Chapter 4

Great Power Competition in Innovation, Key Technologies, and Advanced Manufacturing

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There is broad agreement among government officials, academics, and business leaders that innovation-driven technology and manufacturing will be a primary determinant of future economic and military power. Key leaders of the United States, China, and Russia have all laid out plans to drive such innovation.

In 2015, the People's Republic of China launched the "Made in China 2025" state-led policy. This plan focused government and industry on 10 key technologies that China seeks to dominate. China has seized the lead in electric vehicles, batteries, solar panels, 5G technology, high-speed rail, advanced networks, and ultra-high-voltage transmission lines. It is also making major investments in advanced manufacturing to prevent companies from moving to countries with lower-cost labor.

The U.S. Government has defined 18 critical technologies that it must lead. The Special Competitive Studies Project (SCSP), a U.S.-based nonprofit founded by former Google CEO Eric Schmidt in 2021, has identified artificial intelligence (AI) as the most important new technology and the key to competition. The SCSP reports that the United States continues to lead in the areas of AI, biotechnology, and advanced computing. The United States can also be competitive in advanced manufacturing and next-generation energy, but it has lost competition for commercial advanced networks to China. Vladimir Putin's focus on internal control and his disastrous war in Ukraine have essentially removed Russia from competition in both key technologies and advanced manufacturing.

To compete successfully with China in the coming half-decade, the United States should appreciate and enhance its historic strengths. These may not be fully understood in early 2025, but the second Trump administration could yet see the

> *inherent value to national technological strength by continuing America's leading investment in research and development while increasing its investment in basic scientific research. It also might increase focus and funding for science, technology, engineering, and mathematics (STEM) programs starting in high school and continuing through postdoctoral studies and resolve to increase the number of foreign university students enrolled in U.S. STEM programs by offering them accelerated paths to American citizenship. Government at all levels can best improve U.S. competitive posture by investing in the infrastructure essential to support advanced manufacturing and the shift to renewable energy.*

There is broad agreement among government officials, academics, and business leaders that innovation-driven technology and manufacturing will be a primary determinant of economic and military power during the next few decades. In 2018, no less a disruptor than Eric Schmidt, former CEO of Google, was convinced that two complex sets of factors were altering the distribution of power for this decade, and for three futures beyond—the futures of geopolitics, technology, and democracy. In 2021, Schmidt—dissatisfied with the U.S. Government's efforts to prioritize and stimulate innovation in science and technology—founded the Special Competitive Studies Project (SCSP), a U.S.-based nonprofit. The first set of factors the SCSP foresaw was the arrival of artificial intelligence (AI). As AI continues to proliferate and advance, it and other emerging technologies have continued to gain prominence in U.S.-China competition. Microelectronics, advanced networks, biotechnology, energy, and advanced manufacturing are all key technological battlegrounds on which America and China's relative positional advantages are being decided and, with them, the destiny of the world order.[1]

For its part, Beijing views technology as the "main arena" in its competition with the United States.[2] Xi Jinping stated:

> *From the mechanization of the first industrial revolution in the 18th century, to the electrification of the second industrial revolution in the 19th century, to the informationization of the third industrial revolution in the 20th century . . . disruptive technological innovation* [has shaped history]. . . . *The next ten years will be a key decade . . . a new round of technological revolution and industrial change—artificial intelligence, big data, quantum information, and biotechnology—*[is] *gathering strength.*[3]

Years earlier, Russian President Dmitry Medvedev used his first speech to the Federal Assembly to announce four principles to guide Russia's future economic development. The principles, which came to be known as the four "I"s, were institutions, investment, infrastructure, and innovation. Medvedev believed that if Russia could improve the first three, it would pave the way for an innovation-based economy. These four features were the basis for the 2012 report *Strategy 2020*, Russia's long-term strategy for economic development.[4]

Clearly any discussion of Great Power competition must take a serious look at innovation, the key technologies that are evolving from that innovation, and how to produce those technologies in sufficient numbers to matter. This chapter first provides a brief history of how the U.S., Chinese, and Russian governments came to see innovation and technology as

critical. It then examines where each is focusing and has or has not been successful. Finally, it considers how well each nation is investing in advanced manufacturing to produce the technologies the nation has identified as key. The chapter then concludes with an analysis of how each nation is competing.

