Is China Catching Up to the United States in Innovation?

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If China is only a copier, then the risk to advanced economies is limited. But if China is more like the "Asian tigers" that rapidly evolved from copiers to innovators, the threat is serious.

One of the most important economic questions facing advanced nations is, how innovative is the Chinese economy? For those in the "China cannot innovate, they can only copy" camp, Europe, Japan, and the United States should stop worrying about issues such as intellectual property theft, forced technology transfer, and massive subsidies to Chinese technology companies because China is not an innovation challenger. For those in the "China is rapidly following the path nations such as Japan and South Korea took to become global innovation leaders" camp, advanced economies need to raise their game, including stepping up efforts to roll back Chinese innovation mercantilism. Whether China's economy is innovative has critical implications: If China is only a copier, then the risk to advanced economies is limited. But if China is more like the "Asian tigers" that rapidly evolved from copiers to innovators, the threat is serious. As those nations became more innovative, they took market share from leading companies in Europe and the United States. There is no reason to believe China will not follow the same path—only with significantly greater impacts because the Chinese economy is massive, Chinese policies are more aggressively mercantilist, and it is much more difficult to get China to compete fairly.

ASSESSING CHINESE INNOVATION PROGRESS

A thorough examination and answer to the question of current and future Chinese innovation capabilities is beyond the scope of this report. However, by examining 36 indicators of China's scientific and technological progress vis-à-vis the United States a decade ago versus today, it is possible to get a sense of where China is making the most progress, and to what extent it is closing the innovation gap with the United States. Indeed, China has made progress on all indicators, and in some areas it now leads the United States. In fact, in an average of all the indicators, China has cut the gap to the United States by a factor of 1.5 from the base year to the most recent year. (For example, had China been 80 percent behind the United States a decade or so ago, it would be just 50 percent behind in the most recent year.)[1] In other words, in the span of about a decade, China has made dramatic progress in innovation relative to the United States.

This report briefly highlights Chinese government goals and policies to become a world innovation leader. It then reviews the claims skeptics make about China's ability to innovate—arguing that, for the most part, their definition of the term "innovation" is too narrow—and reviews arguments and evidence supporting the claim that China is successfully innovating. Finally, the report presents the 36 indicators.

Nations that put their mind to it can move from being copiers to innovators. China has put its mind and heart and soul to not just being an innovator, but to being, in the words of Chinese president Xi Jinping, "master of its own technologies."[2] When that is backed up with a powerful, unfair arsenal of state policies, it is extremely irresponsible to blithely ignore this challenge under the hopeful belief that China will fail. As the saying goes, it is better to be safe than sorry.

CHINESE GOALS AND POLICIES TO BECOME A WORLD INNOVATION LEADER

China is attempting to follow well-worn paths other developing Asian economies have followed to become innovation leaders. As Linsu Kim wrote in his definitive history of Korean-innovation upgrading, *Imitation to Innovation: The Dynamics of Korea's Technological Learning*, there are several distinct stages a nation that is catching up to the leaders in innovation usually takes. The first stage involves the transfer of foreign technology to that nation—sometimes by foreign direct investment, sometimes by licensing, and often, as in the case of China, by theft. The second stage involves "the effective diffusion of imported technology within an industry and across industries is a second sequence in upgrading technological capability of an economy."[3] The third stage "involves local efforts to assimilate, adapt, and improve imported technology and eventually to develop one's own technology. These efforts are crucial to augmenting technology transfer and expediting the acquisition of technological capability. Technology may be transferred to a firm from abroad or through local diffusion, but the ability to use it effectively cannot. This ability can only be acquired through indigenous technological effort."[4] The final stage is to become global innovation leaders. As Lim wrote:

> Firms in catching-up countries that have successfully acquired, assimilated, and sometimes improved mature foreign technologies may aim to repeat the process with higher-level technologies in the transition stage in advanced countries. Many industries in the first tier of catching-up countries (e.g., Taiwan and Korea) have arrived at this stage. If successful, they may eventually accumulate indigenous technological capability to generate emerging technologies in the fluid stage and challenge firms in the advanced countries.[5]

China's first step was to attract foreign investment. In the early 1980s, when Deng Xiaoping opened up the Chinese economy to foreign investment, its main economic development strategy sought principally to induce foreign multinationals to shift relatively low- and moderate-value production to China.[6]

China's second step was to attempt to learn from foreign companies, in part by having them train Chinese executives, scientists, and engineers, and also by forced technology transfer. Since roughly 2000, when China joined the WTO, it has deployed an array of unfair tactics, including currency manipulation, massive subsidies, and limits on imports in order to both attract foreign establishments and support domestic manufacturers. As ITIF and others such as MIT's David Autor have shown, this has cost the United States millions of manufacturing jobs.[7]

The third step was to support Chinese companies in their efforts to copy and incorporate foreign technology while building up domestic capabilities. One important marker for the transition from stage two to stage three was the publication in 2006 of "National Medium- and Long-term Program for Science and Technology Development (2006–2020)," which called on China to master 402 core technologies—everything from intelligent automobiles to integrated circuits and high-performance computers. China moved to a "China Inc." development model of indigenous innovation, which focused on helping Chinese firms, especially those in advanced, innovation-based industries, often at the expense of foreign firms.

The fourth and final step was to enable Chinese firms to be independent innovators—as Japan, Singapore, South Korea, and Taiwan have all become. China is attempting to do this through an array of plans and policies: "13th Five-Year Plan for Science and Technology," "13th Five-Year Plan for National Informatization," "The National Cybersecurity Strategy," and, of course, "Made in China 2025 Strategy." For instance, with regard to ICT-enabled manufacturing, the strategy calls for 80 percent domestic market share of high-end computer numeric-controlled machines by 2025; 70 percent for robots and robot core components; 60 percent for big data; 60 percent for IT for smart manufacturing; and 50 percent for industrial software.[8] Transitioning from "fast follower" to "global leader" in innovation is extremely difficult. And while China is close in some areas such as telecommunications equipment, it is much farther away in others such as biotechnology and semiconductors. But that is not for lack of trying.

The core insight needed to understand the Chinese economic strategy is as follows. China attaining global competitive advantage in virtually all advanced manufacturing industries requires significant "learning," as the production "recipes" to make, for example, a wide-body jet, a computer chip, a genomics sequencer, a robot, or a biotech drug are incredibly complex and cannot be obtained from scholarly journal articles or other widely available sources of technical knowledge. The United States gained competencies and leadership in these and a host of other industries the hard way: trillions of dollars of investment in R&D, production testing, workforce training, and other areas in order to master incredibly complex products and production systems. The Chinese government knows that if it proceeds the fair and "natural" way that it will take it many decades or more to seriously close the innovation gap with the global leaders. Most of their firms and universities are just far behind to be able to seriously catch up any time soon through organic and fair means. Hence, it has embraced a multifaceted set of policies and programs to obtain the knowledge it needs from foreign producers; including through theft of intellectual property, forced joint ventures and technology transfer as a condition of market access, and state-subsidized purchases of or investments in foreign advanced industry firms. And once it obtains the technology it then proceeds to lavish subsidies and other benefits on its Chinese business champions so they can advance and scale up before ultimately challenging foreign producers in non-Chinese markets.

It is important to understand that the challenge to advanced nations' leadership in technology-based industries is much different than the process of losing more commodity-based, low-skilled industries.

Even after China has gained global market share in a number of extremely complex, advanced technology industries such as jet aircraft, high-speed rail, solar panels, personal computers, supercomputers, telecommunications equipment, and Internet services, many will still dismiss China's capabilities and assume China will be incapable of even partial success meeting their aggressive MIC25 goals. While mastery of some particularly complex technologies such as semiconductor logic circuits remains a challenge for China, Chinese companies have made significant progress in an array of other technologies, including in some kinds of semiconductors (e.g., chips for devices connected to the Internet of Things). Moreover, the fact that nations such as Japan in the 1960s and 1970s, and Taiwan and South Korea in the 1980s and 1990s could rapidly progress to become advanced technology economies, using similar kinds of approaches (obtaining foreign technology and subsidizing and protecting domestic innovators until they are strong enough to compete on their own) suggests there is nothing inherently keeping China from making similar progress, especially given the massive amount of government support for the effort.[9] Given China's Made in 2025 plan, coupled with unfair mercantilist policies, it is no exaggeration to suggest that, without aggressive action, leading economies such as Europe, Japan, Korea, and the United States will, within two decades, likely face a world wherein their advanced industry firms face much stiffer competition and have fewer jobs in industries as diverse as semiconductors, computers, biopharmaceuticals, aerospace, Internet, digital media, and automobiles.

WHY THIS MATTERS

It is important to understand that the challenge to advanced nations' leadership in technology-based industries is much different than the process of losing more commodity-based, low-skilled industries to China in the 2000s. If, for example, the value of the U.S. dollar were to fall far enough in relation to the yuan, it is possible America could regain a not-insignificant share of the production lost to China in industries such as textiles and apparel, furniture, metal parts, and other similar low- and medium-value-added products. Companies could simply buy machines, set up factories, and restart production in the United States in a cost-effective way. But if America's technology companies were put out of business, no currency decline could bring them back because competitiveness in technology industries is based less on cost and more on a complex array of hard-to-recreate competencies at both the firm and ecosystem level. For example, a firm could not simply buy some semiconductor equipment and start producing chips (if they could, China would be much farther ahead in this industry). One reason is the process of production is incredibly complicated: There are over 1,000 steps involved in making a dynamic random access memory (DRAM) chip, for example. Gaining market share requires not just machines, but deep and complex tacit knowledge embedded in the firm in workers (from the shop floor to scientists to managers) coupled with an innovation ecosystem (universities training the right talent, a network of suppliers, etc.). Gaining market share also requires the ability to produce at a loss for many years until they gain the competencies and scale to effectively compete in the global marketplace—something the U.S. economic system is largely incapable of doing. In short, once advanced industry capabilities are lost, they are essentially gone; almost impossible to resurrect without massive government intervention.

There is an additional reason why losing advanced tech industries is problematic. Most technology-based industries have high barriers to entry. In contrast to, say, the T-shirt industry, wherein entry largely requires simply having enough capital to buy sewing machines, entry into innovation-based industries requires both physical and intellectual capital. In an industry such as semiconductors, for example, firms often spend billions of dollars developing technical capabilities to enable production. Producing the first chip of a particular generation is incredibly expensive because of the amount of R&D involved, and the machines needed to scale up. Producing the second chip is much cheaper because only material and labor costs are involved. In this sense, fixed costs are extremely high, but marginal costs are low. In these innovation industries, losing market share to unfairly competing firms supported by their innovation mercantilist governments means two things. First, sales fall. This is true because global sales are largely fixed (there is only so much demand for semiconductors, jet airplanes, and other similar advanced products), and if a mercantilist-supported competitor gains market share, the market-based competitor loses share. Second, because profits decline more than sales, it is now more difficult for the market-based innovator to reinvest revenues in the next generation of products or services, meaning the mercantilist-supported entrant has an advantage in the next generation of products. This can lead to a death spiral whereby the market-based leader can lose complete market share, and in the process, harm global innovation.

But why worry? After all, as a leading economist once asked, “Computer chips, potato chips: What’s the difference?” Why should leaders in advanced economies not accept a hollowing out of their advanced industries, and instead have the United States sell the Chinese commodities such as natural gas and soybeans and have the Europeans sell tourism services? The reason is because the loss of advanced tech industries has two major negative impacts on the advanced economies. The first is on prosperity, as the average wage in these industries is approximately 75 percent higher than average U.S. wages.[10] Moreover, reduced global market share means national currencies fall in relative value, making the cost of imports higher, and reducing living standards.

The second factor relates to national security and the defense industrial base—a critical issue for the United States as U.S. defense superiority is based is in largely part on technological superiority. American service men and women go into any conflict with the advantage of fielding technologically superior weapons systems. But sustaining that advantage depends on the U.S. economy maintaining global technological superiority, not just in defense-specific technologies, but in a wide array of dual-use technologies. To the extent the United States continues to lose technological capabilities to China, U.S. technological advantage in defense over China will diminish, if not evaporate, as U.S. capabilities whither and Chinese ones strengthen. It is certainly a highly risky proposition to assume the United States can continue its weapons systems superiority over the Chinese if: 1) the Chinese continue to advance, largely through unfair, predatory practices, at their current pace; and 2) the United States loses a moderate to significant share of its advanced technology innovation and production capabilities. As ITIF wrote in 2014, "The United States defense system is still the most innovative in the world, but that leadership is not assured and is in danger of failing. This decline is not only impacting defense innovation and capabilities, but also overall commercial innovation and U.S. competitiveness."[11]

A COMMON MISCONCEPTION: CHINA CANNOT INNOVATE

Notwithstanding the fact that no other government in history has done more to promote an innovation-based economy than China, there is a widespread view that China simply cannot succeed in innovation. The reasons given are many and diverse: Chinese students are taught rote learning and do not know how to think for themselves. China is too far behind the leaders to ever catch up. Weak IP laws and enforcement mean China will always be a copier. And of course, no economy subject to the heavy hand of state planning can ever be innovative

These views are widespread. Zachary Karabell wrote in *The Washington Post,* "Chinese firms excel at copying but not yet at creating. As a result, smart foreign companies realize that the lasting solution is innovation, not courts and lawyers."[12] Kerry Brown, a professor at Kings College London, wrote,

> The Chinese government under Xi can pour all the money they want into vast research and development parks, churning out any number of world class engineers and computer programmers. Even with all of this effort, however, China is likely to produce few world class innovative companies. The fundamental structural problem is that the role of the state and government in China is still very strong… The system that China currently has still rewards conformity.[13]

Others say Chinese business leaders are not creative, or that China cannot develop a creative culture. Former Hewlett Packard CEO Carly Fiorina wrote, "Although the Chinese are a gifted people, innovation and entrepreneurship are not their strong suits. Their society, as well as their educational system, is too homogenized and controlled to encourage imagination and risk-taking."[14] Jason Lim, an editor at TechNode, wrote, "Most Chinese start-ups are not founded by designers or artists, but by engineers who don't have the creativity to think of new ideas or designs."[15] Michael Pettis, a professor at Guanghua School of Management at Peking University, agrees, writing:

> This is not a country we can expect major innovations from. In the west we don't have enough confidence about this. How many governments in the world have decided they're going to become major innovation centers? None of them have succeeded… It's really hard to figure out how to get a culture of innovation and I suspect it doesn't have to do with political will. The types of reforms you need to become a great innovation center are pretty scary for a country like China. If you're running things in Beijing, do you really want to have that kind of country?[16]

There are three major problems with this line of thinking. Two relate to overly limited definitions of innovation. First, for these skeptics, the only real innovation is new-to-the-world, first-of-a-kind innovation. In this framing, the Apple iPhone was an innovation, but Samsung's Galaxy was not. Tell that to Apple, which holds 18.2 percent of the global smartphone market, compared with Samsung's 18.7 percent. And tell that to the top-three Chinese smartphone makers—Huawei, Xiaomi, and Oppo—which together hold 32 percent of the global market.[17] Innovation is not just about who is first, it is also about who gains global market share. The history of technology has shown time and again that fast followers and practitioners of reverse innovation can gain considerable market share—and the nations that host them can gain a significant number of jobs and growth in income from this kind of innovation.[18]

The second problem is that when these skeptics argue China cannot innovate they are focusing mostly on one kind of innovation: science-based innovation. But as the McKinsey Global Institute (MGI) noted in its study of Chinese innovation, science-based innovation (e.g., biopharmaceuticals and semiconductors) is only one of four kinds of innovation. To be sure, China is behind leaders in science-based innovation, although, as we will see, they are making progress here. This is obvious given they recently landed a vehicle on the dark side of the moon and broadcasted back images. Similarly, they are globally competitive in supercomputers. For example, the National Supercomputing Center in Wuxi, China, unveiled the Sunway TaihuLight in 2016, the world's fastest supercomputer.[19] Gregory C. Allen, a fellow at the Center for a New American Security, wrote that China's dominance of artificial intelligence technology and its military applications are not only credible, but likely, in the absence of a massive shift in U.S. policy.

