September 2019

A Report of the CSIS
Technology Policy Program

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Smart Money on Chinese Advances in AI

CSIS | CENTER FOR STRATEGIC & INTERNATIONAL STUDIES

China Innovation
Policy Series

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The China Innovation Policy Series

In 2016, CSIS launched the China Innovation Policy Series (CIPS). The purpose of this initiative is to better understand both Chinese innovation policy and the actual performance record of Chinese efforts at high-technology innovation, and on that basis, assess the implications for industry, China's trading partners, and the global economy.

To address these issues, CIPS research is divided into three categories. The first is an overview of general trends in innovation in China based on examining the inputs and outputs to innovation on cross-national comparison. The second are studies on six sectors that are high priorities for China: the digital economy, new-energy vehicles, commercial aircraft, semiconductors, artificial intelligence, and pharmaceuticals. The third is a stream of research that examines how China's technology progress is related to its overall power and international influence. Specific areas of focus include: China's overall innovation performance, Chinese participation in global R&D ecosystem, China's involvement in international standards setting, and China's effort at civil-military integration. Over the life of the initiative, reports are being issued in each area, and CSIS is hosting events to discuss these reports and the broader issues that will shape China's innovation path and how others in government and industry should respond.

CIPS is managed by the Trustee Chair in Chinese Business and Economics in cooperation with the Technology Policy Program at CSIS. The report authors are: Scott Kennedy, Senior Adviser and Trustee Chair in Chinese Business and Economics; James A. Lewis, senior vice president at CSIS; Samm Sacks, former senior fellow in the Technology Policy Program; and Will Carter, deputy director and fellow in the Technology Policy Program. Research support is headed by Qiu Mingda of the Freeman Chair in China Studies.

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Executive Summary

Artificial intelligence (AI) has become a central theme of global strategic competition. AI promises unprecedented gains in economic and military power to countries that can effectively harness its potential to derive insights from the proliferation of global data. Few countries have embraced the vision of an AI-powered future as fervently as China. China's AI ecosystem is very different from that of the West and remains largely opaque to foreign observers. Unlike the United States, the Chinese government is dedicating significant resources and attention to AI development and creating a supportive policy environment to facilitate innovation and experimentation and proactively manage risk.

Numerous misconceptions and competing narratives around China's innovation economy have made it difficult for U.S. policymakers to understand the AI ecosystem in China and its links to AI innovation in the United States. This report seeks to improve this understanding by examining China's progress toward achieving its four strategic goals.

The centerpiece of China's national AI strategy is the New Generation Artificial Intelligence Development Plan (NGAIDP), released by the State Council in 2017. Part of China's ambitious Made in China 2025 (MIC2025) initiative, NGAIDP outlines a series of strategic initiatives to make China the world leader in AI by 2030. The plan highlights the four strategic goals China seeks to achieve in its pursuit of global AI leadership:

1. Make China the center of fundamental AI research and AI theory development;
2. Lead applied research and development of cutting-edge AI products and services;
3. Build a world-leading domestic AI industry and dominate global markets for AI; and
4. Leverage AI to increase efficiency in traditional industries and move up the global value chain.

But China's approach to AI differs from traditional Chinese state planning. China's high-tech companies are a new breed of Chinese state champions, not having grown up under the wing of the Chinese Communist Party (CCP). In contrast to other industries like banking or telecommunications, companies like the BATs (Baidu, Alibaba, and Tencent) are not former state-owned enterprises (SOEs) and lack the formal links to the CCP that state champions in other industries possess. As Chinese officials and technologists repeatedly emphasize, NGAIDP, MIC2025, Internet+, and other Chinese industrial policies for high-tech industries serve as guidance and signaling mechanisms to the private sector rather than direct government control

Chinese leaders recognize that achieving the four goals requires more than just investment in fundamental research. Rather, they utilize an ecosystem approach, combining workforce development, fundamental and applied R&D, deployment of enabling technologies and infrastructure, and incentives for AI adoption in traditional industries. China's progress in realizing these goals has become a subject of intense interest as the U.S.-China relationship comes to be increasingly defined by technological competition.

China has made significant progress toward developing homegrown AI talent but still struggles to retain the talent it produces. The Chinese government has helped expand AI programs at universities across the country, making China the world's second-largest home for AI talent, and has utilized the Thousand Talents Program to draw technologists and researchers to Chinese institutions. However, China continues to struggle to retain elite talent, who tend to prefer U.S. and global institutions because they provide the opportunity to work with global leaders in their field without any of the concerns over intellectual independence, air quality, food safety, or educational quality for their families.

Aggressive investment in AI R&D from both the public and private sectors has helped drive significant progress in China's AI research and industrial bases, but producing unique research and cutting-edge technologies remains a challenge for China. The United States is still responsible for the highest-impact research, but Chinese scholars are increasingly gaining prominence in the field. Focused investment in strategic AI verticals like autonomous vehicles, facial recognition, and natural language processing has helped to boost industry players in China, and the development of digital platforms by internet giants like the BATs is driving investment in new AI tools and applications.

The development of enabling technologies and infrastructure for AI has benefited from China's ecosystem approach to AI investment. Major national projects to promote investment in key technologies like the internet of things, 5G networks, cloud computing, and robotics are helping China to advance its AI goals by spurring the growth of the requisite physical and digital infrastructure that success in AI will depend on.

Finally, while China is working to spur AI adoption in traditional industries, the country faces a number of significant challenges. In some areas, such as consumer apps and digital services, Chinese companies have developed world-leading applications, leveraging their massive consumer base and bundled app ecosystems to build enormous databases on Chinese consumers. But AI's true potential lies in unlocking significant productivity gains and competitiveness through the integration of AI into enterprises and traditional industries. Low rates of digitization among Chinese enterprises, barriers to accessing public data, lagging cloud adoption, uncertain data quality, lack of data diversity, and protectionist data policies make that difficult. Until these issues are rectified, AI developers in China will struggle to create AI applications that produce value for China's traditional industries.

Overall, China's progress toward AI leadership remains uneven, and the global AI ecosystem, led by the United States and key allies like the United Kingdom and Canada, continues to attract the top talent, produce the highest-quality research, and be best-positioned to capture the greatest value from AI deployment throughout the global economy. However, China is utilizing every available lever of state power and investing significant attention and resources to develop its AI ecosystem and become a leader in AI innovation. Led by private companies and researchers and supported by significant funding and enabling policies from the Chinese government, China will almost certainly continue to grow its contributions to AI research and application development, expand its AI industries and increase its exports of intelligent products and services, and perhaps even overcome its legacy challenges to increase Chinese competitiveness in traditional industries.

While many policymakers in the United States react with alarm to China's growth, AI development should not be seen as zero-sum. The U.S. and Chinese AI ecosystems have benefited heavily from collaboration and competition, and keeping the global AI ecosystem open and vibrant will be the best result for both countries.

This does not mean that the United States should sit back and ignore Chinese efforts to steal intellectual property and acquire unique technologies with potential national security applications from US companies. Instead, the United States should be cognizant of the cost of these efforts to the U.S. innovation base and we should be clear about our concerns.

That China is growing its innovative base and its contributions to the global AI ecosystem is not the problem: the problem is that China has often engaged in illegal and predatory practices to strengthen its domestic AI industry at the expense of U.S. firms and global innovation. The U.S. response should reflect this. One of the United States' greatest advantages over China is that China is pouring its elite talent and investment capital into U.S. companies and U.S. institutions. The United States should protect the products of U.S. innovation, but that does not mean it should send these resources back to China to support the growth of China's domestic AI industry at U.S. expense.

Even more important than combating malicious and illegal practices by Chinese firms, the United States must focus on building its own domestic AI innovation capacity. While China is focusing on building its domestic innovation capacity and shaping domestic incentives to support AI development, U.S. policymakers are instead focused on cutting off China's access to U.S. innovation. China's ecosystem approach is based on American ideas. NGAIDP draws heavily on concepts developed in two 2016 reports developed by the Obama administration outlining the key factors needed to support continuing U.S. leadership in AI.[1] But while China has invested significant resources in implementing these ideas, the U.S. government's commitment has been largely rhetorical.

The Trump administration's February Executive Order on Maintaining American Leadership in Artifi-

cial Intelligence emphasizes the right themes, highlighting the importance of building an AI talent pool, expanding AI R&D, developing enabling technologies and infrastructure, and engaging with international partners. But little has been done to implement the executive order, and in fact, many of the Trump administration's policies run completely contrary to the order's stated objectives, for example, by slashing budgets at federal agencies that support scientific research, cracking down on visas for people with advanced education and skills, and slashing the U.S. education budget.[2]

In order to maintain U.S. leadership, the United States must take a page out of China's book. China is investing significant financial, human, and political capital into its drive for AI leadership, taking a strategic approach that brings together policymakers, business leaders, technologists, and the Chinese public to strengthen domestic innovation and build China's AI ecosystem. China remains behind the United States in fundamental research and key AI technologies, but unless the United States puts its money where its mouth is, China will continue to catch up. Whoever "leads" in the "AI race" or "dominates AI," China's AI industries are growing and innovating, and the Chinese government's strategic approach will continue to drive growth in its AI industry and its contributions to the global AI ecosystem – for better and for worse.

Introduction

The world is undergoing a technological revolution that will transform every aspect of society, governance, and the global economy. Often called the "fourth industrial revolution" (4IR), it is the product of a convergence of technological trends, including the emergence of fifth generation telecommunications networks (5G), cloud computing, the rise of the internet of things (IoT), and next-generation robotics. Whether or not you see it as a new technological revolution or the culmination of the trend of digitization, the unifying trend, and perhaps the most important technology trend of 4IR, is the rise of artificial intelligence (AI), which allows us to derive unprecedented insight from data and analyze and react to those insights at machine speed.