Innovation and Technology

China's Plan

In March 2013, Xi Jinping outlined his plan for China's drive to achieve world-class levels of innovation: "As the global competition in national strength is heating up, we should unswervingly go down the path of innovation with Chinese characteristics. We should strengthen confidence in innovation and reform the ways in which research and development systems are managed. We should also accelerate the building of a pool of scientific talents."[5]

In May 2015, the State Council issued the "Made in China 2025" (MIC2025) policy to provide guidance on turning Xi's instructions on innovation into advances in specific technologies and industries:

- The policy's guiding principles are to achieve innovation-driven manufacturing, emphasize quality over quantity, reach green development, optimize the structure of Chinese industry, and nurture human talent.
- The goal is to comprehensively upgrade Chinese industry, making it more efficient and integrated so that it can occupy the highest parts of global production chains. It also identifies the goal of raising domestic content of core components and materials to 40 percent by 2020 and 70 percent by 2025.
- Although the goal is to upgrade industry writ large, the plan highlights 10 priority sectors:
  - » new advanced information technology
  - » automated machine tools and robotics
  - » aerospace and aeronautical equipment
  - » maritime equipment and high-tech shipping
  - » modern rail transport equipment
  - » new-energy vehicles and equipment
  - » power equipment
  - » agricultural equipment
  - » new materials
  - » biopharmaceuticals and advanced medical products.[6]

Made in China 2025 remains a key element in Xi's long-term plan to "restore" China to its place as a Great Power by 2049. It was not a one-time pronouncement. At the 19th Party Congress in October 2017, Xi laid out specific goals for 2020, 2035, and 2050. He envisioned China as a leading innovator by 2035 and a leading global power by 2050. In support of MIC2025, the Ministry of Industry and Technology proposed a three-step strategy for China to become a leader in advanced manufacturing. First, MIC2025 "identifies the goal of raising domestic content of core components and materials to 40 percent by 2020 and

70 percent by 2025."[7] Then, by 2035, China will be in the front rank of second-tier global manufacturing powers and by 2045 enter the first tier.[8]

Although China remains focused on achieving the goals laid out in MIC2025, Beijing began to downplay the phrase *Made in China 2025* in June 2018. With a potential trade war with the United States looming, Chinese officials sought to de-emphasize competition. Officials stated the aggressive aspects of the plan most antagonizing the West were proposals from academics. Xinhua, the state news agency, reflected the shift in government propaganda. It mentioned MIC2025 140 times from January to May 2018 but made no mention of it in June.[9]

At the World Economic Forum meeting in June 2024, Chinese Premier Li Qiang continued the campaign to reduce global pushback against MIC2025. He warned of negative consequences for the world if nations part ways economically. He said he feared that would only "drag the world into a destructive spiral where the fierce competition for a larger slice ends up in a diminishing pie."[10] At the same time, he countered criticism that his country's industrial policy had led to overcapacity.

Despite toning down their public rhetoric about MIC2025, Chinese leaders remained optimistic that the decade of the 2020s would largely determine who leads the next industrial revolution. The Chinese Communist Party continued to espouse Xi's belief that China was well-positioned to outcompete the United States in the fourth industrial revolution and that China had four main advantages: heavy investment in research and development (R&D); superior institutions and industrial policies supporting China's ambitions; manufacturing prowess and centrality to global supply chains; and a more robust operation to set the global technology standards that could determine the future of key industries.[11]

In September 2023, Xi proposed the concept of "new quality productive forces." With innovation leading, new quality productive forces mean advanced productivity freed from traditional economic growth models. This idea features high tech, high efficiency, and high quality, and it aligns with the country's new development philosophy.[12] Xi plans to continue China's status as a world manufacturing powerhouse, moving up the value chain to align with the highest international standards in a sustainable economy.

How Is China Doing?

To meet Xi's innovation goals, China must overcome numerous challenges from domestic, technological, and international factors:

- Barriers to technological innovation: China has been unable to innovate in key basic materials, core electronic components, and high-precision industrial machinery.
- Pressure for industrial upgrading: China must move from low-cost manufacturing to an innovation-oriented manufacturing powerhouse.
- Environmental and resource constraints: With stronger environmental regulations and increased public awareness of environmental protection, industry must balance environmental protection with sustainable development.
- Shortage of talent: China faces a shortage of professional talent, especially in emerging technologies such as AI and big-data analytics.

- Impact of external policies: China must deal with trade and investment restrictions imposed by the United States and the European Union, such as economic sanctions, trade restrictions, and export controls.
- Issues with s tariffs imposed by the United States: The high tariffs imposed during the first Trump administration aimed at protecting domestic industries have fundamentally affected the balance of global trade.[13] Given the uncertainty concerning tariffs in the second Trump term, it is impossible in early 2025 to predict their potential impact on the technology race.

To increase efficiency and free its industry from its reliance on exploiting U.S. research, China is striving to build a new national innovation system by centralizing control over its academic, government, and industry research laboratories. While this theoretically provides focus to research, it also raises the tough problem of reconciling centralized, highly bureaucratic government control with the inherent need for bottom-up, open discovery. Every reader who has struggled against the bureaucracy of the U.S. Government will certainly understand the problem.

Even with these challenges, China has made progress. It is leading the world in the technological development and manufacturing of electric vehicles, batteries, solar panels, 5G technology, high-speed rail, and ultra-high-voltage transmission lines.[14] China's lead in 5G is allowing it to set technical standards in many parts of the world. It is also making substantial progress in upgrading its manufacturing, chip design and production, AI applications, and space exploration.

