INTEGRATED SUMMARY:

GLOBAL COMPETITIVENESS

There is growing evidence that China is matching or overtaking US leadership of emergent and disruptive science in an increasing number of fields of science, engineering, and medicine. At the same time, the United States and China are each other's most frequent collaborators. A better understanding of these results and of the US S&T funding ecosystem is important to ensure a robust and innovative US research portfolio. Philanthropic foundations are playing a significant role in funding basic science, including riskier scientific endeavors; better data on these investments would help optimize national investment. Also needed, to enhance US competitiveness with a more robust national system of innovation, are better data on biases in government and other funding processes that might preclude investments from funding our top talent, regardless of demographic or institutional affiliations.

Type of critical technology assessment Situational awareness of US versus other nations' capabilities in science and technology (S&T) knowledge and production (and inputs such as funding and human capital)

Lead performers Yong-Yeol (YY) Ahn, James Evans, Joshua Graff Zivin, Cassidy R. Sugimoto

Program management Connect 30,000-foot insights from sophisticated data science models to contextual expert knowledge; red-teaming workshop; synthesis across researcher results

Methods LLMs, machine learning, end-of-program workshop to evaluate and red-team results with analytic, technology, and industry experts

Data Scientific publications, expert surveys

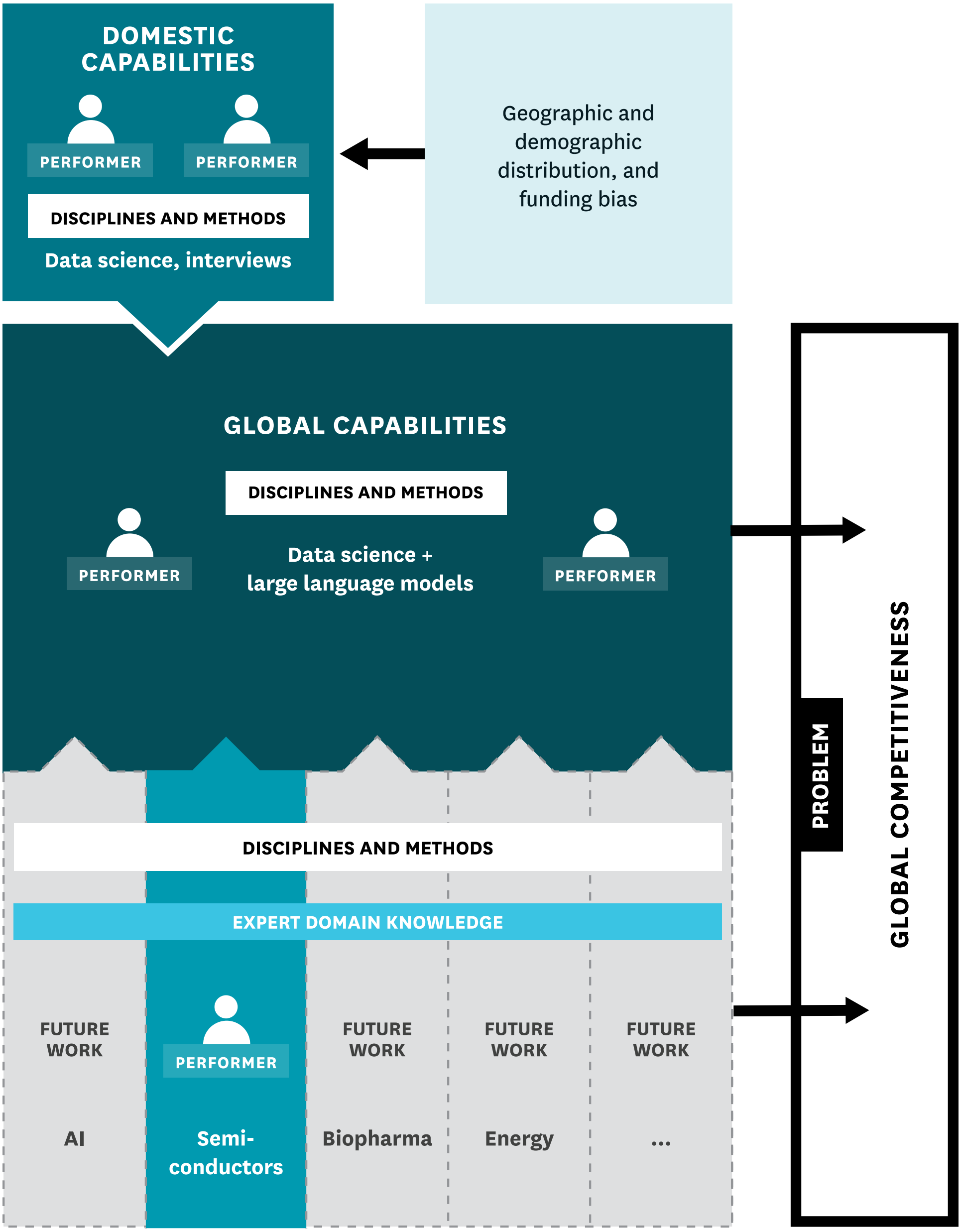
Criticality dimensions measured S&T competitiveness, social well-being

Challenges for future critical technology assessment Insufficient situational awareness of global technology and production capabilities (including product-level supply chains) and relevant human capital inputs

Additional contributors: Sadamori Kojaku, Jeffrey W. Lockhart, Lili Miao, Namrata Narain, Amit Seru, Filipi Nascimento Silva

GLOBAL COMPETITIVENESS

30,000 foot search by algorithms informed by and interpreted through expert domain knowledge.



GLOBAL COMPETITIVENESS

FINDING: China has the highest share globally of disruptive scientific papers and papers that lead to the emergence of new fields.

RECOMMENDATIONS: These findings should be explored at the level of individual scientific fields and individual papers to better understand these provocative, and potentially concerning, early results, what exactly the measures are indicators of, and area-specific implications. The United States should also begin discussions on how best to proactively and ongoingly evaluate and balance its portfolio of support for mature versus emerging science, with an emphasis on cultivating new directions.

FINDING: US and Chinese researchers collaborate on scientific publications in strategic areas (e.g., biotechnology, computing, materials engineering). Collaborative work between US and Chinese researchers represents a significant fraction of each country's publications.