Around the world policymakers have recognized the critical importance of AI to economic growth and competitiveness, as well as national power. The first industrial revolution was driven by revolutions in steam and water power in the United Kingdom and led to the apex of the British Empire. The United States developed and dominated electricity and computers, the second and third industrial revolutions, leading to the golden age of U.S. global leadership in the late twentieth and early twenty-first centuries. Around the world, political and business leaders preparing for 4IR have one key thought in mind: as President Putin put it, "whoever becomes the leader in [AI] will become ruler of the world."[3]

What Is Artificial Intelligence?

AI does not refer to any one specific technology. Instead, the term AI has come to represent the broad range of approaches for building systems capable of performing tasks that previously could only be accomplished by humans. AI systems achieve their "intelligence" by being able to take in information from their users or their environment, process it according to some set of updatable rules, and respond at machine speed. Over the decades, researchers have experimented with many different approaches to achieving intelligence, but many of the new technologies we think of as AI are based on a technique called machine learning.

Machine learning systems rely on computer algorithms to parse through large sets of data, identify patterns, and build models that can be used to make decisions or predictions when given new information. Machine learning is not a new technique, but it has only been in the past decade that advances in computer processors and the proliferation of data available to train algorithms have allowed for the development of systems powerful enough to solve real-world problems. Today, deep learning—a form of machine learning—is being deployed across virtually every sector of the economy, serving as the basis not just for sci-fi technologies like self-driving cars but also for a range of more mundane, yet essential, services like optimizing logistics networks or factory maintenance schedules.

The study of AI encompasses a huge range of fields and applications, but in general the majority of recent advancements have fallen into one of several buckets. Computer vision is one of the largest, which aims to build digital systems that can identify objects in images and video to inform everything from intelligence analysis to the detection of tumors in medical scans. Natural language processing (NLP) and speech recognition are working toward building systems capable of understanding spoken and written language, empowering translation tools, voice assistants, and the analysis of large volumes of unstructured information. Robotics applies the power of machine learning to autonomous agents, enabling everything from a drone to a car to a factory arm to operate intelligently without the direct control of a human.

Beyond these direct applications of AI systems, there are also an abundance of closely-related fields in science and engineering that support AI systems, ranging from the production of AI-dedicated computing hardware to the sensors and IoT devices that will create the infrastructure for providing data to future AI systems.

The AI Ecosystem in China

Few countries have embraced this view as fervently as China. Having played a supporting role in the development of recent generations of core technologies like 4G networks and cloud and mobile computing, China sees an opportunity to catapult itself into a position of global leadership in the AI age. While many countries have developed an AI national strategy, China has multiple layers of AI policy and strategy. Made in China 2025,[4] the New Generation AI Development Plan,[5] and the 13th Five-Year Plan[6] all emphasize the critical importance of AI leadership to China's future. At the 19th Party Congress, President Xi stressed the importance of AI to Chinese growth and development and encouraged Chinese political and business leaders to support Chinese global leadership in AI technologies.[7]

The world has taken notice. AI has taken center stage in the "technology cold war" between the United States and China, and the "AI race" between them has become a central theme in global debates around the future of emerging technologies. A strong competitive dynamic has emerged, as both countries emphasize the importance of "leadership" and "dominance" in AI.

But while interest in Chinese AI is reaching fever pitch, there are many unknowns, misconceptions, and competing narratives around the Chinese AI ecosystem. For U.S. policymakers, the AI race with China has also become intertwined with broader concerns around anti-competitive practices by Chinese firms and the Chinese government, intellectual property (IP) theft and protection of U.S. innovation, and the ongoing trade war between the United States and China. Many have proposed drastic measures intended to curb China's AI development without stopping to understand the state of AI in China. For

policymakers who seek to "regain" U.S. preeminence in high technology, understanding the innovation economy and AI ecosystem in China and its links to AI innovation in the United States is essential.

In this paper, we set out to better understand the Chinese innovation ecosystem. Through open source data collection and on-the-ground interviews with innovators, AI experts, investors, and policymakers in China and around the world, we wanted to answer a series of questions: What are China's goals for AI, and how do they plan to accomplish them? Is China really innovating in AI? What does China do well in AI, and what do they not do well? How should the United States respond to China's progress in AI?

"AI has taken center stage in the "technology cold war" between the United States and China, and the "AI race" between them has become a central theme in global debates around the future of emerging technologies."

The Project

To understand how the AI innovation ecosystem in China is developing, we took a multi-pronged approach. First, we reviewed publicly available data to develop metrics of progress in everything from basic research to startup formation and AI adoption rates. While we focused on metrics for China, we also looked at similar statistics for the United States and other Western economies for comparison.

However, truly understanding China from publicly available statistics is difficult. China is notoriously opaque, and statistics about innovation are difficult to interpret and assess. Chinese experts and policymakers tend to embellish China's achievements, while foreign competitors tend to dismiss major milestones by the Chinese technology industry. Outside experts have evaluated many of the same statistics, weighed conflicting opinions, and reached opposing conclusions.

Truly understanding what is happening on the ground in China often requires visiting China and seeing things for yourself. We took a total of four trips to China over 18 months to visit facilities, see some of China's cutting-edge AI technologies firsthand, and talk to Chinese experts to better understand what is happening in the Chinese AI industry. These experts ranged from reporters and academics to researchers, engineers, entrepreneurs, investors, policymakers, and leaders from China's major technology companies.

We also spoke to a range of experts outside of China to better understand the view of Chinese AI innovation from the outside. One interesting source of perspective came from Western entrepreneurs and executives from the major U.S. platforms, who not only track developments in China but were able to provide insights based on their experiences competing directly with Chinese companies.

China's National Strategy for AI

China's innovation ecosystem is very different from that of the West, and one of the main reasons is the policy environment. AI is a national strategic priority for China, and unlike the U.S. government (USG), the Chinese state is dedicating significant resources and attention to supporting AI development. This supportive policy environment sets Chinese AI companies and entrepreneurs apart from their international competitors in everything from smart consumer services to regulated industries like finance, transportation, and health.

China's Four Key Goals

In July 2017, China's State Council released the New Generation Artificial Intelligence Development Plan (NGAIDP).[8] NGAIDP outlines a series of key initiatives to turn China into the world leader in AI by 2030. NGAIDP builds on a framework of earlier national strategies to dominate technology fields, most famously Made in China 2025, Internet+, and the 13th Five-Year Plan.

NGAIDP outlines a three-step process for China to become the world's leading AI power. By 2020, China aims to "keep up the overall technology and application of artificial intelligence with the advanced level of the world," contributing to the development of AI theory and competing head-to-head in global smart industries. By 2025, NGAIDP calls for China to not only compete in but lead the global AI industry, achieving "leading research

results" and spearheading the development of laws, regulations, and ethics for AI. Furthermore, China will leverage AI in traditional industries to finally deliver on the Communist Party of China's (CCP) goal of moving up the industrial value chain. Finally, by 2030 NGAIDP calls for China to become the world's leader in AI, reclaiming its place in the "forefront of the innovative countries and economic powers."

"AI is a national strategic priority for China, and unlike the U.S. government (USG), the Chinese state is dedicating significant resources and attention to supporting AI development."

To do this, China seeks to achieve four key goals:

- Make China the center of fundamental AI research and AI theory development;
- Lead applied research and the development of cutting-edge AI products and services;
- Build a world-leading domestic AI industry and dominate global markets for AI; and
- Leverage AI to increase efficiency in traditional industries and move up the global value chain.

Not Your Grandmother's Central Planning

It is important to note, however, that China's approach to AI is in many ways different than past approaches to strategic industries. One theme that was consistently raised in discussions with Chinese policymakers is that the AI development plan is different than old-fashioned Chinese state planning; it is focused on building on the organic strength of China's AI industry rather than creating it from whole cloth.

Senior officials from a range of ministries, including the National Development and Reform Commission (NDRC), Ministry of Science and Technology (MOST), and Ministry of Industry and Information Technology (MIIT), all emphasize that, unlike many of China's strategic industries, the AI industry is led by companies that did not grow up under the wing of the party, like Baidu, Alibaba, and Tencent (the BATs). Significant growth and investment in China's AI industry dates back well before the release of NGAIDP and even its precursors, Made in China 2025 (May 2015), Internet+ (March 2015), and the 13th Five Year Plan (November 2015).

The strategy itself reflects this, emphasizing the natural strength of the sector, stating: "The organic combination between the accelerating accumulation of technical capacity, massive data resources, huge application requirements and open market environment forms China's unique advantages of artificial intelligence development."[9] As these officials explained, the steady drumbeat of national strategies, implementation plans, and strategic guidance has not been intended as a strict roadmap for government-dominated AI industrial policy but rather as a signaling mechanism to convey the CCP's priorities to a part of the private sector that lacks the traditional direct party ties of Chinese state champions.

China is also not the monolithic entity often portrayed in Western policy debates. Within the central government, multiple ministries, including MOST, MIIT, and the NDRC, are pursuing their own initiatives to promote AI policy and implement Made in China 2025. Much of China's government investment, tax credits and subsidies, and direct support to AI developers comes from municipal governments, driven by local cadres competing for advancement in the CCP by advancing Chinese AI.

Above BEIJING, CHINA - China's Minister of Commerce Zhong Shan (Center) attends a press conference speak to journalists during a National People's Congress (NPC) press conference on March 9, 2019 in Beijing, China. The second session of the 13th NPC opened in Beijing on Tuesday.

