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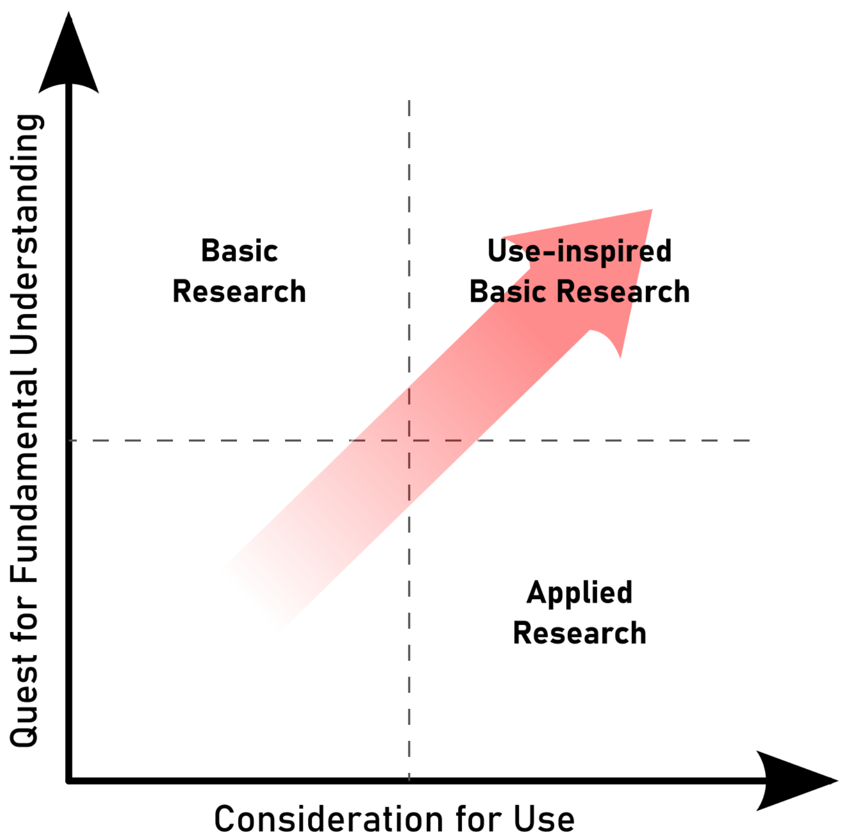
China's Model of Science:
Rationale, Players, Issues



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Abbreviations

CAE	Chinese Academy of Engineering
CAS	China Academy of Sciences
CASC	China Aerospace Science and Technology Corporation
CCDRC	Central Comprehensively Deepening Reforms Commission
CCP	Chinese Communist Party
CLSGCTW	Central Leading Small Group for Coordinating Talent Work
CMC	Central Military Commission
CSU	Central South University
DLUT	Dalian University of Technology
DOD	Department of Defense
DORA	San Francisco Declaration on Research Assessment
EDD	Equipment Development Department
FYP	Five Year Plans
GAD	General Armament Department
IDDS	Innovation-Driven Development Strategy
IF	Impact Factor
LSG	Leading Small Group
MCF	Military-Civil Fusion
MIIT	Ministry of Information and Technology
MLP	Medium to long-term plan for the development of science and technology
MOE	Ministry of Education
MOF	Ministry of Finance
MOST	Ministry of Science and Technology
NIS	National Innovation System
NPG	Nature Publishing Group
NSFC	National Natural Science Foundation of China
NSR	National Science Review
NSTIAC	National Science, Technology, and Innovation Advisory Committee
OECD	Organization for Economic Co-operation and Development
PI	Primary Investigators
R&D	Research and Development
S&E	Science and engineering
SAFEA	State Administration of Foreign Experts Affairs

SCI	Science Citation Index
SoSP	Science of Science Policy
SR&ED	Scientific research and experimental development
STI	Science, Technology, and Innovation

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Key Findings

Historical Experience Continues to Shape China's Approach to Scientific Development

The logic of China's approach to science policy continues to be significantly impacted by the circumstances surrounding the origin of modern Chinese science. Catastrophic defeats the Qing government suffered at the hands of the Western powers in the First and Second Opium Wars led to both the embrace of Western technologies as a means of national salvation and the rejection of other cultural elements that could jeopardize the fundamentals of Chinese culture. Senior leaders today continue to underscore the public's faith in the Chinese model of development and the need for "self-reliance in S&T," while at the same time employ an aggressive set of policies to acquire technology and recruit talent from abroad.

Chinese scholars have also argued that the "saving China through science" school of thought shaped during this period of history conflated the idea of "science" with "technology," leading to a strongly utilitarian view of science as a tool for serving national security and economic needs. This utilitarian view of science, reinforced after the Chinese Communist Party took power, has long-last policy implications, contributing to the policy rationale that strongly favored the "D" of R&D at the expense of funding for scientific research critical to innovation.

Chinese Leaders Continue to Favor a 'Whole-of-Nation' Approach to STI, Despite Skepticism From Leading Chinese Scientists

The 'whole-of-nation' approach, a legacy of Soviet influence, rests on the premise that STI advancement can be planned and managed through comprehensive, highly-specific, top-down authoritative directives and large-scale mobilizations of efforts and resources.

Leading Chinese scientists have questioned both the approach's premise and execution, particularly with regard to its effectiveness in promoting advances in *science*, pointing to the erroneous assumption that scientific advances (unlike technological development) can be planned. Other criticisms point to problems such as a lack of input from the scientific community during the planning stage, misdirected investment due to inadequate technology forecasting, bureaucratic interference, poorly executed performative assessments, among others.

China Has Further Consolidated Responsibility For S&T Planning

The 13th FYP period (2016-2020) saw the further centralization and consolidation of S&T development responsibilities by the Ministry of Science and Technology (MOST). MOST expanded its portfolio to include responsibilities in drafting national basic research plans and crafting policies for recruiting foreign talents following its absorption of the National Natural Science Foundation of China (NSFC), the primary funding vehicle for basic research in China, and the State Administration of Foreign Experts Affairs in March 2018. MOST and NSFC together managed a 45% share of the central government's R&D expenditure in 2018.

MOST houses the offices for two important State Council leading small groups for S&T development—the National Science and Technology Leading Small Group and the National S&T *Tizhi* Reform and Innovation System Construction LSG. MOST is also responsible for convening the *Inter-Ministerial Joint Council* consisting of 31 government bodies. The Joint Council is charged with cross-agency coordination of STI development strategies and policies and making budgetary decisions regarding the centrally-funded STI programs, which were comprehensively restructured during the 13th FYP.

New Science Policy Advisory Bodies Were Introduced During the 13th FYP Period

The 13th FYP period (2016-2020) saw two discernable lines of effort following calls from senior leadership for the development of a national science, technology, and innovation (STI) advisory system to improve STI policymaking.

The first line effort was the creation of a National STI Advisory Committee (NSTIAC). While its exact composition or operational status unclear, it is positioned as the nation's highest-level decision-making and consulting organization with direct communication lines to the central leadership. Envisioned as providing regular briefings to the Party Central Committee and the State Council on the latest trends in international scientific and technological innovation, on paper, the NSTIAC appears to function similarly to the U.S. President's Council of Advisors on Science and Technology.

The second line of effort involves the creation and designation of "specialized high-end think tanks," organizations providing strategic S&T consulting services are becoming increasingly adept at employing new technologies and bid data analysis to conduct landscape analysis in support of STI decision making.

Funding Basic Research is Becoming a Policy Priority

After decades of underfunding, Chinese STI policymakers have pledged significant boost in support for basic research. Trends in China's research and development activities suggest that China's STI policy overemphasizes experimental development and high-tech industries at the expense of basic scientific research. Between 1995 and 2019, share of experimental development increased from 69% to 83%. Basic research averaged around 5 percent of total R&D expenditure, while share of applied research dropped from 26% in 1995 to 11% in 2019, both lower than the OECD average.

The lack of support for basic research caught the attention of senior leaders in 2018. Premier Li Keqiang has attributed many of China's chokepoint technology problems to its inadequate support for basic scientific research. Policymakers have issued new guidance on strengthening support for basic research and pledged to increase share of basic research spending to 8% during the 14th FYP period (2021-2025). The decline in applied research spending, however, continues to be overlooked. Chinese scholars have argued that the decline in applied research, which serves as a critical link in the R&D process, could jeopardize China's ambition to become an innovative country.

China's Strong Performance in STI Indicators Come with Important Caveats

Despite explosive growth in quantity and significant improvement in quality, the research output of the homegrown research base has yet to translate into tangible *gains* desired by the policymakers and the scientific community at large.

Strong performance in major STI indicators such as publication and patent numbers by China's science and engineering research base has engendered perceptions of China as a formidable competitor for global scientific supremacy by the international community. However, domestic discourse on the subject takes on a calmer tone. Senior leaders are concerned about China's struggle in delivering original, transformative scientific breakthroughs and its prospects of achieving self-sufficiency in critical chokepoint technologies. Preliminary research suggests the impact of research from China's indigenously-educated research base lags behind those of returning scientists. China's remarkably low patent commercialization rate points to extremely low return on investment by the central government.