RECOMMENDATIONS: Research should be expanded to understand how breaking or enhancing US-Chinese collaborations could affect scientific outcomes, access to strategically important knowledge, and global competitiveness. The United States should begin immediately to monitor networks of strategic partnerships across the globe to identify existing high-yield international collaborations and potentially fruitful or compromising collaborative ties.

FINDING: The NSF underfunds women, particularly women of color in computing, and does not fund the highest-impact work. Minority and White women tend to undertake research in different topic areas than White men, and thus could enhance the novelty and robustness of the US research portfolio.

RECOMMENDATION: To help overcome reviewer and citation bias, provide targeted funding to women and minoritized scholars in computing, with a focus on strategic areas.

FINDING: Foundations may be playing a significant role in funding basic science, including early funding of riskier scientific endeavors.

RECOMMENDATION: Explore mechanisms for information sharing between public and philanthropic funders to help optimize national investment in emerging and disruptive areas.

Research Questions

How can the United States effectively track worldwide investment, production, position, and trajectory in critical science and technology (S&T)? Specifically, can we develop situational awareness of relative national capabilities in S&T? Where are the next scientific discoveries and technological disruptions most likely to occur? Who, domestically, has capabilities but is left out of scientific discovery and commercialization?

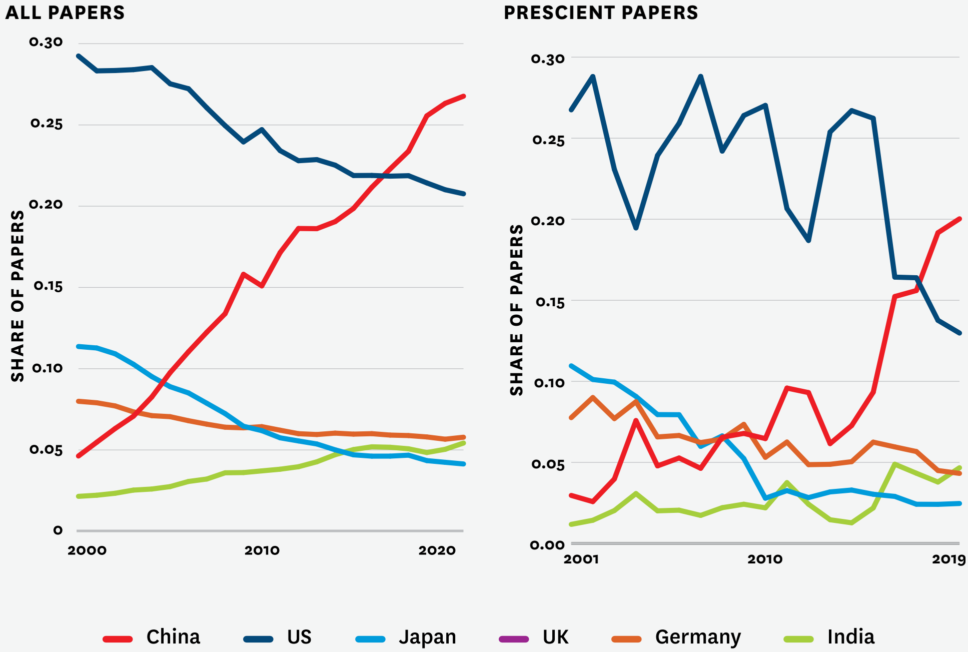
Motivation/Framing

Global situational awareness of emerging technical capabilities is critical to understand what advances are happening, where, and how, and their relevance to national security, health, and environmental challenges. Technological change also drives economic activity, creating new jobs while automating and sometimes resulting in the outsourcing of others. Understanding these changes is key to ensuring sustainable prosperity, security, and equity, buffering against shocks, and reducing the risk of being surprised by other countries' advances. Robust innovation also requires an understanding of how US research promotes or disenfranchises marginalized intersectional identities. Because researchers of different backgrounds can bring new perspectives into science and innovation, it is strategic to have a diverse pool of contributors. Diversity is associated with higher productivity (Hamilton et al. 2012, Smith-Doerr et al. 2017), innovation (Hofstra et al. 2020), and research topics that advance social change (Kozlowski et al. 2022). Therefore, our work seeks both to contextualize US S&T and to explore the degree to which the United States is training and resourcing the full capacity of the nation. The NNCTA work seeks to identify distinct dimensions of S&T leadership. We take three complementary approaches that evaluate national contributions to unfolding global scientific and technological advances both across all areas and within the selected critical strategic areas: AI, biopharmaceuticals, energy and critical materials (batteries for electric vehicles), and next-generation semiconductors. We note that leadership cannot be measured directly, so we employ surrogate measures, recognizing the danger that such proxies may become misleading policy goals in and of themselves.

Our first approach identifies the leadership of each country's scientists in emerging versus established or dissolving areas of science and technology by building a model that embeds more and less probable research pathways through an evolving network of research ideas and scientists. This model reveals that gradual "tectonic shifts" among scientific concepts can predict the emergence of new areas as their component ideas and techniques move toward catalysis (Sourati and Evans 2023). It also directly predicts which scientists and nations are poised to lead in these emerging areas.

Our second approach builds a distinctive model to capture the global prescience versus predictability or irrelevance of scientific contributions by modeling the probability of each combination of concepts through their projection in an embedding of scientific work that evolves over time. In prior work, we showed that papers that are surprising in the year they are published are more likely to become high-citation or hit papers (Shi and Evans 2023). Here we extend that to show which countries produce "prescient" papers that start out surprising when published and become the norm for subsequent research. Insofar as our first approach identifies leadership in areas predicted to emerge based on existing S&T currents, our second identifies leadership in areas that pivot S&T toward new, unexpected directions that violate existing currents.

Our third approach identifies the degree to which emergent and prescient work become recognized as disruptive, in the sense of catalyzing new directions of research. We use the citation-based "disruption index" to quantify the extent to which a new publication displaces by eclipsing prior work in the network of citations (Funk and Owen-Smith 2017, figure 3a). Based on scholars' tendency to cite a work instead of the sources it draws on, the disruption index characterizes how the novelty of a current work has become appreciated by the scientific community. Unlike the other two approaches, this identifies work attributed downstream for new directions responsible for pivots in the pattern of scientific attention.