Moreover, in the other three kinds of innovation, China has had much more success. Engineering-based innovation includes commercial aviation, auto manufacturing, telecommunications equipment, flat panel displays, and high-speed rail. Here, China has had much striking successes. At 28 percent, telecommunications equipment producer Huawei holds the largest share of the world's telecommunications equipment market, in part because it invests over $11.5 billion annually in R&D, ranking it fifth in the world.[20] In 2016, China's high-speed rail car producer CRRC had over two-thirds of global deliveries.[21] China BOE Technology Group is one of the most sophisticated producers of liquid crystal displays (LCDs). As Harvard's Willy Shih noted, BOE's 10.5 factory in Hefei is the most advanced factory in the world for producing LCD screens, a process that requires extraordinary precision at the nanometer level. The factory employs robots to make LCD sheets of glass that are 9.6 x 11 ft.[22]

Shih also wrote that the Chinese have made significant progress in autos:

> Chinese auto manufacturers have come a long way. Fifteen years ago, if you rode around in a Chinese domestic branded car, they felt like copies of Japanese, Korean, or German vehicles." However, leading Chinese automakers have moved on. They have been aided by sophisticated computerized design tools that allow them to do their own design and modeling, a phenomenon that is becoming more and more important as know-how gets embedded in tools.[23] These days, if you ride around in some of the leading Chinese brands, you will find sophisticated engines, turbochargers, complex automatic transmissions, and high levels of interior detailing. The industrial progress in such a short time is remarkable.[24]

While China is behind in first-to-the-world science- and engineering-based innovation, to say that China cannot innovate, and as such is not a threat to the economies of advanced nations, is misguided.

China's state-owned jet aircraft company COMAC has produced and is test-flying its single-aisle jet aircraft, the C919.[25] While it is not nearly as good as the Boeing or Airbus offerings, it flies and is expected to be purchased by China's state-owned airline companies. Moreover, they are expected to improve rapidly. As one aviation industry expert wrote, "Their 3rd or 4th models might compete very well in the market. China has the advantage of mountains of capital to absorb early losses, and they have captive airline customers for the C919 and subsequent models. US suppliers are generally on board with COMAC, too - engines, flight controls, systems, and others."

The next area, according to McKinsey, is customer-focused innovations, including industries such as Internet software and services, appliances, and household products. DJI is the world's top drone maker, while Haier is the world's largest producer of major appliances.[26] And Internet service companies such as Baidu, Alibaba, and TenCent, are the fourth, fifth, and sixth largest Internet companies in the world.[27]

Finally, efficiency-driven innovation includes chemicals, textiles, electrical equipment, and construction machinery. Chinese chemical companies are expected to capture 40 percent of global market share by next year.[28] Its construction equipment industry continues to grow in scope and sophistication. For example, Chinese company XCMG launched a 700-tonne hydraulic excavator with intelligent monitoring and fault self-diagnosis technology.[29]

THE REALITY: CHINA CAN AND DOES INNOVATE

In short, while China is behind in first-to-the-world science- and engineering-based innovation, to say that China cannot innovate, and as such is not a threat to the economies of advanced nations, is misguided. As MGI concluded:

> Overall, Chinese companies show the greatest strengths in markets that require customer- and efficiency-driven innovation, and they have the most catching up to do in industries that rely on science- and engineering-based innovation… China has the potential to meet its "innovation imperative" and to emerge as a driving force in innovation globally.[30]

Likewise, as Don Prud'homme and Max von Zedtwitz wrote, "Supercomputers, unmanned aerial drones, and many innovations in between: These are the new faces of Chinese performers."[31] In their book, *Created in China How China is Becoming a Global Innovator*, Georges Haour and von Zedtwitz *wrote, "*China is fast transitioning from low-cost manufacturing to a higher-value, innovation-led economy."[32] In *China's Next Strategic Advantage: From Imitation to Innovation*, George Yip and Bruce McKern argued, "Chinese companies are much more successful at innovation than previously thought."[33]

At one level, these statements should not be surprising, as China has been catching up in innovation-based industries. In a 2014 survey, two-thirds of foreign executives said Chinese companies are "just as innovative or more innovative" than their own companies.[34] The EU Chamber of Commerce in China found that 60 percent of European firms there expect domestic firms to close the innovation gap by 2020.[35] China's rate of increase in economic activity and technical capability is greater than that of the United States and other Organization for Economic Cooperation and Development (OECD) countries.[36] To wit, despite China ranking 43rd in the 2010 Global Innovation Index, in 2018, it had risen to 17th (and leads all low- and middle-income nations).[37]

While China has made considerable progress, a key question remains: Can it make the transition from its current fast-follower stage and become able to master first-to-the-world innovation, especially in science and engineering industries? As MGI wrote, "China has made science-based innovation a top priority and has invested in building the institutions and capabilities needed for discovery and invention. So far, these investments have not translated into innovation leadership, but they have created a strong foundation."[38]

Clearly, China has shown it can master the stages of reliance on foreign technology and fast followership. We can see this in high-speed rail, wherein the Chinese Ministry of Railways tendered for bids to produce high-speed rail trains, but required successful bidders to transfer advanced technology to its Chinese JV partner, CRRC Corp. Ltd, which has a greater global market share than previous leaders Siemens and Alstom combined. As Prud'homme wrote, "This highlights the dangers of collaborating with Chinese companies that are supported by the state, learn quickly, upgrade their technological capabilities, and have an uncanny ability to quickly scale up operations."[39]

The Chinese model is obtaining foreign technology and combining it with a large number of skilled engineers and scientists. China is also not just relying on Chinese-educated scientists and engineers. It is following the path of other Asian tigers, particularly Korea, and actively recruiting back to China highly skilled workers (through its Thousand Talents program) and also paying very high salaries to recruit foreign engineers and scientists from nations such as Korea, Taiwan, and the United States. This is all supported by state backing in the form of protected markets and government subsidies—which is critical, as it both enables Chinese firms to absorb large early losses before their product quality and process efficiency achieve something close to global parity, and allows them to gain market share in the protected Chinese market initially, and ultimately in global markets. This model has been shown to work, and is likely to continue to work at least for a while.

But can China ultimately transition to the next and final level: global leadership in first-to-the world innovation in science and engineering–based innovation? The authors of a noted Harvard Business School article have their doubts:

> Certainly, China has shown innovation through creative adaptation in recent decades, and it now has the capacity to do much more. But can China lead? Will the Chinese state have the wisdom to lighten up and the patience to allow the full emergence of what Schumpeter called the true spirit of entrepreneurship? On this we have our doubts. The problem, we think, is not the innovative or intellectual capacity of the Chinese people, which is boundless, but the political world in which their schools, universities, and businesses need to operate, which is very much bounded.[40]

It is worth looking at the experience of South Korea. After the Korean war, South Korea was one of the poorest nations on the planet, with a GDP per capita of $940 in 1960; by 2016, it had grown to $25,400. Today, it is a developed nation, whose export economy is powered by a significant number of leading global innovation companies, such as Samsung, Hyundai, and LG.

Korea went through the same process of development China is now following. Like China, Korea was initially focused on copying. As Linsu Kim wrote in his definitive history of Korean innovation progress, *Imitation to Innovation: The Dynamics of Korea's Technological Learning*, "The 1960s and 1970s strategy was largely associated with duplicative imitations, producing on a large scale knockoffs or clones of mature foreign products, imitative goods with their own or original equipment manufacturers' brand names at significantly lower prices."[41] Korea started by relying on foreign technology, finding U.S. companies, usually struggling ones, to license them needed technology. They also relied heavily on Korean researchers at U.S. universities to help them master complex technologies. They invested massively in innovation, including in government-industry research centers and research universities. A combination of government subsidies and cross subsidies from large multi-divisional chaebols allowed companies to invest in money-losing technologies until they were able to sufficiently master the technologies to make a profit—something Western firms operating in free market, capitalist economies could never do. And most importantly, it was a highly competent and authoritarian government that directed state aid toward the industries, firms, and technologies that followed the direction the government envisioned. This was all underpinned by a nation on a mission to overcome its backwardness and build globally competitive, high value-added industries. As Kim noted, "The government held the wheel and supplied the fuel, while private firms, particularly chaebols, functioned as the engines."[42]

This potent combination of a smart and directing government, effective business leaders, and a highly talented population paid off as Korea became the fastest-growing economy in world history. Indeed, by the 1980s and 1990s, as Kim has written, Korean "industrialization increasingly involve[d] creative imitations."[43]

But for Korea to take the next step of being an economy that truly innovates, its government needed to step back from its directed role—something the governments of Japan, Singapore, and Taiwan all did. Well after Korea became a democracy in 1948, the role of state in the 1990s shifted from one of director to one of enabler. And more Korean industries became true innovators. As Kim wrote, "Several industries in Korea, such as semiconductors, electronics, and biotechnology, are stretching their R&D activities to transform themselves into innovators as well as effectively creative imitators." Moreover, "Many skills and activities required in reverse engineering have easily been transformed into activities called R&D, as Korea approached the technological frontier."[44]

The historical evidence suggests that for an economy to successfully master the final stage of innovation and become an economy that can develop first-to-the world innovation it must shift the role of the state from a director to an enabler. For non-communist nations like Japan, Korea, Singapore, and Taiwan, this was not easy, but it was accomplished. It's not clear that China will be able to take that step, at least with the Chinese Communist Party still at the helm. But even if China cannot make the political changes needed to shift the role of the state this way, China can make an enormous progress, including in science and engineering industries. And that progress will significantly harm global innovation leaders (firms and nations).

CHINESE INNOVATION INDICATORS

Actually measuring China's innovation capacity and performance relative to the United States is difficult. Ideal indicators include innovation performance of Chinese and U.S. firms, but that data is not collected. There are, however, a variety of indicators that are available, which can be sorted into three categories: 1) inputs into the innovation process, such as R&D spending and scientific and engineering personnel; 2) outputs from the innovation process, including patents and scientific articles; and 3) outcomes related to actual innovation, including industry sales and exports. To be sure, economies and companies differ significantly in how effectively they translate inputs—even outputs into actual innovation outcomes. The Chinese innovation "machine" appears to be significantly less efficient than the U.S. system in translating inputs to outcomes. Nevertheless, inputs and outcomes matter to innovation success.

The goal of using these indicators is not to come up with a definitive measure of how innovative the Chinese economy is relative to the U.S. economy, but rather to explore Chinese progress relative to U.S. progress on a host of innovation indicators. This report uses 36 indicators to do so, measuring Chinese performance relative to the United States in the most recent year for which data is available, and a base year (usually ten years prior) to assess the rate of Chinese catch-up. For indicators of inputs and outputs, it controls for the relative size of the economies. For most indicators, Hong Kong is included as part of China. On all the indicators China has closed the gap or, in some cases, extended its lead over the United States. In fact, in an average of all the indicators, China has cut the gap to the United States by a factor of 1.5 between the base year and the most recent year. (For example, had China been 80 percent behind the United States a decade or so ago, it would be just 50 percent behind in the most recent year.)[45]

INNOVATION INPUTS

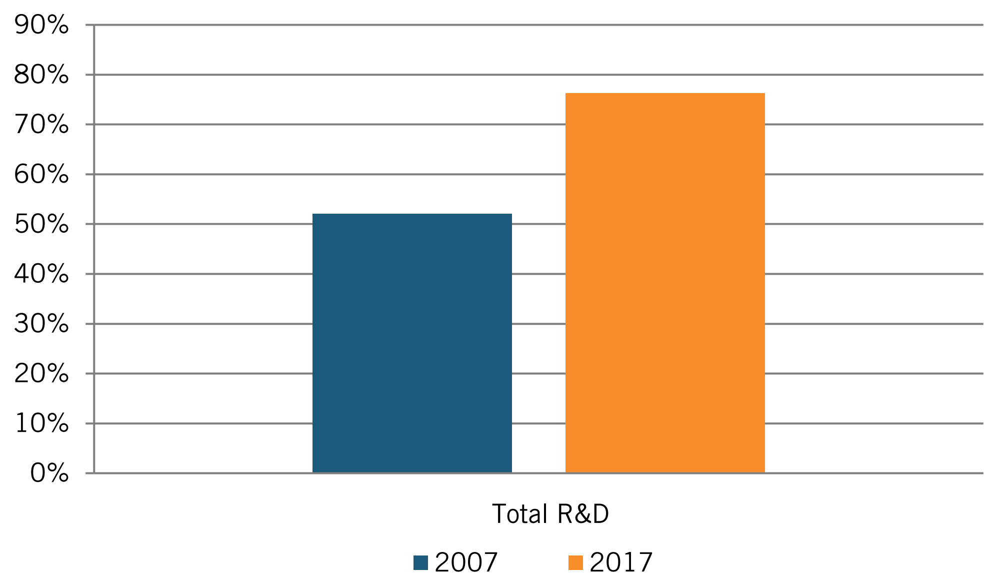
Innovation inputs are those factors that help enterprises be more innovative, and in innovation industries, gain market share. These include research and development spending, academic university quality, and the number of scientists and engineers.

R&D

Indicator 1: R&D as a Percentage of GDP

Among the simplest measures of future innovation is the percentage of economic output being invested in research and development. China's 2007 $129 billion investment in R&D was 33 percent less than the $395 billion invested in the United States, representing 1.37 percent and 2.63 percent of GDP respectively. By 2017, U.S. R&D expenditures had grown at an annualized rate of 2 percent, while China's had grown much more rapidly at 13.1 percent. By 2017, China had significantly closed the gap to the United States, reaching 76 percent of U.S. levels and surpassing the EU, investing 2.13 percent its GDP.

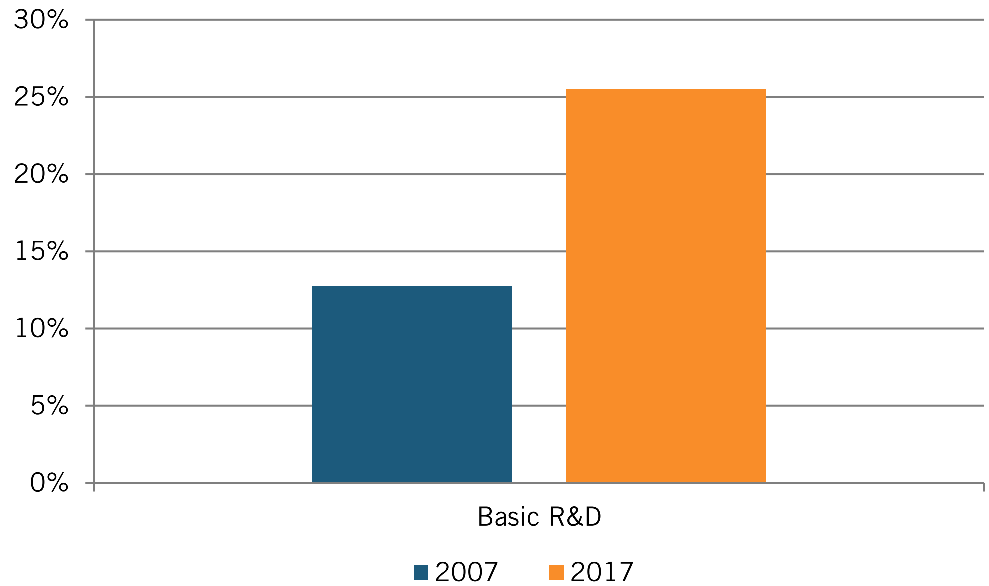
Figure 1: Chinese Expenditures on R&D as a Share of GDP, Relative to the United States, 2007–2017[46]



Indicator 2: Basic Research

Basic research, which attempts to expand scientific knowledge, rather than apply existing scientific knowledge, to address practical problems, has the greatest potential of creating fundamental innovation. By this measure, China lags much farther behind the United States. While Chinese basic research relative to the United States doubled between 2007 and 2017, from 13 to 26 percent as a fraction of GDP, it represents barely a third of China's gap with the United States for total R&D (figure 2).