Chinese scientists have also called attention to the limitations of common STI indicators as measures of scientific progress in the Chinese context, pointing to factors at play that could skew the calculations. Further, overemphasis on simple quantitative metrics to assess individual researchers and institutions has serious negative implications for Chinese STI development. The practice of ‘publication-only evaluation’ has driven many to publish “garbage papers”—research without consideration of plausibility, scientific, or societal value. Leading Chinese scientists warn that the nation faces an unprecedented academic integrity crisis both in terms of the prevalence of the practice of research misconduct and fraud and the severity of the transgressions.

Introduction

On 20 January 2021 newly inaugurated President Biden sent a letter to his science advisor, geneticist Eric Lander, posing five essential questions about how to ensure America's leadership in science and technology for the next 75 years.[1] The letter deliberately invoked a similar letter sent by President Franklin Delano Roosevelt in November 1944 to his science advisor, Dr. Vannevar Bush. Though World War II was far from over, Roosevelt was already starting to look to the future to ensure that the rapid scientific progress made during the war was maintained and directed to address pressing issues at home when peace was achieved. While Roosevelt would not live to see it, the resulting report titled *Science—the Endless Frontier*, published 75 years before Biden's letter, would prove to have a lasting impact on American science. Likely seeing a similar epochal set of challenges and opportunities, Biden noted in his letter that it is time to "refresh and reinvigorate our national science and technology strategy to set us on a strong course for the next 75 years, so that our children and grandchildren may inhabit a healthier, safer, more just, peaceful, and prosperous world."[2] Reflecting on the biggest challenges facing his administration, Biden further noted a pressing need to ensure the United States' security and leading position in scientific and technological progress in the context of a long-term strategic competition with China, which is making unprecedented investments and striving to "eclipse America's scientific and technological leadership."[3]

At the same time that the Biden administration searches for a new blueprint for policies to sustain America's position as a leading scientific and technological power, China has entered a new policy planning period both for its overall economic and social development (the 14th Five Year Plan covering 2021-2025) and for science, technology, and innovation (STI) (the next medium- and long-term science and technology development plan 2021-2035). Having impressed the world with its strong performance in common STI indicators, such as R&D spending and publication and patent output, as well as advances in critical technological areas such as artificial intelligence, quantum computing, and hypersonic flight, China is now striving to achieve two of the remaining milestones outlined in its *Innovation-Driven Development Strategy* (*IDDS*) (2016): joining the front rank of innovative countries by 2035 and becoming a 'Global Scientific Great Power' [世界科技强国] by 2050.[4]

China's rapid emergence as a formidable player in global S&T since the mid-2010s has arguably acted as a second "Sputnik moment" for the United States government and the STI policy community, spurring not only major reinvestment in core competencies but also forcing the policymaking and scientific communities to reflect on American S&T leadership and focus its attention on creating policies and increasing investment in support of education, science, and technology. At the time of this writing, the United States Congress is considering new legislation to significantly increase support for scientific research and technology development to ensure its S&T leadership in the many years to come.[i] For Chinese policymakers and STI stakeholders, increasing geopolitical tensions and U.S.-China decoupling have also engendered a renewed sense of urgency to its search for the best policy formula to strengthen its homegrown research base and make wise government investment decisions in pursuit of scientific and technological self-sufficiency and innovation.

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i Proposed or passed legislation related to this effort includes the following: Congress.gov. "S.1260 - 117th Congress (2021-2022): United States Innovation and Competition Act of 2021." June 8, 2021. https://www.congress.gov/bill/117th-congress/senate-bill/1260; Congress.gov. "H.R.2225 - 117th Congress (2021-2022): National Science Foundation for the Future Act." July 12, 2021. https://www.congress.gov/bill/117th-congress/house-bill/2225; Congress.gov. "H.R.3593 - 117th Congress (2021-2022): Department of Energy Science for the Future Act." July 12, 2021. https://www.congress.gov/bill/117th-congress/house-bill/3593.

While their political ideologies and realities radically differ, science policymakers in both countries have much in common: both are seeking new ways for the government to better support the scientific research community, nurture scientific talents, and to harness the power of science and technology to create innovative solutions to achieve their respective national objectives. Many analysts, both in China and the United States, have pointed to the enduring relevancy of the issues raised in Vannevar Bush's 1945 report, noting that debates that dominate today's science policy discussions are often a replay of those that took place in the 1940s and 1950s. At the center of science policy discussions is an essential question, "What is the best way to organize and oversee scientific research in pursuit of innovation?"[5]

The purpose of this report is to examine and analyze Chinese science policymakers' and stakeholders' answer to that question, and the rationales, beliefs, decisions, and struggles that inform their answers. Particularly given the beginning of two important policy phases, the goal of this report is to provide the information and context needed to understand the state of Chinese science today, its priorities for the near future, and an assessment of China's prospect of becoming "a primary global center for scientific research and an innovation highland."[6] The analysis in this report focuses on answering the following research questions:

- Are there consistencies or unique national features in China's national policy for science across planning cycles, administrations, and individual leaders?
- What policy tools to advance scientific and technological development are preferred by Chinese leaders?
- What is the institutional arrangement for the formulation, coordination, and execution of its national science policy?
- What are the strengths and weaknesses of the Chinese approach for advancing science?
- What are the key policy issues facing Chinese policymakers and STI stakeholders today?

Scope Note

To date, there is a large body of literature that examines China's science, technology, and innovation (STI) strategies, policy initiatives, and its related ecosystems, often with an emphasis on technology and innovation.[ii] There have also been several studies published around 2015 detailing the measures and effects of the latest round of STI reform (initiated in 2014), offering helpful snapshots of the state of Chinese STI at the time of their

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ii Some examples include: Richard P. Appelbaum, Cong Cao, Xueying Han, Rachel Parker, Denis Simon, *Innovation in China: Challenging the Global Science and Technology System* (Medford, MA: Polity Press, 2018); Steven W. Popper, Marjory S. Blumenthal, Eugeniu Han, Sale Lilly, Lyle J. Morris, Caroline S. Wagner, Christopher A. Eusebi, Brian G. Carlson, and Alice Shih, "China's Propensity for Innovation in the 21st Century: Identifying Indicators of Future Outcomes." RAND Corporation, 2020. https://www.rand.org/pubs/research_reports/RRA208-1.html; Micah Springut, Stephen Schlaikjer, and David Chen, "China's Program for Science and Technology Modernization: Implications for American Competitiveness," April 20, 2011. https://www.uscc.gov/Research/china%E2%80%99s-program-science-and-technology-modernization-implications-american-competitiveness publishing.[iii] A separate body of literature examines China's defense STI strategies and R&D ecosystems,[iv] which by nature prioritize mission-oriented research and development. As far as Chinese *science* is concerned, Nature Publishing Group (NPG), part of Springer Nature, interviewed and surveyed more than 1,700 Chinese primary investigators (PI)—researchers who play leading roles in research projects—and compiled its findings in a White Paper called *Turning Point*: *Chinese Science in Transition* in 2015.[7] NPG's White Paper offers an in-depth, nuanced look into how science is funded, conducted, and shared in China. Aside from *Turning Point*, English-language reporting on the subject often center on China's strong performance in leading STI indicators and the implications for the United States.[8] Finally, discussions on China's *national science policy* have been intensely focused on the outward-facing aspect of China's national science policy to include talent repatriation efforts and foreign talent recruitment programs.[v]

This study differs from these bodies of literature and attempts to expand our understanding of China's state and prospects of STI development in two ways: First, it shines a spotlight on *science policymaking*, providing a comprehensive and timely examination of the Chinese model of science by focusing on the players and processes that regulate, guide, or conduct scientific research, the search for "truth" and new knowledge.[9] Second, while used extensively throughout, this report ventures beyond traditional STI indicators to include examination of country-specific factors emerging from cultural contexts and of their influence on China's science policymaking system and processes.

The 'S' in National 'STI' Policies

Despite the importance and popularity of "national science policy" as a subject, it was not clearly defined and systematically studied until the publication of *Beyond Sputnik: U.S. Science Policy in the 21st Century* by University of Michigan professors Homer A. Neal, Tobin L. Smith, and Jennifer B. McCormick in 2008.[10] Noting similar problems in China's STI policy lexicon and conceptualization, Chinese scientists have argued that the lack of clear distinction between "science" and "technology" policies has obscured some of the important differences between the two ideas for policymakers and the broader public, which will be addressed in greater detail in Section 1.3. Paraphrasing Neal et al., we can think of "national science policy" as the Chinese central government's "rules, regulations, methods, practices, and guidelines under which *scientific research* is conducted.[11] It also refers to "the dynamic, complex, and interactive processes and procedures—both inside and outside government—that affect how these rules, regulations, methods, practices, and guidelines are devised and implemented."[12]

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iii Some examples include: Margaret McCuaig-Johnston and Moxi Zhang, "China Embarks on Major Changes in Science and Technology," China Institute Occasional Paper Series 2, no. 2 (2015). https://doi.org/10.7939/R3DB7VQ5V; Richard P. Suttmeier, "An Innovation System for the 21st Century? Reflections on China's Science and Technology Reforms," *Journal of Dialectics of Nature* 37, 1, (February, 2015), http://china-us.uoregon.edu/pdf/DofN%20final.pdf.