In a major study, the Center for Economic Policy Research noted that there is

> *strong evidence that the implementation of "Made in China 2025" has generated significant costs for the Chinese economy. . . . As tariffs, restrictions, and export controls enacted against Chinese firms proliferate, and China responds with trade restrictions of its own, these costs mount.*
>
> *Our findings suggest policymakers outside China may have also overestimated the actual effect of China's "Made in China 2025" initiative. This could have negative consequences. . . . If Western countries view the "Made in China 2025" initiative as a threat to the competitive positions of their firms, they may also begin to introduce more industrial policies as a response. Two recent examples are the U.S. CHIPS Act and the European CHIPS Act. Like the "Made in China 2025" initiative, both of these policies feature targeting certain "strategic" industries and giving taxpayer money to targeted firms.*[15]

America's Plan

In October 2020, the White House published the Critical and Emerging Technologies list, reflecting the 20 technology areas that the U.S. Government identified as priorities.[16] In February 2024, the White House Office of Science and Technology Policy released an updated list of 18 areas:

- advanced computing
- advanced engineering materials

- advanced gas turbine engine technologies
- advanced and networked sensing and signature management
- advanced manufacturing
- AI
- biotechnologies
- clean energy generation and storage
- data privacy, data security, and cybersecurity technologies
- directed energy
- highly automated, autonomous, and uncrewed systems, and robotics
- human-machine interfaces
- hypersonics
- integrated communication and networking technologies
- positioning, navigation, and timing technologies
- quantum information and enabling technologies
- semiconductors and microelectronics
- space technologies and systems.[17]

As with the products of most government-run committees, the list is both too long and not prioritized. The SCSP's panel on future technology identified AI as the most important revolutionary technology that will drive the others—advance manufacturing, biotechnology, education, and defense. It noted that only a small number of well-resourced companies and nations can apply the massive data sets, vast computing power, and intense research to develop proprietary AI models. Historically, open-source collaborative research has proved the fastest path to converting innovative technology to mainstream use. This could open the door to misuse by bad actors from individuals to corporations to political groups to nation-states.

Until late 2024, U.S. companies were the clear leaders in AI, with advances coming almost monthly. Then DeepSeek, a Chinese AI startup, released a new model that performed as well as current U.S. models at a fraction of the cost. The large commercial, political, and technological impact of this sudden change is still evolving as of early 2025.

A key question remains as to whether the rapid progress in AI will lead to artificial general intelligence (AGI). The extraordinary progress in large language models (LLMs) indicates the cumulative progress in the field may lead to AI models that combine goals, memory, and the increasing ability to learn from a wide range of data—text, audio, visual—and use this capacity to act. The capability to act based on the data that AI collects would be an early indicator of AGI developing.

The panel found that AI will be necessary but insufficient for the United States to remain a leader in innovation. It identified five other technologies that, combined with AI, will shape the future of nations in the next two decades. They are:

- Biotechnology: Applying AI to nature's source code—DNA—will make the research and development of drugs, foods, and the fermentation of industrial chemicals faster, cheaper, and more accessible.

- *Advanced Networks: Harnessing the value from AI in real-world situations hinges on the ability to rapidly and reliably transmit data between machines with a latency measured in nanoseconds. Emerging advanced networking standards like 5G advanced, WiFi 7, and 6G will unlock long-anticipated applications like autonomous vehicles, remote human-machine teaming for healthcare, and software-defined intelligent factories.*
- *Advanced Compute & Microelectronics: Moore's Law—the prediction that available computing power would double every two years—faces an uncertain future. Compute and energy demand from AI scaling continues to far outstrip the gains from Moore's Law, creating a bottleneck that threatens AI progress.*
- *Next-Generation Energy: Clean energy technology is now central to the global techno-economic competition, as nations pursue new ways to power their technological advancement while energy innovations converge with AI, compute, transportation, manufacturing, and other strategic sectors.*
- *Advanced Manufacturing: A core set of emerging technologies, from AI to additive manufacturing and robotics, are converging to transform how things are made. These technologies harness the United States' advantages in AI and software to create production systems that are faster, cheaper, and more sustainable.*[18]

While the SCSP focused the research into one overarching and five primary technologies the United States must master, private industry sees a slightly different path. PwC, previously PricewaterhouseCoopers International Limited, is one of the Big Four audit and professional services companies. Since 2016, it has produced a list of "Essential Eight" technologies, culled from a list of 250 key technologies, as a guide for clients. PwC updated this list of technologies and "organized them into three categories that reflect how business leaders can prioritize their efforts: expand [AI, Internet of Things], evaluate [blockchain, virtual reality, augmented reality, advanced robotics], and experiment [quantum, neuromorphic computing]."[19]

One of the great strengths of a system based on free-enterprise democracy is the variety of opinions and approaches that are applied to critical issues. As noted above, the government, nonprofit organizations, and businesses each have a slightly different approach to the issue of innovation but agree on the key technologies of AI, networking, and advanced manufacturing. There are also major disagreements about progress and potential and surprising developments in each field. As noted, SCSP thinks Moore's Law faces an uncertain future and will limit AI scaling. In September 2022, Jensen Huang, the CEO of Nvidia, agreed.[20] And by June 2024, Nvidia had developed new chips that exceeded the Moore's Law curve.[21]

How Is the United States Doing?

