PIIE PETERSON INSTITUTE FOR INTERNATIONAL ECONOMICS

POLICY BRIEF

19-9 The Rise of Global Innovation by US Multinationals Poses Risks and Opportunities

Lee G. Branstetter, Britta Glennon, and J. Bradford Jensen

June 2019

Lee G. Branstetter, nonresident senior fellow at the Peterson Institute for International Economics, is professor of economics and public policy at Carnegie Mellon University, with a joint appointment at its Heinz College, School of Public Policy and Management, and its Dietrich College, Department of Social and Decision Sciences. **Britta Glennon** is assistant professor of multinational management at the Wharton School of the University of Pennsylvania. **J. Bradford Jensen**, nonresident senior fellow at the Peterson Institute for International Economics, is the McCrane/Shaker Chair in International Business and professor of economics and international business at the McDonough School of Business at Georgetown University. He has been affiliated with the Institute since 2003, serving as deputy director from 2003 to August 2007.

Note: The authors gratefully acknowledge financial support from the National Science Foundation through two grants: 1360165 and 1360170. The statistical analysis of firm-level data on US multinational companies was conducted at the Bureau of Economic Analysis (BEA), United States Department of Commerce, under arrangements that maintain legal confidentiality requirements. The authors thank Bill Zeile, Jim Fetzer, and Ray Mataloni for helpful discussions on the BEA data. All errors and omissions remain their responsibility. The views expressed are those of the authors and do not reflect official positions of the US Department of Commerce.

For decades, US multinational corporations (MNCs) conducted nearly all their research and development (R&D) within the United States. Their focus on R&D at home helped establish the United States as the unrivaled leader of innovation and technology advances in the world economy. Since the late 1990s, however, the amount of R&D conducted overseas by US MNCs has grown nearly fourfold and its geographic distribution has expanded from a few advanced industrial countries (such as Germany, Japan, and Canada) to many parts of the developing world, creating an innovation system that spans the globe.

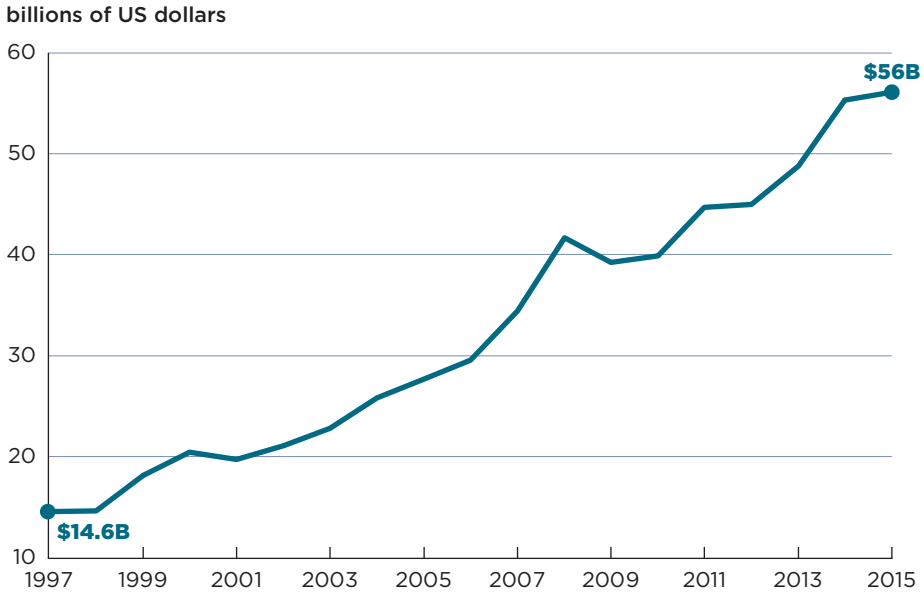
Like many aspects of globalization, including the offshoring of manufacturing over recent decades, the globalization of R&D raises concerns about US competitiveness and loss of technological leadership. At the same time, the spreading geographic location of innovation presents opportunities for US-based companies if the right policies are adopted to seize them. The research presented in this Policy Brief demonstrates, for example, that US innovators continue to remain involved in important ways in US MNCs' global R&D activities, and fears of the danger of hollowing out of US capacity to innovate—based probably on previous fears about the hollowing out of US-based manufacturing—may be overstated. Indeed, the large and growing pool of highly educated scientists and engineers in the developing world could increase the rate of global productivity growth, to the advantage of US-based companies and the world in general. Accordingly, a productive way to capitalize on the globalization of MNC R&D is not to oppose it but to combine emerging-market talent with MNC innovation experience.

This Policy Brief presents a statistical portrait of US MNCs' global innovation system and the technological, organizational, and labor market factors that have changed the system in the last two decades, as discussed in our previous research.[1] The evidence points to an international division of R&D labor akin to the well-documented global value chains in goods production, in which particular R&D activities are located in regions where innovation in those domains appears most efficient. As is usually the case when the benefits of specialization and gains from trade can be realized, this transformed system brings broad-based opportunities by increasing the innovative capacity of US companies. In the context of the productivity slowdown in the advanced industrial world, these benefits should be welcomed, as they appear to offer a plausible pathway to increase productivity growth.

Several challenges could limit these benefits from the globalization of R&D, however. The global rise of economic nationalism poses a potential risk to progress in this area, particularly if the United States retreats from international trade policy leadership, for example. The aggressive use of

1. This Policy Brief draws significantly on Branstetter, Glennon, and Jensen (2019 and 2018).

Figure 1
Growth in R&D expenditures by majority-owned foreign affiliates of US MNCs, 1997–2015



Source: Branstetter, Glennon, and Jensen (2019).

tariffs under the Trump administration is already signaling to companies that the US government no longer supports the internationalization of commercial activities. It may take years to measure the impact on global R&D activity with any precision, but it is not difficult to imagine current rhetoric resulting in a decrease in overseas R&D activity by US MNCs or, potentially worse, decreasing integration and collaboration between US MNCs' domestic R&D labs and their foreign affiliates.

In addition, some important developing countries are resisting effective protection of intellectual property rights and openness to foreign direct investment (FDI), preventing MNCs from taking full advantage of these nations' potential as R&D sites. As the locus of R&D effort shifts from manufacturing to services and digitally traded services become a greater component of global consumption, global trade in services must be liberalized to achieve progress in innovation. The global effort to restrict (or tax) international data flows is another potential impediment. Because movement of skilled workers is a vital element of this system, rising opposition to immigration is another risk. Finally, growing US-China tensions pose a special challenge because of the important role these two economies play in the system. Certain public policies are needed to strengthen intellectual property rights, encourage labor mobility, and liberalize trade in services so that innovation can flourish to improve living standards and fuel economic progress.

STATISTICAL PORTRAIT OF US MNCS' GLOBAL INNOVATION SYSTEM

US MNCs have substantially increased their R&D investment outside the United States

Total US R&D spending as a share of GDP increased slightly from 2.5 percent in 1999 to 2.7 percent in 2016.[2] Multinationals are an important driver of aggregate R&D spending in the United States.[3] Their share of total US R&D spending was 57 percent in 2015.[4] US MNCs play a disproportionately important role in driving innovation within the United States.

At the same time, US MNCs have dramatically increased their overseas R&D expenditures. Figure 1 shows that US MNCs' foreign R&D expenditures increased from nearly $15 billion in 1997 to over $55 billion in 2015. In some industries, the growth of overseas R&D has been especially striking. R&D expenditures by overseas affiliates in professional, scientific, and technical services increased by *more than a factor of 18* between 1999 and 2014, and the

2. World Bank, Research and Development Expenditure data, https://data.worldbank.org/indicator/GB.XPD.RSDV.GD.ZS?locations=US.

3. US Bureau of Economic Analysis (BEA) data, www.bea.gov/iTable/index_MNC.cfm. The BEA is our first principal source of data on US MNCs' global innovation system.