iv Some examples include a series of research briefs published by the Institute on Global Conflict and Cooperation, UC San Diego, which can be accessed at https://igcc.ucsd.edu/research/technology-innovation/innovation-technology-china/sitc-policy-briefs.html, as well as Tai Ming Cheung, *Fortifying China: The Struggle to Build a Modern Defense Economy,* (UC San Diego: Cornell University Press, 2009); *Forging China's Military Might: A New Framework for Assessing Innovation*, Edited by Tai Ming Cheung, (Johns Hopkins University Press, 2014).

v See, for examples, Permanent Subcommittee on Investigations, "Threats to the U.S. Research Enterprise: China's Talent Recruitment Plans," United States Senate, 18 November 2019, https://www.hsgac.senate.gov/imo/media/doc/2019-11-18%20PSI%20Staff%20Report%20-%20China%27s%20Talent%20Recruitment%20Plans.pdf; The "Chinese Talent Program Tracker," Center for Security and Emerging Technology, November 2020. https://doi.org/10.51593/20200066

This definition necessitates a brief discussion of the term "scientific research." Despite the frequent appearance of terms such as "science and technology" (S&T), "research and development" (R&D) in official documents and news media, they are often used without clear accompanying definitions. As Neal et al. pointed out in *Beyond Sputnik*, the differences between these terms confuse not only the general public and policymakers, but even scientists.[13] "Scientific research" is one such troubling term, where the lack of a clear definition risks major exaggeration by conflating very distinct activities. In the English context, 'scientific research' is used by some to refer to two out of three types of R&D activities:[vi] basic and applied research. For example, the Canadian government uses the term "scientific research and experimental development (SR&ED)" to refer to the full spectrum of R&D activities.

However, complicating the matter is the fact that the term is also casually used by some to refer to all three R&D activities. For example, a *Washington Post* article in 2018 on China's potential to "increasingly challenge American dominance of science," used the term "scientific research" spending as a substitute for gross domestic expenditure on R&D.[14] In the Chinese context, "scientific research" [科学研究/科研] is more consistently associated with basic and applied research only, in both daily discussion and particularly for statistical analysis purposes. For example, the China R&D Expenditure Report series, including the latest edition published in April 2021, put out by the Dalian University of Technology (DLUT) clearly defines "scientific research" as combing basic and applied research.[vii,15] As this report discusses Chinese science policy and scientific research activities, it adopts the DLUT team's definition for consistency and scoping purposes; the government bodies and the elements of the STI ecosystem engaged in promoting and conducting "scientific research" are the focus of this report.

Establishing a baseline for understanding the distinctions between national science, technology, and innovation policies is also necessary for the scoping of this report. This is not to argue that science, technology, and innovation policies are separated, but rather that each of the STI policy fields has its own policy focus and preferred policy instruments. In their chapter "Science, Technology, and Innovation Policy" in the *Oxford Handbook of Innovation*, Bengt-Åke Lundvall and Susana Borrás delineated the three policy fields according to their origins, the major issues at stake, the major actors involved and the instruments used (see Appendix 1 for details).[16] Combining insights from Lundvall and Borrás and *Beyond Sputnik*, an effort is made in this study to direct more research attention to the policy areas, elements of innovation system, and policy instruments most relevant to national science policy in China.

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vi The Organization for Economic Co-operation and Development (OECD) *Frascati Manual 2015*, the internationally recognized methodology for collecting and using R&D statistics, defines R&D as comprising three types of activity: basic research, applied research, and experimental development. According to the Manual, "**Basic research** is experimental or theoretical work undertaken primarily to acquire new knowledge of the underlying foundation of phenomena and observable facts, without any particular application or use in view. **Applied research** is also original investigation undertaken in order to acquire new knowledge; it is, however, directed primarily towards a specific practical aim or objective. **Experimental development** is systematic work, drawing on existing knowledge gained from research and/or practical experience, which is directed to producing new materials, products or devices, to installing new processes, systems and services, or to improving substantially those already produced or installed. (The concept of experimental development differs from product development or pre-production development)." OECD, *Frascati Manual 2015: Guidelines for Collecting and Reporting Data on Research and Experimental Development*, The Measurement of Scientific, Technological and Innovation Activities, OECD Publishing, Paris, 2015. https://doi.org/10.1787/9789264239012-en, 44.

vii The DLUT research team published China's first-ever comprehensive report analyzing trends in R&D expenditure between 1995 and 2018 in early 2019. See "Report on China's R&D Expenditure (2018) Officially Released" [中国科研经费报告（2018）正式发布], Zhishi Fenzi, 5 March 2019. http://m.zhishifenzi.com/news/multiple/11239.html

Beyond Leading STI Indicators

The second way this report hopes to expand upon the existing literature is through its examination of country-specific factors emerging from cultural contexts[viii] and of their influence on China's science policymaking system and processes. This is a particularly important point to consider in China's case. This report does not argue that there is an innate distinctiveness to Chinese science or to the process of scientific inquiry an individual Chinese scientist undertakes. Rather, as a group of scholars and analysts argued in a 2020 RAND report on China's propensity[ix] for innovation, due to the fact that Chinese leaders have "affirmatively designed to follow a development path 'with Chinese characteristics,'" common indicators and criteria might not reflect realities on the ground when applied to China because the assumption that "similar systems are at play" is no longer valid.[17] To that end, while analysis of common STI indicators (quantitative metrics such as R&D expenditure and publication and patent output) is featured prominently throughout the report, considerable attention has also been paid to explaining their limitations and the resulting ramifications.

Furthermore, the RAND study also highlighted the "informal institutions de facto" (rules that innovation actors actually play by) as information crucial to understanding China's propensity for innovation.[18] According to authors, "… in addition to formal institutions that may exist de jure, there are also informal institutions de facto. How rules are applied, what people come to understand are the unwritten rules, and a calculation of where interests lie may have a profound effect on venues, processes, and activities that affect innovation."[19] To that end, research attention has also been given to examining the unwritten rules and the so-called 'gray literature'[x] while also presenting authoritative literature, official speeches, policies, and other formal rules.

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viii In 2009, at the request of the Office of the Chief Scientist, Central Intelligence Agency, and the Defense Warning Office of the Defense Intelligence Agency, the National Research Council (NRC) reviewed the science and technology (S&T) advancement strategies of six countries (including China) for the purpose of identifying unique national features and examining how they are utilized in the evolving global S&T environment. In their findings, NRC notes that there is not a single set of common indicators that applies to all countries and concluded that the best indicators are country specific and must reflect both traditional (quantitative measures) and nontraditional factors emerging from cultural contexts. See National Research Council 2010. S&T Strategies of Six Countries: Implications for the United States. Washington, DC: The National Academies Press. https://doi.org/10.17226/12920, 1-2.

ix According to the report, innovation 'propensity,' in contrast with 'potential,' inquires into the ability of China's system to fully elicit its inherent potential. The authors write, "Although innovation requires many inputs and is also affected by external forces, there are also systemic aspects at play. Two nations similarly endowed with innovation assets and so gauged to have the same innovative potential in a static sense may operate under two different internal regimes. One may perform dynamically better than the other—possess a greater systemic propensity—for achieving innovation outcomes with similar resources." See Steven W. Popper, Marjory S. Blumenthal, Eugeniu Han, Sale Lilly, Lyle J. Morris, Caroline S. Wagner, Christopher A. Eusebi, Brian G. Carlson, and Alice Shih, "China's Propensity for Innovation in the 21st Century: Identifying Indicators of Future Outcomes." Santa Monica, CA: RAND Corporation, 2020. https://www.rand.org/pubs/research_reports/RRA208-1.html, xi.

x Examples include "blogs, online discussions, company webpages, and short-form documents," etc. See Popper et al., "China's Propensity for Innovation in the 21st Century," 4.

Organization of this Report

This report is organized into three sections:

Section 1 identifies four recurring themes of China's national policy for science across planning cycle, leadership, or even regime changes:

- **Section 1.1** briefly analyzes the origin of modern Chinese science and how the set of circumstances shaped the mindset of policymakers and scientists on how they view science and technology then and now.
- **Section 1.2** explores the tension between science and politics, as well as its implications. Although a universal issue, the Chinese research community faces some unique challenges in this regard, due to Party's unwavering belief and confidence in its extensive involvement in virtually every aspect of the endeavor.
- **Section 1.3** explains in detail China's 'whole-of-nation' approach to science, characterized by long-term planning and large-scale S&T programs and its perceived weaknesses.
- **Section 1.4** briefly explains how Chinese leaders across generations launch reforms as an important tool to adjust policy measures and rectify errors.

Section 2 outlines the players and processes involved in the formulation, coordination, and execution of its national science policy. Aspects of this arrangement were reshaped during the 13th FYP period, such as the establishment of consulting bodies and the revamping of its funding vehicles and programs, which are given considerable analytical attention in this section.

- **Section 2.1** analyzes China's current institutional arrangement for the formulation of science policies at the highest level of the policy-making process and examines recent efforts to institute new decision-making consulting mechanisms that directly support the central decision-making authorities.
- **Section 2.2** looks at the institutional arrangement for the coordination and implementation of STI policies at the ministerial level. It outlines changes to the national STI funding programs and funding vehicles, as well as new mechanisms and organizations put in place for the management of the programs and vehicles.