According to the World Intellectual Property Organization Global Innovation Index 2023, the United States ranks third for innovation in science and technology, behind only Switzerland and Sweden. It has consistently been near the top during the 16 years the organization has been publishing the rankings. In looking to the future, the United States

was ranked first in those indicators for future innovation, with Singapore and Israel ranked second and third, respectively.[22]

Although the United States ranks near the top of the tables, it also faces some serious challenges. Most important is the shortage of skilled labor for the design, construction, and operation of the most advanced manufacturing plants. While funding for the manufacturing end of certain key technologies has been an issue, Joseph Biden administration initiatives like the CHIPS and Science Act, the Inflation Reduction Act, and the Invest in America Act did provide much-needed investment and incentives to drive innovation.

The SCSP innovation report provided a brief analysis on how the United States is doing in competition with China in each of the five key technologies that it identified:

- *Biotechnology: The United States is entering this race with an early lead in terms of innovation, investment, and talent, but public-private partnerships will be necessary to outcompete a determined* [China] *and secure a "biofuture" that neither the U.S. Government nor industry could achieve alone.*
- *Advanced Networks:* [China] *won the race to deploy commercial 5G networks globally. But as nations and firms compete to shape standards and deploy next-generation networks that underpin cyber-physical systems, the outcome has yet to be decided.*
- *Advanced Compute & Microelectronics: Scaling breakthroughs in novel computing architectures and post–Moore's Law microelectronics—such as in-memory computing, reversible computing, and superconductor electronics—would open new possibilities.*
- *Next-Generation Energy: The United States must catalyze disruptive innovation in technologies like energy fusion, space-based solar power, and long-duration energy storage in combination with policy measures to create new national security, economic, and diplomatic advantages.*
- Advanced Manufacturing: Accelerating the deployment of advanced manufacturing systems could chip away at China's manufacturing dominance and bolster the United States' capacity to restore its industrial base.

Progress across each of these general-purpose technologies either builds on or enables transformative change in AI. As states seek to capture the strategic and economic benefits of general-purpose technologies, emerging sectors have become battlegrounds where strategic competition plays out. Commercial competition notwithstanding, the race to shape technological convergence ultimately breaks down across geopolitical and ideological lines. The outcome of this competition will determine whether these technologies are shaped in accordance with democratic or authoritarian values.[23]

Russia's Plan

As noted, Russian President Medvedev established innovation and economic development as key goals as early as 2008. He laid out the four "I"s to provide guidance. In the runup to 2018 election, President Vladimir Putin proposed a competition among Russian cities to suggest new ideas for technological innovation because with only 50 percent of the world's population, cities produce 80 percent of the world's gross domestic product (GDP).[24] Then in a meeting of the Council for Science and Education, Putin promised that science and

innovation were his top priorities.[25] In 2019, Putin announced a national strategy for AI and proposed a partnership between government and large companies to promote science and technology.[26]

[The following block quotation will be set as a textbox in layout]

Given Russia's rich human capital endowments, Russia is underperforming. Russia should be one of the technological centers of the world; a second Silicon Valley. But so far, that potential has not been realized. None of the largest tech companies in the world are Russian. Russia produces few international patents. Automation in Russian companies is far behind advanced industrial economies. Russians have failed to realize this potential, not because of cultural, historical, and geographical factors, but because of decisions—mostly political decisions—taken by post-Soviet leaders, including first and foremost Vladimir Putin. Russians are well off today, but could be so much more prosperous. Politics are to blame.[27]

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How Is Russia Doing?

Despite President Medvedev's 2008 effort to encourage innovation and advanced technology in Russia, it was clear by 2018 that the effort was failing. Even before the invasion of Ukraine, Russia was lagging in Great Power competition for innovation and advanced technology. In 2021, the Russian Science and Technology Foresight study examined the scientific and technological areas where Russia might excel by 2030, even though it was lagging the United States and China. The study found that Russia lacked the resources that the United States and China could dedicate to R&D. Compounding the problem is Russian preference for domestic supply chains, Russia's declining academic standards, and international sanctions.[28]

While Putin stated that he sought innovation and modernization for Russia, he focused the Kremlin on two primary goals. First and foremost, it must ensure he stays in unchallenged power. Second, Putin wants to return Russia's international influence to the status it enjoyed during the Soviet era. From an external viewpoint, he is succeeding in the first and failing in the second.