US security and economic prosperity require (i) prompt and geographically and demographically distributed investment in emerging, critical technologies that forge national leadership and (ii) engagement of the full capacity of the US S&T workforce (e.g., Chetty et al. 2019). Our research aims to (i) elucidate the current global landscape of national funding and scientific publications via analysis of content (text) and context (metadata); (ii) use generative artificial intelligence and mechanistic models to forecast the position of nations in the global S&T ecosystem; (iii) develop interactive analysis platforms that display each nation's comparative present and future advantage across research fields; (iv) analyze the landscape of individual critical technologies, beginning with post-CMOS semiconductor technologies, to demonstrate the value of this approach; and (v) explore (a) the degree to which national investments sponsor and cultivate a diversity of US talent, using NSF investments as an initial case study, and (b) how nongovernment investments (starting with foundations) are advancing discovery and commercialization of critical technologies. These analyses presume that cutting-edge scientific research is necessary for the development and implementation of critical technologies. Our Vision for Future Analytic Work (below) describes causal analyses to explore this.

Methods and Sources of Data

During the pilot year we focused on the use of publication and citation data and metadata (e.g., authors, institutions, funders) from the Web of Science, Microsoft Academic Graph, and OpenAlex. Use of open datasets will be increasingly necessary to fulfill the OSTP's mandates on open science. In ongoing research, we are also exploring the use of Dimensions (by Digital Science), international patent databases, international publication databases with more coverage of distributed S&T production (e.g., in Chinese), and

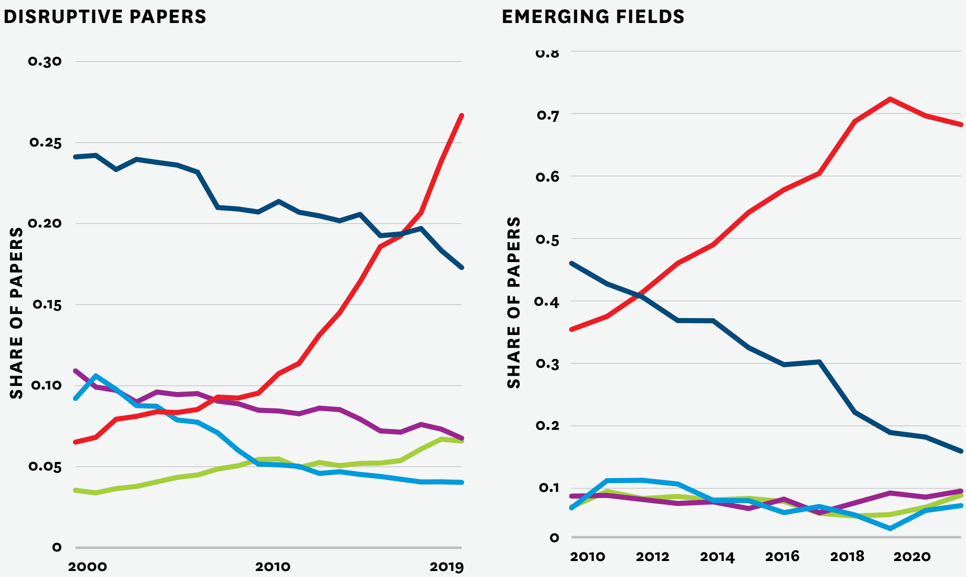


FIGURE 4-2. Chinese scientists lead the emergence of new fields related to critical areas, the production of low-probability work that becomes high probability in the future (prescient), and disruptive scientific advances perceived as the beginning of critical research directions.

downstream databases of products and companies. We relied on machine learning and AI technologies to encode and analyze large-scale unstructured data from article text, metadata, and related S&T artifacts; statistical physics tools to evaluate large-scale networks of collaboration, affiliation, and citation; and data science (scientometrics) and statistical approaches to compare and test national and international patterns of activity and inclusion. We use these data to (i) evaluate the international system of collaboration with bibliometric methods; (ii) assess the global and national distribution of funding with statistical analysis; (iii), using AI methods, describe the leadership of scientists in *emerging* S&T areas and (iv) identify *prescient* research that combines technologies and concepts ahead of their time (**table 4-1**); (v), using bibliometric methods, assess S&T *disruption*—the degree to which it becomes recognized as having catalyzed new directions of research; and (vi) examine the degree to which NSF is fully resourcing the country's talent. Selected examples of emerging areas (denoted by the terms used in our keyword search) are in **appendix 4A-2.**

Integrative Findings

A major global change in 21st century science and technology (S&T) is the rise of China's participation and the simultaneous decline in US leadership in various S&T fields. There is evidence to suggest that China has taken the lead both in producing top scientific research and in the number of scientists engaged in that research relative to the United States, Europe, and the rest of the world. China has also massively accelerated its disruptive science over the past 2 decades, with a higher than average proportion of papers ahead of their time and catalysis of emerging S&T areas, recognized by global researchers with disruptive citation patterns (**figures 4-2, 4-3**). China has been slower in its growth of developmental work across established areas, where the United States maintains (decreasing) leadership.