Photo by Lintao Zhang/Getty Images

An Ecosystem Approach to AI Innovation

▶ Chinese leaders understaxnd that there is more to successful implementation of the AI strategy than throwing money at the problem. Multiple ministries across the central government, in addition to provincial and municipal governments, have released dozens of implementation documents and industrial development plans to support China's four strategic goals.

While the USG has always acknowledged the importance of the broad technology ecosystem to AI development in theory, early USG AI efforts focused almost exclusively on supporting AI research. In contrast, Chinese policymakers have invested significant resources and political capital in building a broad and deep foundation of human capital, supporting the development of enabling technologies, and creating incentives to support AI adoption, in addition to providing strong funding for research.

China's approach to implementing its strategy is four-pronged:

- Develop a world-leading AI workforce;
- Accelerate investment in fundamental and applied R&D;
- Support deployment of enabling technologies; and
- Create incentives for traditional industries to adopt AI and automation.

Develop a World-leading AI Workforce

One of China's first priorities is to develop a pipeline of world-leading AI talent. China's large population and dedication to STEM (science, technology, engineering, and math) education already produce a large number of graduates in computer science and related fields. By the Chinese government's own estimates, it is already second in the world in overall AI talent, with more than 18,000 AI specialists, but remains well-behind the United States, which has over 28,000.[10] However, when it comes to the most elite AI leaders, China ranks itself just sixth in AI talent, with one-fifth the number of elite U.S. AI specialists.[11]

At the center of China's AI talent initiatives are China's elite universities. Currently, Tsinghua University has one of the best computer science departments in the world and is the number two producer of AI talent, right behind Carnegie Mellon University in contributions to major academic AI conferences. Peking University is the only other Chinese university in the top 10. Six of the top 10 are U.S. universities (the other remaining two are Oxford University in the United Kingdom and ETH Zurich in Switzerland).[12] But China is investing heavily in expanding AI programs. China's Ministry of Education recently approved 35 elite universities to offer AI majors. In February 2019, the ministry also approved almost 400 majors in AI-related fields such as robotics and big data.[13]

"China's big problem, however, is not producing AI graduates but retaining elite AI talent to work in China and fostering an environment for cutting-edge research."

China's big problem, however, is not producing AI graduates but retaining elite AI talent to work in China and fostering an environment for cutting-edge research. Of the research papers accepted at the elite NeurIPS conference in 2018, 25 percent of authors were born in China, but of that 25 percent, less than one-third actually work or study in China. Sixty percent of those Chinese-born AI experts are currently affiliated with U.S. companies or universities. More than half attended graduate school in the United States, and of those, 78 percent stayed in the United States to work after graduation.[14]

Chinese leaders have been struggling for more than a decade to address this challenge and attract and retain top-tier talent. In 2008, they launched the Thousand Talents Program to draw elite research talent back to China, both repatriating Chinese researchers working abroad and attracting foreign experts to do research at Chinese institutions.[15]

Despite significant investment and aggressive appeals to Chinese expats and foreign experts, Thousand Talents has failed to draw a significant number of elite researchers to China. The statistics cited above are from 2018, more than a decade after Thousand Talents was launched, and there are few signs of change.

As one Chinese AI expert who chose to stay in the United States explained, truly elite researchers can get research funding from competitive U.S. and global institutions without any of the concerns over air quality, food safety, educational opportunities for children, or intellectual freedom that come with returning to China. Elite researchers are also attracted to the opportunity to work closely with leaders in their field, so the concentration of world-leading AI experts in places like the United States is a significant draw. This suggests that Thousand Talents may be most attractive to mid-tier researchers for whom access to grant funding and prestigious positions in Western research institutions is difficult.

The greatest boon to China's talent retention efforts may in fact come from the Trump administration. After the release of the now-infamous DIUx report on Chinese technology transfer efforts in 2017, the Trump administration has pursued a range of efforts to restrict Chinese talent from entering the United States, limiting access to work visas for Chinese individuals and even threatening to cut off student visas for Chinese students.[16] Like many of its other headline initiatives to dominate emerging technologies, the Thousand Talents Program has gone into stealth-mode in recent months, as Chinese policymakers recognize that their overt efforts to dominate strategic industries are provoking backlash in other countries.[17] China's efforts to retain its

elite AI experts will certainly benefit if the greatest overseas market for Chinese AI talent is closed off.

Investing in Fundamental and Applied R&D

Unlike the United States, China's strategic commitment to AI has been backed by significant government investment. China's commitment to R&D is well-established. In the last two decades, R&D investment by the Chinese government has more than tripled, surpassing USG R&D investment in 2018.[18] Much of that investment has focused on emerging technologies like AI that are priorities for the CCP.

While accurate data on Chinese government R&D investment is difficult to come by, even a small sample of Chinese investments in AI R&D quickly surpasses total USG spending. Even by the most generous estimates, total USG investment in AI R&D is less than $5 billion in 2019, including a new $2 billion program announced by DARPA. In China, the cities of Shanghai and Tianjin are investing $15 billion and $16 billion, respectively, in their AI industries over 10 years. One Chinese province alone (out of 23) committed $5 billion to AI development, and Beijing is investing $2 billion in an AI innovation area.[19] Furthermore, under the NGAIDP, AI has become a top priority for government venture capital (VC) funds from the local to the national level, which collectively control hundreds of billions of dollars of investment capital.[20]

When it comes to applied research, China is harnessing the power of the private sector to channel billions into innovation. In 2017, for the first time, Chinese AI startups raised more money ($4.9 billion) than AI startups in the United States ($4.4 billion), catapulting the Chinese share of global AI funding to 48 percent from just 11.3 percent the year before.[21]

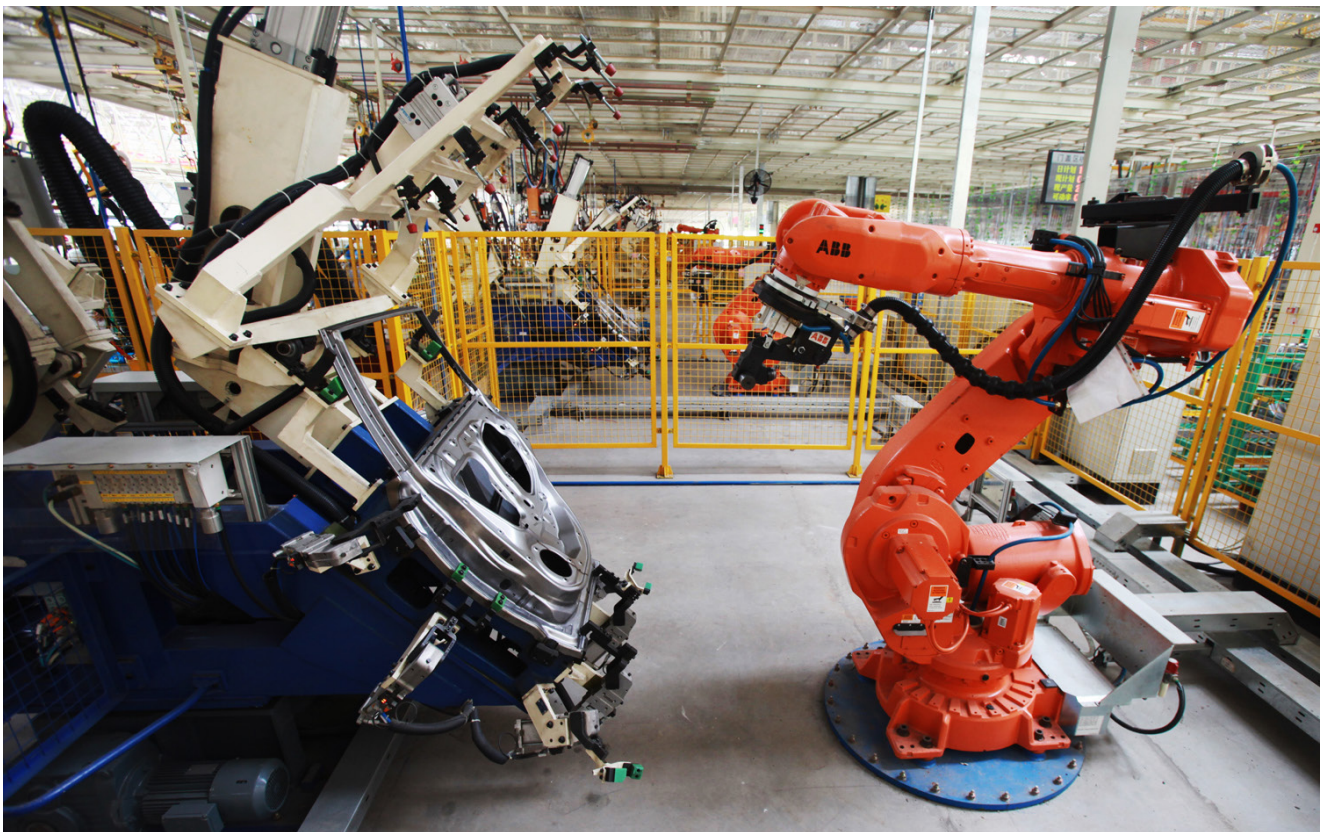
Chinese investors are also pouring money into overseas startups. Chinese investors poured more than $3 billion in U.S. technology startups in 2018, including $1.3 billion from Chinese state investment vehicles.[22] Chinese investors also poured more than $8 billion of investment into Uber in 2018.[23] And they are not just investing in the United States. Tencent, for example, invested $1.2 billion into Indonesian logistics tech company Go-Jek and $1.4 billion in Indian e-commerce platform Flipkart.[24]

Support the Deployment of Enabling Technologies and Infrastructure

AI does not exist in a vacuum. An intelligent society is the product of several technology trends coming together to enable AI to create value from data. The NGAIDP stresses the importance of developing an AI "innovation platform" to support technology development.[25] This foundation comprises a wide range of enabling technologies, including dedicated hardware to support intelligence at the edge, cloud-based support services, public data sets, high-performance computing, sensorized infrastructure, robotics, and 5G connectivity. Advanced AI applications depend on these enabling technologies, and Chinese technology strategy reflects this. NGAIDP is one of many pillars of the broader policy infrastruc-

Above BEIJING, CHINA - Students graduate during a ceremony held for 3,768 master and 898 doctorates being given out at the Tsinghua University on July 18, 2007 in Beijing, China. China faces a major challenge in meeting its goal of creating nine million jobs this year, according to Tian Chengping, Minister of Labour and Social Security. Approximately five million college graduates, the largest number in history, will enter the job market this year, in addition to surplus rural labourers swarming into cities for work.