Section 3 looks at China's science and engineering enterprise, including its composition, trends in R&D activities, and analyzes the quantity and quality of its output.

- **Section 3.1** provides basic information about the key research performers: the intuitions and organizations at the heart of China's STI ecosystem. It places in context one of the 14th FYP top policy priorities: the strengthening of the "National Innovation Systems" and the "national strategic S&T enterprise."
- **Section 3.2** discusses China's model of government-sponsored science through a detailed analysis of trends in R&D activities. Even though government sponsorship is critical to the advancement of science anywhere, the Chinese government again plays a much more integral role in its support of the "national strategic S&T enterprise" compared to the United States.
- **Section 3.3** examines common STI indicators with a critical eye, highlighting reservations expressed about them by Chinese researchers and then the underlying factors that could supercharge or impede Chinese S&T progress. It analyzes some of the critical challenges Chinese science policymakers have encountered in the assessment of China's policy outcomes, particularly with regard to its research and development output.

Section 1. Recurring Themes in the Chinese Model of Science

As the authors of *Beyond Sputnik* pointed out, many of the policy debates over how best to guide the conduct of science in the United States today, while seemingly unprecedented, are simply a reprise of those that took place in the 1940s and 1950s.[20] China is similar in that regard, and this section will address four leitmotifs which represent some of the consistencies in the rationale behind Chinese science policy across planning cycle, leadership, or even regime changes. Together they form the basic context in which Chinese science policy is made. Woven into the discussion are some of China's top policy priorities for the advancement of science and technology outlined in the 14th Five Year Plan (FYP), including the strengthening of basic science and the new 'whole-of-nation' model.

1.1 'Saving China Through Science'

While 1949 may seem to be a logical starting point for examining China's national policy for science, modern Chinese science arguably began its journey at the turn of the twentieth century. The circumstances surrounding its birth shaped the mindset of policymakers and scientists on how they view science and technology then and now.

'Western Learning' and Self-Reliance'

A series of catastrophic setbacks and defeats the Qing government suffered at the hands of the Western powers in the First (1839–42) and Second Opium War (1856–60) led to a rude awakening that China must defend itself through the development of science and technology, the neglect of which had led to China falling far behind the world's great powers, and that it had no choice but to learn science and technology and the means to develop science and technology from its enemies.

In the *Illustrated Treatise on the Maritime Kingdoms* [海国图志], a gazetteer considered the first significant Chinese work on the West, scholar-official Wei Yuan [魏源] and others put forward the idea to "learn skills from the foreigners in order to gain command of them" [师夷长技以制夷]. The "skills" here mostly referred to "warships, firearms, the method of training soldiers."[21] As a Xinhua article states, "learning the skills from the foreigners" was the means, and the goal was to "gain command of them."[22] This argument inspired the Self-Strengthening Movement [洋务运动] (1861–1895), an attempt to adapt Western institutions and military innovations to Chinese needs.[23] As part of the movement, between 1872 and 1881, the Qing government dispatched the first group of Chinese students to study science and engineering in the United States. More significant developments took place in the 1900s. In 1909, the first group of outbound Chinese students funded by President Theodore Roosevelt's Boxer Indemnity Scholarship Program arrived in the United States. In 1911, the Tsinghua School was established in Beijing as the Boxer Indemnity Scholarship Program's official preparatory school.[24] The school became Tsinghua University in 1929 and went on to become one of China's most prestigious research universities.

China's willingness to welcome foreign influence, however, was limited to learning the tools from the 'western powers' for the advancement of science and technology. As University of Edinburgh scholars Xiaobai Shen and Robin Williams noted, when modernization was "forced upon" the Qing government and the Chinese people, Western technologies were embraced by the public as a "means" in service of the "imperative for national salvation," while at the same time broader Western culture was rejected and the fundamentals of Chinese culture were retained.[25] This mentality, they argue, reflected in the *ti-yong* dichotomy ("Chinese learning for fundamental principles; Western learning for practical application"[xi] [中学为体、西学为用]) enabled traditionalists to reject

xi Advocated by the Qing statesman Zhang Zhidong [张之洞].

transformative political and social change: "They could uphold their commitment to China's cultural "essence" and still in good conscience welcome Western technologies, and social, political and economic 'forms' in order to achieve national 'wealth and power."[26] An argument can be made that this mentality still lingers today. Senior Party and state leaders have sought to underscore the public's faith in the Chinese model of development and the need for "self-reliance in S&T," while at the same time aggressively pursuing technology and talent from abroad.

Talent Repatriation

The state of the nation during the early years of modern Chinese science also shaped the mindset of China's first generation of leading scientists, many of them trained abroad, instilling in them a strong desire to bring their war-torn motherland and its people out of poverty, turmoil, and misery. In January 1914, a group of Chinese students studying at Cornell University established the Science Society of China (a predecessor of the Chinese Academy of Sciences).[27] The Society began publication an influential journal titled *Kexue* (Science) in Shanghai, China in 1915, making available to the Chinese public the latest scientific knowledge.

With the Japanese invasion in 1937, the desire to save the motherland gained even stronger convictions. Many of the scientists who studied in the United States and other countries returned despite mounting challenges including a lack of funding and poor working conditions.[28] In spite of these challenges, according to an analysis by a Chinese Academy of Sciences researcher, a total of 1,805 scientists returned to China from overseas by 1956.[29] Among them were some of China's most preeminent scientists and engineers such as Qian Xuesen [钱学森], "father" of Chinese nuclear and space programs. Qian left China in 1935 on the Boxer Indemnity Scholarship to study mechanical engineering at Massachusetts Institute of Technology. Trained in some of the best universities abroad in essential disciplines such as science, engineering, agriculture, medicine and commerce, these scientists became trail-blazers in their respective fields and played instrumental roles in nurturing the next generation of researchers.[30]

Even though the current generation of leading scientists may no longer be motivated by the same sentiment in their scientific career, patriotism and the idea of national salvation through science remains a theme often revisited by Chinese rulers. For example, Xi Jinping frequently calls upon scientists and engineers to let patriotism be the foremost driver of their inquiries and learn from China's first modern generation of scientific leaders. Speaking to a group of senior Chinese academicians (the nation's preeminent scientists), scientists, and engineers in May 2016, Xi Jinping that "science and technology workers must write their papers on the soil of the motherland and apply S&T achievements to the great modernization endeavor."[31] Speaking again to senior scientists in May 2021, he called on Chinese academicians to lead by example by always having the motherland and the mission of serving the people in mind.[32]

> *In the new era, there is a greater need to inherit and carry forward the spirit of patriotism that takes the fate of the country as a person's own mission…academicians should remain true to our original aspiration and keeping our mission firmly in mind, respond to the call of the Party, heed the call of the motherland, maintain a deep sense of affection for the homeland and a strong sense of social responsibility, and work tirelessly for the Party, the motherland, and the people!*[33]

Xi has also extended his message to Chinese students abroad. In a July 2020 letter written in response to Chinese students studying at Moscow State University, Xi told the students that he hoped the students will carry forward the glorious tradition of studying abroad in order to serve the country, study hard and become outstanding talents who could be entrusted with great responsibilities as quickly as possible, so that they can dedicate their skills to the motherland and the people.[34]

Patriotism as a motivator aside, the Chinese government has consistently employed talent repatriation as an important policy tool for the advancement of Chinese science to this day. After the founding of the PRC, the CCP government dispatched outbound Chinese students to the Soviet Union and other Eastern European countries, sending around 4,600 students to these countries between 1954 and 1956.[35] Once the political turmoil of the Cultural Revolution ended in the late 1970s, Chinese leader Deng Xiaoping immediately reopened the door for Chinese students to receive training and education overseas. According to Cong Cao et al. who completed a preliminary study in 2019 examining the returning scientists' impact on Chinese science, a key component of the Deng's policy to improve the quality of China's scientific workforce has included sending a very large number of outbound students and scientists abroad, working under the assumption that a "brain drain" would not be a problem so long as "10 per cent of the dispatched would return."[36]

Based on Cong Cao et al.'s analysis, the Chinese government has recruited back at least 16,000 scientists by 2018 through its various talent programs designed to attract back highly skilled overseas talents.[37] Based on preliminary analysis they performed on bibliometric data from 2005 and 2017, Cong Cao et al. were able to show that returning scientists have had a huge impact on the growth and advancement of Chinese science: First, over 12 percent of mainland China's total number of publications is published by people with overseas experience and this number is likely to be a substantial underestimation.[38] Second, returning scientists have a higher relative impact than domestic researchers and that the citation impact of papers by returnees is considerably higher than those who remained in China throughout their scientific careers.[39]

Science or Technology

As many scholars have argued, in modern Chinese science's infancy, the state of the nation shaped the perception of science as a valuable tool for serving national security and economic needs. In a recent article that traces China's rise as a scientific super power in *Nature*'s 150th anniversary issue, author Shellen Wu also noted the shaping of the "unwavering belief in science as the path to wealth and power" during this period in China's history.[40] This utilitarian view of science is not without its critics. Zhang Zhun [张准] (1886—1976), another Boxer Indemnity Scholarship student who became a prominent chemist and a vocal advocate for science education in China, argued that:[41]

> *Those who advocated for 'western learning,' their purpose was not in the science itself, but in the production of war ships, firearms, and the building of a strong enemy, and seeking wealth and power to save the nation.*
>
> *Those who practiced 'western learning' were enslaved by the imperial examination system. They merely gained some knowledge of some terms related to science, and thought they have gained the key to career advancement.*

After the CCP took power in 1949, this pragmatic view on science and technology was further reinforced. In November 1949, the Chinese Academy of Sciences (CAS) was established as a national science academy "owned by and for the people."[xii][42] Its core mission mandates include "serving industrial, agricultural, and national defense needs through science" and "serving the people through science," and the objective of developing the disciplines of the basic sciences (mathematics, physics, chemistry, and biology) was to "continuously support nation building."[43] These policy rationales form a stark contrast to the way Vannevar Bush recommended these research institutions be run and how research activities should be oriented. Writing in 1945, Vannevar Bush argued that:[44]

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xii CAS replaced the Academia Sinica, an organization created in 1928 primarily staffed with scientists from the Science Society of China. After the Kuomintang [国民党] government moved to Taiwan in 1949, Academia Sinica was re-established in Taipei.