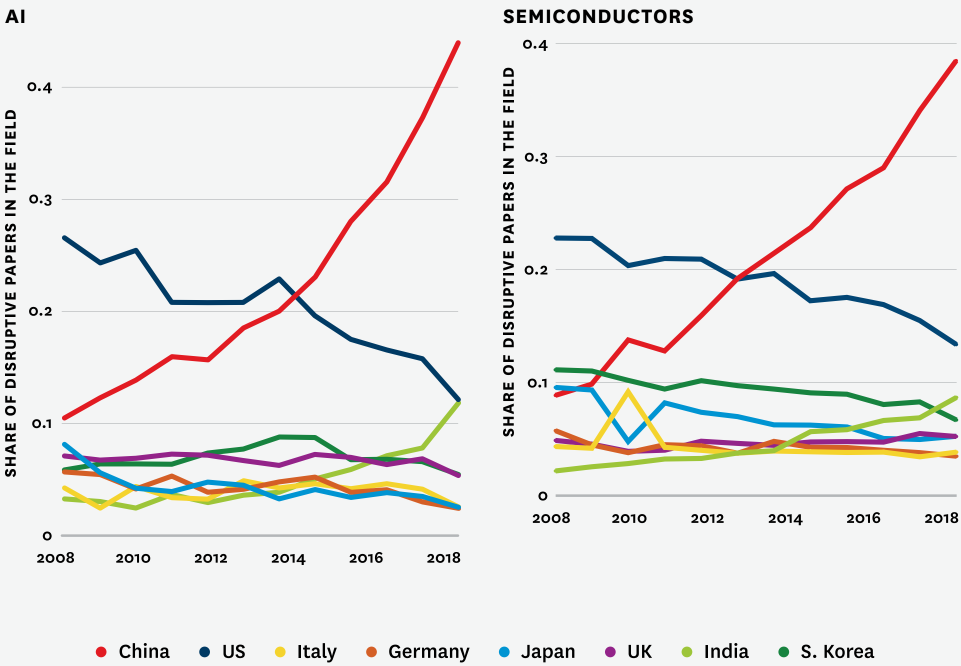


TABLE 4-1. Selected examples of high-prescience papers

Papers	Notes
Wright J, Yang AY, Ganesh A, Sastry SS, Ma Y. 2009. Robust Face Recognition via Sparse Representation. *IEEE Transactions on Pattern Analysis and Machine Intelligence* 31(2):210–27	Extremely well cited paper on facial recognition technology
Gao X, Cui Y, Levenson RM, Chung LWK, Nie S. 2004. *In vivo* cancer targeting and imaging with semiconductor quantum dots. *Nature Biotechnology* 22:969–76	Extremely well cited paper on cancer imaging and semiconductor technology
O'Boyle NM, Banck M, James CA, Morley C, Vandermeersch T, Hutchison GR. 2011. Open Babel: An open chemical toolbox. *Journal of Cheminformatics* 3:33	Paper introducing a research tool that became widely adopted in chemistry
Basar E, Di Renzo M, De Rosny J, Debbah M, Alouini M-S, Zhang R. 2019. Wireless Communications Through Reconfigurable Intelligent Surfaces. *IEEE Access* 7:116753–73	Highly cited paper bridging two areas of research to enable next generation wireless technology

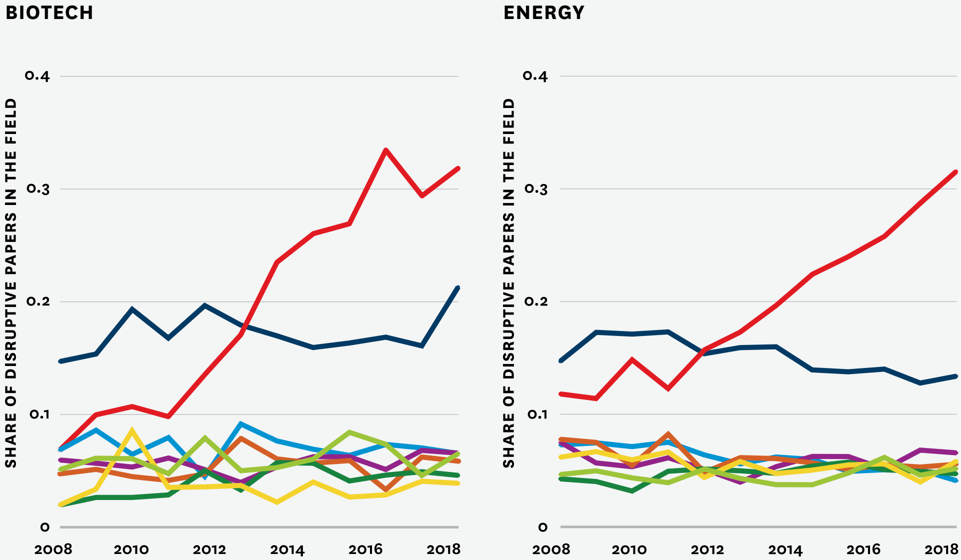


FIGURE 4-3. Since 2008 China has come to dominate disruptive scientific advances perceived as the beginning of critical research directions, with leadership differing by field and specific topics.

The United States retains global leads in interstitial areas that link other regions of critical research (e.g., social science that links AI and biotech), but is markedly less focused on emerging areas and prescient and disruptive research, which will shape technological leadership over the long term. For all figures, we note that changes in global shares are occurring in a context of absolute growth for all categories (including disruptive papers and for all major S&T contributors).

In interpreting these results, two factors are important to note. First, research by multiple Network authors documents a high rate of US-China collaboration (**box 4-1**), although those collaborations have recently stagnated. In 2018 China overtook the United States and Europe in the number of top 1% most cited papers; if all papers with both US and Chinese coauthors are removed, China first overtakes the United States in 2022. Including collaborations with US allies, such as Europe, the United States retains a greater number of the top 1% of most cited papers.

We also document a shift since 2010 in global sponsorship (funding) of the most cited and disruptive papers. The United States is the most critical research partner (in terms of coauthorship and funding) for other countries, but is less likely to fund the most disruptive and impactful domestic S&T research, especially in basic physical sciences and engineering.

We illustrate this with the case of post-CMOS technologies for semiconductors, in which the US and Chinese positions have reversed over the past decade. China now leads in most active post-CMOS technologies.

THE CASE OF POST-CMOS TECHNOLOGY DEVELOPMENT

We analyzed the 2022 *International Roadmap for Devices and Systems* (*IRDS*) report, which documents key post-CMOS technologies and a significant shift in dominance from the United States to China in emerging, prescient, and disruptive publications (**figure 4-4**).

