ITIF | INFORMATION TECHNOLOGY & INNOVATION FOUNDATION
HAMILTON CENTER ON INDUSTRIAL STRATEGY

Wake Up, America: China Is Overtaking the United States in Innovation Output

IAN CLAY AND ROBERT ATKINSON | NOVEMBER 2022

Based on key indicators of innovation and advanced-industry performance, China has surpassed the United States in total innovation output and is getting close on a proportional basis. To regain its leadership, the United States must respond more strategically and forcefully.

KEY TAKEAWAYS

- China is positioned to evolve from an imitator to an innovator, following a path blazed by its Asian Tiger neighbors. It has already shown itself capable of leading the world in a number of advanced technologies such as supercomputers and high-speed rail.
- China's potential for innovation threatens the market share of the United States and allied nations in high-value-added, advanced industries, which are important to U.S. prosperity and security.
- In 2010, China's innovation and advanced-industry capabilities were approximately 58 percent of U.S. capabilities on a proportional basis (accounting for size of its economy, population, etc.) and 78 percent of U.S. output in absolute terms.
- By 2020, China's innovation and advanced-industry capabilities increased to roughly 75 percent of U.S. capabilities on a proportional basis and 139 percent in absolute terms.
- China made notable progress in most of the innovation indicators the Information Technology and Innovation Foundation (ITIF) examined and in each indicator group, with its greatest progress coming in innovation outputs.
- China still faces economic challenges. But its progress in a wide range of innovation indicators suggests that it is on the path to overtake the United States in innovation and advanced-industry output—in both proportional and absolute terms.

CONTENTS

INTRODUCTION

The last decade was marked by dramatic evolution in China's innovation capabilities and strategies, much of which was driven by the transition of Chinese Communist Party (CCP) and state leadership from Hu Jintao and Xi Jinping and the introduction of China's latest major innovation policy framework: Made in China 2025 (MIC). This report updates an earlier ITIF report, applying more recent data to assess the progress China made during the previous decade with respect to the United States across a series of innovation indicators.[1]

Innovation means different things to different people, in part because there are so many different kinds of innovation. One kind is catch-up or copying innovation, wherein China has performed superbly. Another is new-to-the-world or frontier innovation. China's capacity for the latter is one of the most important unknowns in the global economy. Many countries have tried and failed to make the transition from "imitator" to "innovator," and China's ability or inability to fully make that transition will largely define global geopolitical development in the decades to come. If China can surpass the United States in innovation—both catch-up and frontier—the global value chain (GVC) for the highest-value-added products stands to undergo a tremendous change. This would represent a serious economic and geopolitical challenge to the United States and its allies, particularly because of China's predatory trade and innovation policy practices.

The Goal of This Report

This report looks back on the previous decade and gauges the progress China made relative to the United States in a series of innovation indicators. The indicators are grouped into three categories: innovation inputs, innovation outputs, and innovation outcomes. By reviewing a range of indicators, one can develop a better understanding of where China is or is not making progress, specifically relative to the United States.

Furthermore, many analyses of innovation focus on a collection of indicators that is too narrow. Specifically, many analyses devote too much attention to traditional measures of innovation such as research and development (R&D) intensity and patent output. While the accumulation of knowledge and inventiveness are certainly necessary for innovation, commercialization in the marketplace is an equally consequential part of the innovation process. Innovation is not just about who invents a technology but who can use it to deliver the best products or services to potential users. It is with this in mind that this report's analysis of innovation indicators expands beyond just reviewing traditional innovation inputs and outputs and attempts to also gauge the outcomes that these inputs and outputs bring about in markets and society.

This report is structured as follows: The section on "China's Innovation Policy History" describes the goals of China's major innovation policy developments and the methods to achieve them. This is followed by a section on "China's Ability to Innovate," including a summary of the arguments for why China is not capable of innovation at the frontier—at least in the way developed economies are—and why these arguments hold less and less water by the year. Two indices are constructed—one considering indicators that account for the size of each economy and one only considering indicators that do not—and China's scores relative to the United States' at the beginning and end of the decade are reported to provide an overall measure of China's progress. The individual innovation indicators and China's performance in them relative to the United States over the previous decade follow, accompanied by brief analyses. Lastly, the general results, the message they convey, and what can be expected in terms of future developments are discussed, followed by a brief summary and conclusion of the report.

