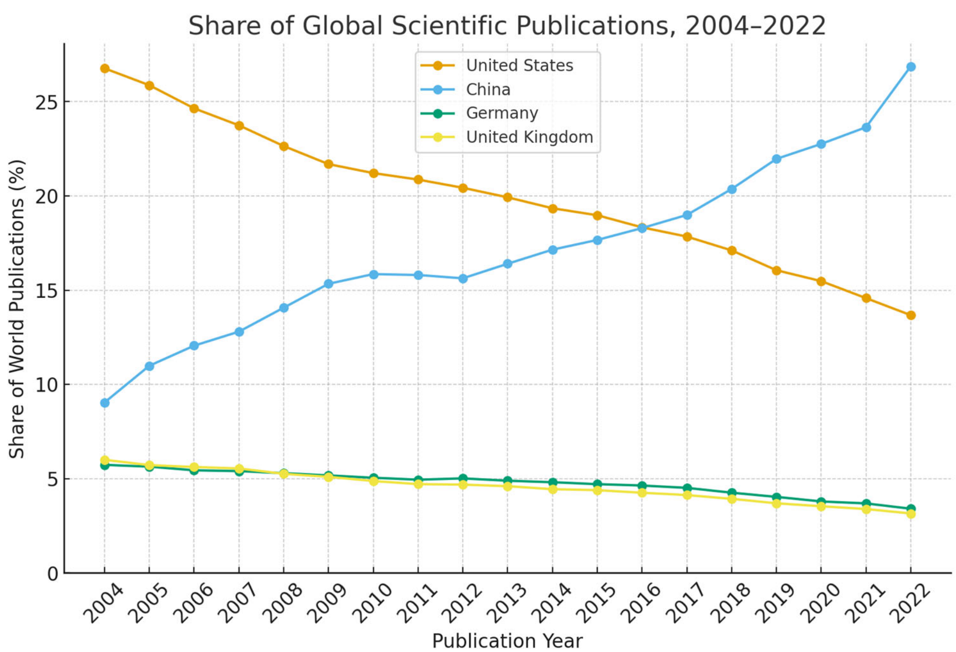
Distribution of scholar counts in the US by year and selected country of origin



Source: Institute of International Education (2024) and authors' calculations.

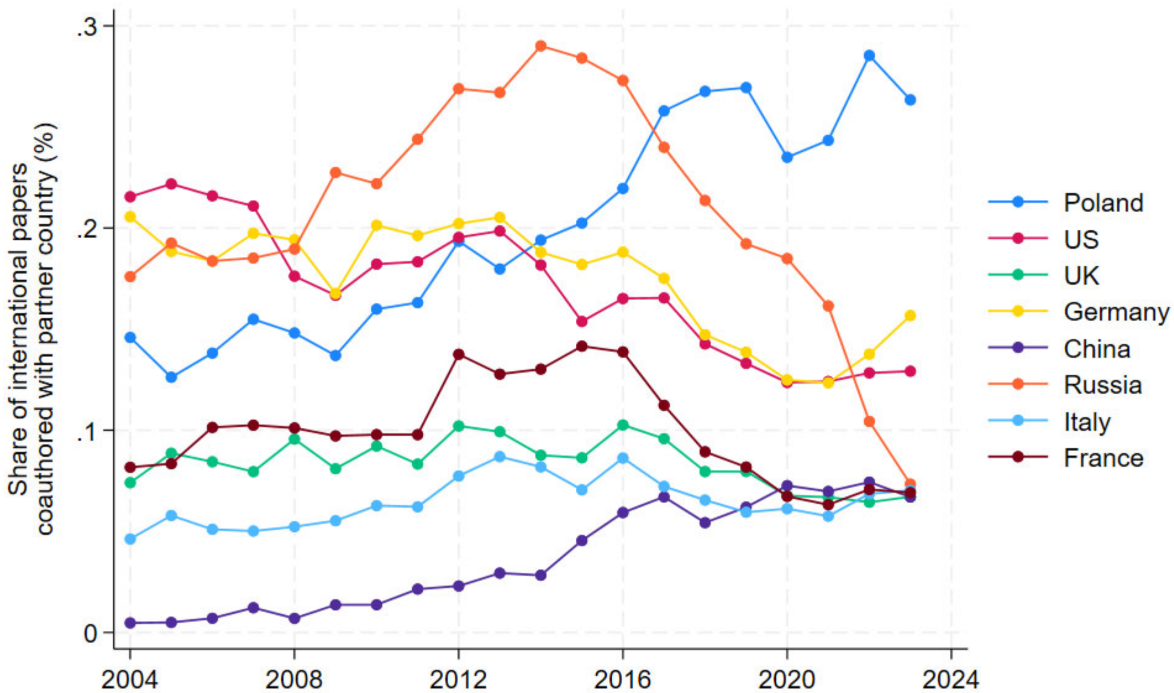
Figure 6





Source: National Science Board, National Science Foundation. 2023. Publications Output: U.S. Trends and International Comparisons. Science and Engineering Indicators 2024. NSB-2023-33. Alexandria, VA. Available at https://ncses.nsf.gov/pubs/nsb202333/.