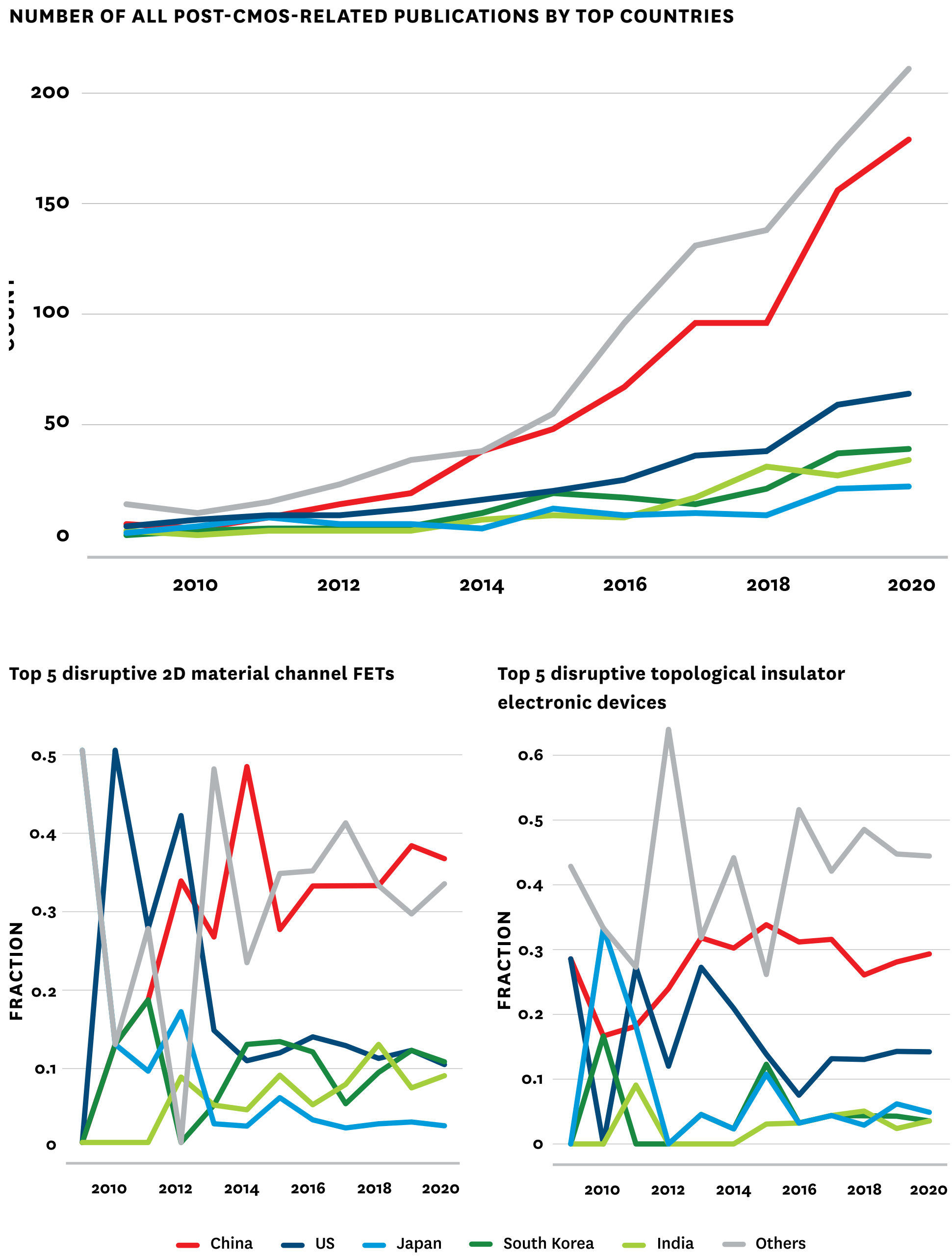


FIGURE 4-4. China has overtaken the United States in the number of beyond-CMOS semiconductor device publications (2010–20). Driving this trend, the beyond-CMOS semiconductor areas that have experienced the largest publication surge in the past 10 years are 2D material channel field effect transistors (FETs) (e.g., those based on graphene) and topological insulators. In both, the US and China have traded places, and China leads in terms of both the quantity and the disruptiveness of papers.

The two technology areas that illustrate this shift and have experienced the largest surge in the past 10 years are 2D material channel field effect transistors (FETs) (e.g., based on graphene) and topological insulators. While the United States retains a comparative advantage around publications on quantum physics applied to topological insulators, China has the greatest quantity of papers and the most disruptive papers across all subfields of 2D material channel FETs and other areas relevant to topological insulators. Nevertheless, US institutions still occupy the central position in the global collaboration network for beyond-CMOS.

FUNDING OF SCIENCE AND TECHNOLOGY

The quantity, direction, and nature (open-ended, mission-oriented) of scientific discovery and technology development as well as the associated human capital are foundational inputs to S&T outcomes. We examined (i) the degree to which national investments support and cultivate a diversity of US talent (using NSF investments as an initial case study) and (ii) how nongovernment investments (starting with foundations) may complement government funding in advancing discovery and commercialization of critical technologies.

Demographic Diversity in Funding and Outputs

The CHIPS and Science Act has been called "the most comprehensive effort in history to create opportunities in science and technology (S&T) for women, people of color, and other underrepresented groups" (Fechner 2022). In particular, the authorization to NSF, including the funding for a new Directorate for Technology, Innovation, and Partnerships, cites a specific mission to broaden participation in science and technology (S&T) (Sec. 10303).

Past research has shown that Black and Asian investigators are less likely to be awarded an R01 on the first or second attempt, Blacks and Hispanics are less likely to resubmit a revised application, and Black investigators who do resubmit have to do so more often to receive an award (Ginther et al. 2011). Past research has also shown that women in research teams are significantly less likely than men to be credited with authorship (Ross et al. 2022). Because grant funding (e.g., NSF, NIH) depends on publication track records, the lack of publication credit for women affects grant outcomes as well.

Our findings extend this research to show that, even when using publications and citations as a measure, the US scientific workforce and NSF funding of scientific work are not representative of the country's scientific talent (**figure 4-5**). The denominator in this figure is "other funded authors." To fully understand the potential loss of valuable talent, other populations should be considered, such as all authors, all those employed in S&T occupations, or all doctoral degree holders. Inclusion of baccalaureate degrees reveals even starker disparities; for example, women have been matriculating at higher rates than men for decades, but do not have parity in funding. Funding disparities have serious strategic implications for innovation, which is enhanced by both the engagement of geographically and demographically diverse researchers and collaborations of diverse teams.

Black and Latinx researchers and White women tend to bring a different topic profile to science and technology, and on teams, different perspectives combine to produce insights that are not equally obvious to everyone, potentially increasing the impact of technological innovations (Hamilton et al. 2012, Smith-Doerr et al. 2017, Hofstra et al. 2020, Kozlowski et al. 2022).