Why This Matters

The consequences of losing the competitive edge in advanced, high-value-added industries are different than those of losing that edge in low-skill industries for three primary reasons: barriers to re-entry, loss of good-paying jobs, and national security risks.

If its unitary cost of labor (the ratio of wages to productivity) were to fall enough, the United States could re-enter low-skill industries quite easily. Relatively little know-how and machinery are required to start producing in these industries, so market entrants could simply purchase the equipment and hire the labor necessary with few obstacles. However, this is not the case in advanced industries such as semiconductor or aerospace manufacturing. Entry into these industries requires high-skill labor, massive investments in specialized equipment, and, in many cases, the ability to tread water until enough know-how is acquired to take advantage of economies of scale. Take semiconductor manufacturing as an example. The process of manufacturing one dynamic random access memory (DRAM) chip consists of over 1,000 steps. Entering the DRAM market and gaining market share requires the procurement of specialized, complex machinery capable of carrying out these tasks, a tacit understanding of the manufacturing process by the firm's workers (from the factory floor to the research laboratory), and the right innovation ecosystem (universities to train talent, a sufficient network of suppliers, etc.) to foster the industry. The firm may have to operate at a loss for some time until it has acquired enough know-how and become productive enough to capture the advantages of economies of scale required to become competitive in the international market. Thus, re-entering advanced, technology-intensive industries is far more difficult than re-entering lower-skill industries.

Beyond extensive barriers to re-entry, the loss of market share in advanced, high-value-added industries means a loss of jobs in these industries, which are typically much higher paying than those in other sectors. For example, the average salary of a worker in information technology (IT) sectors in the United States is approximately 75 percent higher than the average U.S. salary in general.[2] Therefore, lost jobs in these industries mean not only temporary unemployment for affected workers but a long-term overall decrease in aggregate well-being.

Lastly, remaining competitive in advanced, technology-intensive industries is crucial for national security. The superiority of the U.S. military rests largely on its technological superiority. This extends beyond technology for the physical battlefield and now crucially includes areas such as cybersecurity and intelligence gathering. A loss of competitiveness in the production of technologies crucial to national defense and an increase in dependence on other nations to produce them means two things. First—and obviously—it means the United States becomes more dependent on other countries to supply its military. While this may be less concerning (though not *un*concerning) if the production is shifted to an ally country, this dynamic would be incredibly concerning if the production were shifted to a country such as China, which, if not an outright adversary, is a at least a geopolitical rival. Second, even if the United States could reliably count on other countries to provide it with military technologies and supplies, its superiority would be diminished by definition. If the United States must rely on others for the development and production of defense technologies, then its military can only be as technologically advanced as its suppliers'. Again, this may be less concerning if those developing and producing the technologies are allies, but it would be unsettling if the developer were a country such as China.

Related to the issue of national security is that of economic security. The globalization of supply chains has yielded amazing benefits in efficiency and cost reduction as economies specialize in the activities in which they have a comparative advantage. However, as supply chain disruptions triggered by the COVID-19 pandemic have shown, globalization introduces economic fragility. This was especially evident for semiconductors, the shortage of which drove up prices in everything from automobiles to home appliances. The effect of the semiconductor shortage was so widespread because of its prevalence as an intermediate good and the lack of relatively close substitutes. Per a recent blog by the Federal Reserve Bank of St. Louis, one-quarter of U.S. manufacturing industries, accounting for 39 percent of total U.S. manufacturing output, use semiconductors as a direct input.[3] It is therefore important to a country's economic security to be active in these strategically important industries by remaining or becoming a competitively efficient producer (rather than through processes such as import substitution that will jeopardize efficiency and innovativeness).

General Results

Overall, China made notable progress relative to the United States. This progress was strongest and most widespread in innovation outputs and—unsurprisingly—in indicators not accounting for size, where it surpassed the United States. However, China made progress relative to the United States in all three innovation types, both when accounting for size and when not. In summary, China is beginning to make use of its massive economic and demographic endowments to eclipse the United States in gross output of innovation indicators (e.g., number of science and engineering articles published, number of doctoral degrees awarded, advanced-industry output,

etc.). This has translated into slower but still significant progress in indicators accounting for the size of each country's economy or population, where China still lags behind the United States.