4. National Science Board (2018, chapter 4) and US Bureau of Economic Analysis, Activities of US Multinational Enterprises in 2015, https://apps.bea.gov/scb/pdf/2017/12-December/1217-activities-of-us-multinational-enterprises.pdf.

ratio of overseas R&D to domestic R&D by multinationals in this industry has increased from under 10 percent in 1999 to over 40 percent in 2015. While US MNCs' foreign R&D expenditures have increased dramatically, they still conducted about 83 percent of their R&D in the United States in 2015 (down from 92 percent in 1989).

The location of US MNC R&D outside the United States has undergone a pronounced geographic shift

US MNCs' foreign R&D is growing not only on the intensive margin (more spending in existing locations) but also on the extensive margin (conducting R&D in more locations), with an average firm conducting R&D in more places than before. Figure 2a shows a Herfindahl index for how concentrated R&D spending is by location. (A Herfindahl index of 1 would indicate all the R&D is being conducted in one location, presumably the United States.)

In 1989, US MNCs were conducting 74 percent of all foreign R&D in just five countries—the United Kingdom, Germany, Japan, France, and Canada. They were prominent R&D locations because of their historical importance as global centers of scientific research (and as lucrative consumer markets for US MNC products). By 2014, however, only 43 percent of all foreign R&D was being conducted in these five countries. Figure 2b shows the growing importance of new locations and the corresponding decline in the relative importance of traditional R&D hubs.

Many of these new hubs have only recently graduated from the ranks of developing countries, and two of the most important new destinations for US MNC R&D, China and India, still have relatively low per capita incomes. Most economists would see only the most advanced industrial countries as possessing a comparative advantage in innovation, so the shift in R&D investment away from traditional hubs appears to challenge traditional views of comparative advantage and economic development. The apparent paradox fades, however, as we examine the inner workings of the global R&D system. In the same way that multinationals have created global value chains that provide low-wage developing countries with the sophisticated inputs they need to manufacture and export technology-intensive products, US multinationals have created a kind of intellectual value chain that combines the raw engineering talent available in developing countries with sophisticated, specialized knowledge needed to produce frontier innovations for the global market. To see this intellectual value chain in action, we turn to our second principal source of data on US MNCs' global innovation system—patents—and use them to analyze the striking rise in cross-border research collaboration evidenced in patent documents from the US Patent and Trademark Office (USPTO).[5]

US patents reveal rapid growth in cross-border R&D collaboration

US patent law requires that applicants include the list of inventors and their addresses. This requirement implies that patents generated with substantive input from scientists and engineers employed by foreign affiliates of US MNCs will list the foreign addresses of those R&D personnel. Because we know the locations of R&D-performing affiliates around the world, we can match R&D investments made by US MNCs abroad with the patents those investments generate. This matching, however, revealed that many patents listing the addresses of foreign inventors also list the addresses of US-based inventors, suggesting that the patent in question is the work of an international team, collaborating across borders. Branstetter, Li, and Veloso (2015) refer to this phenomenon as "international coinvention."

Earlier research has already noted a rapid rise in international coinvention (Kerr and Kerr 2018; Branstetter, Li, and Veloso 2015). Figure 3 shows that the share of all US MNC patents, including those granted to foreign inventors, that has inventors from more than one country has increased from less than 2 percent in 1980 to more than 10 percent in 2014. For leading multinationals, this fraction is considerably higher. IBM inventors who reside outside the United States contributed to more than 36 percent of the company's 2015 patents.[6]

Further inspection reveals that international coinvention is especially prominent in the sharp rise of patents coming out of developing countries like India and China. Figure 4 tracks the rapid rise in USPTO patents granted to inventor teams with at least one member resident in China. Using information in patent documents, the figure identifies patents owned by multinationals in which all the inventors have Chinese addresses (depicted in orange) and those in which the inventor team contains both Chinese and non-Chinese addresses (depicted in red).[7] It is immediately clear

5. We restrict our analysis to USPTO patents for three primary reasons: (1) our sample is US multinationals, and the use of USPTO patents (2) ensures a common standard that is close to or at the global technological frontier and (3) allows for comparison across countries.

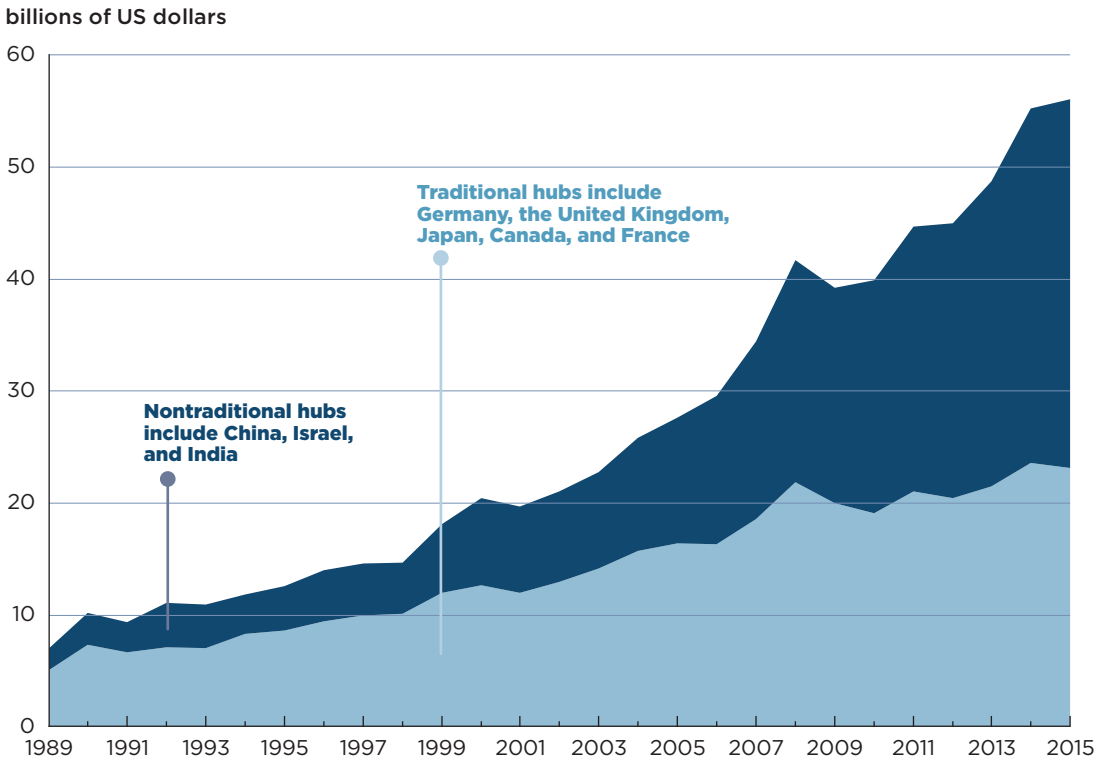
6. See IBM press release, January 13, 2016, www-03.ibm.com/press/us/en/pressrelease/48785.wss.

7. Figure 4 tracks patents assigned to all multinationals, not just those based in the United States. As it turns out, Taiwan-based multinationals generate even more US patent grants through their China-based R&D operations than US-based multinationals do. What is clear, however, is that much of China's recent rapid rise in US patent grants has been driven by the actions of foreign firms, not indigenous ones.