Photo by China Photos/Getty Images



ture of MIC2025 and the 13th Five-Year Plan.

One good example of such an enabling technology is cloud computing. Today's AI applications live in the cloud, which offers efficient access to computing power, storage, and large data sets to drive AI applications. NGAIDP repeatedly emphasizes the importance of building an "artificial intelligence cloud service platform" to support AI development. In 2017, MIIT released its Cloud Computing Development Three-Year Action Plan, which calls for the cloud industry in China to grow to more than 430 billion RMB ($60 billion) by 2020.[26] China's state champions have responded, investing heavily in their cloud efforts, including dedicated AI clouds.[27]

Another enabling technology receiving significant government support in China is robotics. China released its Robotics Industry Development Plan in 2016 as part of Made in China 2025, setting a goal of producing 100,000 industrial robots domestically by 2020, more than double the 43,600 produced in 2018.[28] To develop its robotics industry, China is working to improve its domestic ability to both produce sophisticated robotic systems and components, as well as develop the software and AI systems required to operate those robotic systems in new and more challenging environments. To achieve the first goal, China has subsidized domestic firms and encouraged Chinese acquisitions of Western robotics companies like the German firm KUKA.[29]

China has increased its investment in R&D and new robotics startups. A number of new firms—like Dorabot, backed by VCs like Kai Fu Lee and Aqrose and acquired by Baidu in early 2018—have emerged to develop software for robots, but Chinese contributions to original R&D continue to lag.[30] Of 34 papers receiving best paper awards at the 2018 International Conference on Robotics and Automation—the leading international conference on robotics—only two Chinese teams, one from Hong Kong and one

Above TIANJIN, CHINA - Robot arms are seen on the production line of Hover H6 (SUV) at the company's Tianjian factory on August 17, 2011 in Tianjin, China. The new Tianjin factory of Great Wall Motor Company Limited will be put into operation on August 25, as a most important production line over its five-year plan (2011–2015).

Photo by VCG/VCG via Getty Images

from Intel Labs China, received acknowledgement.[31]

China has also been heavily investing in 5G mobile networks, which will form the communications infrastructure necessary for the coming ecosystem of sensors, IoT devices, and autonomous systems that will fuel AI. The Chinese government began allocating spectrum for 5G network trials in late-2018 and is expected to invest between $130-$220 billion in 5G networks between 2020 and 2025.[32] Rapid development of nationwide 5G networks would give Chinese entrepreneurs the opportunity to immediately begin experimenting with new technologies—especially those related to autonomous vehicles and smart infrastructure—that are currently infeasible due to limitations in communications networks.

"Harnessing AI to generate new growth engines for the economy could help cement the stability of the Chinese state, while failing to adapt could lead to stagnation as China loses manufacturing jobs to automation."

Drive Adoption of AI and Automation in Traditional Industries

But perhaps the most important pillar of China's AI strategy is the integration of AI into traditional industries to move up the value chain and enhance efficiency and competitiveness. Moving up the value chain is arguably China's most important strategic priority, viewed as essential to maintaining economic growth and avoiding the "middle income trap." Continuing to deliver rising standards of living, new products and services, and greater opportunity to Chinese citizens in turn helps to maintain domestic stability and validates the leadership of the CCP.

The manufacturing sector, a critical engine of growth for the Chinese economy, is at the heart of China's efforts to modernize and capture greater value from its place in global supply chains. Harnessing AI to generate new growth engines for the economy could help cement the stability of the Chinese state, while failing to adapt could lead to stagnation as China loses manufacturing jobs to automation.

In December 2016, China released its Intelligent Manufacturing Development Plan (IMDP) to encourage manufacturers to leverage data and automation to increase efficiency and product quality and move up the value chain.[33] The plan provides incentives for companies that pursue digitization and smart manufacturing practices and includes a pilot program for smart manufacturing projects. Smart manufacturing efforts in China remain at an early stage: according to a survey of Chinese manufacturers, nearly 90 percent are still in the nascent stages of digitization, with more than 60 percent still working to computerize production and integrate connectivity into their operations.[34] But the government's commitment to not only driving AI development but leveraging AI in traditional industries is flowing through to the private sector.

Ironically, many of the automation and smart factory efforts in China are driven not by policy but by labor shortages. As standards of living have risen in China, so have the expectations of the younger generation. Companies struggle to attract young workers to perform rote tasks on assembly lines, driving up wages and reducing the competitiveness of Chinese manufacturers. In industries from automobile manufacturing to electronics assembly to mushroom sorting, cheap, low-skilled labor is disappearing, and smart factory technologies are the only solution.

Progress Toward the Four Strategic Goals

How is China progressing toward its four strategic goals? Has China's strategic approach delivered on its ambitious goal of reaching parity with the United States next year?

Fundamental Research and Theory

For many, true "innovation" means coming up with revolutionary new ideas and technologies through fundamental research. Who comes up with the most exciting ideas and figures out how to make them real? This kind of fundamental R&D has traditionally been an area where the United States excels and China struggles. And this remains true. Even the most enthusiastic evangelists of Chinese AI agree: in foundational AI innovation and discovery, the United States remains the leader and China lags behind.

That said, China has made significant gains in recent years, and across many metrics, the gap between the United States and China is closing quickly.

AI Publications

In 2016, many in the United States were alarmed by the news that China had officially overtaken the United States in its output of academic journal articles related to deep learning, a key technique involved in modern AI systems.[35] However, in sheer publication volume, China may have pulled

ahead in AI publishing far earlier than this, overtaking the United States in 2004.[36]

Publication output is an important gauge of progress in fundamental research, as academic journals and conferences are where researchers first share news of their breakthroughs. The processes and techniques developed in universities and research labs form the foundation for new AI systems, from foundational techniques like deep learning to applications like autonomous driving. China's growing productivity in basic research signals that its scientific community is actively embracing AI and accelerating its pace of discovery in the field.

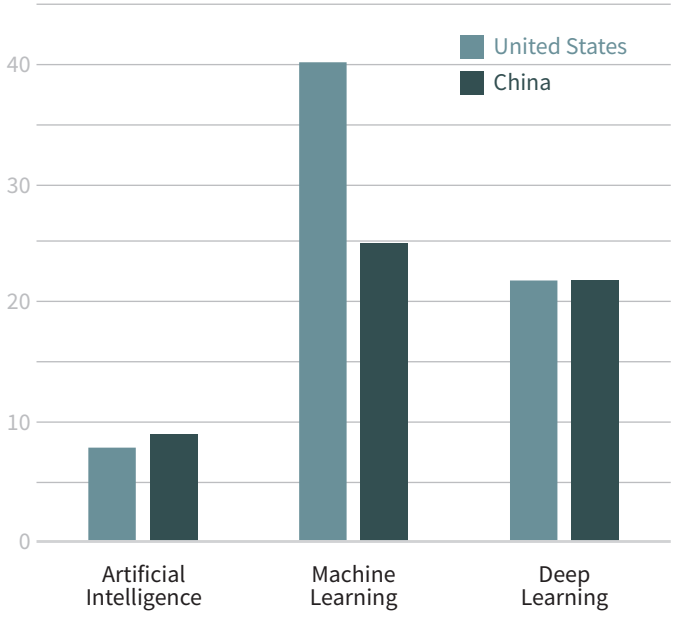
However, leadership in basic research is not just about the quantity of research but also research quality. By this standard, China is still lagging behind. According to the SCImago Journal & Country Rank, which measures publication impact by accounting for the number of times a paper is cited by other researchers as an influence, China's 2018 rating of 236 remains far behind the United States, at 465.[37] Data gathered by *Nikkei* and Elsevier similarly show that, of the top institutions in the world at publishing highly-cited AI papers, the United States accounted for five, while China had just two.[38]

China also trails in participation at prominent academic conferences on AI. Of the top 50 universities represented at the 2017 Conference on Neural Information Processing Systems (NeurIPS) conference, only four were from China,[39] and only one Chinese institution was among the top 30 universities at the 2017 International Conference on Machine Learning (ICML).[40]

China is catching up, however. Participation by Chinese scholars at major conferences is increasing. At the Association for the Advancement of Artificial Intelligence (AAAI) annual conference, for example, Chinese participants have grown from 10 percent to 23 percent of total attendance between 2012 and 2017.[41] At the 2018 AAAI Conference, China had almost the same number of accepted papers (265) as the United States (268), although Chinese researchers submitted 30 percent more papers than their U.S. counterparts.[42]

Chinese scholars are also catching up to their U.S. counterparts in high-impact research. A search of "highly cited" papers listed in the Web of Science database reveals that Chinese researchers published the same number of articles related to the search term "deep learning" as U.S. scientists and a greater number of articles on "artificial intelligence."