CHINA'S INNOVATION POLICY HISTORY

2006–2010: Indigenous Innovation, Thousand Talents, and Strategic Emerging Industries

China's modern innovation policies started in earnest with the "indigenous innovation" movement in the Medium- to Long-Term Program (MLP) for the Development of Science and Technology released in 2006. MLP defined indigenous innovation as "enhancing original innovation through co-innovation and re-innovation based on the assimilation of imported technologies."[4] Specifically, MLP and indigenous innovation constituted a strategy to address six key issues:

1. China's weak capacity for commercial innovation
2. Insufficient technological capabilities in strategic economic and public areas such as resource utilization and public health
3. Overreliance on foreign technology in areas of financial, civil, and national security
4. The exodus of China's top science and engineering talents
5. "Expropriation" by foreign firms in the form of royalties and licensing fees charged to Chinese producers
6. An increasing realization that appropriation of foreign technologies would not lead to sustained long-term economic growth.[5]

To address these issues and to make China more technologically independent and innovative, MLP cited key economic sectors, technologies, and megaprojects that would receive the focus of China's government. The sectors cited were energy, water, and mineral resources; the environment; agriculture; manufacturing; transportation; information and services; population and health; urbanization; and public and national security. The technologies cited were biotechnology, IT, advanced materials, advanced manufacturing, advanced energy technology, marine technology, laser technology, and space technology. And the megaprojects to be funded by the state focused on protein science, nanotechnology, quantum physics, and developmental and reproductive science.[6]

MLP also laid out explicit goals to be achieved by 2020. The Chinese government sought for the nation's R&D intensity (R&D expenditures as a share of gross domestic product [GDP]) to reach 2.5 percent and for basic research to comprise 15 percent of such expenditures. Additionally, the government sought to become first in the world with respect to patents filed and academic articles published.[7]

To achieve these goals, China's government implemented and promoted a range of protectionist and filching policies, most of which fly in the face of the World Trade Organization's (WTO's) rules. The first of these policies was an expansion of the now-infamous forced technology transfers and intellectual property (IP) theft by Chinese companies. Among the primary measures undertaken to achieve MLP's goals was "[adjusting and improving] national policies on industrial

technology so as to reinforce the assimilation and absorption of imported technologies and re-innovation."[8] The second of these policies directed the raising of implicit trade barriers such as stricter quality and assurance testing and industrial and technology standards for foreign companies than those faced by domestic firms. The third policy embraced enhanced subsidies to state-owned enterprises (SOEs), specifically those in the sectors producing the technologies listed above. The final major policy used to achieve MLP's goals was the introduction of a "Buy China" requirement for government procurement of the following technologies: computers and applications equipment, communications products, modern office equipment, software, new energy and related devices, and high-efficiency and energy-saving products. This "Buy China" provision required that all procured goods and services in these technologies be produced using Chinese-owned IP and a commercial trademark registered in China.[9]

Three of China's policies—forced technology transfers and IP theft, implicit barriers on would-be imports, and subsidies to exporting SOEs—are explicitly against WTO laws. Since the Chinese government had not (and still has not) signed WTO's Agreement on Government Procurement (GPA), this final policy is not technically in conflict with China's WTO commitments. That said, China's representative in WTO-accession negotiations made clear that the country intended to become a GPA member soon after attaining WTO membership and would submit an offer to do so "as soon as possible" upon accession.[10] So here, too, China flouted its WTO promises.