Figure 2a
R&D concentration index, 1999–2012

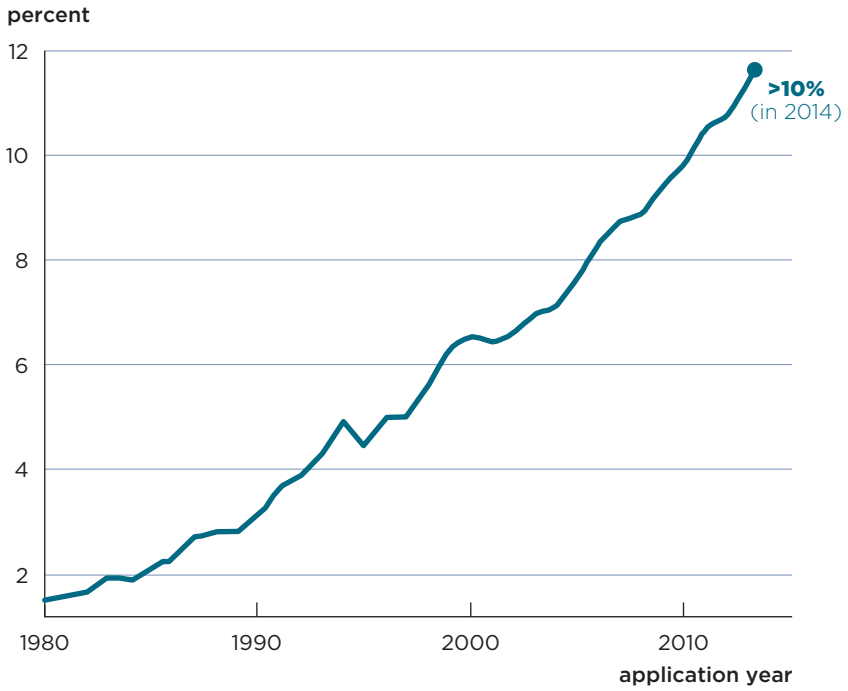
Note: A decreasing index indicates R&D activities are being conducted in more locations than before.

Figure 2b
R&D expenditures of US MNC foreign affiliates, 1989–2015



Source: Branstetter, Glennon, and Jensen (2019).

Figure 3
Share of US MNC USPTO patents with cross-border collaboration, 1981–2014



Source: Authors' calculations using confidential data from the US Bureau of Economic Analysis and US Patent and Trademark Office (USPTO).

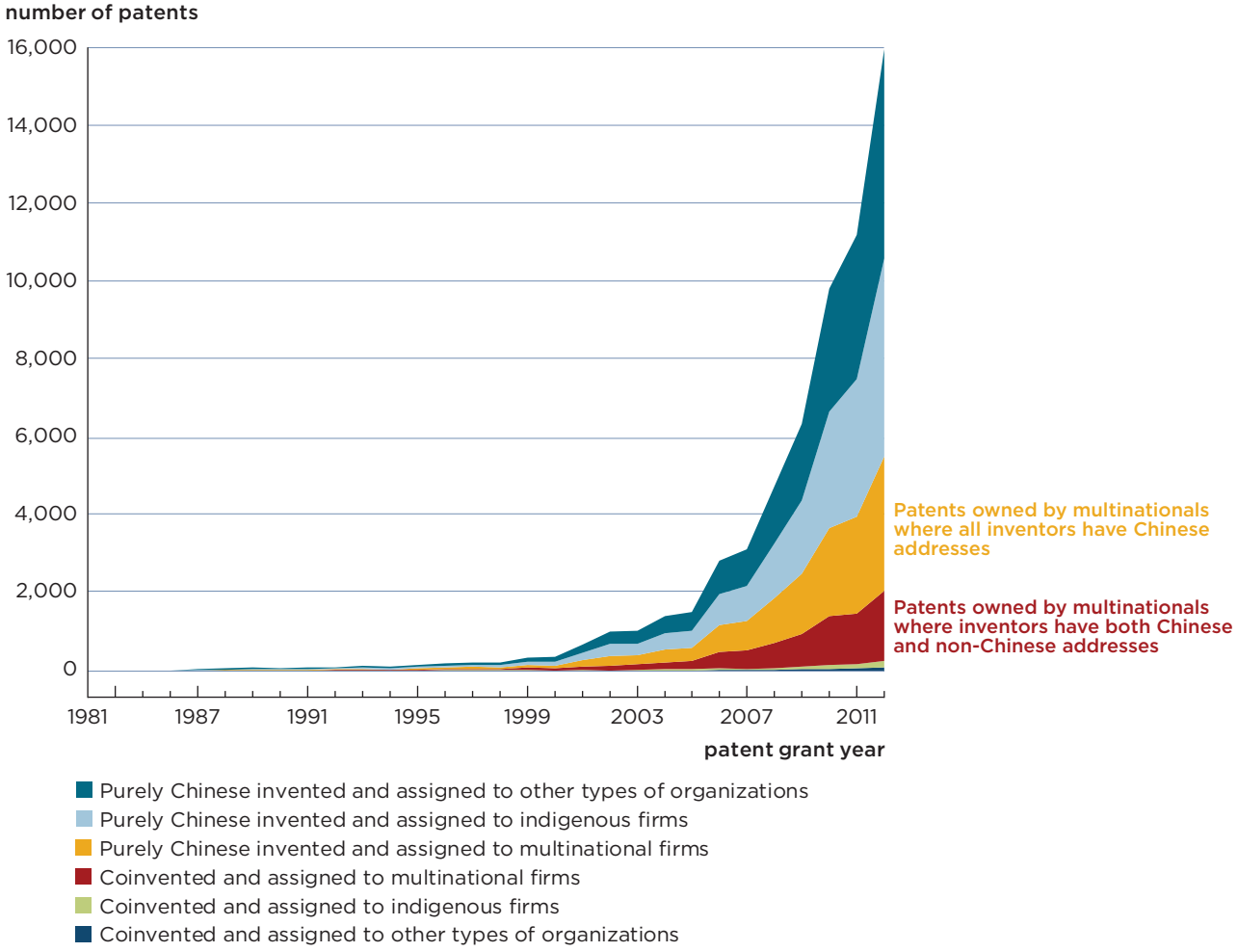
that the dramatic rise of USPTO patent grants to Chinese inventors was driven disproportionately by multinationals, with a conspicuously large role in patents generated through international coinvention. Branstetter, Li, and Veloso (2015) show that the patents owned by multinationals are of systematically higher quality than patents owned and generated by indigenous Chinese firms.[8] These authors introduce the idea that the intellectual inputs provided by the rest of the MNCs' global R&D system help make up for the lack of a sufficiently developed indigenous knowledge base in developing countries. In the same way that a developing country can export a complex product because it imports some of the most advanced components, an R&D center based in a developing country can contribute to innovation for the global market because local staff can "import" the R&D expertise of their colleagues who are often based in advanced industrial economies. The high-bandwidth communications technologies enabled by the global internet and, in some industries, the diffusion of design software explicitly engineered to facilitate collaboration by geographically distributed teams allow for a degree of remote collaboration that was impossible in the 1980s or early 1990s. Further, a series of interviews we conducted with R&D managers in US MNCs reveal that many of the firms with global R&D activities consciously try to create global innovation teams through intentional staff rotation, online collaboration, and other intrafirm networking activities. We believe that these efforts allow US MNCs to tap into the raw talent available in emerging markets in ways that they could not before, and this is a key factor in understanding the geographic shift in R&D activity that has taken place since the rise of the global internet.

Interestingly, international coinvention not only makes up for the initial absence of frontier innovative capabilities in emerging-market R&D centers but also, over time, can help build up those capabilities. Branstetter, Li, and Veloso (2016) follow clusters of patents generated by foreign MNCs operating in China within particular technological domains and show that these firms are very likely to rely heavily on foreign-based inventors at first, but, over time, the patents become more likely to be invented by teams of indigenous researchers.

They suggest that foreign MNCs use international R&D collaboration as a way of sharing advanced expertise

8. While not included here for reasons of space, Branstetter, Li, and Veloso (2015) show that US MNCs play an even more important role in generating US patents granted to teams with at least one Indian inventor than they do in the case of China.