Finally, although we used citations throughout this work as a measure of scientific impact, citation counts themselves are not without bias. Our research shows that Black and Latinx authors and White women are undercited across all fields. Prestigious institutions reinforce dominant topic profiles and citation disparities, and minoritized researchers at these institutions are more likely to pursue traditionally White male topic profiles. Historically Black colleges and universities (HBCUs), Hispanic serving institutions (HSIs), and women's colleges amplify the participation (and topic composition) of minoritized scholars (**figure 4-6**). Research is clear on the bias that women and underrepresented minorities experience in the publication, citation, and funding decision-making processes.

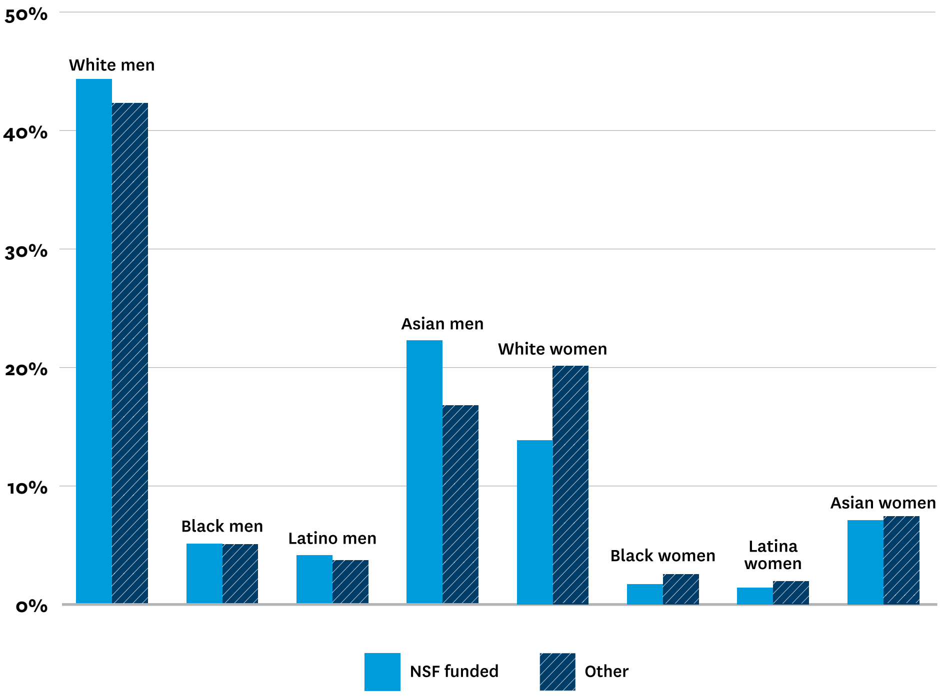


FIGURE 4-5. Distribution of authors by race and gender in NSF-funded and other articles, using an algorithmic approach described in Kozlowski et al. (2022).

Systemic and organizational change will be necessary to change these dynamics. More work is needed to understand which policies will have the greatest success in increasing the participation of women and minoritized groups in grants, and future CTA activities should carefully develop methods and data platforms, and perhaps experiments or scenarios to test the impacts of funding policies to increase such participation. A recent National Academies report also recommends that "Federal funding agencies, private philanthropies, and other grant-making organizations should provide increased opportunities for grants, awards, and other forms of support to increase understanding of how the policies, programs, and practices of…HBCUs and Tribal Colleges and Universities support students and faculty" (NASEM 2023, p. 9).

More than a decade ago a study recognized the higher probability of women and minoritized researchers having to resubmit proposals before getting funding, and suggested that assistance with the grants submission and resubmission process may be a policy lever for diversifying the scientific workforce (Ginther et al. 2011). NSF itself should explore how real-time tools on bias and best practices from decision sciences may help overcome biases in the review process.

NSF should also assess how the institutional portfolio for funding and deconcentration of funding across institutions may change the direction and rate of scientific outcomes to yield higher rates of engagement with minoritized scholars (particularly by increasing funding to minority-serving institutions). One experiment could be to leverage NSF grants to determine whether funding increases not only yield higher participation of minoritized groups but also increase productivity in, say, AI products and processes because of improved outcomes for a broader spectrum of customers. NSF's Committee on Equal Opportunities in

Science and Engineering (CEOSE 2023) has repeatedly stated that the United States needs an ADVANCE-like program for African American, Latinx, and Native American professors to yield any increase in grants, publications, and other indicators for those groups. If CEOSE's proposal is implemented, a CTA program could work with NSF to design the program to measure the impacts of these interventions.

Private Investment in Science and Technology

In terms of nongovernment investment, philanthropy and private seed funding are a unique feature of the US innovation ecosystem that could advantage the production of emergent and disruptive S&T and its commercialization. Before World War II, philanthropy was a major supporter of both higher education and scientific research in the United States; as public funding of science and technology grew after the war, philanthropic organizations reduced their support (NASEM 2020). In the past few decades, however, developments in technology and in the structuring of new and growing businesses have again been creating large individual fortunes, and private philanthropic giving to S&T research has been increasing as wealthy entrepreneurs turn from their businesses to social concerns (NASEM 2020). It is difficult to calculate a precise number, but our estimates suggest that philanthropy accounts for 15–25% of extramural R&D spending in the United States.

While the patterns characterizing US federal funding of S&T and university research are closely monitored (and the subject of spirited policy debates), understanding of the philanthropic ecosystem for S&T research is often limited to summary statistics provided by philanthropic sources and fails to account for the complete spectrum of philanthropic support for scientific institutions, making it difficult to characterize systemic patterns.