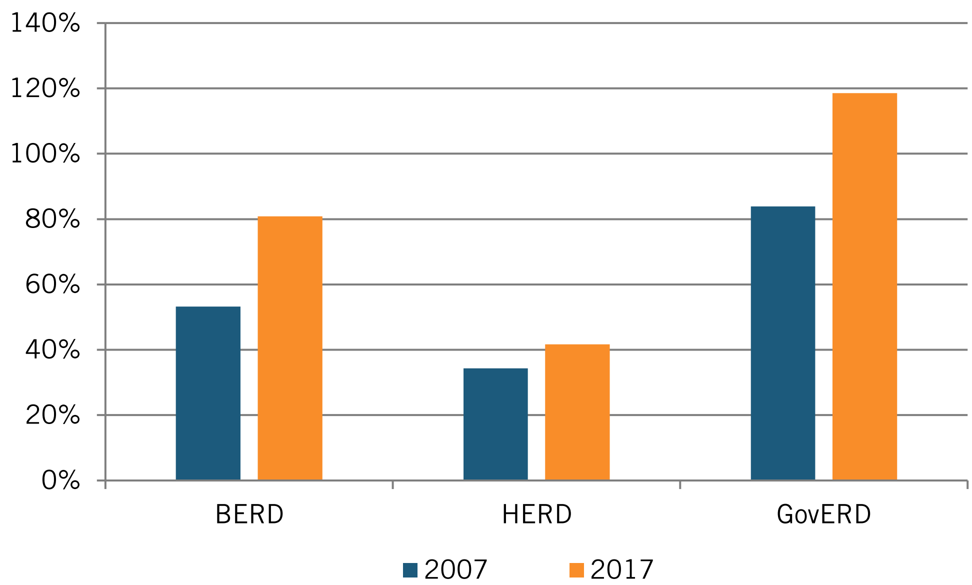
Figure 2: Chinese Expenditures on Basic R&D as a Share of GDP, Relative to the United States, 2007–2017[47]



Indicator 3: R&D by Government, Business, and R&D

Compared with that of the United States, China's R&D performance differs significantly based on the kind of institution performing it. There are three different measures: business R&D (BERD); higher education R&D (HERD); and government R&D (GovERD), which is usually performed in government institutions such as national labs. Given the significant role of the government in the Chinese economy, it is perhaps not surprising Chinese government institutions spend more on R&D as a share of GDP than the United States, going from with 84 percent of U.S. levels in 2007 to 119 percent in 2017. The Chinese Academy of Sciences itself operates over 104 institutes, and the pubic research institutes overall employ more than half a million workers.[48] Businesses in China perform less R&D than businesses in the United States, but the gap in business closed from 53 percent to 81 percent. In contrast, Chinese universities conduct much less R&D than U.S. universities, at a rate of only 42 percent of U.S. levels, increasing from 34 percent in 2007. (See figure 3.)

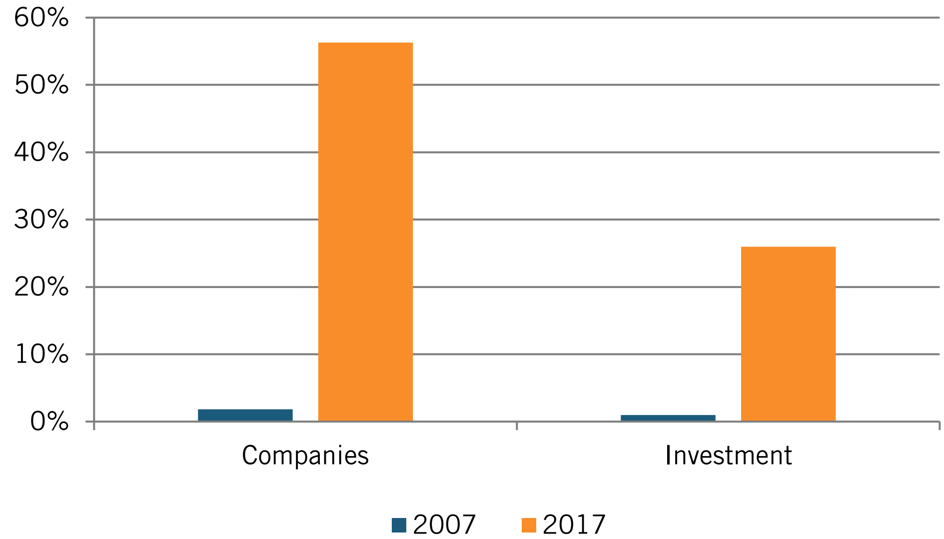
Figure 3: Performers of Chinese Expenditures on R&D as a Share of GDP, Relative to the United States, 2007–2017[49]



Indicator 4: Top Firms by R&D Investment

One important indicator is the extent to which a nation's firms are in the top 2,500 of global R&D investors. While many American companies, such as Alphabet, Microsoft, Intel, and Apple are among the leaders, China has made remarkable progress in the last decade. In 2007, China had just 2 percent of the companies on the list compared with the United States, but by 2017, had closed the gap to 56 percent. The gap for total R&D invested (as opposed to number of companies) is still large—with China at 26 percent of U.S. levels in 2017—because there are fewer Chinese companies that invest large amounts in R&D (figure 4). However, some do. In 2017, Huawei ranked 5th, Alibaba 51st, Tencent 61st, ZTE 76th, and Baidu 81st.

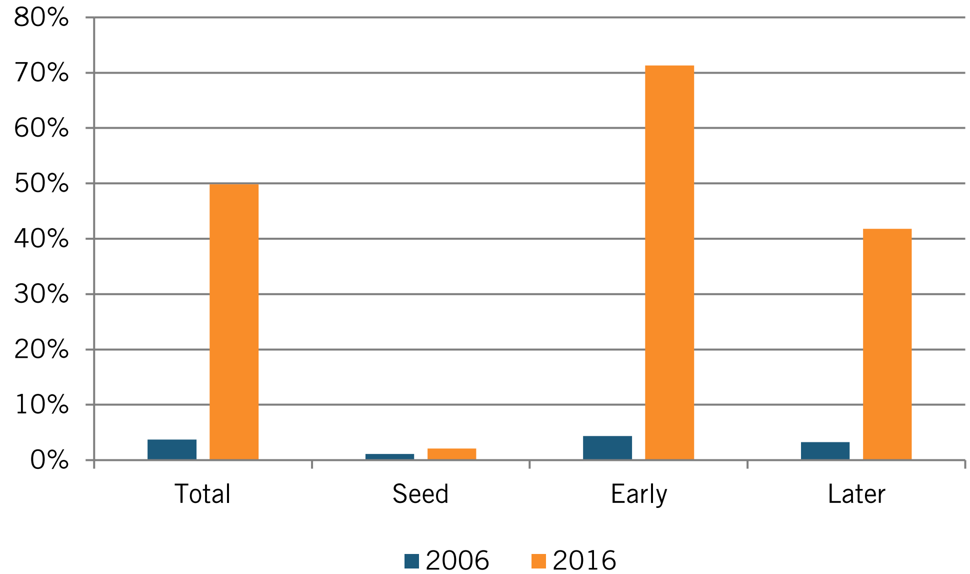
Figure 4: Chinese Firms Among the Top R&D Investors as a Share of GDP, Relative to the United States, 2007–2017[50]



Indicator 5: Venture Capital

Venture capital is crucial for innovation, connecting inventors with the funding—and often management assistance—necessary to develop their products. Chinese venture capital markets were extremely small in 2006, at 3.7 percent of U.S. venture capital funding (see figure 5). However, growth has accelerated dramatically in recent years such that in 2016 venture capital firms in China provided 50 percent as much funding as firms did in the United States. China's growth has been heavily focused on investments in early-stage firms, where China funds 71 percent of U.S. totals (and to a lesser extent late-stage firms, which grew from 3.2 to 42 percent), while providing almost no funding to seed ventures, which grew from 1.1 percent to 2.1 percent of U.S. levels. Thus, it is more difficult for a Chinese innovator to acquire funding finding for a very early stage start-up.

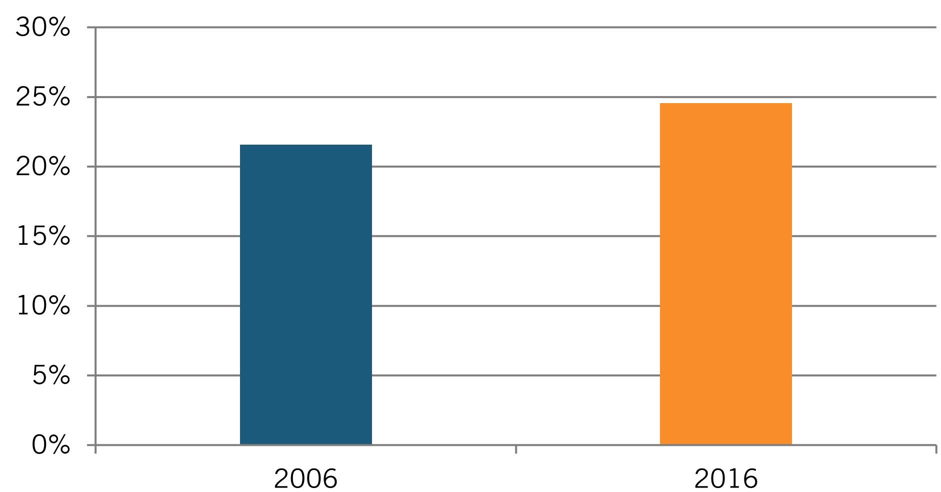
Figure 5: Chinese Venture Capital Funding by Stage as a Percentage of the United States', 2006–2016[51]



Indicator 6: Researchers

Scientific and technical researchers are the core fuel for an innovation economy. While the quality of Chinese researchers has improved, they are, on average, not as good as those in the United States.[52] Moreover, China lags far behind the United States in the number of researchers as a share of total workers, at just one-quarter of the U.S. level, up 3 percentage points from 2006. This suggests Chinese government figures for R&D investment may be significantly overstated, as they show Chinese R&D as only 24 percent less than that of the United States, whereas the number of researchers is 75 percent less. Some of this discrepancy may be due to the fact that relative to Chinese researcher wages, research equipment is more expensive compared to their American counterparts. However, this is unlikely to account for such a large discrepancy. A more likely reason is both government labs and Chinese companies, particularly state-owned enterprises (SOEs), have strong incentives to inflate R&D numbers when reporting to the central government because the government has made R&D a top priority (figure 6).

Figure 6: Chinese Researchers as a Share of Total Workforce, Relative to the United States, 2006–2016[53]



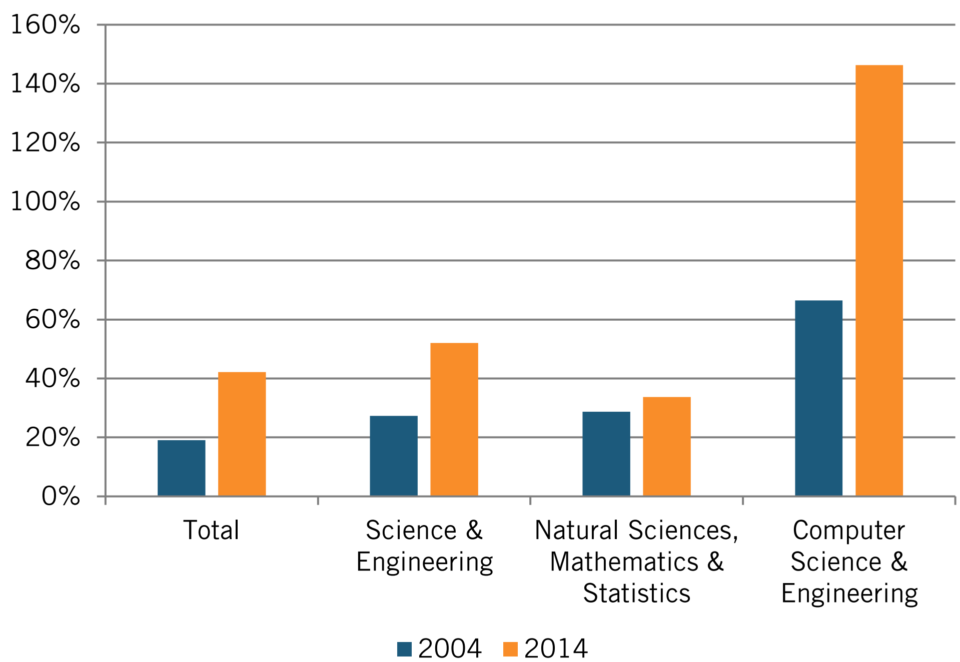
University Performance

Research universities play a key anchor role in national innovation systems, not only producing skilled scientists and engineers, but also generating knowledge and discoveries entrepreneurs and companies can build upon.

Indicator 7: Bachelor's and Master's Degrees

One key measure of future innovation capabilities is the number of university degrees being earned, which will influence nations' job skills in the coming decades. Nearly 7 million students obtain a bachelor's degree annually in China, with over 30 percent getting a degree in engineering, compared with just 5 percent in the United States.[54] The number of China's bachelor's and master's graduates increased from 1.2 million in 2004 to 3.4 million in 2014, overtaking the United States to reach 181 percent of America's annual degrees in 2014. Not surprisingly given its level of development, China still lags significantly on a per capita basis, growing from 19 to 42 percent of U.S. levels (see figure 7). However, China does better in science and engineering degrees (which include social sciences), reaching 52 percent of U.S. levels in 2014. Within science and engineering, most growth has been in computer science and engineering, where China rose to 146 percent of U.S. levels in 2014, from 66 percent in 2004. In other words, as a share of its population, China produces 46 percent more computer science and engineering degrees than the United states. However, natural sciences and mathematics degrees have seen slower growth, increasing from 29 to 34 percent of U.S. levels over the same period.

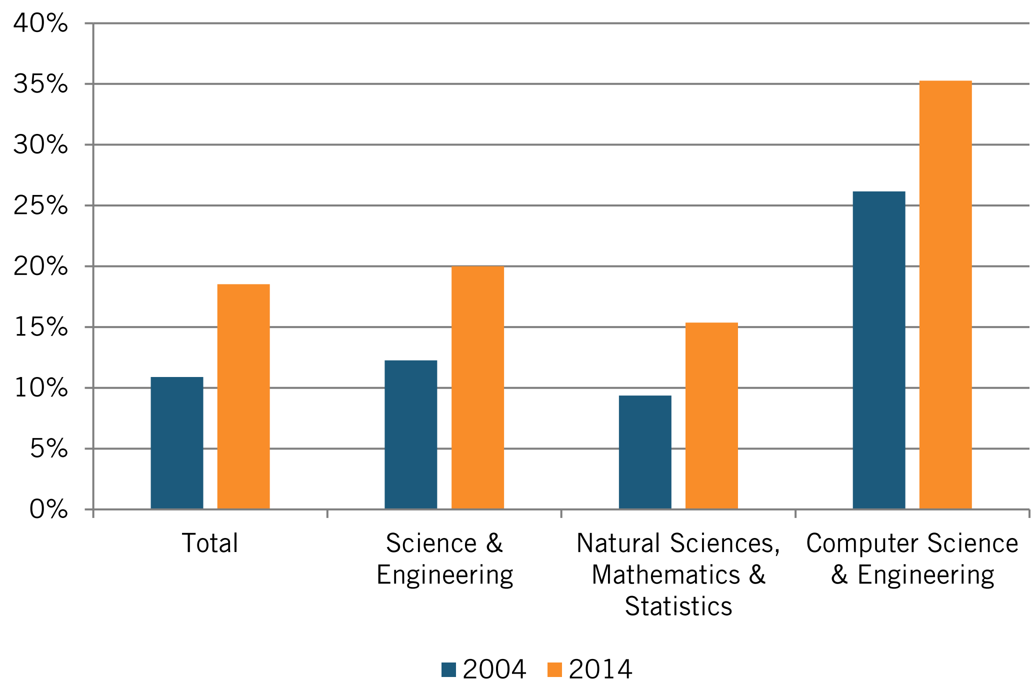
Figure 7: Chinese Per Capita Bachelor's & Master's Degrees as a Percentage of the United States, 2004–2014[55]



Indicator 8: Doctoral Degrees Earned

Compared with the United States China performs much worse in doctoral degrees per capita. China's share of total doctorates compared with the United States has nearly doubled, as have science and engineering doctorates. China is closest to the United States in computer science and engineering doctorates (35 percent, up from 26 percent in 2004) (see figure 8). Furthermore, growth in Chinese doctorates between 2010 and 2014 slowed significantly, failing to keep up with U.S. gains across all three measures.