Figure 4
Rise of coinvented and MNC-sponsored USPTO patents in China, 1981–2012



USPTO = US Patent and Trademark Office

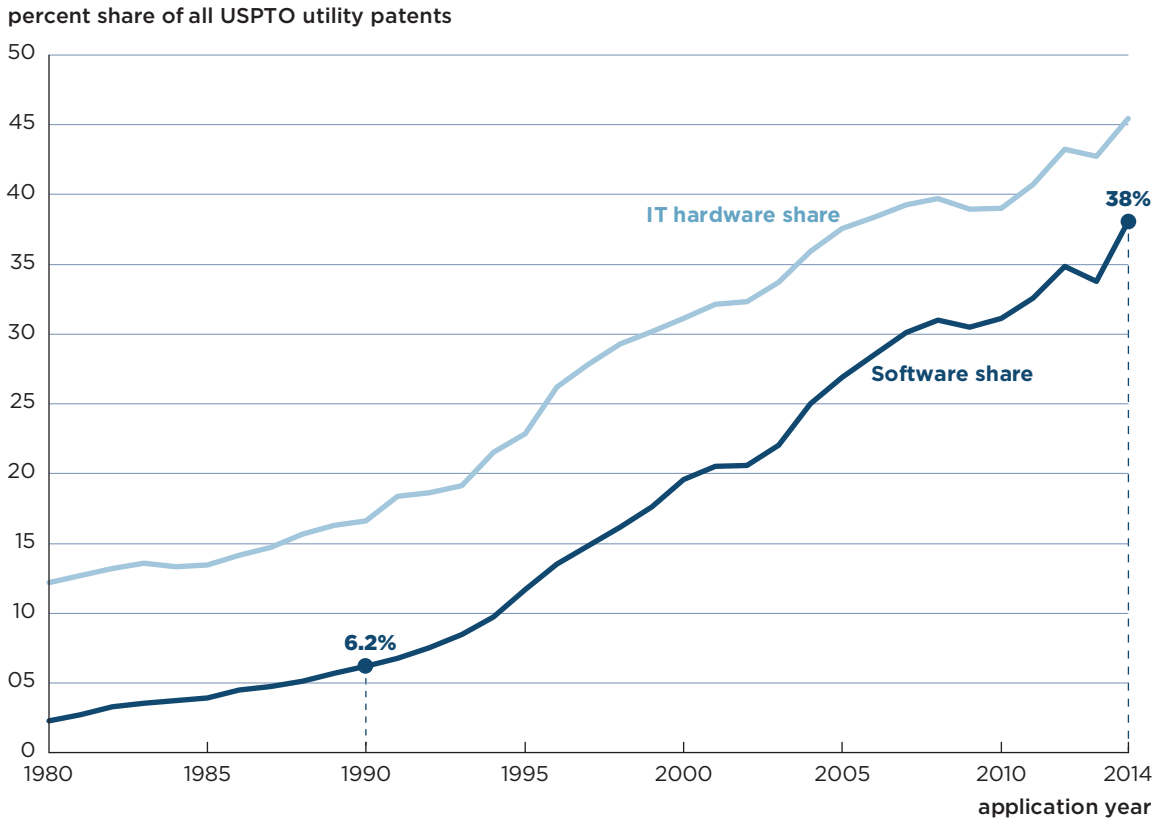
Note: This area graph is stacked. For example, there are 3,474 patents purely Chinese invented and assigned to other types of organizations, not 16,000.

Source: Branstetter, Li, and Veloso (2015).

with local Chinese teams. Over time, this expertise gets transferred to the local team, which becomes more intellectually independent, as evidenced by a decline in the number of foreign inventors appearing in patent documents generated by a given research stream.

We expand on this idea in Branstetter, Glennon, and Jensen (2018), using data drawn from all US multinational affiliates that consistently report R&D spending and patenting. We find patterns strongly consistent with the notion that the inception of new research streams in developing countries tends to be more reliant on intellectual input from US-based inventors than is the case in developed countries, though the degree of reliance on US input tends to converge over (long periods of) time. This work further builds out the notion of international coinvention as a mechanism for enabling MNCs to do frontier research in countries with limited indigenous capability for frontier innovation. Our interviews with R&D managers at US MNCs strengthen our interpretation of the declining significance of US inventors in the research streams of foreign affiliates. R&D managers and engineers describe the organizational structures and practices designed to promote knowledge sharing within the firm. International collaboration is deliberately enhanced through short-term personnel exchanges between more and less established R&D subsidiaries, and regular videoconferences help maintain these ties once the exchanges end. Internal systems track networks of expertise around the world, enabling research teams in one

Figure 5
Growth of software and IT hardware patents, 1980–2014



USPTO = US Patent and Trademark Office
Source: Branstetter, Glennon, and Jensen (2019).

location to find necessary expertise elsewhere within the system. All interviewees pointed to the growing capabilities of research teams in emerging markets.

Nevertheless, an examination of the patents generated by even mature, long-running research streams underscores the enduring centrality of US-based R&D facilities within US multinationals' global R&D systems. Patents generated by foreign research streams seem to show that the United States remains an important source of new ideas for all foreign hubs, even in the very long run and even in the most mature research streams. Our measure of reliance on US intellectual inputs generally does not fall below 30 percent, suggesting that those who worry that the globalization of R&D will eliminate demand for US-based engineers might be overly pessimistic. Our results are consistent with those of Macher and Mowery (2008). Arora and Gambardella (2005b) hold a similar view for the India case, arguing that the type of software work offshored to India is software production rather than software design, which continues to be located in the United States.

Innovation is now much more software/IT hardware intensive—and that has reinforced the globalization of R&D in two important ways

Software and information technology (IT) patents have been growing in importance since the 1990s; as figure 5 shows, the share of software patents in all USPTO patents grew from 6.2 percent in 1990 to nearly 40 percent by 2014. This growth is in aggregate, across all classes and firms, but in some industries, it is even more striking. More important than the simple fact that software/IT intensity in innovation is increasing is the evidence suggesting that firms that do not invest in software and IT are actually left behind. Arora, Branstetter, and Drev (2013) show that in the IT industry, the success of American IT firms relative to Japanese IT firms can be at least partially explained by their difference in software intensity. Japanese IT firms that were less software-intensive were actually less productive than their American counterparts; failing to invest more in software can harm a firm. Branstetter, Drev, and Kwon (2018) document that the importance of software is not limited to

the IT sector; they show that innovation in four traditional manufacturing industries (autos and auto parts, aerospace and defense, medical devices, and pharmaceuticals) has also become more software-intensive.; Furthermore, firms that took a more software-intensive approach to innovation outperformed their less software-intensive peers.

The increasing use of software and IT hardware in innovation is an important global technological development (Branstetter, Drev, and Kwon 2018). Engineers can now enhance product functionality increasingly through software engineering rather than mechanical, chemical, or electrical engineering. Decades of rapid advance in the computational power of microprocessors had, by the 1990s, created a suite of cheaper tiny computers that could be easily (re)programmed to direct the behavior of very different devices in increasingly sophisticated ways.[9] Advances in microprocessors were complemented by advances in sensors and digital control systems that made it easier for those electronic brains to alter the way these devices worked, often through rapid response to even fairly subtle changes in the devices' environment. As these trends advanced, software engineers built a steadily expanding menu of routines and subroutines in standardized languages that could be used and reused to direct the actions of different devices.

The economic literature on general purpose technologies (Bresnahan and Trajtenberg 1995, Helpman and Trajtenberg 1998) can help us think about these developments as a new wave of technological change. The suite of basic components that had "arrived" as early as the 1980s—microprocessors, sensors, memory, and digital control systems—was extremely broadly applicable, but every effective application required product- and industry-specific knowledge, embodied in the software that makes these standardized components work in fundamentally different contexts. So, firms across a broad range of industries needed to invest in IT and software engineering capabilities, and the intensity of this imperative increased over time.

The widespread use of software and IT in innovation has enabled and reinforced the globalization of R&D in two important ways. First, the inherently modular nature of IT hardware and software facilitates the division of innovative effort across multiple locations within an MNC. Because different components of a larger system fit together through standardized interfaces, product development of the components can take place simultaneously and, to some extent, independently. This capability allows multinational firms to decompose innovation in these domains into pieces that can be distributed to the location that can perform the R&D most efficiently. The emergence of modern telecommunications technologies centered on a global internet has enabled a richer, faster, cheaper exchange of data than was possible in earlier eras, and in some technological fields, software-enabled collaboration tools have been specifically developed to enable teams of engineers separated by distance to work on the same project. To put it differently, advances in IT and software have created technologies of collaboration that make cross-border R&D far more feasible. Then, a lead R&D center, possibly in the United States, can reassemble the constituent pieces to produce the full innovation.