Putin is succeeding at his most important goal. He has controlled information flows to the population, ensured that loyal political elites dominate the socioeconomic sphere within Russia, and selectively applied laws and judicial pressure to aggressively suppress internal opposition through a variety of means—not the least of which is an apparent willingness to murder political opponents.[29] With his opponents dead, jailed, or exiled, Putin easily won the 2024 sham election to start his fifth term as president.[30]

However, Putin is failing at his second goal. As noted, politics or—more precisely—one-person rule is to blame. The Soviet legacy left Russia economically weak but with a well-educated class. The Soviet Union supported higher education with a particular emphasis on hard sciences. Even after it suffered a massive brain drain following the collapse of the Soviet Union, Russia still managed to develop leading software companies.[31] In the 1990s, Yandex competed with western search engines, and Mail.ru competed with Yahoo

Mail. Kaspersky emerged as a leader in cybersecurity, even securing some U.S. Government contracts.

But when Putin returned to the presidency in 2012, he focused on internal control. That, combined with ongoing corruption, drove increasing numbers of foreign companies to leave Russia. Corruption continued to grow as Putin consolidated power by ensuring his supporters were well compensated. As a result, even more companies left. To sustain Russia's economy, Putin emphasized arms sales, and Russia became the world's second-largest arms exporter from 2013 to 2023.[32] As part of the effort to increase sales, Putin heavily publicized Russia success in developing hypersonic cruise missiles.[33]

Building on the early Russian success in the information technology (IT) industry, Putin pushed cyber as a propaganda tool and weapon. He invested heavily in propaganda by funding RT (formerly Russia Today), the Russian state-owned news agency and radio broadcast service Sputnik, and the publication *Russia Direct*. Russia also provided a haven for hackers and cyber criminals. By 2014, Moscow-based cybersecurity company Group-IB reported the cybercrime market in Russia to be $2.3 billion.[34] Numerous Russian groups have been identified as "advanced persistent threats."[35] Russian groups have been behind ransomware attacks, credit card fraud, and infrastructure attacks but have been careful not to target people in the former Soviet Union. Therefore, Russian police do not pursue them. However, as the perceived threat of Russian exploitation of their data grew, Russian IT companies struggled to expand their markets in the West. Customers worried their data would be available to the Russian government. Oddly, despite indications that Russian intelligence was using Kaspersky for espionage, the United States did not ban the sale of the company's products in the United States until July 20, 2024.[36]

With the February 2022 Ukraine war, Russia suffered another major brain drain. Over 100,000 IT professionals were among the roughly 900,000 Russians who emigrated after the start of the war.[37] At the same time, major international software firms like SAP exited the Russian market. Compounding the problem, Russia banned the use of foreign-made software for Russian companies' critical infrastructure. While Russian companies are trying to fill the software gaps, the energy sector has requested an extension to 2026 or 2028 to replace its foreign software.[38]

With the unexpected duration of the war, Russia has struggled to provide weapons for its own forces, so it has been unable to meet contracts for exports. Furthermore, outside observers note that the poor performance of Russian equipment virtually assured that Russia will not recover its previous share of the international arms market. Part of its rise to the position of second-largest arms exporter was based on hype around its weapons systems. Its Kinzhal hypersonic missiles were supposed to be unstoppable. Then, on May 4, 2023, Ukraine used a Patriot missile to shoot one down. Twelve days later, Ukraine shot down six more.[39] Russia's vaunted S-400 Triumf antiaircraft missiles have fared no better. By early June 2024, Ukraine used ATACMS (Army Tactical Missile System) to destroy "parts of four or five S-400 batteries" as well as several S-300 batteries.[40]

Long known for tough, reliable tanks, Russia took a major hit to its reputation when its T-72s and T-80s suffered catastrophic secondary detonations that were filmed and distributed worldwide. Then Russia's much-hyped T-14 Armata tanks proved so unreliable that it withdrew them before they entered combat.[41] In June 2024, Indian news outlets were

reporting that the Indian army was planning to purchase 2,000 U.S.-produced Stryker armored vehicles in place of the previously planned 2,000 Russian BMPs.[42] While the Russian arms industry is providing adequate supplies of ammunition and weapons for its forces in Ukraine, its armor production is limited mostly to refurbished equipment taken from long-term storage. In short, it is highly unlikely Russia's arms exports will recover to prewar levels.