Highly Cited Papers Published by U.S. and Chinese Researchers in 2018 (Web of Science)



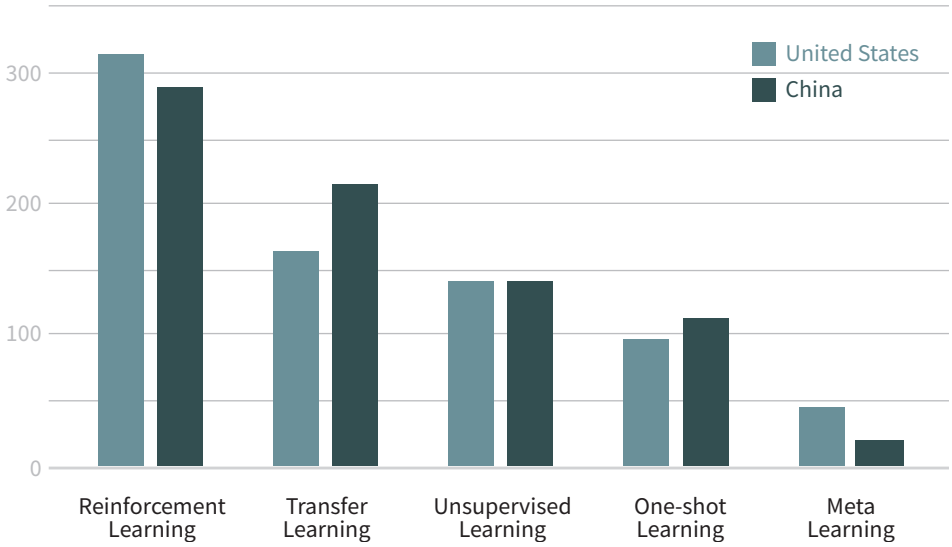
Source: "Web of Science Core Collection," Clarivate, Accessed December 5, 2018, http://webofknowledge.com/.

Post-DL: Next-Generation AI Methods

Chinese researchers are also making contributions at the very cutting edge of AI research, where scientists are experimenting with new techniques that could form the basis of the next generation of AI systems.

Currently, the majority of new AI systems are based on deep learning, which leverages massive data sets to train multiple layers of artificial neural nets that roughly mimic the functioning of a human brain. But deep learning also has significant drawbacks and challenges: deep learning requires massive data sets; its outputs are often nearly impossible to analyze and explain; deep learning algorithms are difficult to apply to new domains; and its models are not well-suited to understanding of context and causality.[43] Many researchers are looking at new approaches to AI that may address some of these issues.

Papers Published by U.S. and Chinese Researchers in 2018 in Emerging AI Research Domains (Web of Science)



Source: "Web of Science Core Collection," Clarivate, Accessed December 5, 2018, http://webofknowledge.com/.

These cutting-edge AI fields include reinforcement learning, transfer learning, unsupervised learning, one-shot learning, and meta learning, and in many of these fields Chinese researchers are equivalent with their American peers. Of these five domains of research, Chinese academics led the United States in three (transfer, unsupervised, and one-shot learning) in terms of 2018 publications and were close behind in both of the others. Further, Chinese academics published 26 highly-cited papers in these five domains between 2016 and 2018, right behind U.S. researchers, who were responsible for 29.

Despite this work, some have raised the question of how quickly China's broader AI ecosystem could adapt if a breakthrough in a new field of AI research were to force scientists to, in the words of neural net inventor Geoff Hinton, "throw it all away and start again."[44] The top-down approach of the Chinese government in directing research and development means that the country could be slow to react to significant changes in the research landscape.[45]

Applied Research and Product Development

AI innovation is about more than basic research, however. When discussing a country's "leadership" in AI, it is necessary to look not only at who is responsible for foundational breakthroughs in the field but also who has been the most successful at building real-world products and services using AI.

Chinese companies have been at the forefront of many AI deployments, often rolling out AI features more quickly and at far greater scale than others in the domestic Chinese market. Major Chinese firms have also been innovative in the way they combine data sets from across platforms to build products and services that would be impossible to build anywhere else and that take advantage of a permissive regulatory environment to innovate in areas like health care and autonomous vehicles.

Patents

One measure of leadership in AI applications is patent filings, which show the pace at which engineers are creating new AI-enabled products and services. According to the China Academy of Information and Communications (CAICT), China accounts for 37.1 percent of global AI patent applications, compared to 24.8 percent for the United States.46 In 2017, CBInsights found that China files six times as many patent applications related to deep learning as the United States and five times as many for AI.[47]

As in the case of academic papers, however, quantity is not everything. Only 37 percent of Chinese patents are maintained past five years, compared to 85.6 percent in the United States.[48] This extremely high patent disposal rate suggests that many Chinese patents are of little value. Further, only 23 percent of Chinese patent applications even claim

to be new inventions, rather than minor tweaks to existing products. In other measures of patent quality, including grant rates, international patent grants, claim numbers, and citation counts, China also continues to lag behind the United States.[49]

Taken together, these figures indicate that while China is generating a significant amount of AI IP, they continue to struggle with patent quality and lean heavily on foreign innovations, adapting them to the Chinese market instead of developing wholly new products and applications.

Chinese Progress in Key AI Verticals

That said, Chinese developers are aggressively pursuing new AI applications, and while it is hard to argue that China has reached true technical superiority, it has certainly moved quickly to harness and deploy AI technologies in key fields. Instead of taking a broad-brush approach to AI development, China has focused its short-term efforts on a few strategic verticals, pushing billions of dollars into catching up with global leaders.

Autonomous Vehicles

In autonomous vehicles, for example, Chinese companies like Baidu and Didi have made significant strides despite slightly late entry into the autonomous vehicles (AV) race. Achieving full parity with foreign leaders remains a distant goal, but there are signs that the gap is closing. Real-world driving experience is critical to AV development, and while Baidu has a strong lead in China, having logged more than one million miles across 13 different cities in China,[50] Google's Waymo reached more than one million miles per *month* in 2018 by comparison.[51]

That said, Baidu insists it will have fully autonomous vehicles in circulation by 2020. Even if this deadline is ultimately pushed back, they may be able to bring a less advanced product to market quickly with the strong support of the state. Waymo, while currently leading in terms of technology and road miles, is likely to be held to a significantly higher, and

Above A driverless car by Baidu Apollo is seen at the 2018 International Intelligent Transportation Industry Expo in Hangzhou in China's eastern Zhejiang province on December 2018.

Photo by STR/AFP/Getty Images

potentially infeasible, regulatory standard before it can put fully autonomous vehicles on U.S. roads.

Facial Recognition

In facial recognition, market development in China has been strong, but true technical parity remains elusive. Chinese facial recognition companies like SenseTime, Megvii, and Hikvision are among the most valuable AI companies in the world and have partnered with Chinese government agencies and companies on some of the largest deployments in the world.[52] But interviewees from facial recognition leaders from around the world, including China, agreed that U.S. companies generally remain ahead from a technical perspective, and while China has closed the gap in recent years, U.S. companies have redoubled their efforts to retain their edge. Tellingly, while Chinese firms were all eager to tout their own technical leadership in interviews, many privately discounted the claims of their Chinese competitors and argued that, while *they* were ahead of U.S. AI companies, the rest of the Chinese AI industry remains behind.

Robotics

Since 2013, China has been the world's largest market for industrial robotics, with almost 140,000 shipped in 2017 alone.[53] The majority of these robots were supplied by foreign companies, however, with domestic firms accounting for only around one-third of sales.[54] China's government has set aggressive targets for growing the country's robotics industry, with the goal of achieving 50 percent market share domestically by 2020 and 70 percent by 2025.[55]

China's robotics industry has been characterized by relatively poor quality and an overall reliance on copying Western innovations, evidenced by the few Chinese robotics companies holding their own IPR.[56] Chinese experts have voiced similar concerns from within government think tanks, noting that copycat production and foreign acquisitions will be unable to

Above A display for facial recognition and artificial intelligence is seen on monitors at Huawei's Bantian campus on April 26, 2019 in Shenzhen, China.

Photo by Kevin Frayer/Getty Images

Above An employee checks robots used for customer services at a factory in Lianyungang in China's eastern Jiangsu province on December 4, 2018.

Photo by STR/AFP/Getty Images

make up for a lack of original research.[57] China is in a stronger position in the domain of service robots, however, with commercial UAV development in particular being driven by Chinese firms like DJI.

Natural Language Processing

Natural language processing (NLP) is a field of AI focused on creating systems that can interpret raw, unstructured language from the real world. In terms of algorithm quality, NLP leadership is largely bifurcated along linguistic lines. Chinese researchers lead the world in building AI models for interpreting Mandarin text and speech, as demonstrated by performance across a number of major international competitions and benchmarks.[58] When Microsoft announced in 2016 that it had created an AI that could surpass human-level English speech recognition, then-head of Baidu AI group Andrew Ng took a jab by reminding the Microsoft team that Baidu had accomplished the same feat for Chinese speech recognition a year before.[59]

And while Chinese universities and companies have been deliberately working to improve their ability to translate from languages in countries along the Belt and Road, a lack of language data on consumers in foreign countries has prevented Chinese companies from expanding their offerings into new markets.[60] In contrast to Google Assistant, which supports 30 languages, or Siri, which supports 21, China's voice assistants are almost entirely limited to Mandarin and other Chinese dialects.[61] The only Chinese NLP product marketed outside of China has been Baidu's Aladdin smart speaker, released in Japan after seven years of training on data Baidu gained access to through its acquisition of a Japanese keyboard app developer.[62]

AI Industry Development and Global Competitiveness

AI Development by Major Platforms

China's leading internet platforms, the BATs, are also investing heavily in AI, integrating data from across their wide variety of services to provide world-leading AI-enhanced services. An example of this is Hema, the grocery/convenience store chain established by Alibaba. Hema takes a unique approach to grocery shopping, embracing an online-to-offline model that offers customers the ability to use Alipay—a mobile payment app also owned by Alibaba—to pay for groceries in any of their physical locations, or else order their food online and have it delivered to them for free within 30 minutes.[63] Alibaba has designed Hema from the ground up based on the data it has collected through its other businesses, using algorithms to optimize every aspect of the rapidly growing chain.