"The publicly and privately supported colleges, universities, and research institutes are the centers of basic research. They are the wellsprings of knowledge and understanding. As long as they are vigorous and healthy and their scientists are free to pursue the truth wherever it may lead, there will be a flow of new scientific knowledge to those who can apply it to practical problems in Government, in industry, or elsewhere. … Scientific progress on a broad front results from the free play of free intellects, working on subjects of their own choice, in the manner dictated by their curiosity for exploration of the unknown."

Some Chinese scholars have argued that throughout modern Chinese history, the idea of "science" is often used as a substitute for "technology," leading to a lack of clear distinctions between its science and technology policies (see Section 1.3 for more details). In an article examining the evolution of the "saving China through science" [科学救国] school of thought in modern Chinese history, Zhang Jian [张剑], historian of Shanghai Academy of Social Sciences, argues that the whole movement in fact had little to do with "science," in the pure sense of the word. Rather, the nature of the movement is "saving China through technology."[45]

The utilitarian view of science persists to this day and has serious national science policy implications. It contributed to the policy rationale and funding decisions for the following 60 years that strongly favored the "D" of R&D, at the expense of supporting scientific research critical for innovation (discussed in Section 2.3). The insistence on the paramount significance of S&T progress over personal gains also has serious policy implications. "Scientific and technological progress" as was written into law in 1993,[46] but a law to promote the commercialization of scientific research achievements was not passed till 1996 and, until its amendment in 2015, offered minimal protection of intellectual property rights.[47][xiii]

In a sense, the unique blend of nationalism, patriotism, and pragmatism surrounding the origin of modern Chinese science mirrors what nowadays scholars refer to as the "techno-nationalist" or the "techno-security state"[xiv] perspective, which strive to marry national security and technological advances and capabilities. Some Chinese scientists have argued that even though the movement was carried out under the banner of "saving China through *science*," science, in the purest sense of the word representing the search for "truth" and new knowledge, has yet to fully take root.[48]

xiii In the United States, however, protection of intellectual property rights was written into the constitution. According to Article I Section 8 of the Constitution of the United States: "To promote the progress of science and useful arts, by securing for limited times to authors and inventors the exclusive right to their respective writings and discoveries."

xiv For more on the techno-nationalist perspective, see Tai Ming Cheung, *Fortifying China: The Struggle to Build a Modern Defense Economy*, (UC San Diego: Cornell University Press, 2009); Tai Ming Cheung and Eric Hagt, "Civil-Military Integration and the Rise of China's Techno-Security State: Implications for Great Power Competition with the United States" Naval Postgraduate School 16th Annual Acquisition Research Symposium, 9 May 2019, https://calhoun.nps.edu/handle/10945/62943

1.2 “Science cannot be divorced from politics, and is dominated and governed by politics.”

The tension between science and Party politics is another recurring theme of Chinese science. The CCP leadership has long asserted its leadership over China’s science and technology endeavors and has always considered its direct political influence over the direction and conduct of scientific research as entirely positive.

Three months before the actual founding of the PRC in July 1949 at the First National Congress of Scientists in Natural Science, soon-to-be Premier Zhou Enlai [周恩来] stated that “Science cannot be divorced from politics, and is dominated and governed by politics,”[49] and further, that “The modern history of China has made fully clear that all scientists with a conscience can only have a bright future in a new China that is under the people’s democratic dictatorship [在人民民主专政的新中国里].”[50] Since taking office, Xi Jinping has tightened Party control and strengthened Party leadership over all aspects of the S&T ecosystem. According to Xi, having the CCP firmly in the driver’s seat “provides a fundamental political guarantee to China’s STI advancement endeavor.”[51] By contrast, while Vannevar Bush argued that science is a “proper concern” of government, he painstakingly underscored the importance of preserving freedom of inquiry and removing rigid government controls.

China’s Party/state-science dynamic manifests itself in a myriad of ways. First, and most importantly, it almost goes without saying that China’s scientific community functions within the same political system that has been criticized for a lack of rule of law, suppression of freedom of speech, human rights abuse, heavy media censorship, corruption, nepotism, cronyism, among many other issues.[xv] Chinese researchers and research institutions must operate in accordance with and within the confines of the “logic of the system,” therefore are vulnerable to many of the same problems such an authoritarian regime tends to engender. To date, the loudest voices decrying the political system’s negative effects on science were from three top Chinese scientists in an article published by *Nature* in 2005 in a special issue called *China Voices II*, a Chinese language supplement discussing science policy in China.[xvi] In the article, neurobiologist Rao Yi [饶毅], neuroscientist Lu Bai [鲁白], and biochemist Zou Chenglu [邹承鲁] [xvii] argued that China must fundamentally change the politics-science relation to achieve genuine progress in science and technology. They argue that the Chinese scientific community is subjected to the “rule by man” [人治] political culture,[xviii] (in this case) chiefly characterized by the arbitrary and boundless power of the government and government officials, which has prevented a true merit-based competitive

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xv According to an index produced by Freedom House, a U.S.-based non-partisan NGO, ranks China as “Not Free” following a scoring system examining political rights and civil liberties. See: “China,” Freedom in the World 2021, Freedom House, Accessed July 2021. https://freedomhouse.org/country/china/freedom-world/2021

xvi Rao Yi, Lu Bai, and Tsou Chen-lu (Zou Chenglu), “The Transformative Change Needed for China’s S&T Development: from Traditional ‘Rule-by-man’ to meritocracy” [中国科技需要的根本转变: 从传统人治到竞争优胜体制], Nature 432 (Suppl), A12-A17, November 18, 2004.

xvii At the time of writing, Rao Yi was professor of neurology at Northwestern University Feinberg School of Medicine in Chicago and associate director of Northwestern University Institute for Neuroscience; Lu Bai was chief of the Neural Development and Plasticity Section of the US National Institute of Health and a science advisor to the Chinese Ministry of Science and Technology; Zou Chenglu was a CAS academician and researcher with the Institute of Biophysics, Chinese Academy of Sciences.

xviii “Rule by man” [人治], as opposed to rule by law or rule of law, is a high-frequency term in Chinese political discourse. For more details see Jenco, Leigh K. “‘Rule by Man’ and ‘Rule by Law’ in Early Republican China: Contributions to a Theoretical Debate.” *The Journal of Asian Studies* 69, no. 1 (2010): 181-203. Accessed June 2021. http://www.jstor.org/stable/20721775 incentive environment from taking root. They proposed a clear "separation of politics and science" [xix] [政科分离] as a first step in fixing many of the ailments of Chinese science. The criticism and suggestions were not well-received by the senior leadership. According to *Nature*, MOST officials were "upset" by the content and resorted to obstructing the supplement's distribution and circulation.[52] Rao Yi, who is arguably the most outspoken critic of Chinese national science policies, reposted this article in April 2021 on his personal social media account, arguing that many of the same problems they raised in 2005 persisted to this day. Another indication of the concern about his arguments can be seen in that while the article itself remains online, it has been barred by the platform from being shared for "violating rules and regulations."

While the tension between science and policy making is not unique to China, in a liberal democracy, the tension can be mitigated to a degree if the scientific community and the policymakers respect each other's differences.[53] In China's political system, however, the Party's authority is paramount. The conduct of science, the search for the "truth," must operate within the confines of Party ideologies—the "truer truth." The Ministry of Science and Technology (MOST), an agency under the State Council, is mandated to implement the Party Central Committee's STI policies and vows to consistently uphold the Party's centralized and unified leadership over STI work.[54] "Strengthening Party leadership" is a "decisive factor" in the evaluation of China's top universities and faculty departments by the Ministry of Education.[55] Party-related news is always placed front and center (see image below) on the website of the Chinese Academy of Sciences (CAS), China's largest research organization for the natural sciences. Party education and Party building efforts are held frequently, which, to the outside observers, pose a great opportunity cost for the advancement of science due to the sheer amount of time devoted to these activities. Senior leaders, who are often Party members themselves, must frequently show allegiance to the Party. For example, Bai Chunli [白春礼], who served as the Party secretary and director of CAS between 2011 and 2020, penned multiple articles extolling the Party's leadership in science and technology. Bai, a Party member since his early 20s, argued that Party leadership and Party building efforts in research organizations serve as one of the most powerful driving forces for innovation.[56] When a group of defense S&T historians summarized the key takeaways from the PRC's defense S&T development, they noted that leadership by the CCP Central provides "fundamental guarantee" [根本保证] to China's defense S&T endeavors.[57]

Figure 1 Chinese Academy of Sciences Conducts In-depth Studies into Party History

Image Credit: Chinese Academy of Science accessed June 2021, http://www.cas.cn/.

xix Note that the term 'politics' here mostly refers to administrative interference. Their argument has little to do with the current debate in the United States about whether science should or should not be 'political.' For an example of the debate currently taking place in the U.S. scientific research community, see "Yes, Science Is Political," Scientific American, 8 October 2020, https://www.scientificamerican.com/article/yes-science-is-political/.