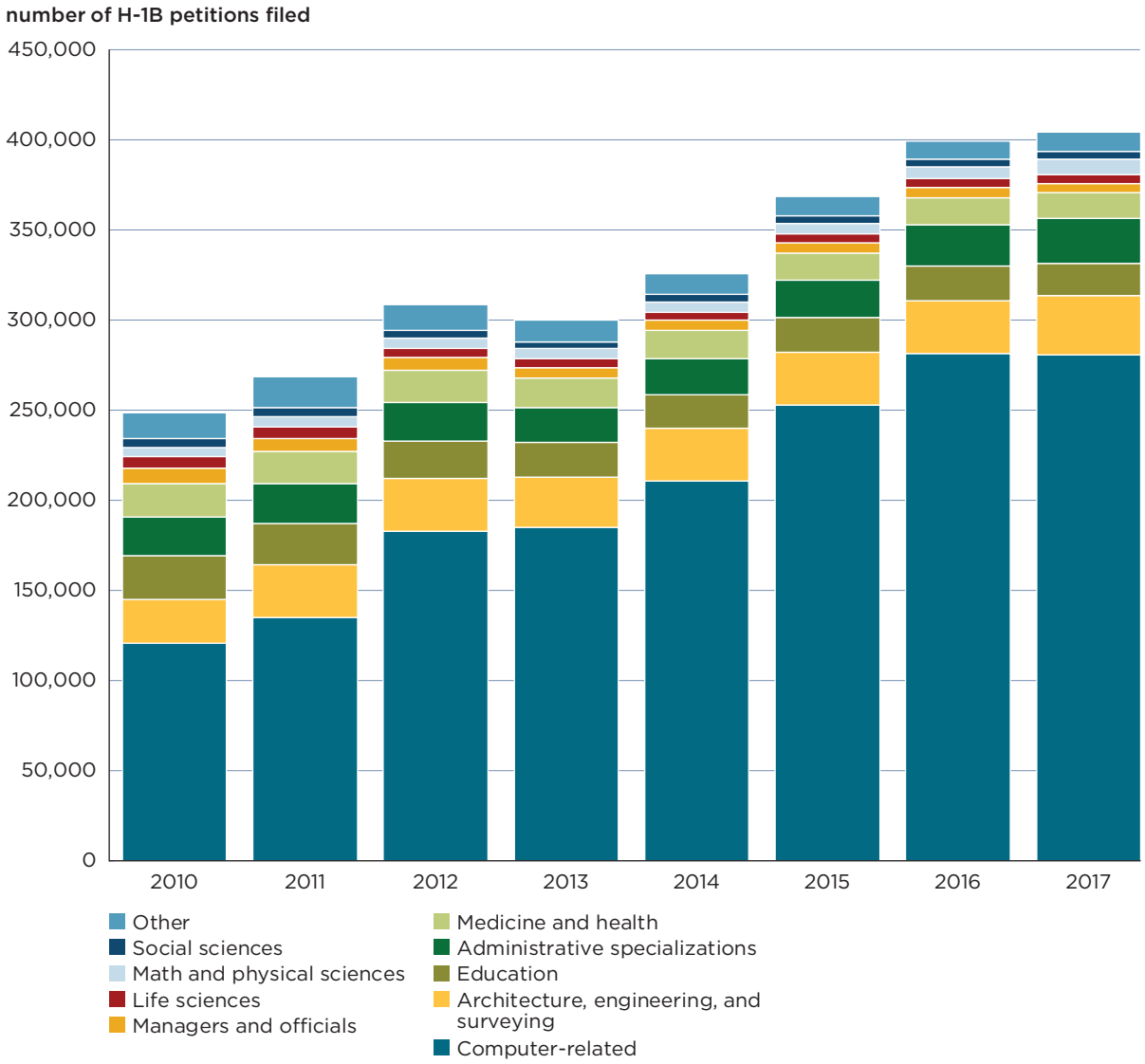
All of this suggests that technology has partly driven the globalization of R&D documented here—as IT hardware and software have become much more important parts of the R&D portfolios of US firms, research in these domains is inherently easier to distribute across countries, and modern telecommunications and computer-aided design technologies facilitate the dense exchange of information (i.e., data) necessary to support cross-border collaboration in R&D.

The second way in which the growing importance of software and IT in US innovation has contributed to the globalization of R&D is in the human resources required to realize the benefits of the IT revolution. As demand for IT and software engineers expanded in the 1990s, the United States began importing foreign engineers on a large scale. Bound et al. (2015) document the increase in high-skilled foreign-born IT workers in parallel to the rising importance of IT in the United States. According to the National Survey of College Graduates,[10] the US IT workforce, made up of programmers, computer scientists, and electrical engineers, grew by 112 percent between 1993 and 2010, while the overall US workforce grew by only 70 percent. The share of foreign IT workers in total IT workers grew from 16 percent in 1993 to 32 percent by 2010. The H-1B visa program for skilled workers was one of the mechanisms through which foreign engineers were brought into the US labor market. Figure 6 illustrates the extent to which this entire visa program has become dominated by workers in "Computer-related" occupations. The annual quotas (i.e., the maximum number of new H-1B visas issued every year to private sector firms) were raised during the internet boom of the 1990s. Arora, Branstetter, and Drev (2013) argue that the ability of American firms to access foreign-born software engineers enabled them to respond to technological opportunities much more effectively than their Japan-based rivals, reinforcing the speed and extent of the IT revolution in the United States.

9. Byrne, Oliner, and Sichel (2018) review the literature on rapid declines in the prices of semiconductor devices and show that these price declines continued through the 2010s.

10. National Science Foundation, National Survey of College Graduates, https://nsf.gov/statistics/srvygrads/.

Figure 6
H-1B petitions filed, by beneficiary occupation category, FY2010–FY2017



Source: US Citizenship and Immigration Services.

A closer examination of the countries supplying this talent suggests that the supply of technically skilled workers is abundant in many of the same countries—notably India and China—where we see a parallel increase in US MNC foreign R&D activity. In 2016, 62 percent of new H-1B visa applications were for Indians.[11] Indian and Chinese students combined earned 18 percent of doctorates in science and engineering from US universities in 2016,[12] and this share is even larger for some key disciplines. If we view the large number of Indian and Chinese students pursuing graduate education at American research universities as the extreme right tail of a distribution of science and engineering talent, most of which remains at home, then this suggests that a significant supply of software- and IT-trained human capital is available in China and India. Arora and Gambardella (2005a and 2005b) have also documented the abundant supply of engineering and technology graduates in emerging-market economies. Especially as H-1B visa quotas tightened in the 2000s, it made

11. USCIS Fiscal Year 2016 Annual Report to Congress, *Characteristics of H-1B Specialty Occupation Workers*, www.uscis.gov/sites/default/files/USCIS/Resources/Reports%20and%20Studies/H-1B/h-1B-FY16.pdf.

12. National Science Foundation, National Center for Science and Engineering Statistics, Survey of Earned Doctorates.

sense for US MNCs to broaden their activities in emerging markets where the needed human resources were available in relative abundance and at low cost.[13] In Branstetter, Glennon, and Jensen (2019) we explore the connection between IT and R&D globalization in greater depth. Figures 7a and 7b, taken from that paper, demonstrate that this connection extends beyond China and India.

Figure 7a illustrates the strong positive correlation between US firms' IT and software intensity[14] and their innovative activity in emerging markets.[15] Figure 7b shows the positive correlation between US MNC aggregate R&D activity in a country, obtained from Bureau of Economic Analysis (BEA) aggregate data, and a country's software and IT hardware intensity,[16] conditioning on country fixed effects. These two graphs together suggest that foreign R&D is most pronounced in IT/software-intensive countries and that it is most intensively done by IT/software-intensive firms.

R&D globalization allows US multinationals to tap into the different innovative strengths of different countries

The growth in R&D in "new hubs" has been a significant driver of the overall increase in overseas R&D spending, but traditional hubs remain an important component of the global R&D system created by US MNCs. R&D performed by US MNC affiliates in the new hubs of China, India, and Israel is concentrated in different industries than in the traditional R&D hubs. R&D by affiliates in Germany, Japan, Canada, the United Kingdom, and France is concentrated in traditional manufacturing sectors such as chemicals, food, and machinery, while R&D by affiliates in China, India, and Israel is in professional, scientific, and technical services (a category dominated by software engineering). Figure 8 presents the breakdown.