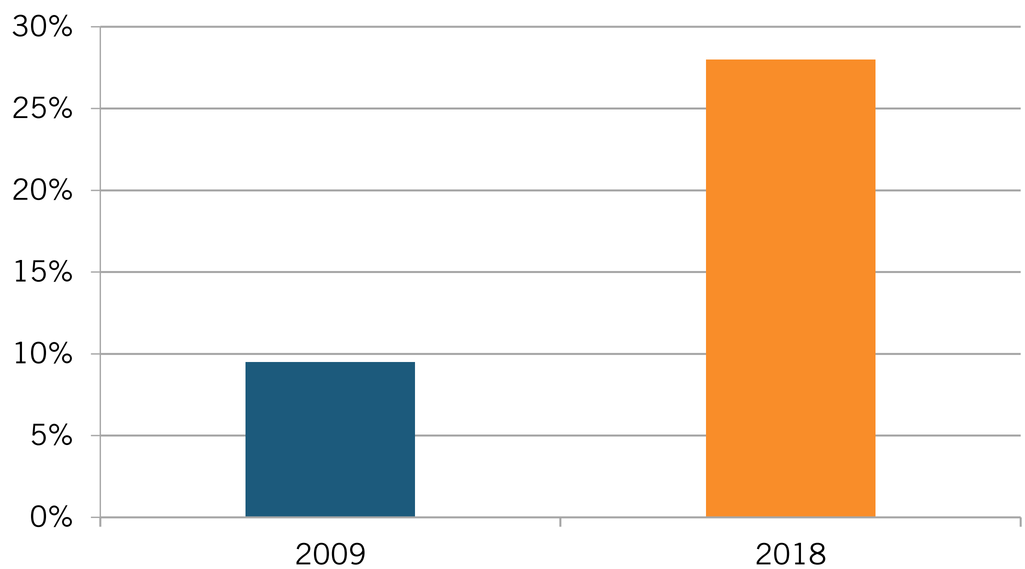
Figure 8: Chinese Per Capita Doctoral Degrees as a Percentage of the United States, 2004–2014[56]



Indicator 9: Quality and Number of Research Universities

Strong research universities are an important component of national innovation systems, not only generating science, technology, engineering, and math (STEM) graduates to help drive innovation in companies, but also performing research the results of which can help companies innovate. While Chinese universities overall lag U.S. universities, they are closing the gap. Using data from the Shanghai Academic Ranking of World Universities to look at the top 500 universities (a rank of 1 generates a score of 500; a rank of 500 generates a score of 1, etc.), Chinese research universities scored just 9.5 percent of the U.S. score in 2009, but closed the gap to 28 percent by 2018.[57] The United States' score decreasing from 47,420 to 40,239—in part because of federal and state government funding cutbacks for higher education funding—is largely to blame. But a bigger factor was the increase in China's score from 3,490 to 11,288. At number 45, for example, China's Tsinghua University is the highest ranked Chinese institution, jumping from 201 to 302 in the 2009. This increase in quality is one reason why 60 African and Asian nations sent more students to China than the United States.[58]

Figure 9: Chinese Universities Among the Top 500 Relative to the United States, Weighted by Ranking[59]



OUTPUTS

This section measures two kinds of output: scientific articles published and patents issued.

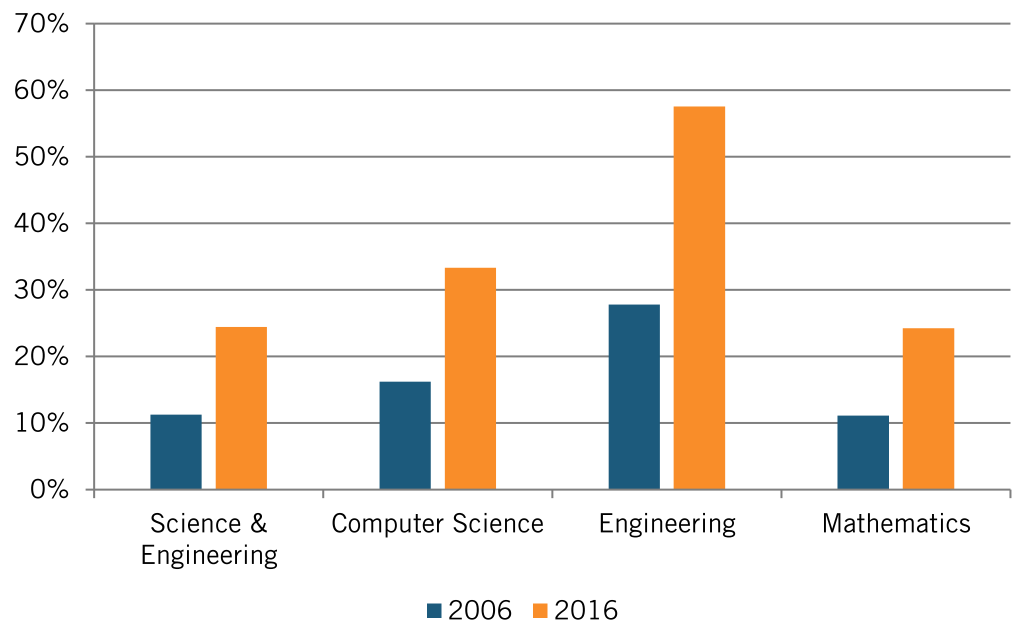
Scientific Articles

Peer-reviewed scientific research articles provide one indicator of how technically sophisticated and capable a nation's researchers are.

Indicator 10: Total Scientific Articles

In 2016, 426,165 Chinese peer-reviewed science and engineering articles were published—surpassing the United States for the first time. However, China's output is still well below the United States on a per capita basis, although it has made significant progress, more than doubling its output relative to the United States between 2006 and 2016. Not surprisingly, given its significant strengths in engineering, China is closest to U.S. levels (58 percent) in engineering articles, and 33 percent in computer science articles (see figure 10).

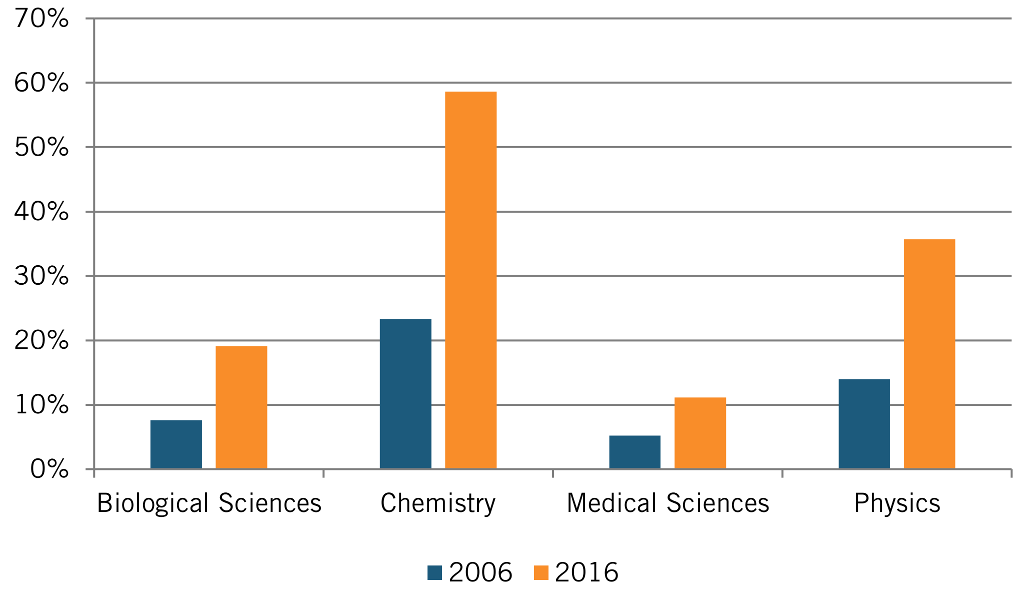
Figure 10: Chinese Per Capita Science and Engineering Articles as a Percentage of the United States, 2006–2016[60]



Indicator 11: Natural Science Articles

For natural sciences, China performs best in chemistry articles, which reached 59 percent of U.S. levels per capita in 2016 (see figure 11). Chinese physics articles have seen less significant increases. However, while the number of China's biology and medical sciences articles relative to U.S. articles grew by 161 percent and 147 percent respectively, they still lag relatively far behind. China publishes only 19 percent as many biology sciences articles as the United States, and only 11 percent as many medical sciences articles. However, the Chinese government has targeted biotechnology in its Made in China 2025 plan, so it is likely this gap will get smaller going forward.

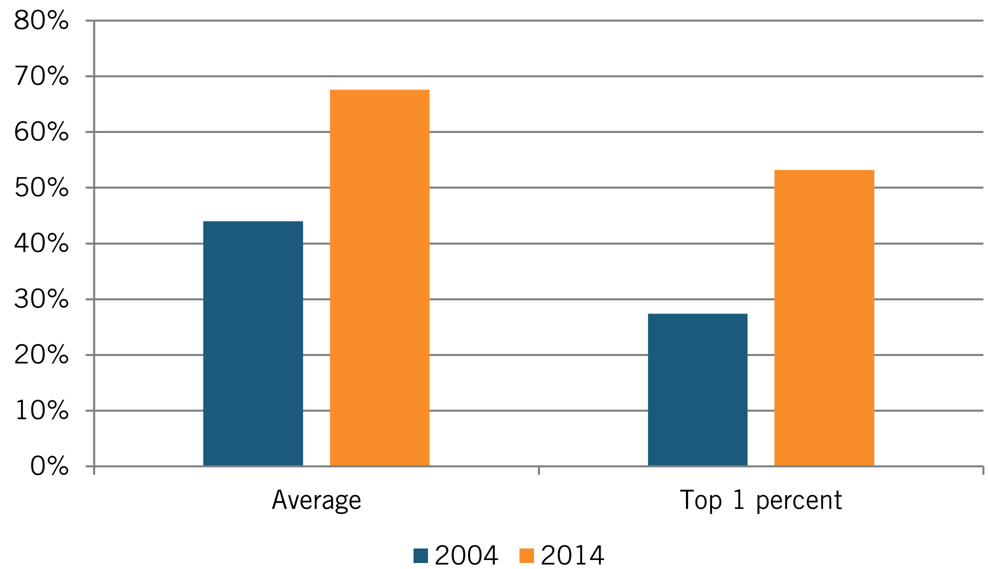
Figure 11: Chinese Per Capita Natural Science Articles as a Percentage of the United States, 2006–2016[61]



Indicator 12: Citations of Scientific Articles

Beyond the sheer number of articles produced, Chinese scientific articles have also become more impactful. In 2004, Chinese articles were cited only 62 percent as frequently as the average article was cited globally in the three years following publication, compared with 141 percent for U.S. articles (see figure 12). By 2014, however, Chinese articles had nearly reached the global average, at 96 percent of the expected citations. As a result, China reduced the gap with the United States, going from 44 percent to 68 percent. Furthermore, Chinese articles have become more than half as likely as U.S. articles to be among the top 1 percent most-cited articles in their fields (up from 27 percent), surpassing the global average.

Figure 12: Relative Citations of Chinese Science and Engineering Articles as a Percentage of the United States, 2004–2014[62]



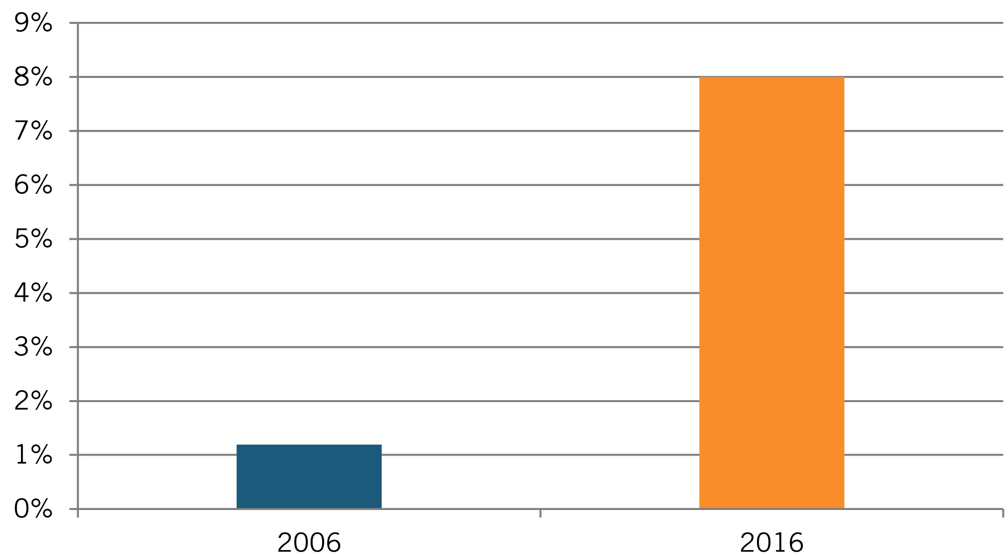
Patents

Many patents issued by the Chinese Patent Office (SIPO) are of relatively poor quality, and therefore patent counts from China cannot be compared against patents issued by the U.S. Patent and Trademark Office (USPTO). As a result, this section includes USPTO patents as well as patents filed internationally.

Indicator 13: USPTO Patents Granted

Approximately half of the patents granted by the USPTO each year go to foreign inventors or institutions. In 2006, it granted 1,066 Chinese patents, 1.2 percent of which went to U.S. inventors (see figure 13). By 2016, the number had risen to more than 11,000, the equivalent of 8.0 percent of U.S. patents. At the same time, other major nations held steady. In fact, China has overtaken every foreign nation in this measure other than Taiwan (8.1 percent of U.S. levels), Germany (11.2 percent), and Japan (35 percent).

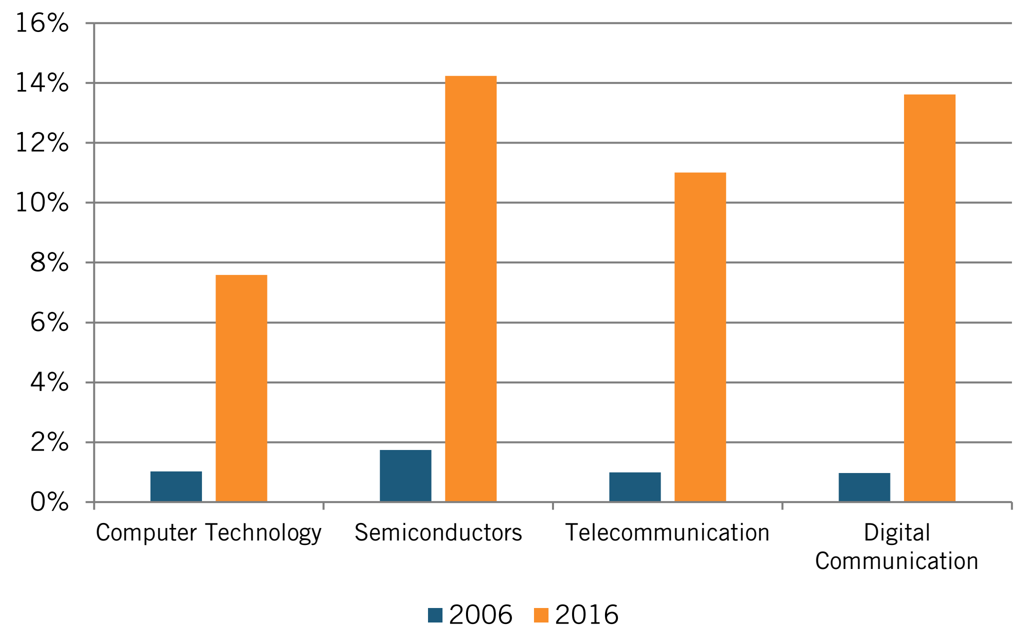
Figure 13: U.S. Patents Granted to China as a Percentage of the United States, 2006–2016[63]



Indicator 14: ICT Patents

In 2006, USPTO-issued patents in information communication technology (ICT) fields accounted for 28.8 percent of all USPTO patents issued to Chinese firms. That figure grew to 45 percent in 2016, which was significantly greater than the 34.1 percent for patents issued to U.S. firms. China has made rapid progress in ICT patents, closing the gap with the U.S. from 1 percent of computer technology patents in 2006 to 7.6 percent in 2016. (See figure 14.) Semiconductor patents grew even more (1.7 to 14.2 percent), while digital communication increased from 1.0 to 13.6 percent, and telecommunication from 1.0 to 11 percent. This growth reflects, in part, the growth of Chinse ICT companies Huawei, ZTE, Lenovo, Baidu, and Alibaba.