There is no way to know whether the plaudits amount to genuine praise or are simply a form of flattery or performative devotion, as routinely professing loyalty to the Party is necessary for officials in high-profile positions to progress in their careers. While there is room for input from the scientific community on specific issues related to science policymaking, funding, and the management of R&D programs, there is no room for negotiation on the "fundamentals" such as the centrality of Party leadership. Many researchers and analysts outside of China have underscored the inherent tension between the fundamental nature of science and scientific inquiries and China's political system. *The Economist*, posing the question of whether China can become a scientific superpower, argues that the "culture of unappealable authority" runs counter to the goal of obtaining "truly reliable or great science."[58] Richard P. Suttmeier, professor of political science (emeritus) at the University of Oregon, pointed to the difficulty of having a "self-governing professional (scientific) community" under China's political system.[59] The 2020 RAND study examining China's propensity for innovation in the 21st century concludes that "innovation with Chinese characteristics" ultimately means reconciling the two thrusts of "striving for excellence and innovation on the one hand while maintaining the primacy of Party guidance (and control) on the other."[60]

1.3 'Whole-of-Nation' Approach to STI Advancement

To advance scientific progress and other nation-specific science policy objectives, main policy actors, regardless of their nationalities, invariably share many of the same policy concerns and have largely the same policy instruments at their disposal. A top priority for science policy is the efficient allocation of resources and the proper distribution of research activities.[61] The policy instruments employed, although prioritized differently across nations, often include a combination of budgetary decisions on funding, regulations on the STI ecosystem, initiatives to nurture STI talents, tax incentives and relief, intellectual rights protection, and other measures designed to shape an institutional environment conducive to STI development.[62] Among these policy tools, the PRC government, largely due to strong Soviet influence, has consistently favored centralized up-down long-term planning for the advancement of both science and technology and the large-scale mobilization of efforts in the execution of those plans. This approach often referred to as the 'whole-of-nation' approach (*juguo tizhi*[xx]) [举国体制] to S&T advancement, is the third long-running theme of the Chinese model of science.

The shaping of the approach traces back to theories and practices adopted in the 1950s. Similar to how Vannevar Bush's report is referred to as "the basis for the [United States'] existing science policy,"[63] the formulation of the PRC's first medium- and long-term S&T plans, along with its subsequent execution and success, laid the foundation for this policy model, which Deng later summarized as "pooling efforts together to achieve great things" [集中精力办大事]. Since taking office, Xi Jinping has been promoting his variation, called the "*new* whole-of-nation model" [新型举国体制], as a primary means of achieving S&T self-reliance.[xxi] The phrase has since become a mainstay in policy documents such as the 13th FYP[64] and the 14th FYP.[xxii] According to Chinese policy experts, the new model is consistent with Deng's philosophy to "pool resources together to achieve great things."[65] The main differentiator, according to interpretations of policy and industry experts and Central Party School researchers, is a more prominent role of the marketplace and the closer connections with the international research community.[66]

The rest of this section examines two prominent features of this model and presents arguments from the Chinese scientific community about its weaknesses.

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xx The Chinese term is *tizhi* [体制], arguably the most essential term in China's political lexicon. *Tizhi* is defined by authoritative dictionary *Cihai* [辞海] as "a general term for the systems, institutions, methods, forms, etc. involved in matters related to the institutional setup, leadership affiliation, and management authority of state organs, political party organizations, enterprises, and public institutions."

xxi At an event celebrating the success of the Chang'e 5 lunar exploration mission with scientists and engineers on 22 February 2021, Xi Jinping remarked that the mission is a manifestation of the success of utilizing the "new whole-of-nation model" in overcoming critical technical difficulties. See: "Xi Jinping: climb the peak of science and technology to serve the overall development of the country and to make new and greater contribution to the peaceful use of space for mankind" [习近平：勇攀科技高峰 服务国家发展大局 为人类和平利用太空作出新的更大贡献], Xinhua, 22 February 2021. http://www.xinhuanet.com/politics/leaders/2021-02/22/c_1127125801.htm

xxii The latest 14th FYP noted, front and center in the section on STI, the need to formulate action plans for achieving China's S&T Great Power goal and to build a new whole-of-nation system under socialist market economy conditions. See "14th Five-Year Plan (2021-2025) for National Economic and Social Development and the Long-Range Objectives Through the Year 2035 of the People's Republic of China" [中华人民共和国国民经济和社会发展第十四个五年规划和2035年远景目标纲要], Xinhua, 13 March 2021. http://www.gov.cn/xinwen/2021-03/13/content_5592681.htm

National S&T Plans and Programs

National S&T Plans [科技规划]

In early 1956, Premier Zhou Enlai expressed concerns for the slow progress in the development of science and technology in China and attributed the cause to a lack of a comprehensive planning. Zhou believed that a comprehensive national S&T development plan was the only way to set priorities and to systematically utilize Soviet S&T achievements."[67] In the same year, Mao gave the marching orders toward scientific advances "[向科学进军]" and requested "an ambitious plan to change China's economic, scientific, cultural backwardness within a few decades, and quickly reach a globally advanced level."[68] The senior leaders' orders resulted in what became the *Long-term Plan for the Development of Science and Technology for 1956–1967* [1956-1967年科学技术发展远景规划] (often referred to as the *Twelve-Year Plan*).[69] Drafting the plan involved more than 600 scientists of various disciplines and nearly 100 Soviet experts. The finalized draft outlined 616 specific topics in 57 research areas and 12 key S&T issues as a top priority.[70] Among these, six research areas were further designated as issues of the utmost urgency: atomic bombs, missiles, computing technology, semiconductors, radio electronics, and automation, and long-distance remote-control technology.[xxiii]

The implementation of the plan, while hampered by the impact of the Great Leap Forward (1958-1962) and the deterioration of Sino-Soviet relations, was considered a huge success by the central leadership. In Mao's calculus, the testing of China's first atomic bomb and hydrogen bomb in 1964 and 1976, respectively, is the primary indication of the completion of the plan.[71] Marshal Nie Rongzhen, one of the key figures behind the drafting of this plan, described the Twelve-Year Plan as a "pioneering undertaking" [创举].[72] According to Nie, the plan not only provided a clear roadmap for the S&T enterprise, down to specifying the types of research projects to take on, but also greatly enhanced morale, guided the creation of new disciplines, and research institutions, nurtured the scientific and engineering research base, promoted constructive discussions, and afforded the CCP an incredible opportunity at honing its S&T policy planning skills.[73] Chinese researchers noted that 50 out of the 57 major projects were completed ahead of schedule.[74] Through the implementation of this plan, they argue, China not only solved some of the major scientific and technological problems it faced at that time but also established new disciplines and trained new scientists in critical technological areas.

As far as science policy goes, the success of the plan gave credence to the assumptions that S&T development can be planned and managed through comprehensive, extensive, and highly authoritative directives covering virtually all aspects of the country's scientific and technological undertakings, and that S&T advancement can be achieved by large-scale mobilizations. As a Chinese researcher noted in a journal article from 1995, the planning and execution of the *Twelve-Year Plan* shaped a policy approach that relies heavily on administrative *directives* (as opposed to *guidance*) and a top-down process in promoting S&T progress, instead of spontaneous grassroots interests and efforts.[75]

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xxiii When the draft was presented to Premier Zhou Enlai, Zhou reportedly asked Zhang Jingfu [张劲夫], then-Party Secretary of CAS and secretary of the S&T Planning Committee, "With such a large pile of paper and so many priorities, what should the State Council actually focus on?" Zhang proceeded to convene more meetings with China's top scientists and, with significant input from Qian Xuesen, Qian Sanqiang and others, finally arrived at six research areas with the utmost urgency. The development of atomic bombs and missiles as the top priority was undisputed and had been prioritized prior to the *Twelve-Year Plan*; the latter four areas were chosen because they were integral to the development of the "Two Bombs and One Satellite" program. See: Zhang Jiuchun, Zhang Baichun, "Planning Science and Technology: Working out and Implementing the Long-term Program for Developing Sciences and Technology from 1956 to 1967" [规划科学技术：《1956—1967年科学技术发展远景规划》的制定与实施]. Bulletin of Chinese Academy of Sciences, 2019, 34(9): 982-991.