No particular hub completely specializes in one domain, and, as we noted earlier, US-based coinventors play an important role in the innovative activities of all hubs. Nevertheless, the data reveal a clear pattern of specialization, with US MNCs clearly focusing their R&D investment in ways that reflect the distinctive relative strengths of the countries in which they are investing. The ability to access this broad range of strengths through a global R&D system helps maintain the innovative dynamism of US MNCs.

R&D globalization could help end the global productivity slowdown

Maintaining—and, where possible, increasing—the innovative dynamism of US firms is especially important in light of the challenge posed by the global productivity slowdown (Syverson 2017; Byrne, Fernald, and Reinsdorf 2016). Despite hopeful talk by industry leaders and consultants of an imminent fourth industrial revolution, the available data suggest that the most important hallmark of past industrial revolutions—a significant and persistent acceleration in the growth rate of labor productivity—is still missing. Gordon (2016) argues that the productivity slowdown evident since just before the global financial crisis is only the beginning of a permanent deceleration in the productivity growth rate, a consequence, he argues, of the grim reality that no current or future inventions will have the same impact on human welfare as the "great inventions" of the 19th and 20th centuries.

Many knowledgeable commentators have dismissed Gordon's techno-pessimism, but leading economic theories of endogenous innovation suggest that Gordon's basic tenet has a core of truth—innovation is getting harder.[17] According to the widely cited model of Jones (2009), it is harder to innovate now because of the "burden of knowledge." Human technological knowledge has expanded dramatically, but every generation must first master the knowledge accumulated by previous generations before it can build upon that knowledge. As the amount of prior knowledge grows, it becomes more difficult to master. Increasingly, would-be innovators are forced to specialize in narrow domains of expertise, and innovation requires ever

13. Glennon (2019) quantifies the impact of tighter H-1B visa limits on US MNCs in the 2000s, showing that the tighter limits induced firms to expand knowledge-intensive activities abroad, especially in the countries that supplied a large portion of the H-1B labor force.

14. US firm IT and software intensity is measured as the firm's USPTO software or IT hardware patent stock, with software and IT hardware patents classified in the same way as described for country IT or software intensity (see footnote 15).

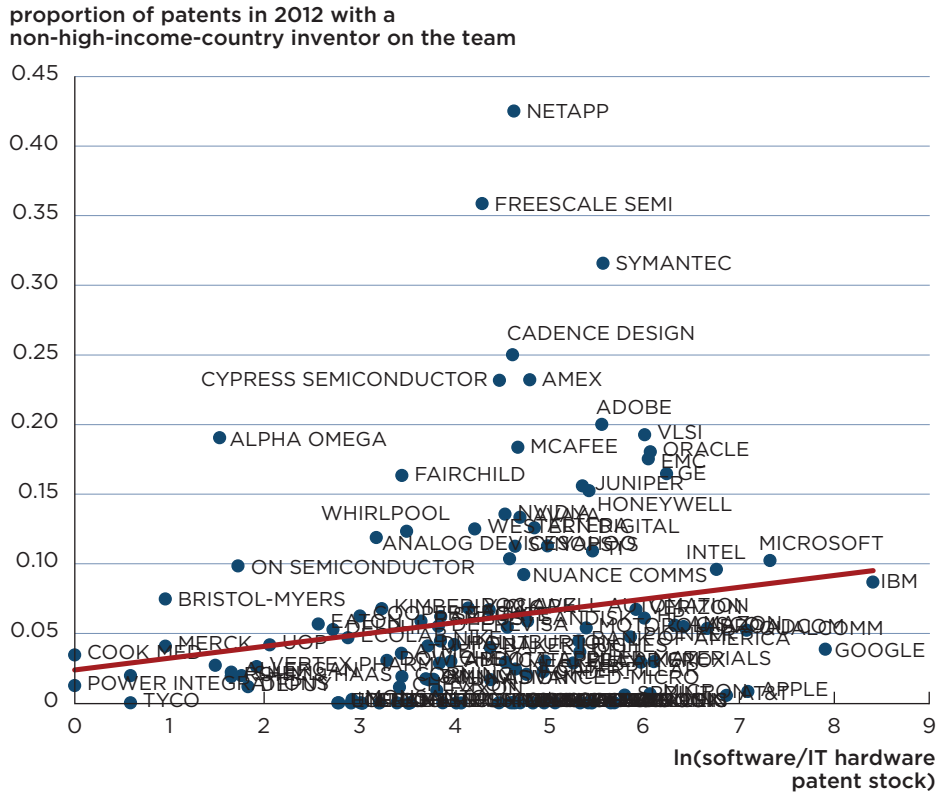
15. We define a firm's innovative activity in emerging markets as the proportion of its USPTO patents with an inventor from a non-high-income country, as classified by the World Bank (see note below figure 7a).

16. We define a country's software or IT hardware intensity as the share of its cumulative USPTO citation-weighted patent stocks classified as software or IT hardware. We determine the location of a patent using inventor addresses; if an inventor lists their address on a patent in country *j*, we define that patent as originating in country *j*. Software is defined using the Arora, Branstetter, and Drev (2013) methodology, and IT hardware is defined using the Hall, Jaffe, and Trajtenberg (2001) NBER technology classification. We define IT hardware as encompassing the following NBER technology classifications: 21 (communications), 22 (computer hardware and software), 23 (computer peripherals), 24 (information storage), 41 (electrical devices), and 46 (semiconductor devices).

17. For a more optimistic take on America's productivity growth prospects, see Branstetter and Sichel (2017).

Figure 7a

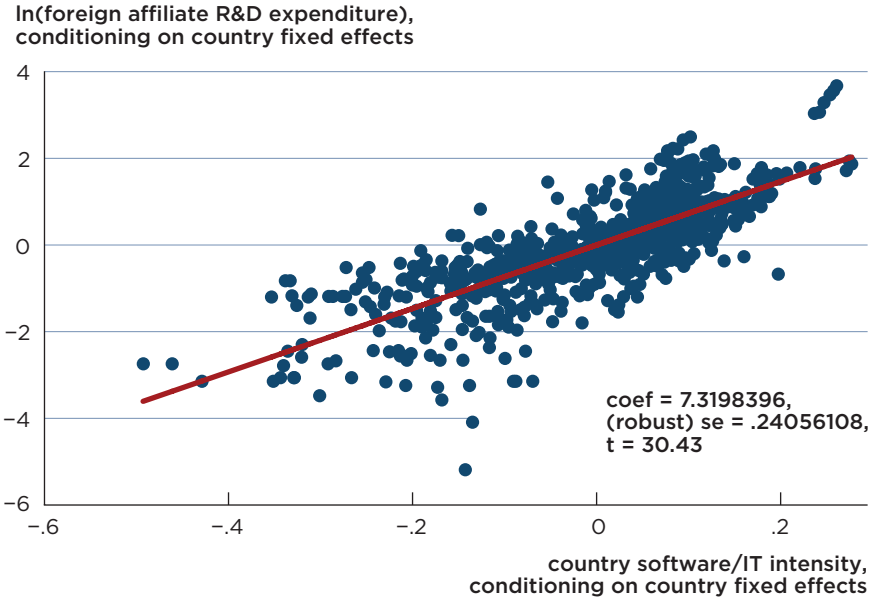
Figure 7a Correlation between US firms' IT and software intensity and their innovative activity in emerging markets



Notes: The sample contains all patents granted by the US Patent and Trademark Office since 1980. Figure shows firms with 100 or more patent stock. High-income countries as defined by the World Bank, https://data.worldbank.org/income-level/high-income.