Alibaba uses the data it has collected through its e-commerce sites Taobao and Tmall and its food delivery platform Ele.me to determine the best locations for new stores and then uses the same data to optimize the store's product selection according to local taste preferences.[64] The logistics of stocking the stores and delivering orders to customers is optimized thanks to algorithms crunching the data from Ele.me and Alibaba's logistics company Cainiao. Finally, the content displayed to each user when they pull up Hema's app is deeply personalized based on data from across all of Alibaba's platforms to improve convenience and engagement by shoppers.

Hema is already being described as a model for

Amazon's plans for Whole Foods.[65] Alibaba opened Hema in 2015 and has already expanded to over 100 locations, with plans to expand to 2,000 more branches over the next five years.[66] In contrast, Amazon's Go stores number at just 13,[67] and Amazon's cross-platform integration is not nearly as extensive or sophisticated as what is already being accomplished by Alibaba.

Baidu is also deploying a wide range of AI-enabled services. Baidu has partnered with over 200 companies to incorporate its DuerOS voice assistant into a wide range of smart devices and has been making inroads not only with Chinese manufacturers like Huawei, Vivo, and Oppo but also foreign companies like BMW, Daimler, Ford, and Hyundai.[68] In July 2018, Baidu launched its first DuerOS-powered product outside of China with the release of its Aladdin smart speaker in Japan.

Baidu also released Apollo, its autonomous driving software platform, as an open-source platform in 2017. With Apollo, Baidu hopes to do the same thing for autonomous vehicles that Google did with its Android mobile operating system. By encouraging early and widespread adoption of its own platform, Baidu is aiming to establish Apollo as the default platform for AVs and secure its position as the dominant controller of data produced by AVs around the world. Baidu has already formed partnerships with 90 companies, including foreign brands like Ford, Honda, and Daimler, which it hopes will contribute test data the company can combine with its own data to improve its AI products.[69] If successful, this strategy could lead to Baidu gaining a powerful advantage over many other companies in access to AV- and map-related data sets.

AI Startups

China has also seen a surge in investment and startup foundation centered around AI applications. But whether this is the flowering of a healthy AI startup economy or a bubble of overvalued firms riding the AI hype wave remains to be seen.

China is now home to over 1,000 AI companies, which is half as many as the United States but 20 percent of the global total.[70] More than 14 AI unicorns—startups with valuations over $1 billion—now reside in China, whose market for AI services grew by 67 percent in 2017.[71] As opposed to the United States, where private investment was spread over 155 investments, funding in China was funneled into just 19 high-profile deals, an indication that investors' focus has been on supporting more mature AI applications with a greater likelihood of commercial viability.[72]

It may also reflect groupthink among Chinese innovators and investors. As one group of investors explained, China continues to struggle with "garage innovation," and many startups spin out of university or PLA research labs or major companies. While this points to the success of Chinese government programs to help researchers commercialize new ideas, it also means that Chinese AI innovators tend to come from similar backgrounds and be backed by larger institutions, limiting the growth of truly disruptive innovations and driving investors to cluster around similar ideas in a few fields.

"Chinese AI innovators tend to come from similar backgrounds and be backed by larger institutions, limiting the growth of truly disruptive innovations and driving investors to cluster around similar ideas in a few fields."

Despite overtaking the United States in startup investment in 2017, private-sector funds channeled to Chinese startups in the first half of 2018 fell sharply and represented a total value less than one-third of U.S. investment.[73] According to one report, the average rate of investment for Chinese AI startups is 69 percent, compared to 51 percent in the United States, indicating that the primary barrier in China's AI ecosystem is not access to funds but rather the availability of technology and talent.[74] And of startups that have already been funded, more than 90 percent are reporting losses, causing the head of one investment fund to describe China's AI ecosystem as a bubble ready to burst.

For savvy investors, the most attractive investments have roots outside of China. In interviews,

entrepreneurs and investors agreed that more sophisticated VCs tend to look for one of three things in a new startup: a founder that was educated in the United States or at a prestigious Western university, a founder that worked at a major U.S. technology company, or a business model that has already been proven in foreign markets and is being adapted for the Chinese market. While they emphasized that this is far from a universal requirement, virtually all agreed that having one of these qualities is a significant leg-up for startups seeking early-stage funding.

International Competitiveness

Despite the overwhelming success of companies like Baidu, Alibaba, and Tencent at dominating the Chinese market in sectors like internet search, e-commerce, and social media, none of these internet giants, let alone smaller Chinese startups, have had much success penetrating foreign markets. This has left China's AI leaders with huge troves of data on the preferences and behaviors of Chinese users but almost no insight into any other markets. Compared to their competitors in the United States, whose reach extends across the globe, China's AI leaders are deeply handicapped by the lack of diversity in their training data for new AI products and services.

This lack of data diversity makes it more difficult for Chinese companies to develop AI products and services for international customers. A prime example is search engines. Chinese search engine Baidu has grown over the past two decades to become the fourth most-visited website in the world, with a search service that commands more than two-thirds of the Chinese market.[75] However, despite its success within China, Baidu has struggled to expand its reach into international markets, with highly-publicized failures in Japan, Vietnam, and Thailand.[76]

Without data on the browsing habits, language, and behavior of local customers, Baidu has had a much harder time accurately indexing webpages and interpreting queries from that population, putting it at a significant disadvantage compared to other competitors. As of September 2017, less than 7 percent of all visitors from Baidu.com came from outside of China.[77] In comparison, 73 percent of visitors to Google.com come from outside the United States.[78]

"Compared to their competitors in the United States, whose reach extends across the globe, China's AI leaders are deeply handicapped by the lack of diversity in their training data for new AI products and services."

Despite these challenges, AI companies in China have been actively working to expand their reach through other means to gain access to international data for their AI services. Companies like Huawei, Baidu, and Alibaba have invested billions in expanding their international operations in recent years and have established crucial strategic partnerships with foreign companies.

The Chinese government is also working to expand the international footprint of its technology champions. A major emphasis of the Digital Silk

Above People sit in "Garage Cafe"on March 18, 2016 in Beijing, China. The cafe serves as a hub for investors and entrepreneurs to meet and create startups.Beijing boasts the world's second-largest number of most valuable tech startups.

Photo by Emmanuel Wong/Getty Images

Road is to promote smart city development across Europe and Asia. Alibaba has been deeply involved in these initiatives, which began with the City Brain initiative in Kuala Lumpur.[79] Built off Alibaba's cloud infrastructure and data processing systems, the City Brain project aims to integrate traffic data, emergency response systems, and other urban management infrastructure into a single platform that would allow for the intelligent supervision of the city's infrastructure.[80] Along the way, Alibaba would gain access to a river of new sensor and logistics data it could use to improve the AI systems it has already begun to deploy in smart city initiatives across China.

Integrating AI into Traditional Industries

To date, most of China's greatest AI success stories have involved relatively low-value innovations in the consumer sector (chatbots and digital marketing) or internally-focused enhancements to the operations of already high-tech firms (voice assistants for Cainiao and logistics optimization for Hema).

While exciting, innovation in these domains effectively amounts to picking the low-hanging fruit. One industry analyst, reacting to the sudden drop in Chinese private-sector AI investment in 2018, noted that China is "at a juncture where the generic use cases have been addressed . . . And building generic general purpose chatbots is much easier than specific algorithms for industries like banking, construction, or mining because you need industry knowledge and buy-in from the industry."[81]

The real test will be whether China's industrial base is able to leverage AI to enhance its productivity and create new value. Factories could use AI to cut down on repair costs and minimize downtime by monitoring system processes for anomalies and using predictive analytics to optimize maintenance schedules. Financial institutions could leverage AI to identify fraudulent transactions on their networks, and insurance companies could use AI-powered techniques to improve the accuracy of their risk assessments. In the IT industry, AI can help optimize data routing and network performance, and governments can use AI to greatly improve the efficiency and quality of public services like transportation and environmental management. These use cases will account for the majority of the value created by AI, raising the question of whether Chinese businesses are prepared to take advantage of these new opportunities.

Above Chinese President Xi Jinping attends a news conference at the end of the Belt and Road Forum for International Cooperation on May 15, 2017 in Beijing, China. The Forum, running from May 14 to 15, is expected to lay the groundwork for Beijing-led infrastructure initiatives aimed at connecting China with Europe, Africa and Asia.

Photo by Jason Lee-Pool/Getty Images

Digitization and IT Infrastructure

One of the most important factors impacting Chinese firms' ability to leverage AI is the current state of their IT ecosystems. Companies with inadequate IT infrastructure or legacy IT environments will lack

data about company operations and will struggle to transition to AI-enabled services.[82]

Chinese companies are behind in digitization and IT modernization compared to their global competitors. U.S. industries are 3.7 times more digitized than those in China, giving them a stronger base from which to incorporate AI services.83 One survey found that AI was not yet a strategic priority for more than 40 percent of Chinese companies in traditional industries, which means that many companies have likely not even begun the process of collecting and organizing the data they will need to have about their business processes to support future AI adoption.[84]

"The real test will be whether China's industrial base is able to leverage AI to enhance its productivity and create new value."