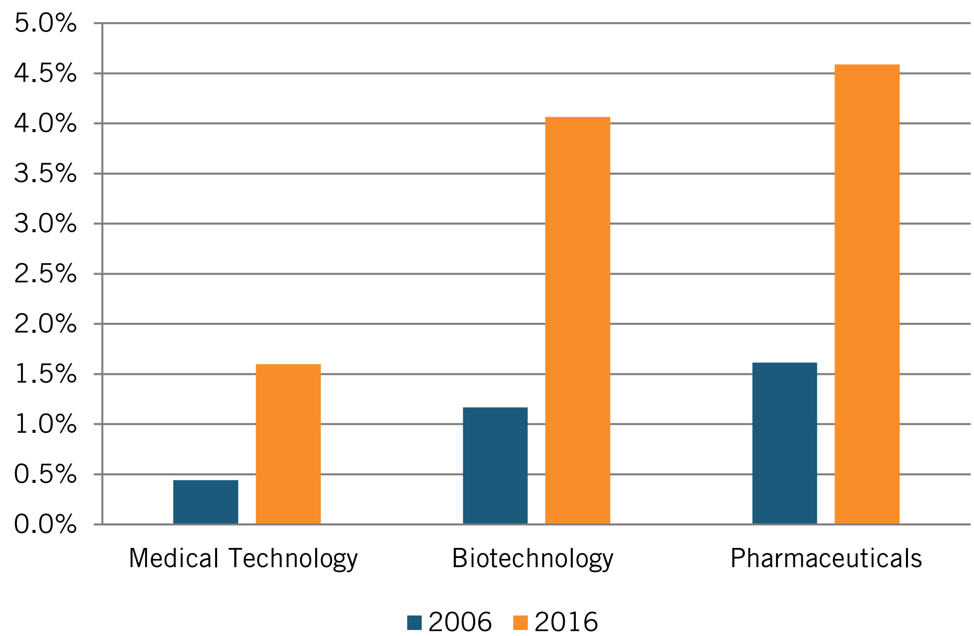
Figure 14: U.S. ICT Patents Granted to Chinese Inventors as a Percentage of the United States, 2006–2016[64]



Indicator 15: Life Sciences Patents

China lags even further behind the United States in life sciences. Only 481 life sciences patents (in medical devices, biotechnology, and pharmaceuticals) were granted to Chinese inventors in the United States in 2016. Relative to the United States, Chinese biotechnology and pharmaceuticals patents are issued at about half the rate of U.S. patents issued to Chinese companies overall, reaching 4.1 and 4.6 percent respectively of the patents granted to U.S. inventors. Medical technology patents have increased most quickly of the three in absolute terms— more than eightfold from 2006 to 2016—but only accounted for 1.6 percent of the U.S. figure due to significant domestic growth in U.S. patents. (See figure 15.)

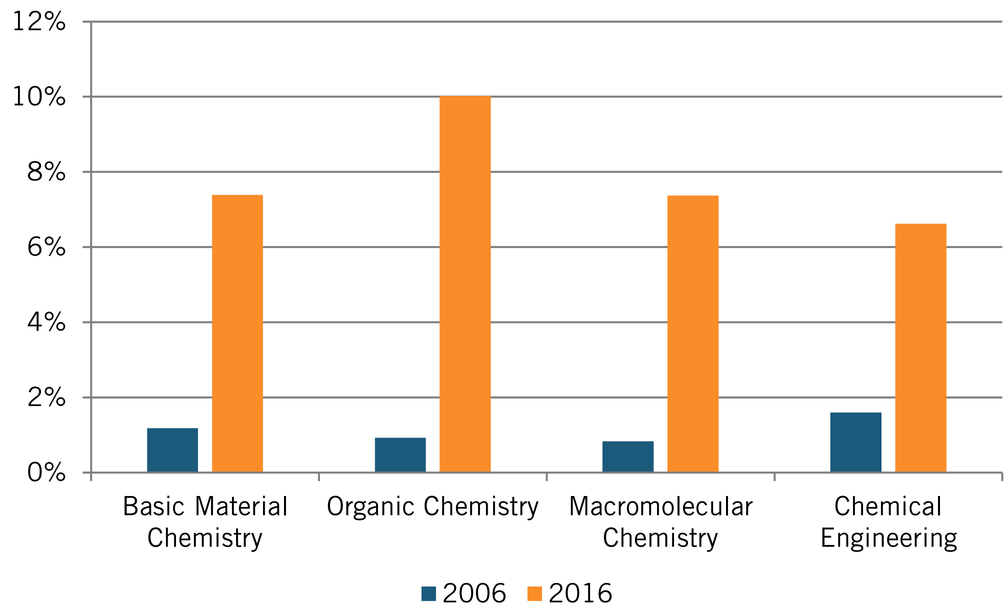
Figure 15: U.S. Life Sciences Patents Granted to Chinese Inventors as a Percentage of the United States, 2006–2016[65]



Indicator 16: Chemical Patents

China has made rapid progress in chemical patents, increasing its rate relative to the United States by four or five times between 2006 and 2016. Relative to U.S. patents, U.S. patents issued to Chinese companies in chemical fields are at about the same level as Chinese patents overall (see figure 16). China performs best in organic chemistry, reaching 10 percent of the United States in 2016. Other chemistry fields are below the average for Chinese patents overall, at 7.4 percent for basic material chemistry, 7.4 percent for macromolecular chemistry, and 6.6 percent for chemical engineering.

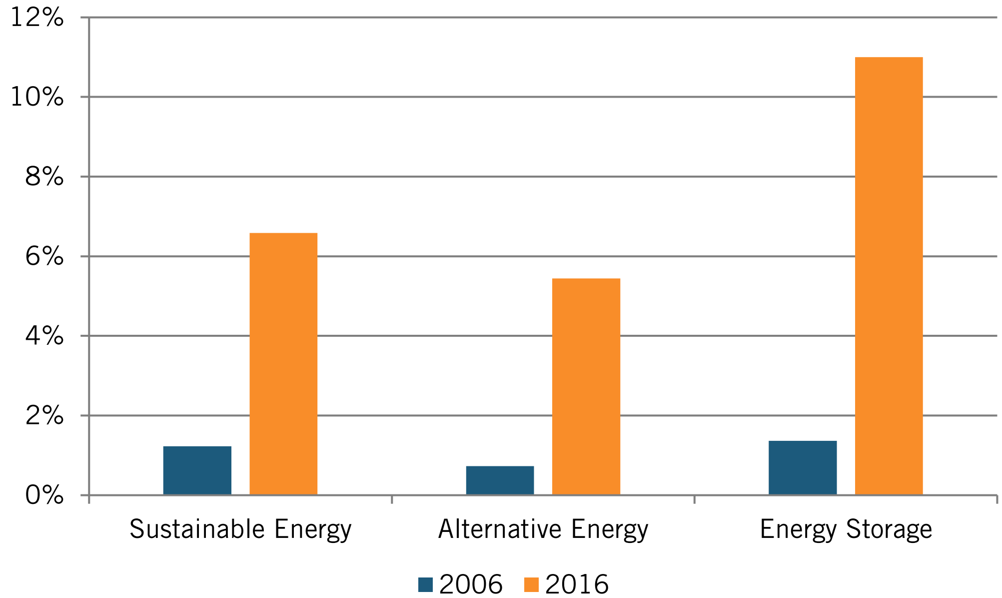
Figure 16: U.S. Chemical Patents Granted to Chinese Inventors as a Percentage of the United States, 2006–2016[66]



Indicator 17: Clean Energy Patents

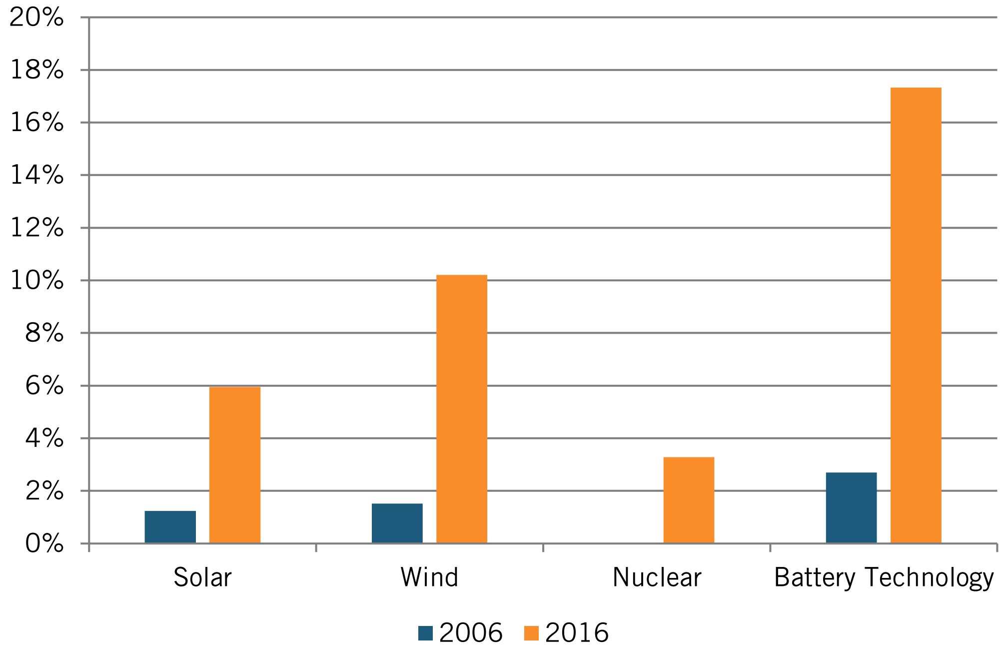
In the 2000s, China grew its clean energy industry largely through subsidies and copying, rather than through innovation. In fact, in 2006, Chinese inventors received only 32 U.S. patents related to clean energy technologies—just 1.1 percent of the number granted to Americans. However, over the following decade, Chinese patents grew by a factor of 15.4 versus 2.7 for U.S. patents, resulting in patent levels of 6.6 percent for sustainable energy (alternative energy, energy storage, smart grid, and pollution mitigation) 5.4 percent for alternative energy (e.g., bioenergy, solar, wind, nuclear, fuel cells, hydropower, wave/tidal, geothermal, and electric vehicles) , and 11 percent for energy storage (e.g., batteries, compressed air, flywheels, superconducting magnets, ultracapacitors, hydrogen, and thermal). (See figure 17.)

Figure 17: U.S. Clean Energy Patents Granted to Chinese Inventors as a Percentage of the United States, 2006–2016[67]



In 2006, Chinese clean energy patents were limited (see figure 18). However, by 2016, China had made considerable progress, particularly in battery technology, whose patents were issued at a rate of 17.3 percent of U.S. patents. Wind energy patents have seen smaller but above-average increases, growing from 1.5 to 10.2 percent of U.S. patents from 2006 to 2016, while solar energy patents increased from 1.2 to 6.0 percent. China did not receive a patent in nuclear energy until 2012, but represented 3.3 percent of patents issued by the USPTO in the field in 2016.

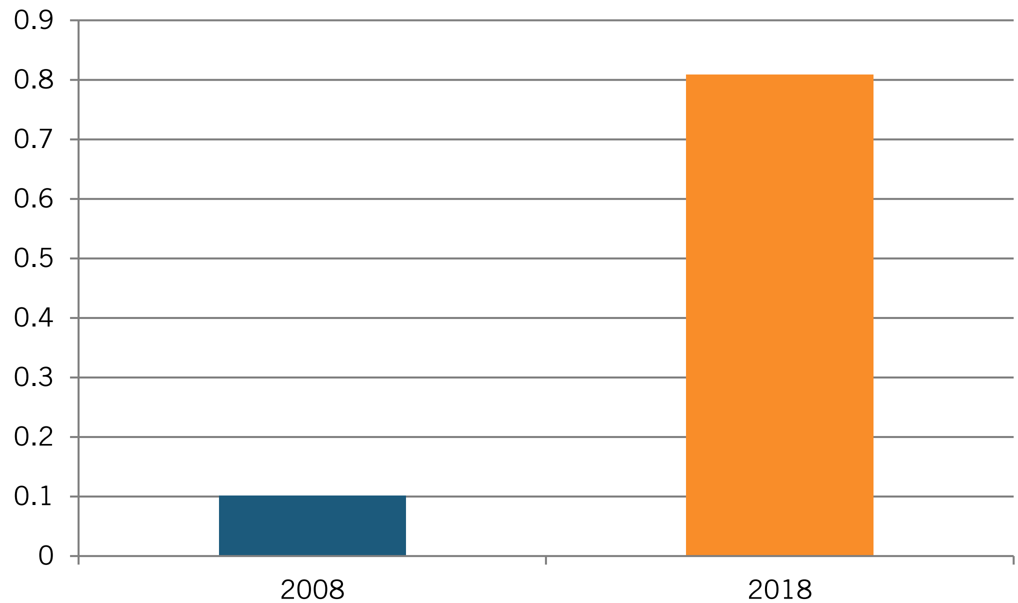
Figure 18: U.S. Selected Clean Energy Patents Granted to Chinese Inventors as a Percentage of the United States, 2006–2016[68]



Indicator 18: PCT Patents

Another measure of patents is patents filed under the international Patent Cooperation Treaty (PCT). In this category, China has made dramatic progress compared with the United States. It filed at just 10.1 percent of the rate of the United States in 2008, but by 2018 had closed the gap to 80.9 percent (see figure 19). This was because Chinese patents increased by 7.2 times, while U.S. patents increased by just 3 percent. Chinese patents grew fastest in control systems (61 times); optics (22 times); IT methods of management (20 times); computers (19 times); measurement (15 times); and microstructural and nanotechnology (14 times). Out of 35 total patent categories, the number of U.S. patents filed declined in over half of them (18), such as telecommunications (down 35 percent), surface coatings (down 25 percent), and organic fine chemistry (down 20 percent). In no category did Chinese patents fall; in fact, the slowest rate of growth was 290 percent! To be sure, some of this growth may reflect foreign companies with R&D centers in China filing internationally—and some may reflect overall weaker and lower-quality patents in China.[69] Nonetheless, the increase is significant.

Figure 19: Chinese Patents Filed Under the International Patent Cooperation Treaty as a Percentage of the United States, 2008–2018



OUTCOMES

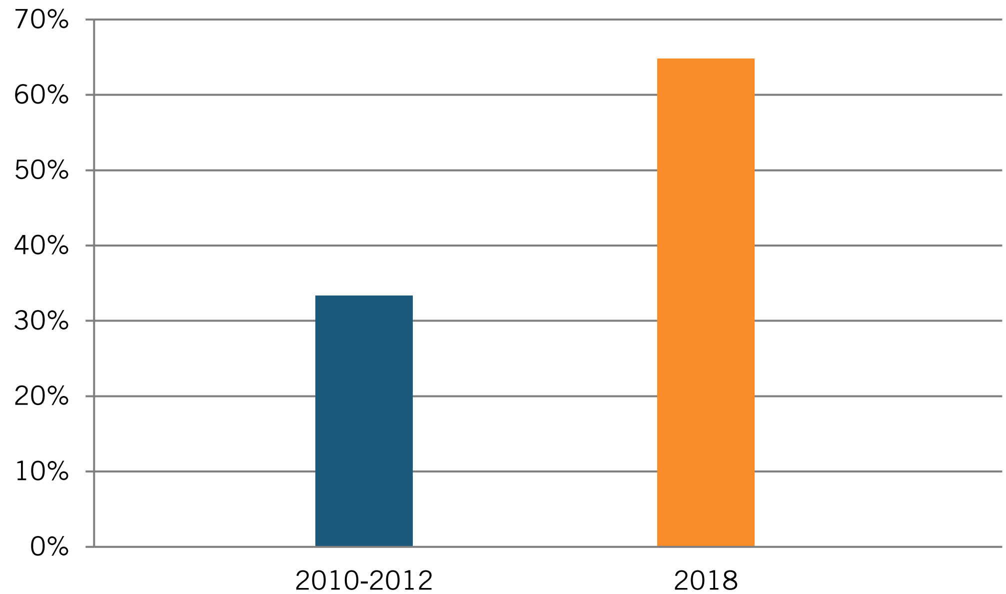
This section looks at innovation outcomes. As previously noted, the ideal measures would include those on innovation activities within firms, such as the rates at which they introduce new-to-the-world products and services, and their shares of global sales. But this data is not available. As a result, these measures mostly focus on entrepreneurial activity as well as advanced industry sectors' growth in output and trade.

Entrepreneurial and Company Performance

One measure of entrepreneurial activity is fast-growing firms, within which are unicorns: privately held start-ups valued at over $1 billion. China has performed relatively well in this measure relative to the United States in part because the Chinese economy is the second largest in the world, making it easier for domestic firms to reach the $1 billion valuation mark. In 2010 (the earliest year available for data), China had about one-third the number of unicorns as the United States did. However, by 2018, China had closed the gap to two-thirds (see figure 20).