Russia's failure to rapidly conquer Ukraine in 2022 gave time for the West to assemble a package of economic sanctions to punish Russia. In December 2023, the U.S. Department of Treasury reported:

> *Sanctions and export controls are damaging Russia's economy and limiting its access to the financing and material goods needed to wage its illegitimate war of choice. . . . While Russia has the resources to maintain its war in the short-term, its leaders face increasingly painful tradeoffs that will sacrifice long-term prospects—as underinvestment, slow productivity growth, and labor shortages will only deepen. . . . As a result of these forces, the Russian economy is reorienting away from private consumption and towards defense spending at the expense of Russian citizens, who will face a long-term decline in living standards.*
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> This late 2023 Treasury paper offered four key conclusions:
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> - *Russia's macroeconomic performance is suffering due to its war and the impact of the United States and* [its] *partners' sanctions and economic measures. Russians are voting with their feet and leaving the country.*
> - *Russia is experiencing increasing fiscal pressure due to growing expenditures and the impact of sanctions on its revenues.*
> - *Russian's own policy responses to U.S. sanctions are growing increasingly expensive for Russia.*
> - *The United States and* [its] *partners have taken innovative measures to spare the global economy from unnecessary damage from Russia's war.*[43]

In summary, Russia must innovate to compete, but upon his return to power, Putin chose to focus on control instead. While only tight control could ensure his continued hold on the country, it also severely restricted Russia's ability to develop fourth industrial revolution industries. Putin's disastrous decision to invade Ukraine has further set the country back. Today, except for its nuclear weapons, oil, and grain, Russia has no claim to Great Power status.

Status of the Innovation and Technology Competitions

As with all interactively complex (or wicked) problems, experts disagree on the status of the technology competition between the United States and China. However, there does seem to be consensus that Russia's war with Ukraine has set the Russians well back in any economic or scientific competition. Think tanks—foreign and domestic—and journalists provide a range of opinions.

The Australian Strategic Policy Institute (ASPI) created the Critical Technology Tracker to follow the number of high-impact research papers each country produced on 44 critical

technologies (see table 4). The research looked only at published papers, not any actual products. It tracked the papers covering a range of crucial technology fields spanning defense, space, robotics, energy, the environment, biotechnology, AI, advanced materials, and key quantum technology areas. ASPI used published research papers as a proxy to rank each nation based on the total number of papers per technology.

In August 2024, ASPI stated:

> *China has strengthened its global research lead in the past year and is currently leading in 57 of 64 critical technologies. This is an increase from 52 technologies last year, and a leap from the 2003–2007 period, when it was leading in just three technologies. Over the past 21 years, China's rise from a mid-tier position in global research in the late 2000s to mid-2010s into a research and science powerhouse today has been gradual but consistent. It's been able to convert its research lead into manufacturing in some fields such as electric batteries, though there are other areas in which China has been slower to convert its strong research performance into actual technology capability.*
>
> *The* [United States] *is losing the strong historical advantage that it has built: Over the 21-year period, the* [United States] *has been unable to hold its research advantage. In the early to mid-2000s, the* [United States] *was by far the dominant research power. Its performance between 2003 and 2007 saw it leading in research for 60 out of 64 technologies. Over two decades, however, that research lead has slipped to only seven technologies (in the 2019–2023 ranking). Some notable holdouts include quantum computing and vaccine and medical countermeasures, in which the* [United States] *still maintains a dominant position. The knowledge, expertise, and institutional strengths built over decades of investment and pioneering research are likely to continue to benefit the* [United States] *in the short term, but China is catching up rapidly through an unsurpassed investment in its own* [science and technology] *areas and top-performing institutions, especially in key defence and energy technology areas.*[44]

While the ASPI report is optimistic about China's innovation, it does acknowledge that China's academic system rewards focusing on quantity rather than quality of papers. The Chinese efforts to game the academic ratings for personal and professional gain may mean the statistics are not as favorable to China as they appear. That said, the *Economist* provided charts of publications in key scientific journals that generally agree with ASPI's report (see figures 4.1 and 4.2). It noted that the Chinese government has focused on money, equipment, and people as the necessary tools to reshape Chinese science. The *Economist* also noted that while China's R&D investments have increased 16-fold since 2000, its current total of $668 billion still lags America's $806 billion at purchasing power parity.[45]

Other researchers believe the focus on academic papers is too narrow. RAND published an article stating that competition requires a broader set of metrics to capture the true status of technological progress:

Take, for example, attempts to measure U.S. and Chinese progress in the field of artificial intelligence. China has a large number of AI scientific articles and patents, suggesting Beijing's global leadership in this area.

However, the United States maintains a strong foothold in advanced AI developments, with organizations like OpenAI, Microsoft, and Alphabet leading in large language model creation and diffusion. These organizations are part of a broader innovation ecosystem that allows new technologies to thrive and be widely adopted throughout the global economy. U.S. tech unicorns—start-ups valued over a billion dollars—and the venture capital firms that back them signal both financial success and significant technological advancement.

In this thriving open market, a product of the United States' commitment to an open society and the free exchange of ideas, metrics like commercial success, technology adoption, and real-world impact become more telling than raw measures. These metrics, in the context of the strategic competition with China, underline the United States' penchant for turning research into impactful, scalable innovations.[46]

Caroline Wagner, professor of science policy at The Ohio State University, notes that while China has "fantastic quality at the top level, it's on a weak base." Chinese research is focused on application rather than curiosity-driven research. As a result, it publishes far fewer papers in the most prestigious science journals—*Nature* and *Science*.[47] This is creating a gap between the scant basic research and the robust industries that could build on that research.