While each generation of CCP leaders has its own set of STI development priorities, the primary set of policy tools employed consistently throughout the decades includes the design and execution of long-term STI development plans and R&D megaprojects with specific industrial objectives. Since 1949, the central leadership has issued a total of eight national science and technology long-term development plans, with the 9th, covering 15-years between 2020 to 2035, currently in the making at the time of this writing (see table 1).[76] They vary in duration, covering somewhere between eight to sixteen years, as well as in scope—some of the more ambitious plans mobilized significantly more resources than others.[77]

Table 1

PRC's Long-Term S&T Development Plans[78]		
1	Long-term Plan for the Development of Science and Technology for 1956–1967 [1956—1967年科学技术发展远景规划]	Known as the "Twelve-Year Plan"
2	Plan for the Development of Science and Technology for 1963-1972 [1963—1972年科学技术发展规划]	Known as the "Ten-Year Plan"
3	National Plan for the Development of Science and Technology for 1978-1985 [1978—1985年全国科学技术发展规划纲要]	Known as the "Eight-Year Plan"
4	Plan for the Development of Science and Technology for 1986-2000 [1986—2000年科学技术发展规划]	
5	Ten-Year Plan for the Development of Science and Technology for 1991-2000 [1991—2000年科学技术发展十年规划和八五计划纲要]	A revision of the previous version reflecting changing priorities and new S&T development guidance.
6	National Plan for the Development of Science and Technology during the 9th Five-Year Plan Period and Long-Range Objectives through 2010 [全国科技发展九五计划和到2010年远景目标纲要]	Not publicly disclosed
7	Science, Technology, and Education Development Plan (as part of the) 10th Five-Year Plan for National Economic and Social Development [国民经济和社会发展第十个五年计划科技教育发展专项规划]	
8	2006 Medium to Long-term Plan for the Development of Science and Technology (2006-2020) [国家中长期科学和技术发展规划纲要(2006—2020年)]	
9	2021-2035 Medium to Long-term Plan for the Development of Science and Technology (?)	Currently under deliberation

The most recent development plan, the *2006 Medium to Long-term Plan for the Development of Science and Technology (2006-2020)* (*2006 MLP*) laid out a blueprint for China to become an innovative nation by 2020 and a global S&T great power by 2050.[79] The drafting of the plan reportedly took close to three years, involved twenty working groups, 2,000 scientists, and a total cost of $10 million.[80] Just as comprehensive and detailed as the Twelve-Year Plan (see Appendix 2 for details), the roughly 38,000 word MLP identified 68 priority areas in 11 domains that are likely to achieve technological breakthroughs in the near term and outlined 16 megaprojects, 27 frontier technologies in eight technology areas, 18 basic science issues, and four major scientific research programs. Four years into the implementation of *2006 MLP*, the Party Central Committee and the State Council jointly also issued the *Plan on National Medium- to Long-Term for the Development of Talent (2010-2020)* [国家中长期人才发展规划纲要(2010－2020年)], a comprehensive plan for the development of human capital.[81]

National S&T Programs [科技计划]

During the 1978-1985 S&T plan (Eight-Year Plan) period, large-scale S&T programs[xxiv] were formalized and given a designated platform. Policymakers condensed the priorities outlined in the 1978-1985 S&T plan into a total of 38 R&D programs to be executed during the 6th FYP period (1981-1985),[82] and launched in 1982 the *National S&T Gongguan* ("storming a strategic pass" i.e., tackling key problems) *Program* [国家科技攻关计划]. Between 1982 and 2000, the *Gongguan Program* invested 37.9 billion RMB in 534 projects involving sectors such as agriculture, electronic information, energy, transportation, materials, environmental protection, medical and health, and others.[83] Many S&T programs similar in scale, taking various forms from *renwu* [任务/missions], *xiangmu* [项目/programs], to *jihua* [计划/plans] and *jijin* [基金/funds], were introduced over the years, as well as additional programs for constructing S&T facilities, recruiting talents, among others.

These programs were designed to address different sets of issues to advance STI development. Some support R&D activities in specific sectors, others promote a specific type of R&D activities or aim to foster linkages between science and innovation. There are also the so-called megaprojects [重大专项], which focus on product models, industries, and technologies (civilian and military) that reflect the country's strategic intentions. Historically, scientific projects at this scale included programs such as the atomic bomb, ballistic missiles, satellites, and manned space flights. Similar to the *Gongguan* program, most of the S&T programs in their lifespan invested large amounts in hundreds of smaller R&D projects. By 2015, a total of 40 state ministries and other government agencies together operated close to 100 S&T programs funded by the central government (Table 2 lists some of the most well-known programs).[84]

Table 2

Examples of China's National S&T Programs*	
Year	**Programs**
1982	National S&T Gongguan Program [国家科技攻关计划]
1984	State Key Laboratory Construction Program [国家重点实验室建设计划]
1986	National Natural Science Foundation Program
1986	863 National High Technology Program [国家高技术研究发展计划]
1988	Torch Program [火炬计划]
1991	National Basic Scientific Major Research Program [国家基础性研究重大项目计划（攀登计划）]
1997	"973" National Basic Research Program [国家重点基础研究发展计划（973计划）]
1998	National Knowledge Innovation Program (KIP) [中科院知识创新工程]
*These programs have been reorganized and integrated into five new categories (see section 2.3 for details)	

xxiv In Chinese, these programs fall under the umbrella term 'Keji Jihua' [科技计划/S&T Plans]. To differentiate these programs from long-term S&T plans [guihua/规划], they are all translated as 'programs.' For an official overview of some of the S&T programs, see "S&T Programs" [科技计划], gov.cn, 23 September 2005, http://www.gov.cn/test/2005-09/23/content_69569.htm.

Problems with the 'Whole-of-Nation' Policy Approach

While the 'whole-of-nation' approach has played an important role in advancing the nation's S&T development, some in the scientific community have questioned its overall effectiveness in service of some of China's overarching S&T development goals.

1. Can scientific advancement be planned?

Several leading Chinese scientists have questioned the premise that advancement in science can be achieved through long-term planning. According to neuroscientist Lu Bai, the lack of clear distinction between 'science' and 'technology' has blinded both policymakers and the public to some of the important differences between the two ideas.[85] Most importantly, he argues, science as a fundamental quest for the 'why' requires independent thinking and freedom of exploration, whereas technology development requires discipline and teamwork. Planning can facilitate advancement in technology, but not science, which is characterized by uncertainty. At a 2014 round-table discussion organized by *National Science Review (NSR)*, a journal run by the Chinese Academy of Sciences, Tsinghua University chemist Li Yadong [李亚栋] said that long-term plans such as the *2006 MLP* are often inadequate in forecasting STI development trends.[86] According to Li, more often than not, "the chosen fields had passed their prime time when the projects were launched. This means we are often a step behind. This is okay for capacity building and training a large number of scientists in a particular field, but is not good enough strategically if China aspires to be a world leader in science."[87]

According to Rao Yi, Chinese STI planners often overlook the fact that the success of the *Twelve-Year Plan* was represented by and limited to successes in the technological areas, as opposed to scientific advances.[88] The lack of distinction between 'science' and 'technology,' again, led some to erroneously assume that advances in science can be planned. These officials subsequently misdirected their energies on the planning and organization of 'big science' projects that are often repetitious, unscientific, or directing efforts in unfruitful directions.[89] Rao uses the metaphor of the trees and the forest to illustrate his point about the ideal role of the government in promoting advancement in science: The government can plan, nurture, and take care of 'forest areas' (a sound institutional environment, incentive structure, ample funding, and proper management approaches) but it is not appropriate for the government to plant specific 'trees' (identifying exact research direction and topic areas).[90] Chinese officials have misplaced their priorities, spending much time planting trees instead of taking care of the forest area, he argues.[91]

2. The 'science' of science policymaking

The second key issue leading Chinese scientists have raised concerns about is the decision-making process in the drafting and design of long-term plans. Because long-term plans and R&D megaprojects represent enormous government investments and opportunity costs, it is important that the process the government has adopted to arrive at its final draft is sound and rigorous.[xxv] However, scientists who were involved in the formulation of the *2006 MLP* were concerned that that was not the case. Wang Pinxian [汪品先], a geologist at Tongji University in Shanghai, who was involved in the planning process of the *2006 MLP* admitted that he was "rather disappointed" with the process: "It mobilized thousands of scientists but bowed to the judgements of only a small number of

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xxv In the United States, scientists such as Harvey Brooks have been advocating for "science for public policy" since the 1980s, which calls for blending technical and nontechnical considerations and using "scientific evidence, data, and insights to illuminate policy issues that are not primarily scientific, but that are strongly dependent on scientific and technological information." Harvey Brooks, Chapter 1 - Introduction and Overview, in *Science for Public Policy*, Editor(s): Harvey Brooks, Chester L. Cooper, (New York: Pergamon Press, 1987), 1-2. This later gave rise to the interdisciplinary research area called "science of science policy" (SoSP).

authoritative figures. The whole exercise was quite superficial and lacked genuine debate."[92] Lu Bai noted similar problems in his 2019 article that during such deliberations, the government officials often overstep and are eager to offer opinions on what projects to propose and how to execute the projects.[93] Furthermore, when the scientists' opinions collide with the government officials' viewpoints, a different group of scientists is convened for a second round of deliberation until their conclusion matches the officials' ideas.[94]