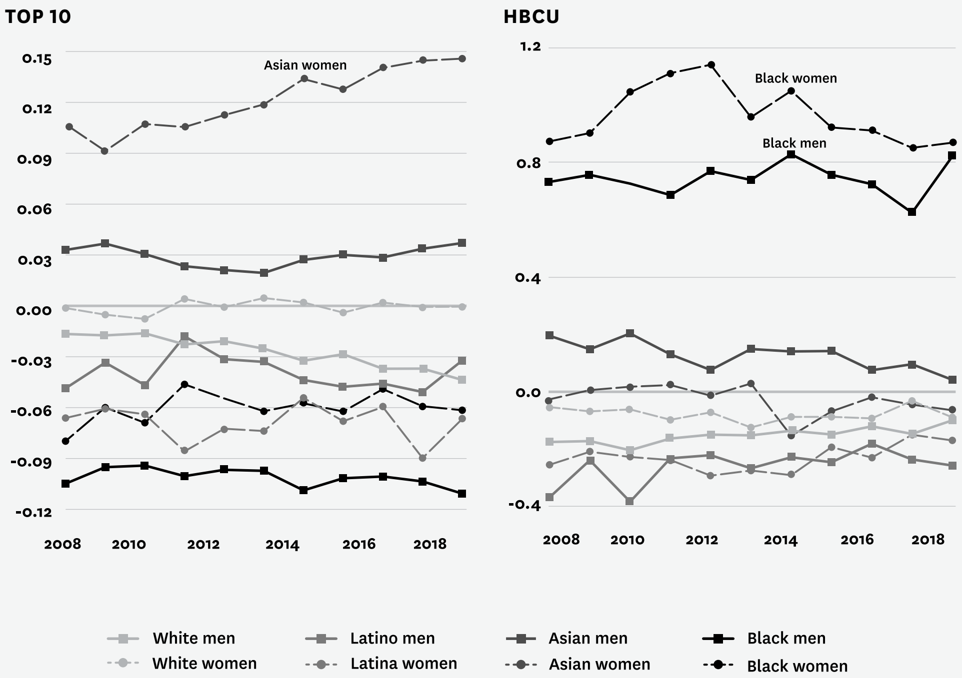
Philanthropy contributed up to 44% of basic research funding at US universities in 2016 and has been credited with the support of high-impact outcomes such as the work of Chemistry Nobel Prize recipients Frances Arnold and Jennifer Doudna. But much research tends to be limited to only the largest philanthropic gifts. In interviews by Joshua Graff Zivin and team, many foundations report funding risky research that federal agencies fund only later. Graff Zivin's work suggests that philanthropy generally invests in basic science and that its investment in critical tech is quite small and focused on AI, robotics, and data.

Options and Tradeoffs for the US Government

Our work begins to illuminate the vast array of information the United States could develop to guide its technology policy and strategic awareness toward enhancing its international leadership in science and technology. Analyses to date have relied on measures such as counts of publications; advanced modeling with high-quality data could enable much deeper understanding and foresight into not only the technical innovation landscape but also the policy options for advancing technological development. Infrastructure for such intelligence is extremely sparse, and creating a centralized database of US government-funded research to track outcomes will be a difficult task.

The United States could be a world leader in developing advanced infrastructure for monitoring and evaluation of scientific research and technological development. Such infrastructure requires long-term investment to build, maintain, and make accessible to analysts. For example, the National Center for Science and Engineering Statistics has maintained meticulous data on a narrow set of education and occupation measures in the S&T workforce since the 1920s, but these rich data are often not made available in a way that allows for integration across datasets or robust external analyses. As a result inferences and algorithms are used on variables such as race because, although these data are already collected, they are not made available in ways that allow for intersectional analyses.

Funding for related initiatives or expansions comes at the cost of long-term investment, not only to collect and maintain data on the S&T workforce, funding, or outputs but also to link them in ways that enable advanced analyses and strategic insights.



Those insights could guide US S&T policy to improve policy goals like efficiency and equity and maximize advances in strategic areas like environment, energy, health, AI, and semiconductors.

Our findings also suggest more direct policy options and tradeoffs. US S&T investment could evaluate its research portfolio to rebalance the distribution of risk, allowing more direct funding for higher-risk emerging and unexpected work with the potential to open up new areas. The United States could also target funding to younger and minoritized scientists, smaller and flatter teams, and high-risk collaborations between areas that correlate with emerging and prescient work near the innovation interface. We do not advocate US adoption of China's near exclusive targeting of specific S&T domains, as the United States still leads in global collaboration and its diverse domestic funding supports interstitial areas that will contribute to combinatorial advances in years to come. US educational and research funding needs to overcome its neglect of potentially high-performing women and minoritized scholars in computing and other areas in science, technology development, and commercialization.

Finally, our results suggest that philanthropy is playing a significant role in basic science and some role in critical technologies and early funding of riskier science. Although less is known about local foundation funding of regional ecosystems and commercialization-relevant activities, research shows that foundations' funding streams are generally locally concentrated and, as reported in their tax documents, support training programs, local incubators, and other physical infrastructure that could play a catalyzing role in commercialization and its location (Shekhtman et al. 2022). Dialogue and data on the size and scope of foundations' role throughout the S-curve (both basic science and technology commercialization) could help inform strategies for both public and private foundation funding so that, ideally, the two types of investment might complement each other.

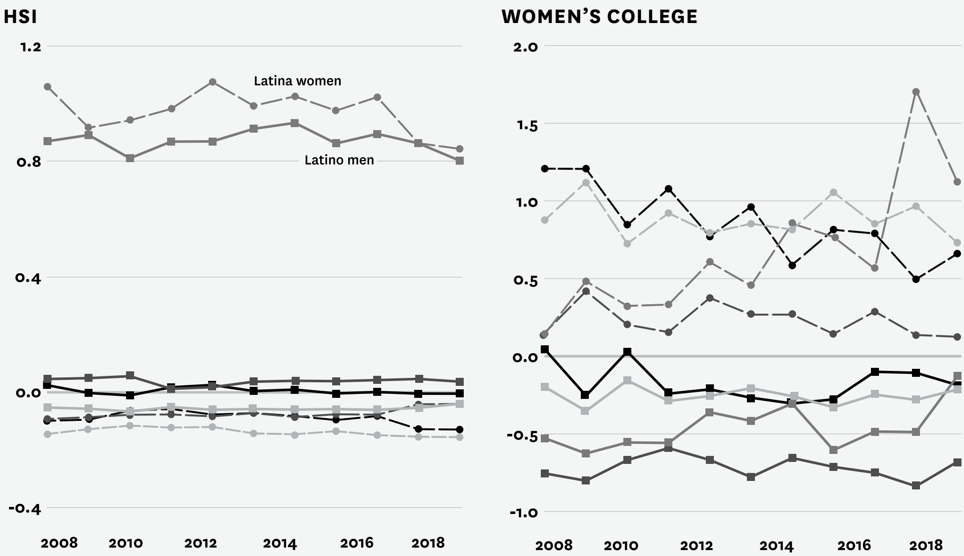


FIGURE 4-6. Authorship representation of racial and gender groups at different kinds of institutions, relative to their representation in the population, 2008–18. HBCU = historically Black college or university; HSI = Hispanic serving institution