Indicator 19. Unicorns

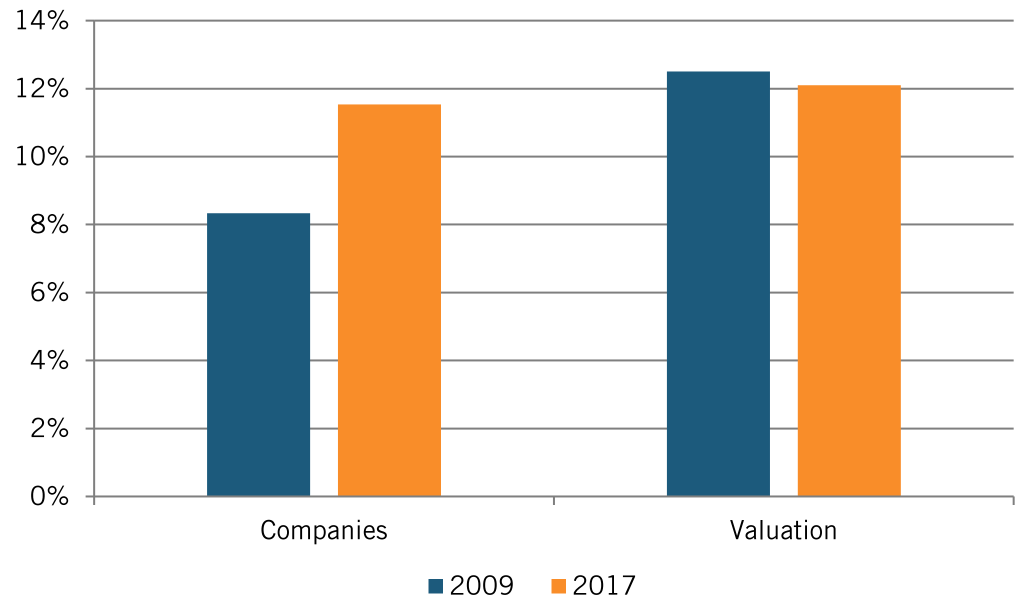
Figure 20: Number of Chinese Unicorn Firms Relative to the United States, 2010–2018[70]



Indicator 20: Leading Innovation-Based Companies

One indicator of innovation performance is the number of leading technology companies (software, hardware, Internet, telecommunications, and pharmaceuticals) and their market valuations. In 2009, China had 2 technology companies in the top 100 companies in the world in valuation, while the United States had 24. By 2017, China had 3, including Tencent and Alibaba, while the United States had 26—thus increasing the gap from 8.3 percent to 11.5 percent. Meanwhile, total market valuation for Chinese companies decreased from 12.5 percent of U.S. levels to 12.1 percent. One reason there are not more Chinese companies on the list is a number of leading Chinese technology companies, such as Huawei and ZTE are not publicly traded (see figure 21).

Figure 21: Share of Chinese Innovation Companies in the Global 100 Relative to the United States, 2009–2017[71]



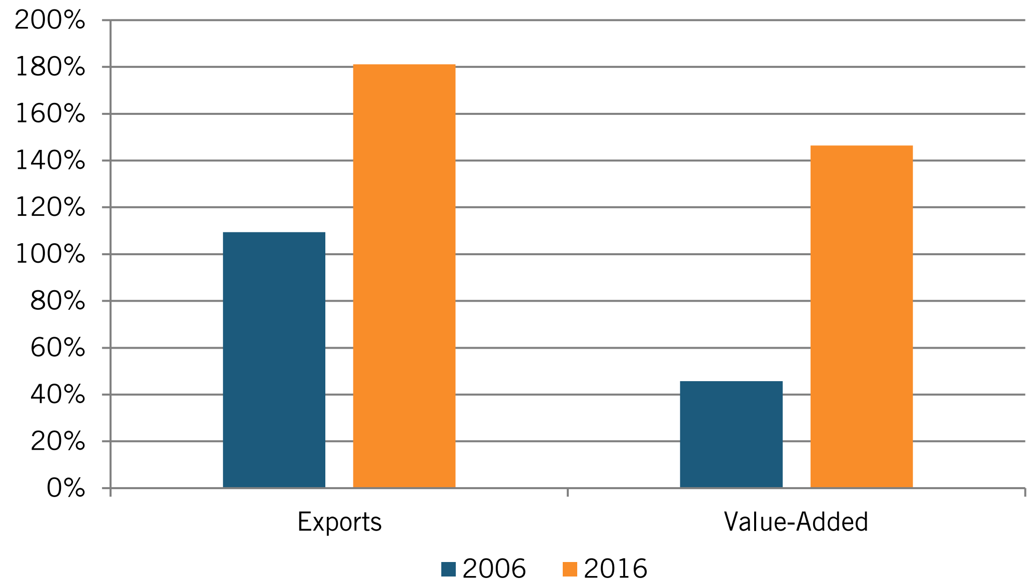
Trade and Industry

This section examines indicators of industrial output and trade for advanced industries.

Indicator 21: Manufacturing

In 2006, China exported 9 percent more manufactured goods than the United States did, while manufacturing value-added were at levels half the U.S. rate (see figure 22). By 2016, Chinese exports were 81 percent more than U.S. exports. Chinese manufacturing value-added more than tripled between 2006 and 2016 relative to U.S. levels, and in 2016, they were 46 percent greater than U.S. levels. Value-added measures output minus industry inputs (e.g., raw materials, energy, etc.).

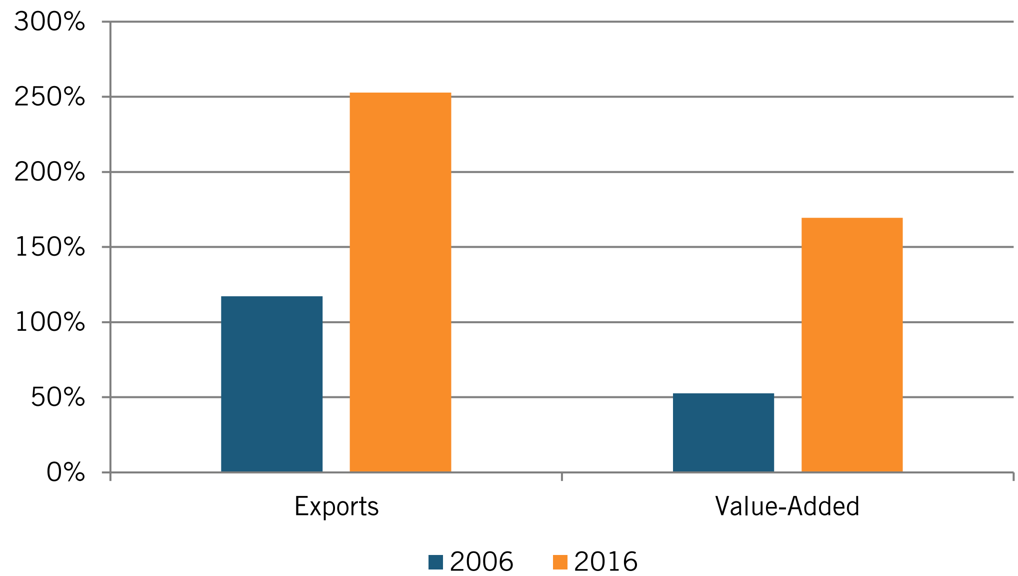
Figure 22: Chinese Manufacturing Trade and Production as a Percentage of the United States, 2006–2016[72]



Indicator 22: Medium-High-Tech Manufacturing

Output from more technologically intensive industries, including the medium-high-tech (MHT) manufacturing sector, provides more insight into China's innovation than overall manufacturing. MHT manufacturing includes industries such as motor vehicles, electrical machinery, and chemicals (not including pharmaceuticals). As figure 23 shows, Chinese MHT exports in 2006 were 17 percent higher than U.S. levels, and grew to 153 percent higher in 2016. Total value-added in MHT grew from roughly half of U.S. levels in 2006 to 69 percent greater in 2016.

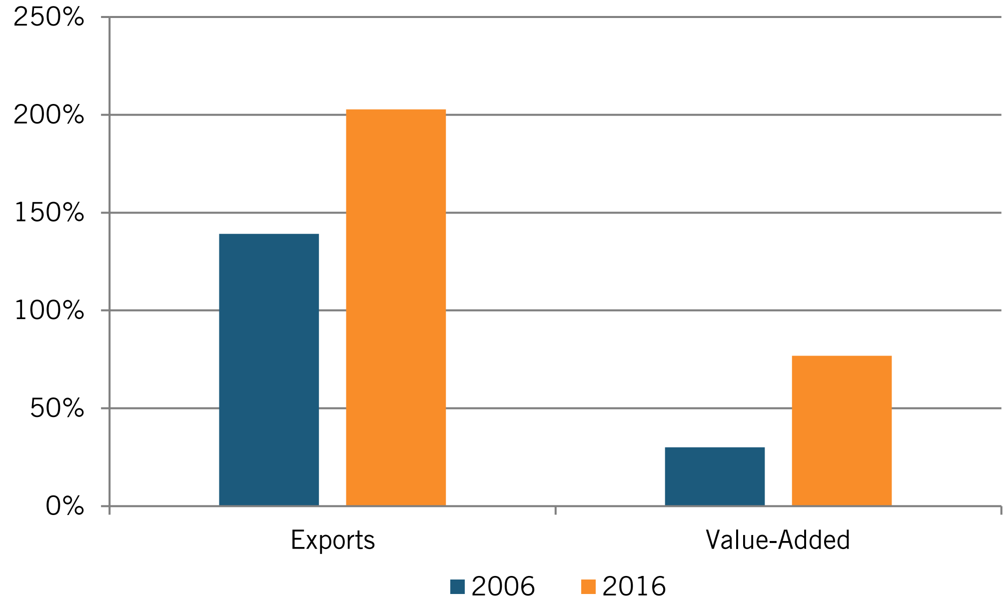
Figure 23: Chinese MHT Manufacturing Trade and Production as a Percentage of the United States, 2006–2016[73]



Indicator 23: High-Tech Manufacturing

High-tech manufacturing includes industries such as semiconductors, computers, and pharmaceuticals. It has shown the least growth relative to the United States over the decade in MHT and total manufacturing—yet the growth is still impressive. High-tech exports grew from 139 percent of U.S. levels in 2006 to 203 percent in 2016 (see figure 24). Value-added grew from 30 percent in 2006 to 77 percent in 2016. If this rate of growth were to continue, China would exceed the United States in high-tech manufacturing value-added by 2020.

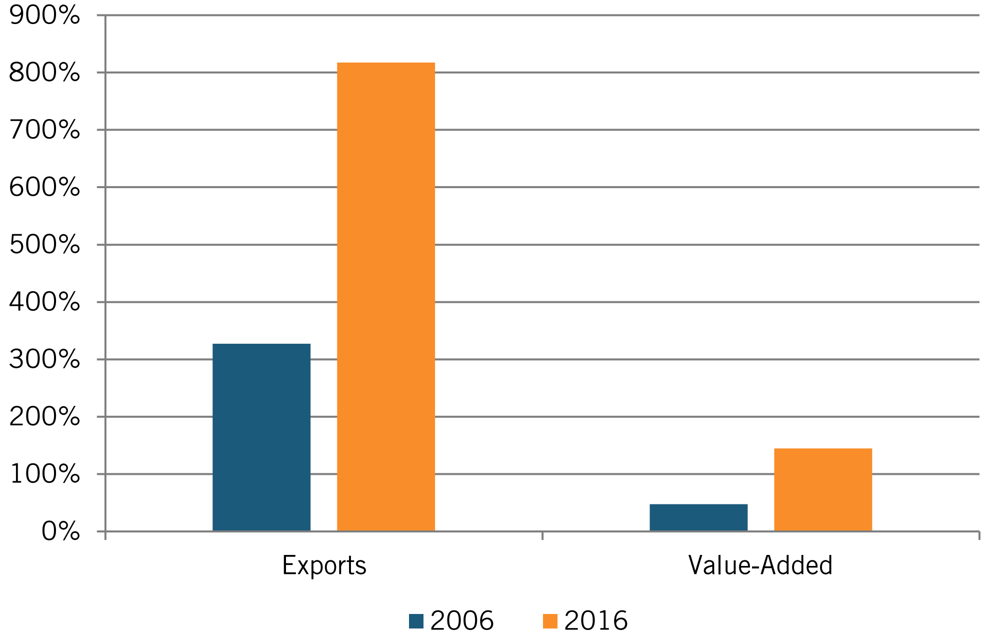
Figure 24: Chinese High-Tech Manufacturing Trade and Production as a Percentage of the United States, 2006–2016[74]



Indicator 24: ICT Goods

China has become the largest producer of information and communication technology goods (e.g., computers, smartphones, telecommunications equipment, etc.) in the world. In 2016, China exported $520 billion worth of ICT goods, over eight times the number of American ICT exports. Over the same period, ICT value-added went from about half of U.S. levels to approximately 50 percent more (see figure 25).

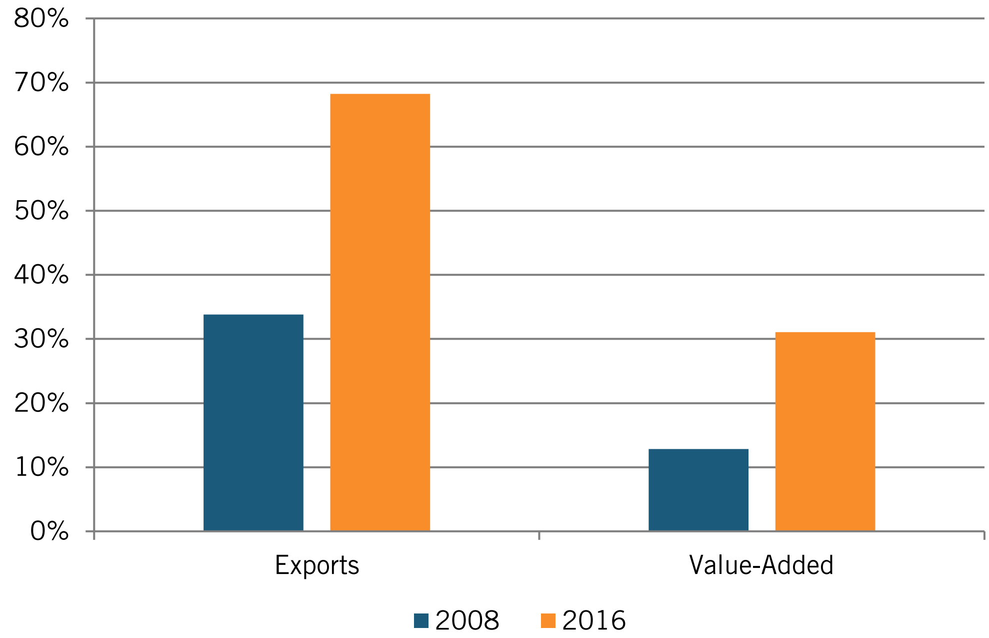
Figure 25: Chinese ICT Goods Trade and Production as a Percentage of the United States, 2006–2016[75]



Indicator 25: ICT Services

Although China leads the United States in ICT goods, it lags in ICT services (e.g., computer programming and data processing). As U.S. global ICT goods exports fell by 33 percent between 2008 and 2016, making it easier for China to increase its lead over the United States, U.S. ICT services exports grew by 61 percent, making it more difficult for China to catch up. Nonetheless, because China's ICT services value-added and exports grew much faster—313 and 325 percent growth respectively in ICT services (albeit from a lower base)—Chinese exports grew from 33 percent of U.S. levels to 68 percent, while value-added increased from 13 to 31 percent (see figure 26).

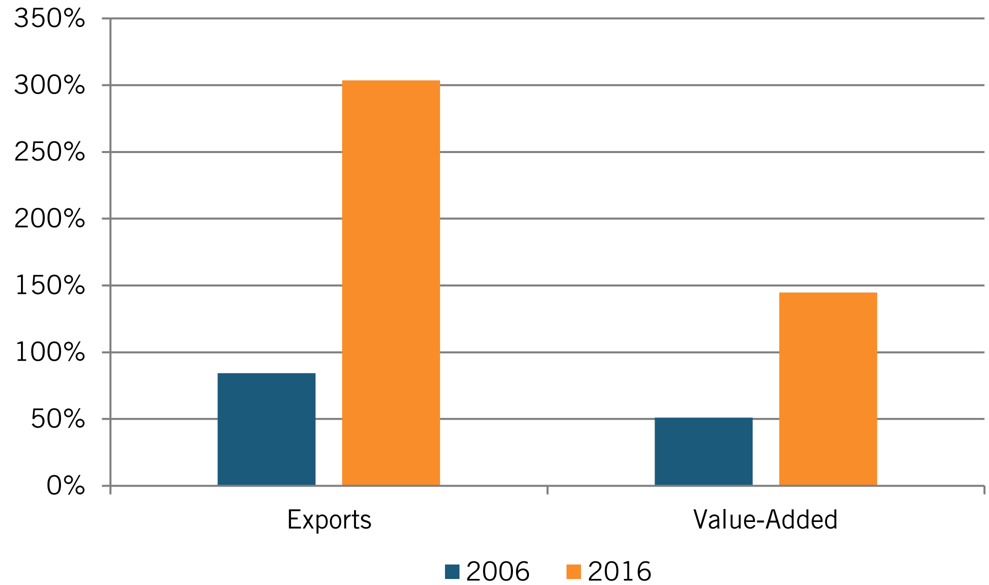
Figure 26: Chinese ICT Services Trade and Production as a Percentage of the United States, 2008–2016[76]



Indicator 26: Semiconductors

If there is one advanced manufacturing sector wherein China lags the most with the United States it is semiconductors—which is one reason why the Chinese government has targeted the industry as being key to future development. In 2016, China imported $295 billion in semiconductors, or 2.8 times the value of all the crude oil it imported that year. In fact, only 16 percent of the semiconductor chips consumed in China are produced domestically.[77] Nevertheless, Chinese semiconductor value-added relative to U.S. levels has increased from 51 to 145 percent, and its exports have grown from 84 to 304 percent (see figure 27).