In part, this is driven by Chinese companies' reticence to spend on enterprise software and services. In 2018, Chinese businesses and government departments are predicted to spend $23 billion on software. In comparison, organizations in the United States are predicted to spend $295 billion—13 times as much.[85] Software accounts for just 5 percent of Chinese IT spending, compared to 30 percent in the United States.[86] Historically, Chinese companies have been more likely to turn to hardware, labor, and pirated software to solve problems rather than purchase enterprise software or IT services.

This culture is beginning to change, however, as a new generation of business leaders emerge who have been brought up with a greater respect for efficiency and who are more accustomed to the practice of paying for software and services online. The shift away from enterprise software and toward cloud services is also helping to ease the transition, as small monthly subscription fees are easier to justify to penny-pinching managers then large up-front purchases.[87] But while Chinese spending on software and services are growing, they still remain well-below companies in other countries.[88]

Cloud Adoption

Another related measure of China's preparation for widespread AI deployment is the penetration of cloud services. Cloud services are an important enabler of AI deployment for companies, providing scalable compute and storage to manage and process the massive amounts of data that drive machine learning.

Cloud providers like Google and Alibaba also increasingly offer AI services to their enterprise customers, enabling a wide range of companies that lack the talent and expertise to develop machine learning systems in-house to leverage AI.[89] The firms who are already utilizing cloud services in their business processes are well-positioned to leverage new machine learning and AI applications, making cloud penetration rates a strong indicator of positioning for future AI deployment.

Though improving, enterprise cloud adoption rates in China remain low. Fewer than half of companies in the manufacturing, travel, logistics, and industrial services sectors in China have deployed cloud computing in their operations.[90] And even for those companies who have begun to experiment with cloud offerings, cloud services are not yet a

Right A Huawei engineer opens the door to a server unit during a tour on April 25, 2019, in Dongguan, China.

Photo by Kevin Frayer/Getty Images

leading priority in their IT strategies. By the end of 2020, it is predicted that just 29 percent of workloads for Chinese companies will be located on the public cloud, compared to 45 percent in the United States.[91]

Cloud adoption in China is hindered by a number of factors, including obsolete, cobbled-together technology stacks used by many Chinese firms, cloud providers primarily oriented toward consumer rather than enterprise services, and concerns over regulatory compliance and security. The wide diversity in IT stacks and service providers at Chinese companies also creates obstacles for Chinese cloud providers, who must develop tools to accommodate a variety of IT ecosystems in their migration to the cloud.[92] Most cloud offerings in China were initially developed to serve consumers in sectors like e-commerce or gaming, creating a challenge for cloud providers as they work to create products fit for the complex needs of enterprise customers.[93]

Chinese businesses have also been held back by concerns over security and regulatory compliance. According to one study by Bain and Company, "Heightened awareness of the vulnerabilities of information security has created a preference among Chinese businesses to maintain close control of their workloads and data . . . [reinforcing] a reluctance to put workloads on the public cloud or otherwise outsource IT."[94] This conclusion is also supported by survey data, which indicates that Chinese executives are sharply differentiated from their counterparts in the United States in citing security concerns as a primary barrier to adoption.[95]

Access to Public Data

Though Chinese companies have access to vast quantities of consumer data on Chinese internet and mobile users, the highest value data for industrial applications is often not clicks and web searches but government-controlled data sets like weather data, high-resolution maps and satellite imagery, and census data. In the United States, enormous value has been created by companies building applications off these public data sets.

Ensuring access to public data sets is one of the most important ways a government can support AI innovation. However, China has made little of its public data accessible for developers. In 2015, Open Knowledge International scored China 93rd out of 122 countries in data openness, placing it far behind the United States, ranked 8th.[96]

High-quality mapping data is another essential public data set, critical for AI applications ranging from AVs to smart city services. The value of GPS location data is estimated to be $55.7 billion, reflecting the wide range of services that have been built off of GPS data.[97] However, China has placed severe restrictions on creating high-resolution maps, and many other types of geospatial data and forbids any foreign company from creating maps of China except through partnerships with one of 14 specially-licensed Chinese firms.[98]

"Ensuring access to public data sets is one of the most important ways a government can support AI innovation. However, China has made little of its public data accessible for developers."

Under the restrictions, public maps are not allowed to be accurate beyond 5 meters and cannot present the dimensions of key bridges or tunnels or other details like road gradient or curvature. Navigation products are forbidden from displaying, recording, or storing any geographic data involving state secrets (such as elevation or location coordinates),[99] and all data must undergo strict examination by the National Administration of Surveying, Mapping, and Geo-Information (NASG) before release.[100] The Chinese government also prevents businesses from easily translating GPS coordinates to China's deliberately unique geospatial coordinate system,[101] and additional restrictions will only serve to further isolate China and prevent it from leveraging foreign innovations to improve its own AI services.

This comes at the cost of slowing innovation by discouraging competition and preventing foreign firms with superior technology from helping China's AV industry grow and improve. AVs need high-resolution, high-quality data sets of their environments to operate safely, so restrictions on high-resolution

maps and detailed data sets on infrastructure and behavior are a significant impediment to Chinese AV development.

Data Quality

Data quality represents one of China's biggest hurdles to building a smart economy.[102] "Garbage in, garbage out" is particularly relevant to machine learning, where incorrect and incomplete information can lead to incorrect inferences and responses from algorithms. In China, data quality is a persistent challenge. Rampant data manipulation has tainted official Chinese figures for everything from regional economic growth and pollution data to clinical drug trial results and crime statistics.[103] AI systems trained off this manipulated data will only magnify errors in the data sets they work from, spitting out predictions and analysis founded on a skewed understanding of their operating environment.[104]

The issue is further exacerbated by the lack of institutional processes for identifying and correcting incorrect or missing information. This issue is particularly relevant in the case of AI systems based off the personal data of citizens. China's emerging social credit system, for instance, is being created without the safeguards that would allow citizens to correct false information, producing a data ecosystem ripe with the potential for abuse.[105] So long as Chinese developers are limited to unreliable data sources, the solutions they build will never be as powerful as those created in the West.

The Downside of Protectionism

Anchored by legislation like the 2016 Cybersecurity Law and supported by a bevy of sector-specific regulations, China's restrictions on cross-border data transfer impose significant barriers for companies looking to partner with Chinese firms on the development of AI. From localization requirements to mandatory security checks and source code review, China's data controls work to strongly discourage foreign groups from partnering with Chinese firms and greatly complicate collaboration for those joint ventures which do form. Though intended to give Chinese companies a protected market in which to grow, the effect of such controls is to deny Chinese firms access to opportunities for international cooperation, cutting them off from new sources of data and research outside China's borders.

Furthermore, in an attempt to protect the market position of its leading domestic firms, China has advanced a standards regime for data management, cloud computing, industrial software, and big data which in many cases has been deliberately designed to contradict international standards.[106] This state of affairs makes it far more difficult for foreign companies to make headway in the Chinese market, protecting the likes of Baidu, Alibaba, and Tencent from outside competition. This dissonance also isolates these companies from their international equivalents and creates barriers to collaboration.

"China's restrictions on cross-border data transfer impose significant barriers for companies looking to partner with Chinese firms on the development of AI."

Above A taxi driver uses the Didi Chuxing app while driving along a street in Guilin, in China's southern Guangxi region on May 13, 2016. - Apple has invested 1 billion USD in Chinese ride hailing app Didi Chuxing, the Beijing company said on May 13, as it vies with bitter US-based rival Uber for market share in China.

Photo by GREG BAKER/AFP/Getty Images

Though China would eventually like to see its national standards adopted globally, its determination to achieve harmonization by pushing its own standards rather than by working with others will have the effect of setting the Western and Chinese tech ecosystems at loggerheads for the foreseeable future. This will deny companies on both sides the opportunity to take advantage of each other's data and innovations.[107] The negative effects of this conflict will be especially pronounced for Chinese firms, who have fewer alternative options for gaining access to international data sets.

Above People walk past an Apple store in Beijing on December 11, 2018. - Apple stores in China continued with business as usual on December 11, despite a Chinese court-ordered ban on iPhone sales that could hurt the US tech firm in one of its most crucial markets.

Photo by GREG BAKER/AFP/Getty Images

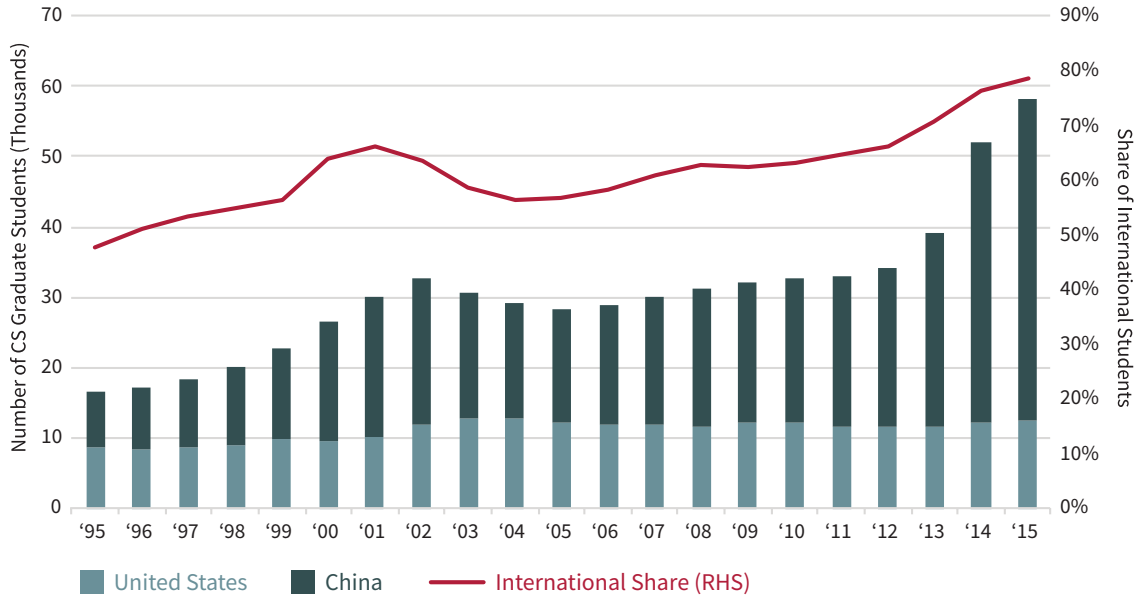
Conclusion: How Should the United States Respond to Chinese Progress in AI?