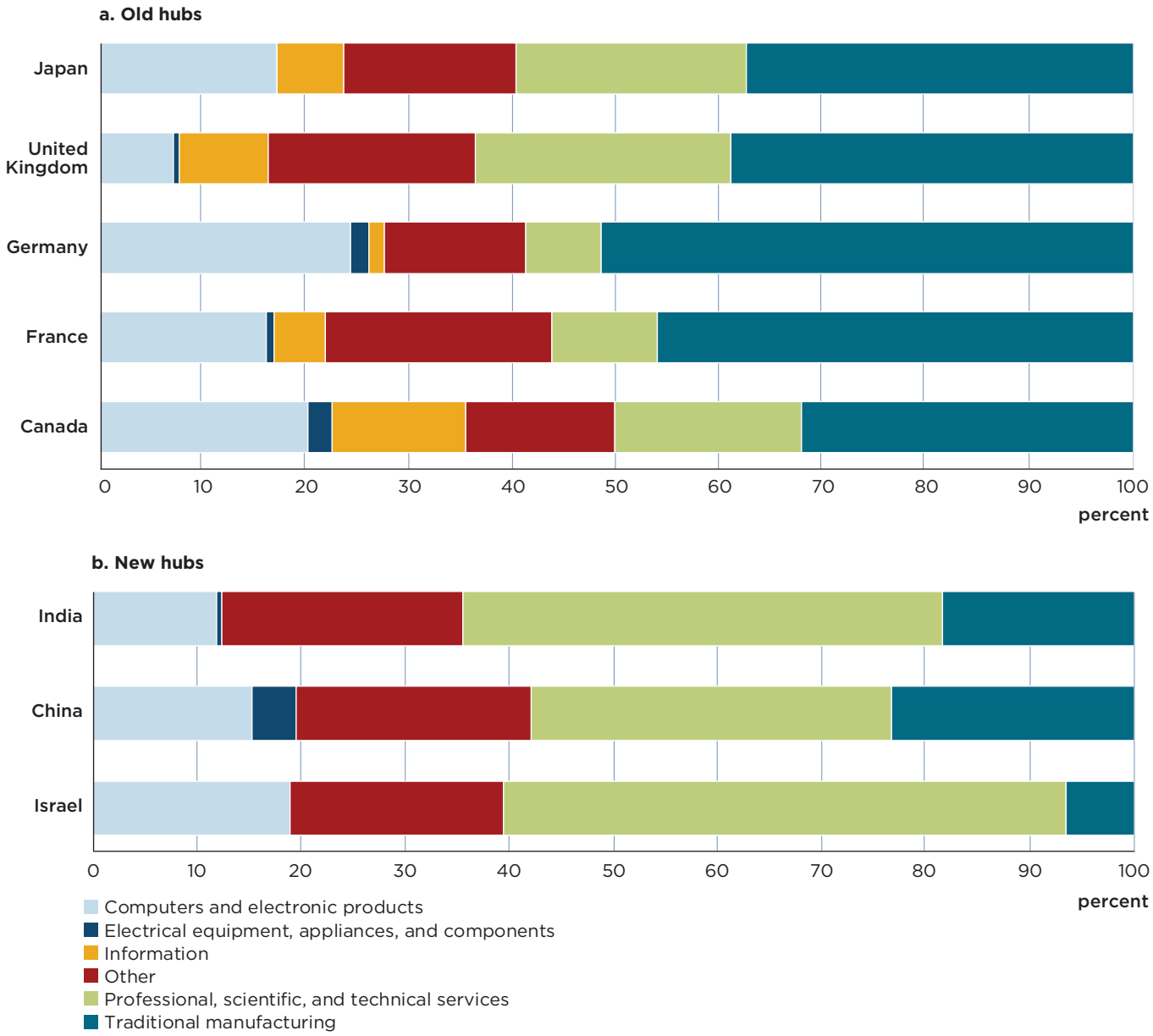
Figure 7b

Correlation between US MNC aggregate R&D activity in a country and that country's software and IT hardware intensity



Source: Branstetter, Glennon, and Jensen (2019).

Figure 8
R&D performed, by industry of affiliate, in 2014



Note: "Traditional manufacturing" includes chemicals, food, machinery, primary and fabricated metals, and transportation equipment. "Other" includes mining and trade.

Source: Branstetter, Glennon, and Jensen (2019).

larger and more difficult-to-manage teams that bring this expertise together. Jones (2009) presents persuasive evidence of these increasing costs, and Bloom et al. (2017) provide even starker evidence of apparent diminishing returns to innovative effort in advanced countries.

There is a silver lining in these pessimistic models of innovation, however: They all imply that the scale of investment in innovation matters, and the globalization of knowledge creation could be a powerful force for boosting productivity growth. A small number of mostly British engineers, tinkerers, and entrepreneurs produced the breakthroughs of the first Industrial Revolution. The second Industrial Revolution went farther and achieved more, because it could draw upon a larger pool of potential inventors that extended beyond Great Britain. This broader mobilization of Western inventive talent had its limits: The research technology of the era required collaborators to be in the same place at the same time. Innovation labor markets were, at best, national in scope, limiting the array of research teams that could be created. Human industrial advance still

rested on a narrow foundation, with most of the human race effectively excluded from participation.

Today, this situation is changing in a way that has important implications for future productivity growth. Higher education is spreading rapidly in emerging markets like China and India (Freeman and Huang 2015). In just the past dozen years, China expanded the number of bachelor's degrees it grants in science and engineering by about 300,000, to more than 1.3 million per year (National Science Board 2016). By contrast, the United States awards only about 250,000 bachelor's degrees in science and engineering per year. The average quality of an engineering education in China or India remains well below that of Western countries, and the ability of either China or India to innovate at the global technology frontier through the efforts of its indigenous firms is still limited (Freeman and Huang 2015). But multinationals have responded to this growing talent pool by ramping up the amount of R&D they undertake in emerging-market countries. With computer-assisted design software, internet videoconferencing, and the ability to quickly access terabytes of test data, it is now increasingly possible for Chinese and Indian engineers to collaborate closely, in almost real time, with seasoned technology experts in the United States, Western Europe, and Japan.

This combination of developed-economy technological experience and emerging-market talent appears to produce impressive results.[18] In a comprehensive study of US patents granted to teams that included at least one Indian or Chinese inventor, Branstetter, Li, and Veloso (2015) find that Chinese engineers working for foreign-based multinationals produced inventions in China that appear to be at least as good as the inventions produced by the same multinationals in their home countries. IBM or Intel engineers in China can be as productive as IBM or Intel engineers in Silicon Valley—and the number of good engineers in China is rapidly growing.

China is not the only emerging market where US multinationals are finding high returns to their R&D investments. Figure 9 presents results from a comparison of patent output across R&D sites. These results were obtained by regressing patents on foreign R&D expenditure by US MNCs, controlling for firm-country and year effects. The residuals from this regression were then regressed on country dummies, and the figure plots the coefficients of the country dummies.

This graph raises the possibility that the foreign engineers US MNCs can access through their global R&D systems could power an acceleration in the rate of productivity growth around the world.[19] Fernald and Jones (2014) estimate that about 1.3 percentage points of the average 2 percent annual increase in US labor productivity from 1950 to 2007 stemmed from higher research intensity (that is, a rising fraction of the population engaged in invention) in advanced countries. Research intensity outside the traditional developed economies is already increasing rapidly and will likely continue for decades. As investment in higher education spreads through the developing world, it is easy to imagine global research intensity doubling or more than doubling in coming decades. R&D globalization could help ensure that this growing global talent pool is utilized in the most efficient and effective possible way, maintaining the expansion of the global technology frontier even in the face of powerful economic forces that would otherwise slow that rate of expansion.

As Nobel laureate Paul Krugman (1992) once noted, productivity is not everything, but in the long run, it is *almost* everything. R&D globalization could be a key contributor to maintaining or increasing global productivity growth.

POLICY CHALLENGES TO THE GLOBAL INNOVATION SYSTEM

Over the past 20 years, the growing importance of software and IT has driven US MNCs to significantly increase the scale and scope of their R&D activities outside the United States. New R&D hubs like China and India are not only yielding high returns for US MNCs but also, as hosts of these R&D activities, benefiting directly from the innovation supported by US MNCs and indirectly from spillovers through technology transfers to local firms. The globalization of R&D activity, and the global innovation system it supports, has the potential to increase global productivity growth—a clear "win-win" opportunity for the world.