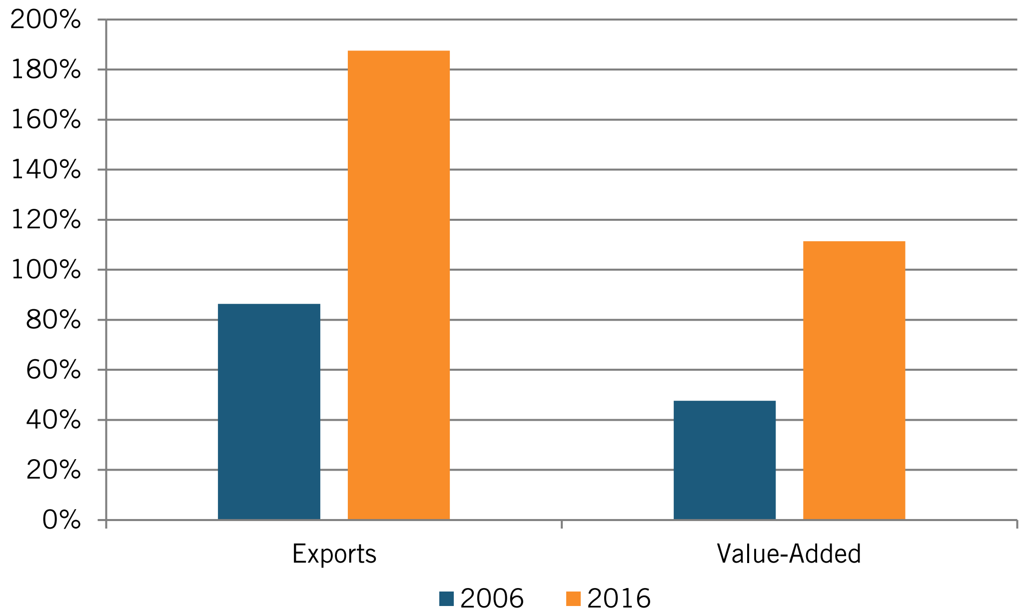
Figure 27: Chinese Semiconductor Trade and Production as a Percentage of the United States, 2006–2016[78]



Indicator 27: Chemicals

China has made considerable progress in the chemicals industry. In 2006, it ran a $34 billion trade deficit with the rest of the world. By 2016, that deficit had turned into an $18 billion surplus. This was in large part due to Chinese chemical exports (not including pharmaceuticals) increasing from parity with the United States in 2006 to 88 percent greater in 2016. Value-added grew by 325 percent over the same decade—more than doubling that of the United States—with Chinese chemical value-added exceeding U.S. levels in 2016, despite the widespread use of fracking in the United States and the low price of natural gas feedstocks domestically (see figure 28).

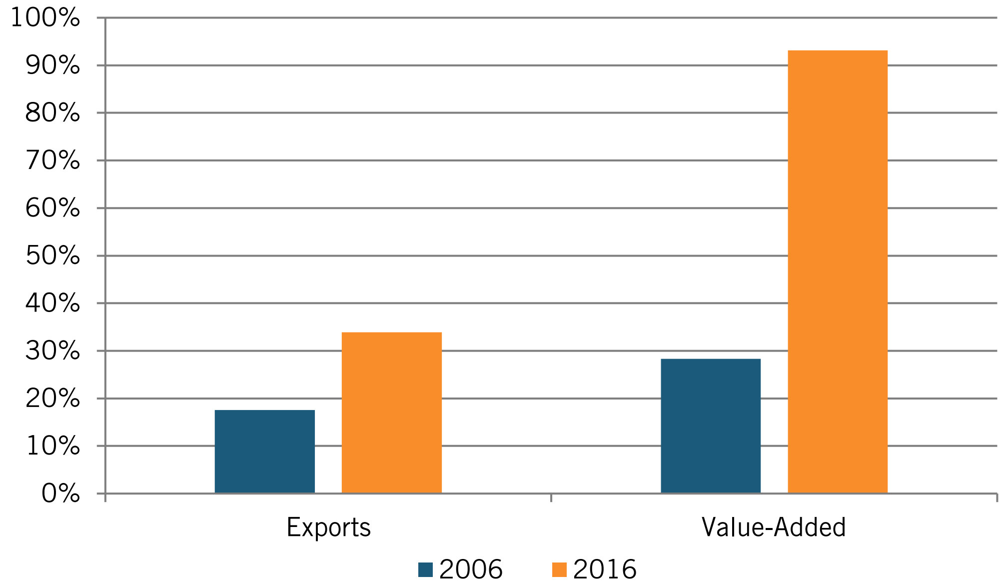
Figure 28: Chinese Chemical Trade and Production (Not Including Pharmaceuticals) as a Percentage of the United States, 2006–2016[79]



Indicator 28: Pharmaceuticals

As a subsector of chemicals, pharmaceuticals manufacturing is generally considered higher-tech and significantly more R&D intensive. Chinese pharmaceuticals value-added rose in production to $119 billion in 2016, or 93 percent of U.S. industry levels (see figure 29). However, this fivefold increase is not reflected in the trade data, according to which China exported one-third that of the United States. This suggests that despite China's pharmaceuticals industry having grown significantly to meet local demand, it trades a relatively low number of its products. This, in large part, is because the industry is still focused on generics and production of inactive ingredients.

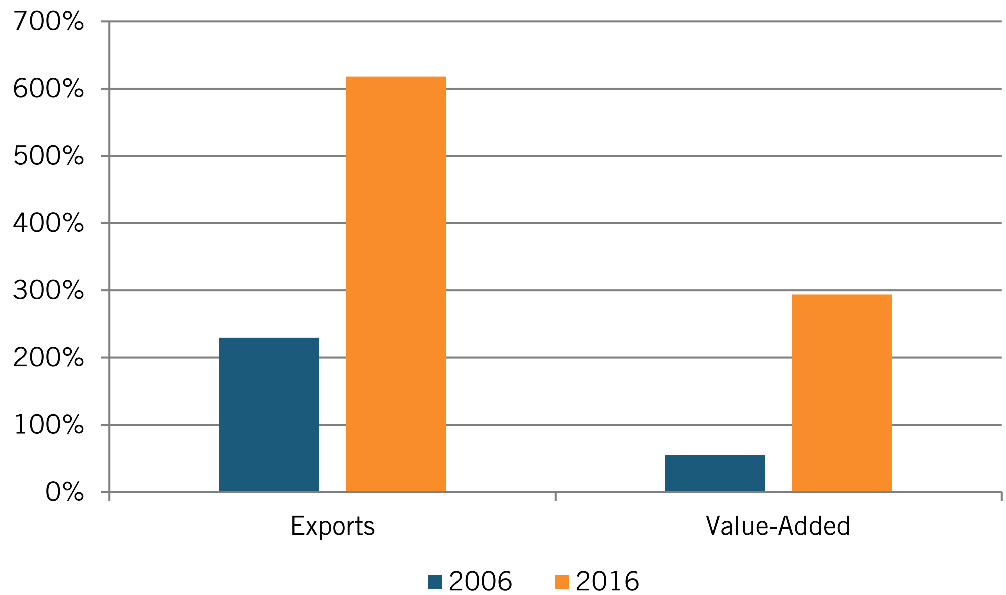
Figure 29: Chinese Pharmaceuticals Trade and Production as a Percentage of the United States, 2006–2016[80]



Indicator 29: High-Speed Rail

In 2004, China's State Council developed a railway strategy that was based on requiring, in violation of World Trade Organization rules, foreign rail companies to enter into joint ventures and transfer technology as a condition of market access. By 2016, state champion CRRC was making over two-thirds of the world's deliveries.[81] In fact, between 2006 and 2016, Chinese rail output grew more than six-fold to reach nearly triple that of U.S. production. Over this same period, exports grew from 230 percent of the U.S. level to 618 percent (see figure 30).

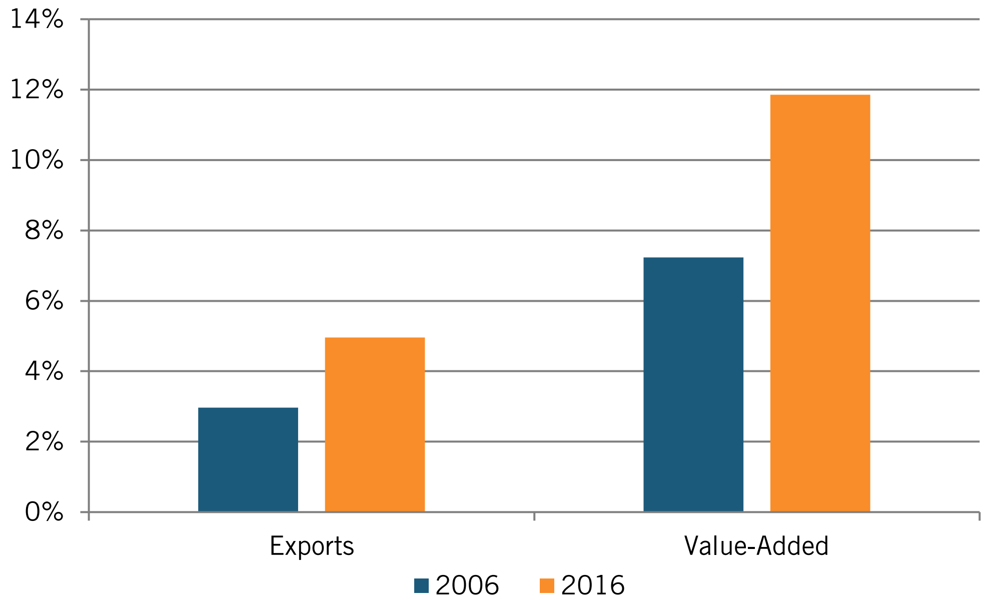
Figure 30: Chinese Railroad Equipment Trade and Production as a Percentage of the United States, 2006–2016[82]



Indicator 30: Aerospace

China's aerospace industry remains small and this was one reason China's Made in China 2025 plan has targeted the sector. Although exports and value-added have grown from 3 to 5 percent and 7 to 12 percent of U.S. levels in 2006 and 2016 respectively (see figure 31), given that state champion COMAC is now producing and test-flying its single-aisle c-919 jet, output is expected to grow significantly over the next decade.[83]

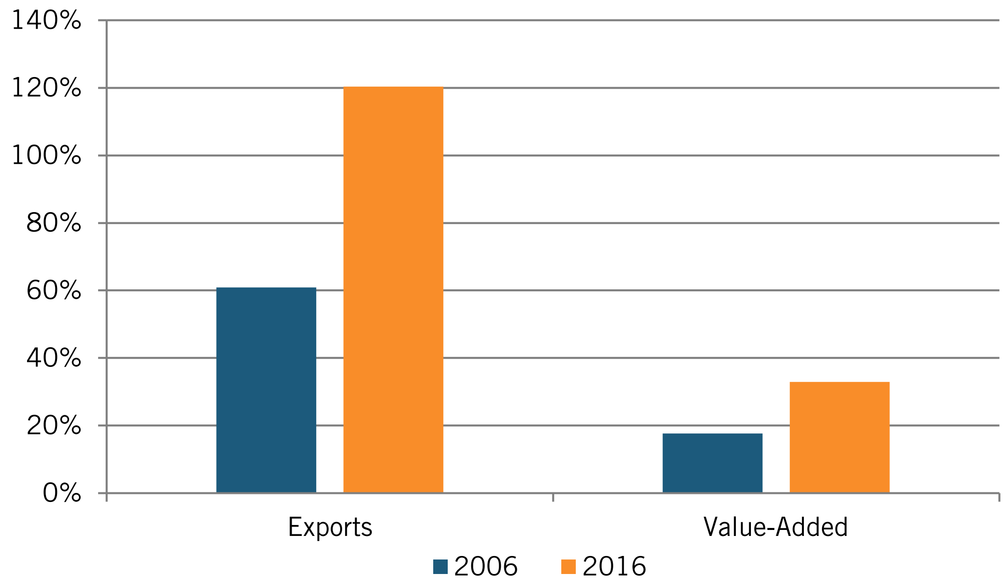
Figure 31: Chinese Aircraft and Spacecraft Trade and Production as a Percentage of the United States, 2006–2016[84]



Indicator 31: Testing, Measuring, and Control Instruments

Testing, measuring, and control instrument exports grew from 61 percent of U.S. levels in 2006 to 120 percent in 2016 (see figure 32). Over the same period, the industry's value-added grew from 18 to 33 percent.

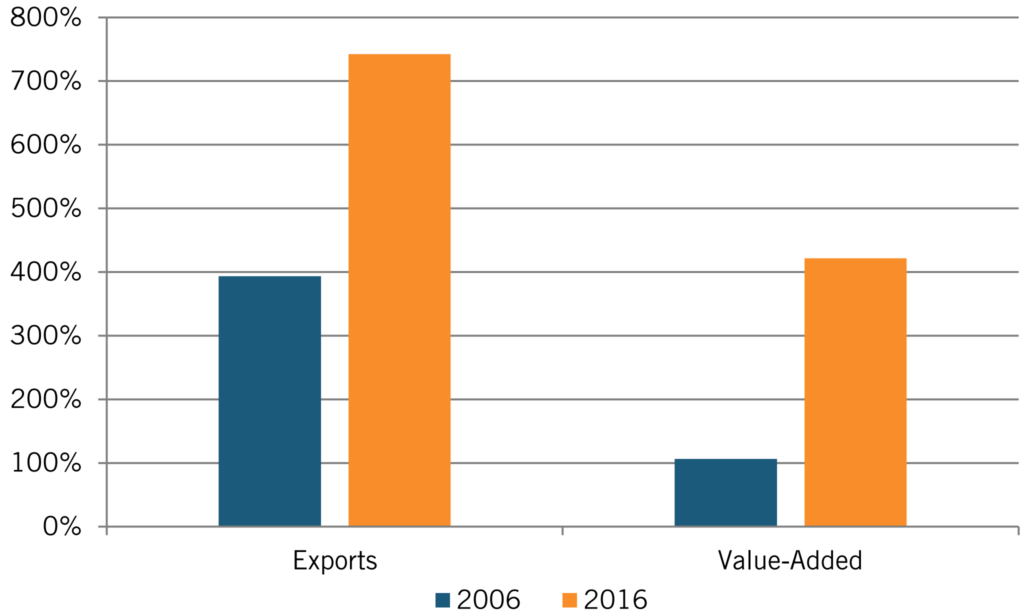
Figure 32: Chinese Testing, Measuring, and Control Instrument Trade and Production as a Percentage of the United States, 2006–2016[85]



Indicator 32: Electrical Machinery

Between 2006 and 2016, as figure 33 shows, Chinese electrical machinery imports stayed flat, growing from 60 to 65 percent of U.S. levels. In contrast, electrical machinery exports nearly doubled from 394 to 743 percent, and value-added nearly quadrupled from 107 to 422 percent compared with U.S. levels during that time.