As such, multinational corporations seeking to expand their business in China voiced their opposition to MLP, and "indigenous innovation" was seen as a thinly disguised pretense to introduce mercantilist policies. Affected parties took particular issue with the inclusion of the terms "co-innovation" and "re-innovation" in the government's definition of indigenous innovation, fretting over the technical and implied definitions and (often correctly) fearing that they referred to forced transfers of technologies and trade secrets in return for access to the Chinese market. Additionally, Chinese-national scientists and engineers abroad expressed concern about the government's planned megaprojects, arguing that such massive, state-run undertakings would diminish competition among involved scientists, increase bureaucratic inefficiencies, and bias results toward the preferences of China's Ministry of Science and Technology.[11]

Two years following the release of MLP, the Chinese government announced its Thousand Talents Program to address China's inability to retain and attract science and engineering talent. The program was launched first to attract top ex-patriot professors and scientists in the West to return to China and, starting in 2010, to attract foreign nationals as well. The benefits offered as part of the program include a starting bonus of over $150,000 and the ability to apply for a $450,000 to $800,000 research grant. Foreign nationals accepted as part of the program receive additional benefits such as housing subsidies, paid-for trips home, and a job or stipend for their spouse.[12] As of 2018, the program had attracted over 7,000 professors and scientists.

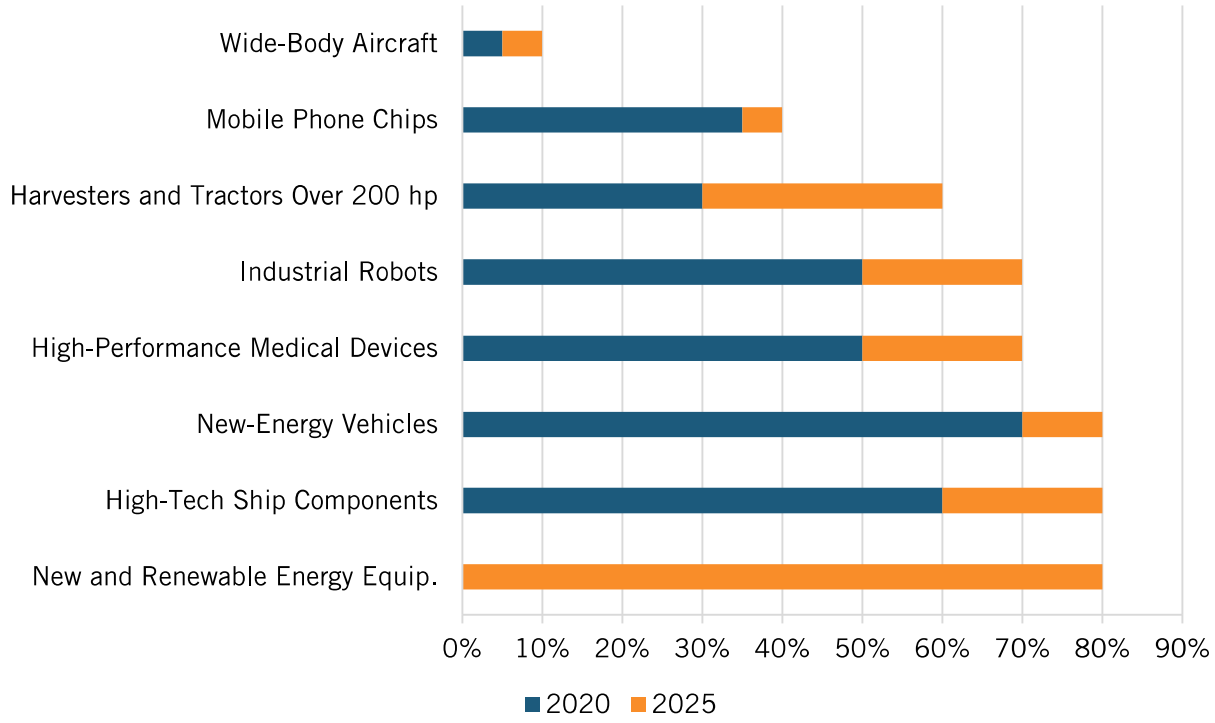
The Decision on Accelerating the Cultivation and Development of Strategic Emerging Industries—or, more simply, the Strategic Emerging Industries (SEI) strategy—updated MLP by announcing seven key sectors in which China hoped to become a world leader: energy efficiency and environmental technology, next-generation IT, biotechnology, high-end equipment manufacturing, new energy, new materials, and new-energy vehicles. Funding and administrative

support for these technologies were primarily shouldered by the country's local and provincial governments rather than the central government in Beijing.