Yet, in spite of the promise this opportunity holds, a number of policy challenges threaten the continued health of the global innovation system.

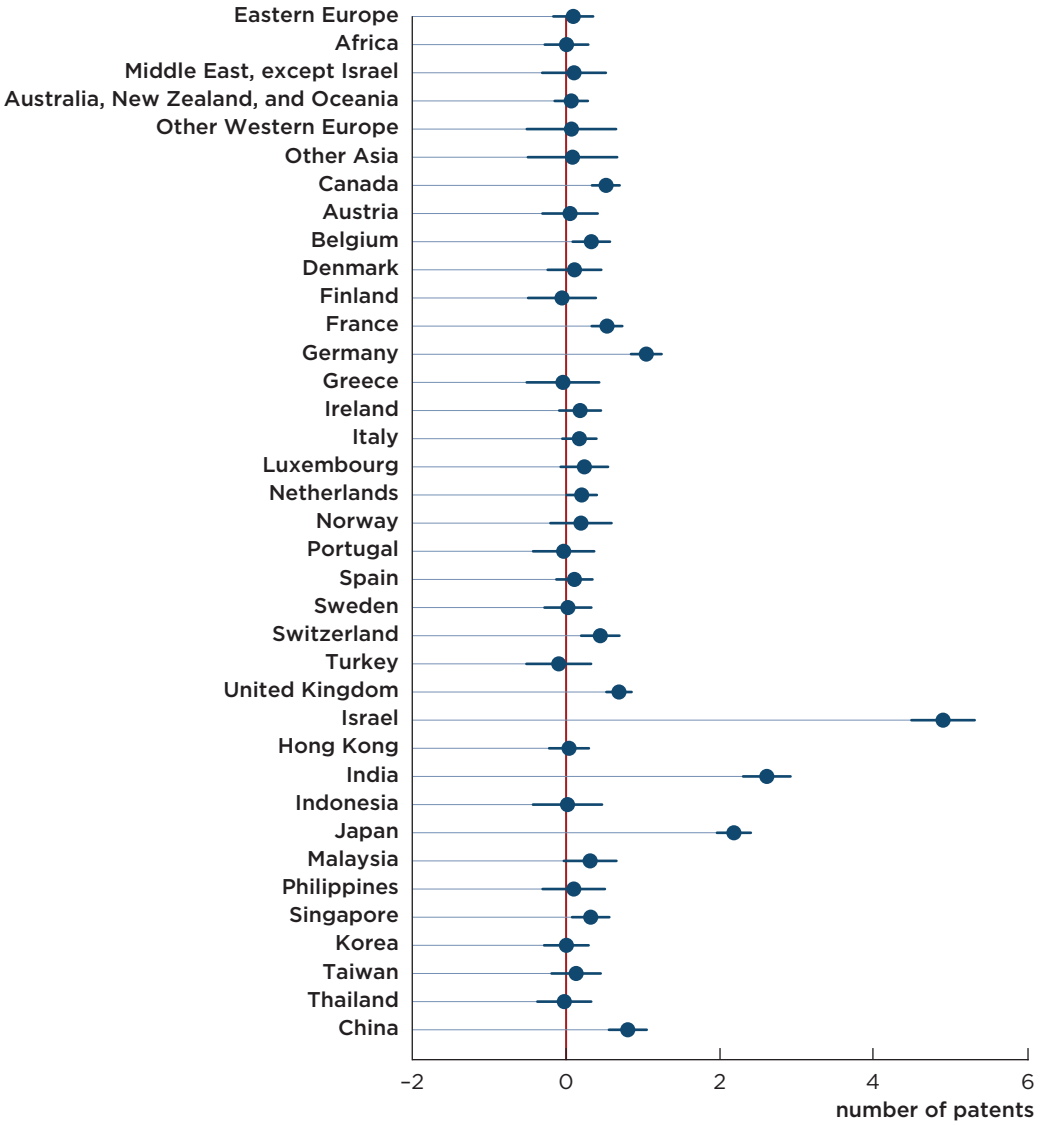
As already noted, the trade policies of the Trump administration increasingly pose a risk to the global innovation system. It may take years before data are available to measure the impact of these policies on global R&D activity, but the risk they will decrease cross-border collaboration is real.

We have also emphasized how critical skilled immigration is for the global R&D system. Immigrant engineers have long served as a human bridge between their American

18. For example, Hufbauer, Moran, and Oldenski (2013) report that US MNCs that do not perform R&D outside the United States also do not perform R&D within the United States, suggesting that foreign R&D and domestic R&D are complements, not substitutes, for US MNCs.

19. This paragraph draws from Branstetter and Sichel (2017).

Figure 9
Average additional patents per US MNC affiliate, by country/ region (controlling for affiliate R&D spending and year effects)



Source: Confidential data from the US Bureau of Economic Analysis and authors' calculations.

employers and the research communities in their former countries (Foley and Kerr 2013). While in the United States the moves to reduce immigration are largely those of the Trump administration,[20] the EU nations and Japan have long maintained relatively restrictive immigration policies, which hold back their own economic growth. A greater global commitment to (skilled) immigration and temporary movement would facilitate the development of a more global R&D system.

An ongoing concern is the protection of intellectual property. Prior research documents that stronger intel-

20. For example, President Trump signed a "Buy American and Hire American" executive order, directing government officials to "rigorously enforce" immigration laws. As a result, more H-1B and L-1 visa applications have been rejected, with rejection rates for H-1B visas actually tripling. Starting in April 2018, the Trump administration suspended premium processing of H-1B petitions subject to the visa cap. In November 2018, the administration introduced a new Labor Condition Application form requiring more information from companies applying for H-1B visas, which some believe might reduce interest in H-1B visas. The Trump administration is also proposing changes to the H-1B visa application process. These changes, at a minimum, increase uncertainty around the visa process.

lectual property rights in reforming countries attract more investment and more technologically intensive MNC activity (Branstetter, Fisman, and Foley 2006; Branstetter and Saggi 2011; Bilir 2014). The shortcomings of enforcement systems in China and India are particularly salient, because both countries have so much to contribute to human innovation through greater participation in a global R&D system. R&D managers we interviewed suggest that global MNCs would invest more in R&D-intensive activity in China if intellectual property were better protected there and technology transfers were not forced. Likewise, the unwillingness of the Indian government to enact pharmaceutical patent reform truly consistent with the Agreement on Trade-Related Aspects of Intellectual Property Rights (TRIPS) has gravely discouraged MNCs from investing in R&D in the Indian pharmaceutical industry. This is a major lost opportunity, given this sector's rising potential (Arora, Branstetter, and Chatterjee 2008). Strengthening intellectual property rights around the world would foster a more robust global innovation system.

The importance of telecommunications infrastructure and the global internet cannot be emphasized enough. The global innovation system depends on the free flow of data between R&D facilities of MNCs and restricting it (for example, forced data localization) poses a serious threat. A greater global commitment to the free flow of data would ensure a robust global R&D system.

The last challenge is the emerging Western response to an increasingly authoritarian and ambitious China. China is an important destination for US MNC R&D and an important supplier of scientists and engineers to the US education system and US firms. The Trump administration has sought to limit technology transfers and exchange of researchers (e.g., by limiting visas to Chinese engineers) in a series of policies that look increasingly like an attempt to decouple the US and Chinese economies. This Policy Brief does not assess the relative merits of a US policy of economic engagement with China versus a US policy seeking to isolate it economically. But a major bipartisan shift is under way with regard to how best to engage (or not) with China in the hopes of incentivizing changes in its political and economic behavior. It is difficult to foresee how the economic relationship between China and the United States will evolve, but the current direction will likely harm the global R&D system. The potential costs and benefits of having China inside the global innovation system should be carefully weighed in any reassessment of these policies. Branstetter (2018) outlines a series of policies that could provide a useful response to the challenges China presents, while maintaining a significant degree of economic integration.

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