Vision for Future Analytic Work

Future analytical and data-driven work on situational awareness could inform (i) national technology strategy by leveraging global S&T data linked across funders, researchers, and performing organizations; and (ii) the design and use of the most advanced analytical and predictive methods in order to

- validate bibliometric measures of prescience and disruptiveness with qualitative methods such as expert assessments.
- identify the current position, direction, and capacity of each national innovation system in terms of science, technology, and use in and impact on society.
- predict the future position, direction, and capacity of each national innovation system in terms of science, technology, and use in and impact on society.
- identify natural experiments in funding and focus that allow causal evaluation of R&D investments and organizations needed to yield sustained progress and leadership in areas critical to national prosperity and security.
- ongoingly evaluate the US portfolio of research investments, comparing S&T funding support across general and mission-driven agencies as well as nongovernmental sources, S&T areas, and the demographic distribution of funding recipients in order to advise on strategic investments to diversify the S&T workforce.
- identify natural and controlled experiments to unleash US talent, and harness international talent by expanding pathways to broaden participation in science, technology, and downstream development and commercialization.

This program will require a commitment to data infrastructure and continuous innovation in adapting emerging methods for inference and prediction to produce actionable S&T intelligence that guides more effective S&T policy. Open infrastructures will need to be built and supported in order to nimbly address contemporary issues, engage expertise, and make results available to all stakeholders. In the immediate future, we will better leverage the structured predictions of transformer models designed to forecast S&T futures and generatively simulate alternatives that could guide policy experiments and commitments. These and future efforts would support the development of a US S&T infrastructure that both informs and benefits from sustained leadership in the world.

It will be particularly important as this work proceeds to test and evaluate the quality of the relationship between the indicators and the underlying concepts. In the pilot year effort, the similarity in general trends revealed by the different indicators—each based on distinct underlying data—provides evidence that something real is being measured. Going forward, it will be crucial to evaluate in detail trends by S&T domain. For example, in the 1980s, it was initially not clear whether a rise in patenting indicated an increase in the rate of invention or changes in the patenting process itself. Researchers showed that the acceleration was present across essentially all fields of technology and concluded that this represented an increase in propensity to patent rather than an increase in invention. This example highlights the possibility of misinterpreting indicators and the importance of designing policy to stimulate desired outcomes, rather than indicator increase (Godin 2002, 2004).

Potential Broader Lessons for Critical Technology Assessment

Our first-year pilot demonstrated a number of striking potential early indicators "hiding in plain sight." By systematically analyzing data within and across scientific and technological areas and annotating valuable data from research artifacts (e.g., assaying metadata for countries, author identities, and funding agencies), our team generated insights contrary to conventional wisdom, pointed to new policy considerations, and illuminated critical tradeoffs. Some of these insights, such as China's growing strength in emerging critical S&T areas, flouted our expectations.

We believe that these pilot investigations have demonstrated the power that could be achieved through sustained investment in data linkage and analysis that takes advantage of emerging intelligence technologies and insights. Such analyses can clarify certainty and uncertainty to guide S&T investments and enable the United States to maintain its support of global public goods and a reservoir of diverse capacities while taking advantage of the new opportunities and combinations this capacity provides.

BOX 4-1

US and Chinese Research Depend on Collaborations

China's spectacular surge as a major economic and technological actor has raised concern in the West that the country could soon overtake Western advanced economies. An alternative view is that, absent democracy and freedom, China will not be able to fully transition from imitation-based growth to growth based on frontier innovation, and may even face the possibility of falling into a "middle income trap." Evidence suggests that China's research performance owes much to US collaborations. A main source of information on the scientific production of Chinese researchers and their coauthors is the Scopus bibliometric database, which covers 43,132 scientific journals, 78 million publications, and 16 million authors. **Figure 4B1-1** depicts the evolution since 2000 of the top 1% cited scientific publications for US and Chinese researchers. It also shows the number of top publications excluding papers with a "collaborator" from the other country, defined as a coauthor based in the other country or a coauthor based in the same country who previously published papers in the other country.

To provide more direct evidence of the dependence of Chinese research on US collaborations, information from the Scopus database is used to analyze how the China Initiative shock has affected the volume, quality, and direction of Chinese research. Launched in November 2018 by the Trump administration, the China Initiative was meant to "protect US intellectual property and technologies against Chinese Economic Espionage." In practice, it made administrative procedures more complicated and funding less accessible for collaborative projects between Chinese and US researchers, and some US-based researchers faced criminal investigations for lack of compliance with disclosure and funding regulations. The Initiative had a negative effect on the average quality of both the publications and coauthors of Chinese researchers with prior US collaborations. Moreover, this negative effect is stronger for Chinese researchers who demonstrated higher research productivity and/or worked in US-dominated fields and/or topics before the shock. Finally, Chinese researchers with prior US collaborations, in particular those in basic research, pulled away from US researchers after the shock. The fact that these Chinese researchers do not switch to new Chinese coauthors (or to coauthors from the rest of the world) suggests that a main beneficiary of the policy should be Europe.

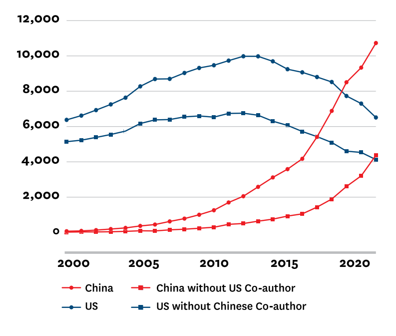


FIGURE 4B1-1. Chinese research hinges on US collaborations

This discussion draws from Aghion et al. (2023). Scopus data provided by Elsevier through ICSR Lab, subject to the license of CC-BY-NC-ND.