▶ The United States remains the global leader in AI, but China is investing significant resources in developing its innovative capacity and domestic AI industry. While China's short-term goal of achieving true parity with the United States in AI by 2020 seems ambitious given where they stand today, at their current rate of growth, becoming the world's leading AI power by 2030 is possible, if not a given. How should the United States respond to China's progress in AI?

Avoid a Zero-Sum Mentality

While this is a top priority for many U.S. policymakers, in some ways it is also the wrong question to ask. AI development is not zero-sum, and the U.S. and Chinese AI ecosystems have benefited heavily from collaboration and competition. Perhaps nowhere is this more evident than in university research. The United States has the top university research system in the world, producing many of the foundational innovations of modern computer science and AI, but this ecosystem depends on foreign talent. Nearly 80 percent of graduate students in U.S. computer science programs are international students, and more than a third are from China.[108]

Composition of Computer Science Graduate Programs in the US



This collaboration and mutual exchange is not limited to university programs. China's leading AI companies have opened AI R&D centers in the United States. Tencent has two AI labs in the United States, employing more than 20 researchers in Seattle and Silicon Valley to work on natural language processing and autonomous vehicle development.[109] Baidu also has two U.S.-based R&D labs, including its 200-strong Silicon Valley AI lab, opened in 2014, and its newly-opened Robotics and Autonomous Driving Lab in Sunnyvale, intended to eventually house 150 AI researchers.110 Alibaba, as part of its recently-announced Academy for Discovery, Adventure, Momentum, and Outlook (DAMO Academy), has committed $15 billion through 2020 to establish seven AI R&D labs around the world, including centers in the United States, Israel, and Singapore.[111] Aside from the BATs, other Chinese AI companies like Didi, iFlytek, and Huawei also operate U.S. R&D facilities centered around AI research.[112]

Similarly, major U.S. companies, including Google, Qualcomm, Amazon, IBM, and Microsoft, have established AI R&D centers in China,[113] and both countries have seen their companies back a growing number of cross-border equity deals into each other's startups, with China responsible for 31 deals to U.S. startups in 2017 and the United States responsible for 20 in China.[114] Firms on both sides of the Pacific are leveraging innovation in both the United States and China, and the level of integration between the two ecosystems is only likely to deepen as time passes.

Focus on Maintaining U.S. Leadership, Not Defeating Chinese Progress

Progress in AI is beneficial for the United States, irrespective of China's advancement. AI has the potential to drive significant economic growth, new business formation, and job creation in the coming decades. And Chinese advances in AI can complement and accelerate U.S. and global AI development through collaboration and competition.

For many in the U.S. policy community, however, maintaining U.S. leadership in AI is viewed through the prism of defeating China's efforts to advance in

"While China is focusing on building its domestic innovation capacity and shaping domestic incentives to support AI development, U.S. policymakers are instead focused on cutting off China's access to U.S. innovation."

AI. While China is focusing on building its domestic innovation capacity and shaping domestic incentives to support AI development, U.S. policymakers are instead focused on cutting off China's access to U.S. innovation.

February's Executive Order on Maintaining American Leadership in Artificial Intelligence emphasizes the right themes, highlighting the importance of building an AI talent pool, expanding AI R&D, developing enabling technologies and infrastructure, and engaging with international partners. But little has been done to implement the executive order, and in fact, many of the Trump administration's policies run completely contrary to the order's stated objectives, by slashing budgets at federal agencies that support scientific research, cracking down on visas for people with advanced education and skills, and slashing the U.S. education budget, for example.[115]

While little has been done to implement a positive U.S. agenda to develop AI, significant effort has been put in to undermining Chinese progress. Congress has managed to pass little legislation at all in the last few years, much less meaningful legislation to advance U.S. AI development, but has managed to pass two major pieces of legislation to curtail Chinese progress in AI. FIRRMA and ECRA restrict Chinese investment in "emerging and foundational technologies," including AI, and limit exports of those technologies to China. The Trump administration has even suggested that it might cut off student visas for Chinese students to curb Chinese efforts to acquire sensitive technologies being researched at U.S. universities.

Above The US and China flags stand behind a microphone awaiting the arrival of US Senator John McCain, who was joined by Senators Lindsey Graham Amy Klobuchar for a press conference at the US Embassy in Beijing on April 9, 2009 during the China stop of the Congressional Delegation's fact-finding Asia-tour. Senator McCain said he urged Chinese officials in talks here to back a strong United Nations response to North Korea's rocket launch, but indicated China had resisted.

Photo by FREDERIC J. BROWN/AFP/Getty Images

What Would a Positive U.S. AI Agenda Look Like?

The USG must implement a positive agenda to advance U.S. AI development. We know what needs to be done but have failed to muster the resources and political will to have a meaningful impact on the ground. The five pillars outlined in February's AI executive order are the right ones: R&D, infrastructure and enabling technologies, workforce development, international engagement, and governance. But the administration must deliver action to match its words.

First, that means allocating meaningful amounts of resources to AI development. While the administration's rhetorical commitment to AI is strong, its efforts to invest in AI technology development add up to, at best, $3–5 billion, or about 0.1 percent of the $4 trillion federal budget. This is a paltry investment in a family of technologies that will form the foundation of the next generation of economic growth for the United States and the world and also coincides with significant cutbacks in broader USG funding for scientific research.

"The five pillars outlined in February's AI executive order are the right ones: R&D, infrastructure and enabling technologies, workforce development, international engagement, and governance. But the administration must deliver action to match its words."

Technology development is also not the only area where we need to invest. Infrastructure de-

velopment, financial incentives for AI adoption by traditional industries, and research in security, risk management, and governance for AI will also benefit from USG financial support.

Second, we need to align policies around a wide range of issues (e.g., immigration, education, export controls, research partnerships, and data protection) with our stated goals for AI. Calling for the development of both an elite AI technical workforce and technical literacy for the broader workforce is inconsistent with limiting the ability of elite foreign talent to join the U.S. education system and U.S. workforce and making dramatic cuts to the national education budget.

This does not mean that we should ignore our other equities and policy priorities, but we should be cognizant of the costs of these policies to U.S. AI innovation. For example, on one hand Washington wrings its hands over Chinese companies' advantages in free access to consumer data, while at the same time we work to impose greater restrictions on data use by U.S. companies. Many Americans would not want to follow China's lead in data governance, and rightly so, but framing the debate in terms of enabling responsible use of data could lead to more constructive and balanced policy proposals. Similarly, growing AI businesses and AI-enabling technologies in the United States is more difficult if we cut off access to global markets for companies that build their technology here. However, we can take reasonable steps to avoid transferring unique technologies with direct military applications to potential adversaries.

Finally, we need to proactively develop a governance model for AI that manages risk without throttling innovation. Perhaps the greatest risk to the U.S. AI ecosystem is public fear. In China, new technologies are met with enthusiasm, and AI is viewed as an exciting opportunity. In contrast, AI is viewed with suspicion and distrust in the United States. U.S. policymakers have tended to take a precautionary approach to many AI applications, for example, by placing onerous restrictions on autonomous vehicle testing. San Francisco even went so far as to ban the use of facial recognition by government agencies and law enforcement.[116]

Policymakers must take the lead in building public trust in AI, instead of perpetuating narratives of fear and risk that are one-sided and often based on a misunderstanding of the technology. Proactively managing the *real* risks of AI is important to building and sustaining public trust in the technology, but we must also avoid counterproductive regulations that undermine our innovative capacity to little or no gain.

"Perhaps the greatest risk to the U.S. AI ecosystem is public fear. In China, new technologies are met with enthusiasm, and AI is viewed as an exciting opportunity. In contrast, AI is viewed with suspicion and distrust in the United States."

Smart Money on China Continuing to Advance in AI

China's strategic approach to AI and the strong commitment of policymakers and private business leaders to AI development and adoption are a potent mix. China is putting significant financial, human, and political capital into its drive for AI leadership, while the United States struggles to align its rhetorical commitment to AI leadership with concrete policies. China remains behind the United States in fundamental research and key AI technologies but is closing the gap quickly, and the smart money is on continuing Chinese advances in AI, both in technology development and deployment.

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Cover: China's 19-year-old Go player Ke Jie prepares to make a move during the second match against Google's artificial intelligence programme AlphaGo in Wuzhen, eastern China's Zhejiang province on May 25, 2017. Chinese netizens fumed on May 25 over a government ban on live coverage of Google algorithm AlphaGo's battle with the world's top Go player, as the programme clinched their three-match series in the ancient board game. (Photo credit STR/AFP/Getty Images)