Figure 7



Source: Scopus, from Bezvershenko, Ganguli, Talavera, Gorodnichenko, 2025

Table 1

Relative citation index for 15 largest producing regions, countries, or economies: 2020

(Index)

Citing region, country, or economy	Cited region, country, or economy														
	China	United States	India	United Kingdom	Germany	Italy	Japan	Canada	France	Australia	Spain	Russia	South Korea	Brazil	Iran
China	2.43	0.74	0.48	0.69	0.56	0.56	0.54	0.69	0.54	0.95	0.52	0.13	0.96	0.32	0.73
United States	0.48	3.24	0.25	1.37	0.96	0.87	0.52	1.29	0.93	1.07	0.64	0.11	0.56	0.34	0.32
India	0.90	0.62	5.43	0.78	0.53	0.79	0.39	0.68	0.57	0.82	0.65	0.17	0.93	0.58	1.52
United Kingdom	0.52	1.34	0.35	6.52	1.19	1.15	0.51	1.29	1.14	1.60	0.91	0.13	0.54	0.42	0.41
Germany	0.46	1.27	0.26	1.65	6.80	1.20	0.62	1.05	1.31	1.06	0.92	0.21	0.56	0.37	0.31
Italy	0.56	1.08	0.36	1.44	1.05	8.69	0.51	0.96	1.29	0.92	1.36	0.15	0.60	0.55	0.60
Japan	0.64	1.13	0.33	1.14	1.04	0.92	8.64	0.86	1.01	0.93	0.70	0.16	0.94	0.32	0.33
Canada	0.60	1.55	0.36	1.61	0.93	0.95	0.47	8.91	1.00	1.47	0.77	0.12	0.62	0.46	0.65
France	0.53	1.26	0.33	1.63	1.37	1.47	0.66	1.16	8.66	1.08	1.13	0.20	0.57	0.51	0.40
Australia	0.67	1.21	0.40	1.83	0.88	0.83	0.46	1.39	0.82	11.02	0.77	0.11	0.63	0.45	0.61
Spain	0.58	1.03	0.42	1.49	1.04	1.78	0.48	1.04	1.21	1.16	8.84	0.16	0.63	0.75	0.66
Russia	0.61	0.75	0.50	0.90	0.96	1.01	0.55	0.70	0.91	0.73	0.79	10.15	0.60	0.47	0.70
South Korea	1.02	0.97	0.63	0.89	0.74	0.84	0.76	0.84	0.67	0.95	0.67	0.14	8.99	0.38	0.78
Brazil	0.62	0.86	0.68	1.10	0.71	1.23	0.39	0.94	0.89	1.03	1.23	0.15	0.59	10.51	1.00
Iran	1.04	0.62	1.06	0.70	0.46	1.00	0.33	0.78	0.56	0.85	0.74	0.17	0.80	0.63	11.93

Note(s):

Citations refer to publications from a selection of journals, books, 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) listed in the article. Articles are credited on a fractional count basis (i.e., for articles with collaborating institutions from multiple regions, countries, or economies, each region, country, or economy receives fractional credit on the basis of the proportion of its participating institutions). Citation counts are based on all citations made to articles in their publication year and in the following 2 years (i.e., 3-year citation window; scores in 2020 are based on citations to articles published in 2020 that were made in articles published in 2020–22). The relative citation index (RCI) normalizes cross-national citation data for variations in relative size of publication output. RCI is computed by dividing the share of the citing region, country, or economy's outgoing citations attributed to the cited region, country, or economy, then dividing that amount by the share of publications attributed to the cited region, country, or economy. An RCI of 1.00 means that the citing region, country, or economy cites publications from the cited region, country, or economy as much as would be expected to happen randomly, showing no particular affinity between the regions, countries, or economies. Scores higher than 1.00 mean that the citing region, country, or economy has a higher-than-expected tendency to cite the cited region, country, or economy's S&E literature. For more detail, see Table SPBS-39. Cells in which the region, country, or economy collaborates at or above the world average for that year are shaded green.

Source(s):

National Center for Science and Engineering Statistics; Science-Metrix; Elsevier, Scopus abstract and citation database, accessed April 2023.

Table PSB-2 of the National Science Board's *Science and Engineering Indicators* 2023.