In 2022, the *Economist* suggested the competition was just getting started when the Biden administration banned the export of most cutting-edge chips as well as the software and equipment needed to design and make them.[48] This was a continuation of the first Trump administration's attempt to stifle Chinese corporations when it temporarily banned the Chinese telecommunications company ZTE from buying chips and other sensitive components from American companies and also pressured Huawei. But, as in all competitions, Huawei reacted. Although its profits dropped by 70 percent in 2022, Huawei bounced back. Its profits in 2023 were over $12 billion, or on par with Cisco Systems. Huawei also pumped $23 billion into R&D and hired 12,000 new workers. While its overseas sales are down, Huawei is restructuring itself to focus on domestic consumers while restricting its supply chain for greater independence from U.S. suppliers.[49]

Xi Jinping made chips one of the key technologies when he announced MIC2025. His goal was to produce 70 percent of the chips China used by 2025. Yet in 2024, the *Global Times*, a Chinese Communist Party–controlled newspaper, quoted an industry official who said that China was thought to have reached only 30 percent self-sufficiency in 2023. Huawei has managed a 7-nanometer chip, but that trails the 3-nanometer chip being mass-produced by the industry-leading Taiwan Semiconductor Manufacturing Company (TSMC).[50]

China has provided massive subsidies for all high-tech industries through the three steps of its National Integrated Circuit Industry Investment Fund, commonly known as the Big Fund, but several of its managers are currently under investigation for corruption.[51]

Further reducing the impact of the funding, subsidies have encouraged Chinese companies to build legacy chip factories using old technology. Xi's preference for state control seems to be undermining China's private-sector innovation.

As part of the global restructuring of supply chains, TSMC and Intel are building campuses in the United States to make these venues the seats of American chipmaking. The Biden administration passed the $280 billion CHIPS and Science Act to provide massive subsidies to both. For its part, Japan is spending $13 billion in a similar approach to encourage domestic chipmaking. Europe has dedicated $47 billion, and India has invested $15 billion.[52] It remains to be seen whether these government-subsidized factories will be able to compete in the market.

To conclude, Russia has essentially dropped out of the technology competition. China is doubling down on government direction and control but still has significant leads in several key technologies. The United States has been combining governmental and private investment to sustain its lead in key areas while trying to overcome China in others.

Advanced Manufacturing Competition

Because of explosive growth in the past few decades, China is widely considered the world's factory. Manufacturing went from 9.7 percent of China's GDP in 1978, when Deng Xiaoping opened China, to 64 percent by 2006. At that point, the Chinese began to expand in other areas. So, although China's GDP continued to grow rapidly, the percentage of GDP generated by manufacturing dropped to 35 percent by 2022.[53]

China still tops the list of manufacturing countries, producing 31.6 percent of global manufacturing output. Despite the pessimism among American politicians about the decline of American manufacturing, the United States remains second, producing 15.9 percent—over twice that of Japan's 6.5 percent.[54] China continues its efforts to shift from an export-based to a consumer-based economy but remains heavily dependent on exports of goods and services. Exports make up 20.7 percent of its GDP, compared to only 11.8 percent for the United States.[55] Both nations are exporting powerhouses. Everyone is aware that China leads the world in exports, totaling $3.5 trillion in 2023. Less well known is the fact the United States exported products worth $3 trillion that same year.[56]

Although statistics are easily available concerning total manufacturing, it is much more difficult to differentiate between older manufacturing processes and advanced manufacturing. A major difficulty is the way trade statistics are recorded. Although most of the actual value of an iPhone lies in its intellectual property and, thus, benefits the United States, trade statistics assign the entire value of each phone to China, which does the final assembly and shipping.

One important indicator of—and potential proxy for—progress toward advanced manufacturing is the number of installed robots per 10,000 employees in a country's manufacturing industry. There has been massive global growth in the use of robots recently. In 2016, the world average was 74 robots per 10,000 workers. By 2022, it had more than doubled to 151. South Korea remained the world leader, growing from 631 robots per 10,000 workers to 1,012 robots per 10,000. The United States expanded, but not as fast as the world average, increasing from 189 to only 285, dropping from seventh in the world to tenth.

Deeply concerned that cheaper labor is attracting manufacturing to Southeast Asia, China has invested heavily in robotics. Much of this investment is to protect its low-tech manufacturers that are being undercut by the lower labor costs of Southeast Asia. Not even in the top 20 in 2016, China raced up to fifth in the world by 2022, with 392 robots per 10,000 workers.[57] China's massive investment in robots is not slowing. In 2022, China installed 290,000 industrial robots—more than the rest of the world combined.[58]

Even as global investment in robots explodes, the average price of an industrial robot has halved over the past decade, from $47,000 in 2011 to about $23,000 in 2022, according to ARK Invest, which predicted that costs would fall a further 50 to 60 percent by 2025.[59] For those companies that do not want to invest capital, the automation company Formic rents robots for $8 per operating hour.[60] This is well below the average wage for an industrial worker in developed countries, and it is eliminating the wage advantage of less-developed nations.