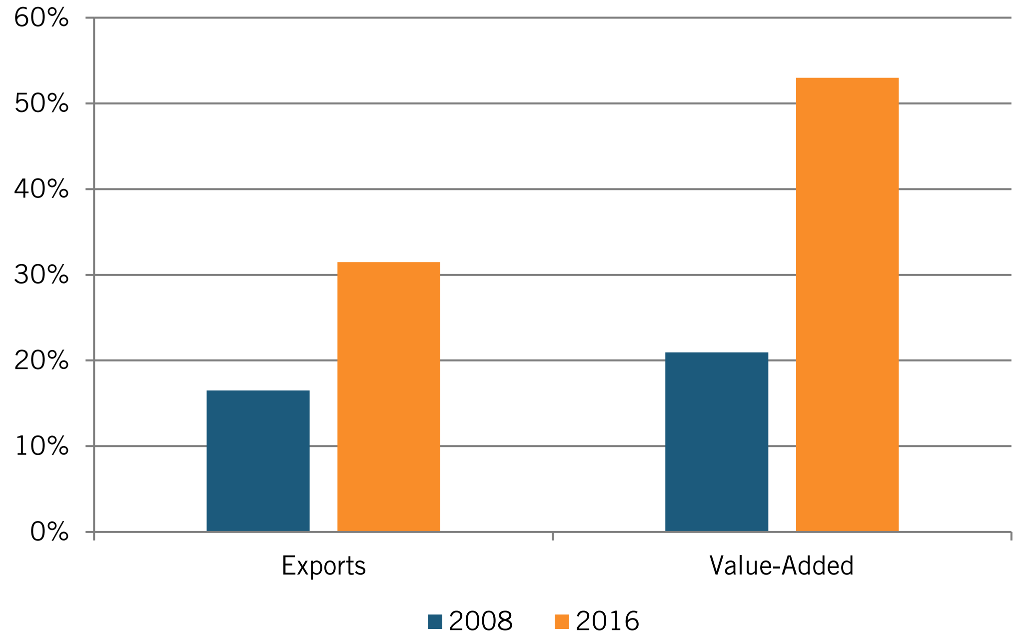
Figure 33: Chinese Electrical Machinery Trade and Production as a Percentage of the United States, 2006–2016[86]



Indicator 33: Commercial Knowledge Intensive Services

Commercial knowledge intensive (KI) services encompass some of the most innovative service sectors, such as business, financial, and information services. China has grown significantly across these sectors but still lags considerably(see figure 34). Commercial KI exports and value-added stood at 17 and 21 percent of the United States respectively in 2008, with the gaps between the two widening to reach 31 and 53 percent in 2016.

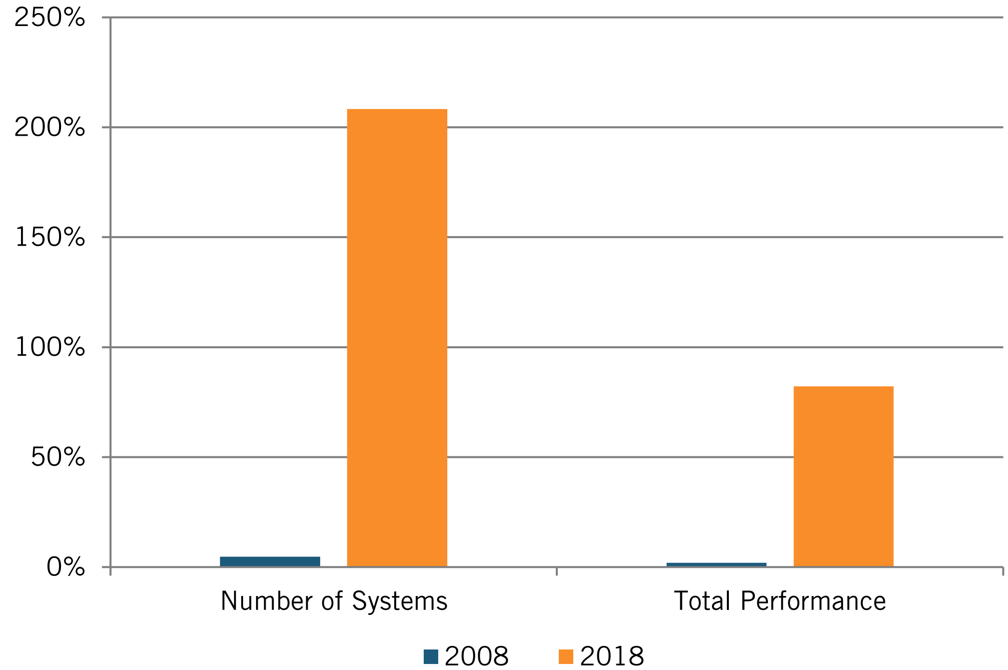
Figure 34: Chinese Commercial Knowledge Intensive Service Trade and Production as a Percentage of the United States, 2006–2016[87]



Indicator 34: Supercomputers

Supercomputers require cutting-edge technology and capabilities to produce. In 2008, only 12 of the world's 500 most powerful supercomputers were built in China, while the United States produced 258. And the United States' dominance was even greater when taking into consideration the advanced processing power of U.S.-made computers. The United States maintained a majority of the global top 500 until 2014, when China produced one-third as many supercomputers. Since then, Chinese production has grown dramatically, for example producing 227 of the world's top supercomputers, compared with 109 for the United States in November 2018 (figure 35). However, Chinese supercomputers still tend to be less powerful, with only 82 percent as much collective performance capacity as U.S. systems.

Figure 35: Chinese Supercomputers Among the top 500 as a Percentage of the United States, 2008–2018[88]

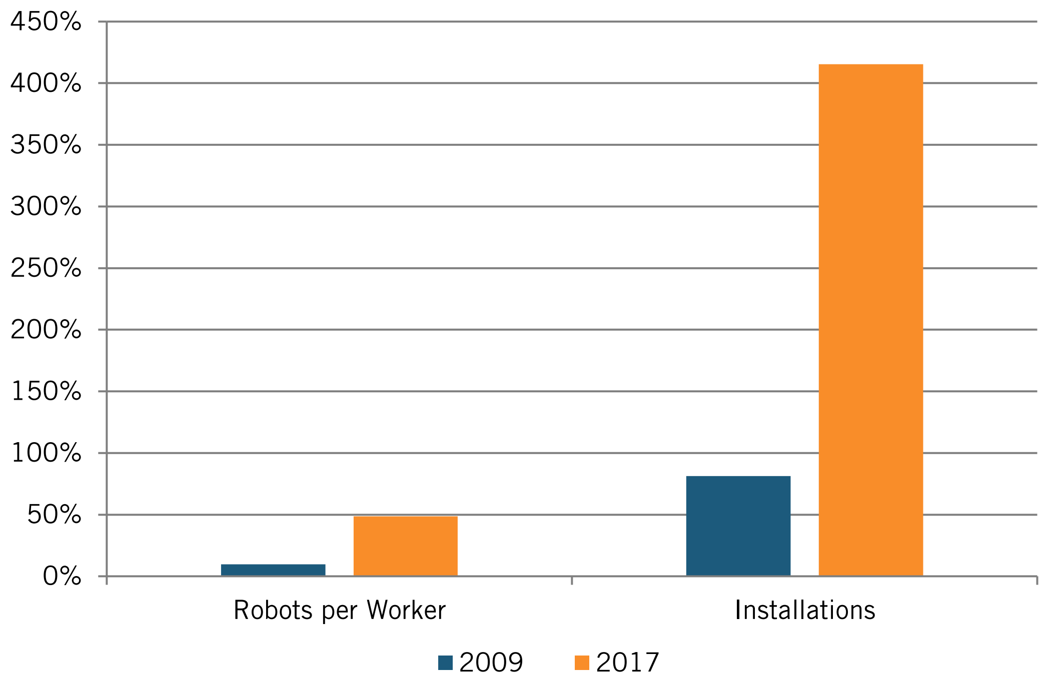


Technology Use

Indicator 35: Industrial Robot Usage

In 2009, China had 11 industrial robots for every 10,000 manufacturing workers—or 10 percent of U.S. levels—and installed 81 percent as many new robots as the United States that year (see figure 36). However, in part due to the central government making robot adoption a key priority, China's relative industrial robot density reached 49 percent of U.S. levels in 2017, while new installations were 416 percent of U.S. installations.

Figure 36: Chinese Industrial Robots per Industrial Worker and Industrial Robot Installations Relative to the United States, 2009–2017[89]



Indicator 36: Broadband Usage

Broadband is an enabling infrastructure for digital innovation. China has made significant progress its access to high-speed Internet. In 2007, fixed broadband subscriptions as a share of the population was 5 percent, and increased to 27 percent in 2017, reaching 79 percent of the U.S. level (see figure 37). Growth in per capita mobile broadband subscriptions has been more recent, from 15 percent in 2011 to 63 percent in 2017. While China has made progress in fixed broadband subscriptions, its fixed broadband speeds are slower than those in the United States, having grown from 21 percent in 2008 to 31 percent in 2014 (see figure 38). In contrast, China has made rapid progress in mobile. In 2011, the share of its total mobile connections that were 3G was just 10 percent that of the U.S. level. But by 2017, the share of mobile connections that were 4G was 97 percent of U.S. levels (see figure 39).

Figure 37: Chinese Fixed Broadband and Mobile Cellular Subscriptions Per Capita Relative to the United States, 2007–2017[90]

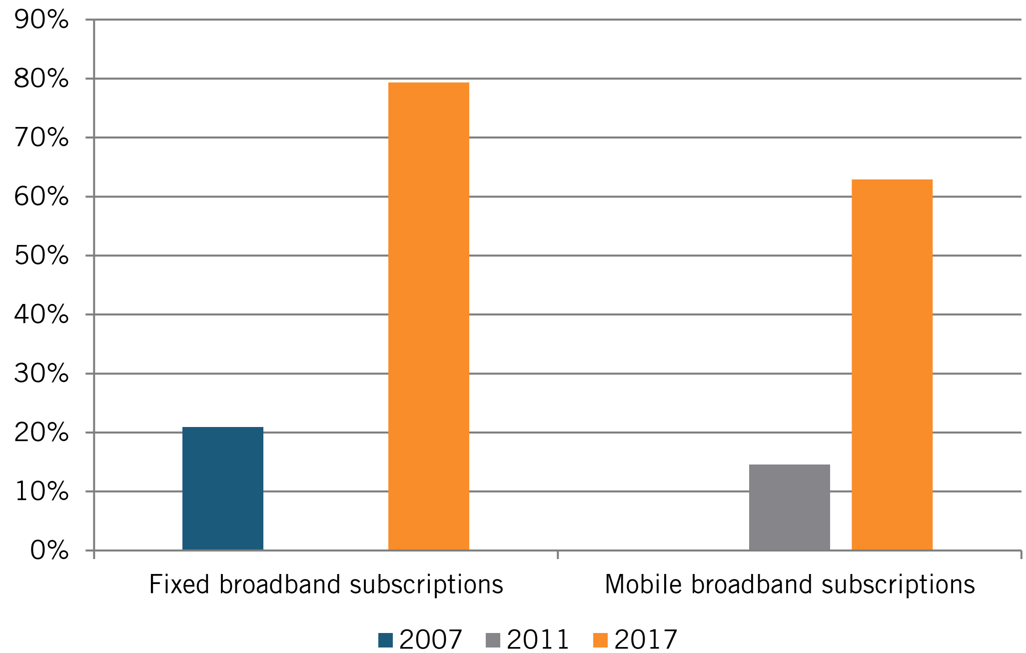


Figure 38: Chinese Fixed Average Broadband Speeds Relative to the United States, 2008–2014[91]

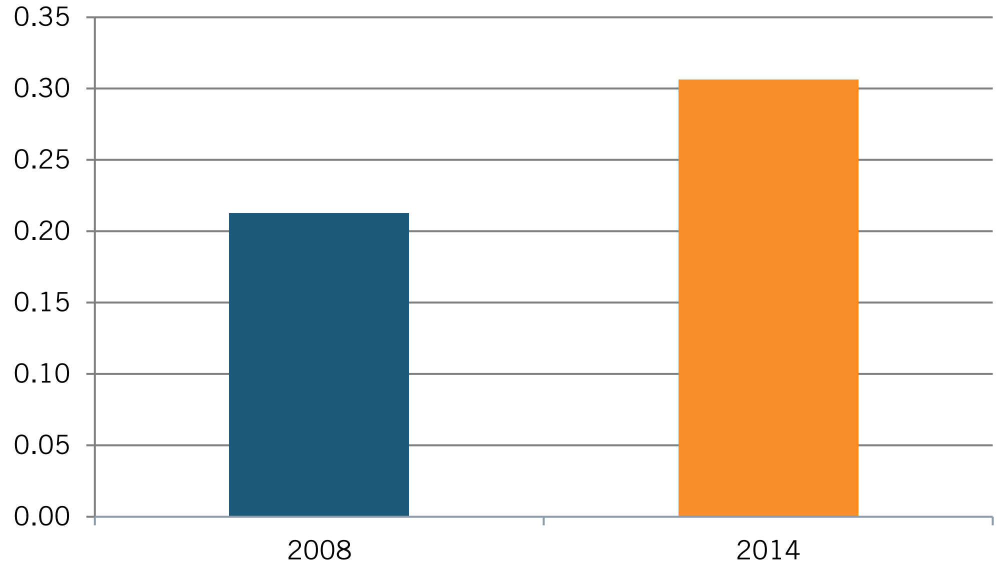
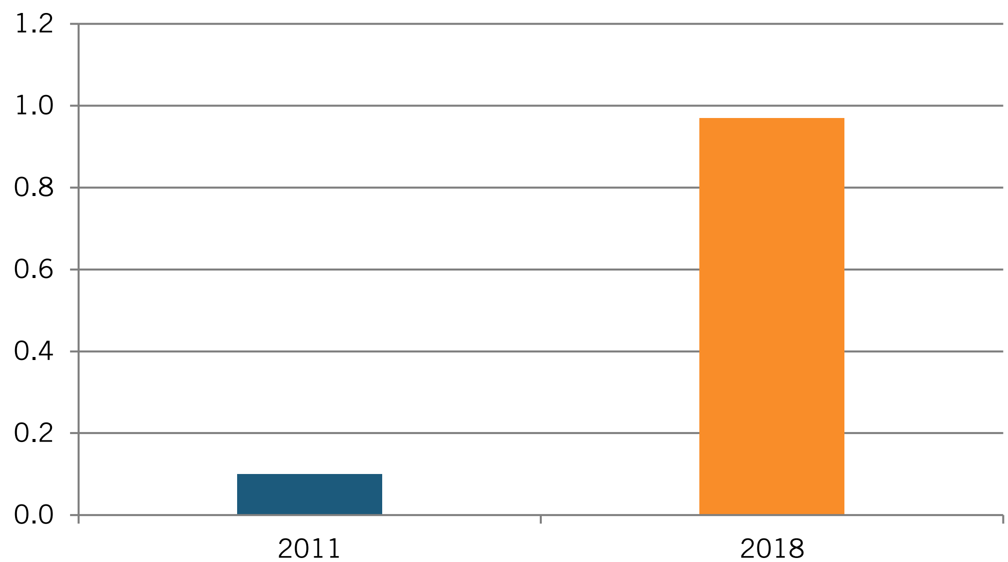


Figure 39: Chinese Advanced Mobile Connections as a Share of Total Connections Relative to the United States, 2008–2014[92]



CONCLUSION

It is beyond the scope of this report to lay out a comprehensive policy agenda for the United States in response to Chinese progress in innovation and advanced industries. ITIF has already done that in other reports.[93] However, the data presented here is a clear indication China is making more rapid progress in innovation and advanced technology industries than the United States. There is no reason to believe this progress will slack over the next decade, particularly if China continues its commitment to Made in China 2025, and advanced nations fail to successfully push back against Chinese innovation mercantilist practices and policies. But to ensure continued U.S. leadership, the United States must do more than join with allies to convince China to play by the rules, it must put in place its own robust national innovation and competitiveness strategy. In the early 1960s, in response to Sputnik, the U.S. government took prompt action to build a significant civilian and military advanced technology capability, investing more in R&D than the rest of the world's businesses and governments combined—and it paid off in spades, leading to the United States becoming the dominant technology economy for a half century. If the United States wants to retain that mantle of leadership, and enjoy the vast benefits that come from winning in advanced technology industries, it will need a major overhaul of national policies.

ENDNOTES

1. Because these indicators do not include all relevant indicators of Chinese innovation progress (due to a lack of data) and there is no adequate data to accurately weigh all the indicators, it is not possible to come up with a combined, total score for how China compares with the United States in innovation. Rather, the collection of indicators provides a broad picture of different areas of Chinese progress. However, it is possible to estimate overall how fast China is closing the gap with the United States on all the combined indicators.
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ACKNOWLEDGMENTS

The authors wish to thank the following individuals for providing input to this report: Stephen Ezell and MacKenzie Wardwell. Any errors or omissions are the authors' alone.

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