2015: Made in China 2025

The next and most-recent major milestone in China's innovation policy timeline was the announcement of MIC. Rather than a simple extension or update of MLP or SEI, MIC shifts the focus of innovation policy toward putatively market outcomes and enhancing the entire manufacturing process, places more emphasis on measurable goals, and carves out a greater role for market mechanisms (at least for Chinese firms).[13] The broad goals laid out in MIC are to introduce innovation-driven "smart" manufacturing through the implementation of industrial robots and advanced IT (specifically the Internet of Things); to attract and nurture human capital; to gain market share in high-value-added parts of the GVC; to strengthen IP rights and protections for small and medium-sized enterprises (SMEs) and to make more strategic use of IP; the harmonization of Chinese companies' technology standards with those of the international community to increase exports; and increased international brand recognition of national champion firms.[14] As Scott Kennedy of the Center for Strategic and International Studies (CSIS) points out, MIC is more like Germany's "Industry 4.0" than it is MLP, at least in its intent to modernize manufacturing.[15]

Figure 1: Semi-official targets for domestic market share of Chinese products under Made in China 2025[16]



Like MLP, MIC enumerates specific priority sectors. It also introduced benchmarks to hit in these industries by 2020 or 2025. The priority sectors mentioned are new advanced IT; automated machine tools and robotics; aerospace and aeronautical equipment; maritime equipment and high-tech shipping; modern rail transport and related equipment; new-energy vehicles and related equipment; power equipment; agricultural equipment; new materials; and

biopharmaceuticals and advanced medical products.[17] The specific goals in MIC are (or were) that the domestic content of core components and materials reach 40 percent by 2020 and 70 percent by 2025; to establish 15 innovation centers by 2020 and 40 by 2025; for corporate R&D intensity to reach 1.68 percent by 2025; for labor productivity to increase by 7.5 percent per year between 2015 and 2020; and for energy and water consumption per unit of value added to decrease by 35 percent by 2025.[18]

MIC represents an insightful shift in focus for China's innovation policy. Innovation is about much more than just the number of academic publications or patents a society produces (although these are important), especially if such activity is more of a response to government incentives than to market incentives. Rather, the oft-forgotten aspect of the innovation process is bringing the invention to market, or the *implementation*, both in general and, importantly for China, at scale. Thus, this shift in focus toward market outcomes and commercialization rather than pure invention indicates China's ability to see the whole picture.

China's innovation policies are centered not necessarily on increasing productivity and technical know-how to move up the value chain, but to supplant foreign competitors and substitute imports in the industries it deems necessary.

Many outsiders fear that MIC reiterates China's commitment to protectionism to achieve its economic goals. While MIC places more emphasis on market mechanisms by strengthening IP protections for SMEs and liberalizing firms' setting of technology standards, the enhanced IP protections appear to only serve domestic enterprises, and the liberalized technology standards were implemented to increase domestic firms' exports. Moreover, the government's explicit desire to establish national champion firms and support SOEs in internationally important sectors indicates both that the government will still very much play a commanding role in the Chinese economy and the extent to which multinational firms are allowed to participate in it.

China is well within its right to develop and implement a strategy to boost its competitiveness and innovativeness, and ITIF would advise all nations to do so.[19] However, China appears determined to subsidize its national champions and restrict market access to foreign competitors in advanced industries where it cannot achieve a comparative advantage. First and foremost, China's innovation policies are centered not necessarily on increasing productivity and technical know-how to move up the value chain, but to supplant foreign competitors and substitute imports in the industries it deems necessary. This fundamental goal is encapsulated in MIC, prompting the United States Trade Representative to describe the strategy as follows:

> While ostensibly intended simply to raise industrial productivity through more advanced and flexible manufacturing techniques, Made in China 2025 is emblematic of China's evolving and increasingly sophisticated approach to "indigenous innovation," which is evident in numerous supporting and related industrial plans. Their common, overriding aim is to replace foreign technologies, products, and services with Chinese technologies, products, and services in the China market *through any means necessary to enable Chinese companies to dominate international markets* [emphasis added].[20]