While robot-to-worker ratio is often used as a proxy for national progress toward advanced manufacturing capability, several organizations use a broader range of factors to rank the potential of various countries to succeed in advanced manufacturing. According to the World Economic Forum's Global Manufacturing Index, China, India, Japan, the United Kingdom, and the United States are among the countries best positioned to benefit from the rise of advanced manufacturing and smart factories. Japan ranked number one, followed in order by South Korea, Germany, and Switzerland. China was ranked fifth, while the Czech Republic, the United States, Sweden, Austria, and Ireland stood at sixth, seventh, eighth, ninth, and tenth positions in the index, respectively.[61] In contrast, Marc Getzoff, writing for *Global Finance*, stated that currently the most technologically advanced countries were South Korea and the United States, with China a distant thirty-eighth.[62]

Reshoring due to increasing labor costs overseas; increasing automation; freight costs; inventory costs; a desire to be closer to the market; green considerations; government incentives; and a desire to combine desire, manufacturing, and marketing in a single location are shifting manufacturing jobs back to the United States. In 2021, companies announced they were reshoring 260,000 jobs, and by 2022, they announced 350,000 new jobs due to reshoring.[63]

Ylli Bajraktari, CEO of the SCSP, noted that China has major issues to overcome but still has the potential to be the world leader in innovation, technology, and advanced manufacturing:

> *Innovation power is a nation's ability to adapt, adopt, and invent new and emerging technologies. China's core competencies in manufacturing have enabled it to* adapt *to shifting supply chains, and lead globally in* adopting*, scaling, and deploying these technologies. A command over these two aspects of innovation power has propelled China to the forefront in strategic sectors such as electric vehicles, solar panels, and digital infrastructure. . . .*
>
> *The missing piece in Beijing's innovation power, however, is* invention*, or the ability for a nation to develop breakthrough discoveries and field generation-setting, first-of-a-kind platforms. . . .*

U.S. leadership in fundamental R&D and scientific breakthroughs however is not to be taken for granted—Beijing is mobilizing all of its national resources for tech supremacy. . . . [I]*n 2023, China allocated 2.64 percent of its growing GDP to R&D . . .* [but] *Beijing still lags behind the U.S. in R&D expenditure. In 2022, the United States spent 3.44 percent of its* [significantly higher] *GDP on R&D.*[64]

Policy Recommendations

The United States continues to lead in innovating technology and manufacturing. At mid-decade, the United States continues to lead in the areas of AI, biotechnology, and advanced computing. It is competitive in advanced manufacturing and next-generation energy but has lost the competition for commercial advanced networks to China. It remains second in manufacturing but has been applying advanced manufacturing to reshore or nearshore manufacturing facilities during the Biden administration and may commence a tariff war to coerce even more global manufacturers to relocate into the United States.

However, China's highly skilled manufacturing centers and vast government investments have made the PRC better at turning those innovations into products that penetrate global markets. In many areas, it continues to use the strategy of the "fast follower" by producing a significantly cheaper but less-capable version of a leading U.S. product. Under Xi's "new quality productive forces" concept, it is also striving to lead the United States in selected areas—and is succeeding. China has seized the lead in electric vehicles, batteries, solar panels, 5G technology, high-speed rail, advanced networks, and ultra-high-voltage transmission lines.

In short, the United States excels in innovative manufacturing while China leads the world in capital-intensive manufacturing.

To compete more effectively with China over the remainder of this decade and beyond, the United States should act in concert with its historical advantages and upgrade in areas experiencing relative weakness:

- The United States should continue its world-leading investment in R&D while increasing its investment in R&D of basic scientific questions, such as mapping the human genome or developing the theory of a laser. Pure as opposed to applied research has historically been the source of major technological transformations, and the United States has been a global leader in funding pathbreaking pure research. This is an area where government investment can lead. Private industry can continue to focus on applications of R&D.
- To exploit increased R&D investments, the Unites States should increase focus and funding for STEM programs, starting in high school and continuing through postdoctoral studies.
- The American university system should be encouraged to sustain its leadership in STEM programs by continuing to welcome talented overseas students. Foreign university students constitute much of the enrollment in U.S. university STEM programs. The Federal Government might support this important human capital project with predictable, fair student admission policies and incentivize accelerated

paths to U.S. citizenship for STEM graduates who will stay on to build American technological strength.

- Government at all levels should improve infrastructure essential to support advanced manufacturing and renewable energy. Accelerating demand for energy to power AI means that the United States can best remain strong in comparison to China if it encourages development of clean energy and transmission lines to move it to where it is needed.
- The Federal Government should also explore tax breaks to accelerate the adoption of advanced manufacturing.
- As a society, the United States needs to encourage and assist more people to train as industrial workers to operate and maintain the evolving advanced manufacturing industrial base.

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