Scientists also noted a need for Chinese science to find its own path, instead of "following what is hot and trendy in the West."[95] As a Chinese researcher who studied the history surrounding the formation of the *Twelve-Year Plan* argued in a journal article from 1995, in contrast to the "market push" and "technology pull" paradigm driving S&T progress in many of the world's market economies, China's S&T progress was strongly driven by two different factors: "state push" [国家动力] and "disparity pull" [比差引力], for much of its history even after the founding of the PRC.[96] As a result, China's scientific and technological undertakings have always been placed in context of comparing and adjusting itself with the global international scientific and technological powers, and this mentality is reflected in its STI plans and projects. According to Poo Mu-ming [蒲慕明], neuroscientist at the Chinese Academy of Sciences Institute of Neuroscience in Shanghai, "China needs to establish its own research directions and priorities that are catered towards a set of scientific questions unique to the country and its needs and interest."[97]

3. Difficulty measuring policy outcomes

With the conclusion of the *2006 MLP* in 2020 and the start of a new S&T planning horizon, an intriguing question for China's S&T policy makers, stakeholders in the research community, and general observers alike is whether China has achieved what it set out to accomplish. Answering this question is not an easy task, given the mass scope of the plan.[xxvi] The Ministry of Science and Technology, yet to disclose its final official assessment, in 2018 initiated a series of formal evaluation procedures involving expert panel discussions, self-evaluation conducted by the state ministries with S&T responsibilities, reports drawn by top think tanks, big data analysis, and mass surveys of the S&T workforce.[98] The technical nature of the R&D programs meant that input from subject matter experts is essential in any kind of assessment at a granular level in specific domains and areas.

The MLP is meant to be ambitious, and it is unlikely that the central leadership anticipates success with every project. Many factors complicate 'grading' the success of the MLP as a whole or as individual megaprojects. Furthermore, other than a few ill-defined indicators, the majority of the MLP's objectives are difficult to quantify. In February 2021, Science and Technology Minister Wang Zhigang [王志刚] discussed several of the few quantitative indicators specified in the MLP and revealed that China's R&D intensity (R&D expenditure as a percentage of GDP) is projected to reach 2.4% in 2020 based on preliminary data, just narrowly missing the *2006 MLP* target of 2.5%.[xxvii][99] The "rate of contribution of S&T progress to the economy"—an ill-defined indicator—is said to be on track to surpass 60%.[100] Wang, however, did not comment on the MLP's goal of reducing "foreign technology dependency rate" [对外技术依存度] by 30% by 2020.[101]

China's political culture and rampant bureaucratic interference could also affect the evaluation process, particularly when it comes to the S&T programs. According to Rao Yi, funding agencies naturally prefer an

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xxvi For a translated version of the *2006 MLP*, see https://www.itu.int/en/ITU-D/Cybersecurity/Documents/National_Strategies_Repository/China_2006.pdf.

xxvii Nonetheless, China's fast growth in R&D spending has already drawn significant attention from foreign observers. According to the U.S. National Science Foundation (NSF), China's R&D spending grew by more than 17% per year between 2000 and 2017, compared to an average of 4.3% per year for the U.S. in the same period. See "China is closing gap with United States on research spending." Nature, 15 January 2020. https://www.nature.com/articles/d41586-020-00084-7 evaluation result in their favor, a fact that is tacitly understood by the expert panels convened to conduct these assessments.[102] The larger the project, the more government investment is involved, and the greater the chance that the agency would not accept an assessment with an unfavorable outcome indicating that billions of RMB had been wasted. As a result, "evaluation is meaningless," Rao concludes.[103]

4. The problems with S&T programs

The over 100 S&T programs operated by 40 state ministries and other central agencies have drawn criticism about its implementation, management, and overall effectiveness not only from the scientific community but also from the government itself. Ineffective management and low return on investment were among some of the chief complaints.

Given their massive scale, these programs not only represented a monumental management challenge for the central ministries but also created numerous bureaucratic obstacles for the programs' applicants. According to researchers from the Central University of Finance and Economics, grant applicants had to expend much time and energy in keeping with the latest guidelines, especially for core programs such as "863" and "973," which introduced numerous new guidelines every five years.[104] According to 2015 findings by NPG in *Turning Point*, programs operated by the National Natural Science Foundation of China (NSFC) has an overwhelmingly positive reputation among Chinese scientists. They describe it as being open, fair, and professional in its grant authorization decisions and evaluation process.[105] The majority of other agencies, however, tend to suffer from unnecessary bureaucratic interference [行政干涉], mostly due to the fact that the officials are administrators [行政人员], not scientists.[106]

Li Yadong, the Tsinghua University chemist, notes that most of the major projects involve hundreds of scientists from tens of institutes, and sometimes funding agencies suggest involving certain scientists who do not possess the necessary expertise.[107] In that situation, given the number of people involved, the influence of *guanxi*'[xxviii] is more difficult to discern, Li says, implying that it made it harder to differentiate those with the expertise versus those with political or personal connections. According to Wang Pinxian, the geologist from Tongji University, the power these administrators have over funding and staffing decisions for the large R&D projects incentivizes researchers to "schmooze with those in power," or engage in bribery and other corrupt practices.[108]

NPG's survey of Chinese scientists also pointed to problems with megaprojects, an important part of the national S&T programs. According to the White Paper:[109]

> *Megaprojects across the world, are typically aligned with national strategies and have resulted in spectacular outcomes. In China they are often proposed by a small group of high-profile experts selected by policy makers and the decision-making process is perceived as lacking input from the broader scientific community. Moreover, megaprojects usually have narrowly defined guidelines and conditions, restricting recipients to a pre-determined few. This could confine exploration and stifle innovation."*

NPG further notes that young and rising scientists are often excluded from consideration for funding from megaproject grants, each ranging from tens of millions to hundreds of millions of RMB, which are usually awarded to a small group of high-profile scientists.[110] NPG argues that this practice could also adversely impact advances in science, as securing stable funding for scientists who are in their productive 30s and 40s is crucial to innovation.[111]

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xxviii According to definition provided by Oxford Languages, "Guanxi refers to the system of social networks and influential relationships which facilitate business and other dealings."

For the central government, the programs' return on investment has been a central concern. According to the Ministry of Science and Technology's own analysis, there has been a mismatch between the input and output of these programs, noting a failure of these programs to deliver the kind of technological breakthroughs China urgently needs to ease its reliance on foreign technology.[112] Interestingly, the dissatisfaction did not result in the loss of faith over these large-scale national programs themselves. Rather, the root of the problem, MOST argued, was with the way these programs were managed.[113] The *Notice on the Plan for Deepening the Reform of the Management of Centrally-Financed S&T Projects (Programs, Funds),* issued by the State Council in December 2014 was targeted at addressing this issue. Despite its mundane title, measures proposed in the *Notice* comprehensively reorganized the national STI programs and funding vehicles.[114] The restructuring integrated the close to 100 centrally-funded S&T programs and funding vehicles into five broad categories for streamlined management via an open and unified national S&T management platform operated by MOST (see section 2.2 for more details). Some researchers suggest that the annual funding of these programs amounted to $39.5 billion (~244.9 billion RMB) at the start of the reform around 2015.[115]

1.4 Reform, Reform, Reform

Reform has historically been an important tool that Chinese leaders employ to adjust policy measures and rectify errors. Reforms can be broad and all-encompassing, or focus on specific policy areas. Since the Central Committee of the Chinese Communist Party initiated the first round of post-Mao era S&T Reforms [科技体制改革] in March 1985, almost every aspect of China's scientific research and management ecosystem has been subjected to some form of reform. While each round of reform is designed to address a certain set of issues, some of the overarching goals include: 1) strengthening the Party's leadership over the S&T establishment while enhancing the role of the market; 2) increasing efficiency by breaking down compartmentalization within the R&D establishment; 3) identifying more efficient ways of funding science, assessing output, and incentivizing scientists; 4) promoting the role of enterprises in R&D and the commercialization of technology; 5) facilitating technology transfer; and 6) enhancing original innovation capabilities.[xxix]

The overarching goal of the reform initiated after the 18th Party Congress in November 2012 was to establish a "National Innovation Systems with Chinese characteristics conforming to the laws of the socialist market economy and the laws of technological innovation development" (explained in detail in Section 3.1) that meets the requirements of the innovation-driven development strategy, a top strategic priority of the Xi Jinping administration.[116] In August 2015, the CCP Central Committee and the State Council jointly issued a reform roadmap titled *Implementation Plan for Deepening Reform of the Science and Technology Tizhi* [《深化科技体制改革实施方案》] (hereafter referred to as the "2015 *Implementation Plan*" that included 32 measures and a checklist of 143 actionable items in ten STI policy areas (see table below).[117]

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xxix It is worth noting that S&T reform is a broad topic whose components also include "organizational reform" and "policy system reform." As a group of Chinese researchers underscored in a 2017 study, S&T reform and organizational structure reform are not necessarily in step with each other. See Wan Jinbo et al., "Comparative Study on Science and Technology Innovation Policy-making and Advisory System."

Table 3

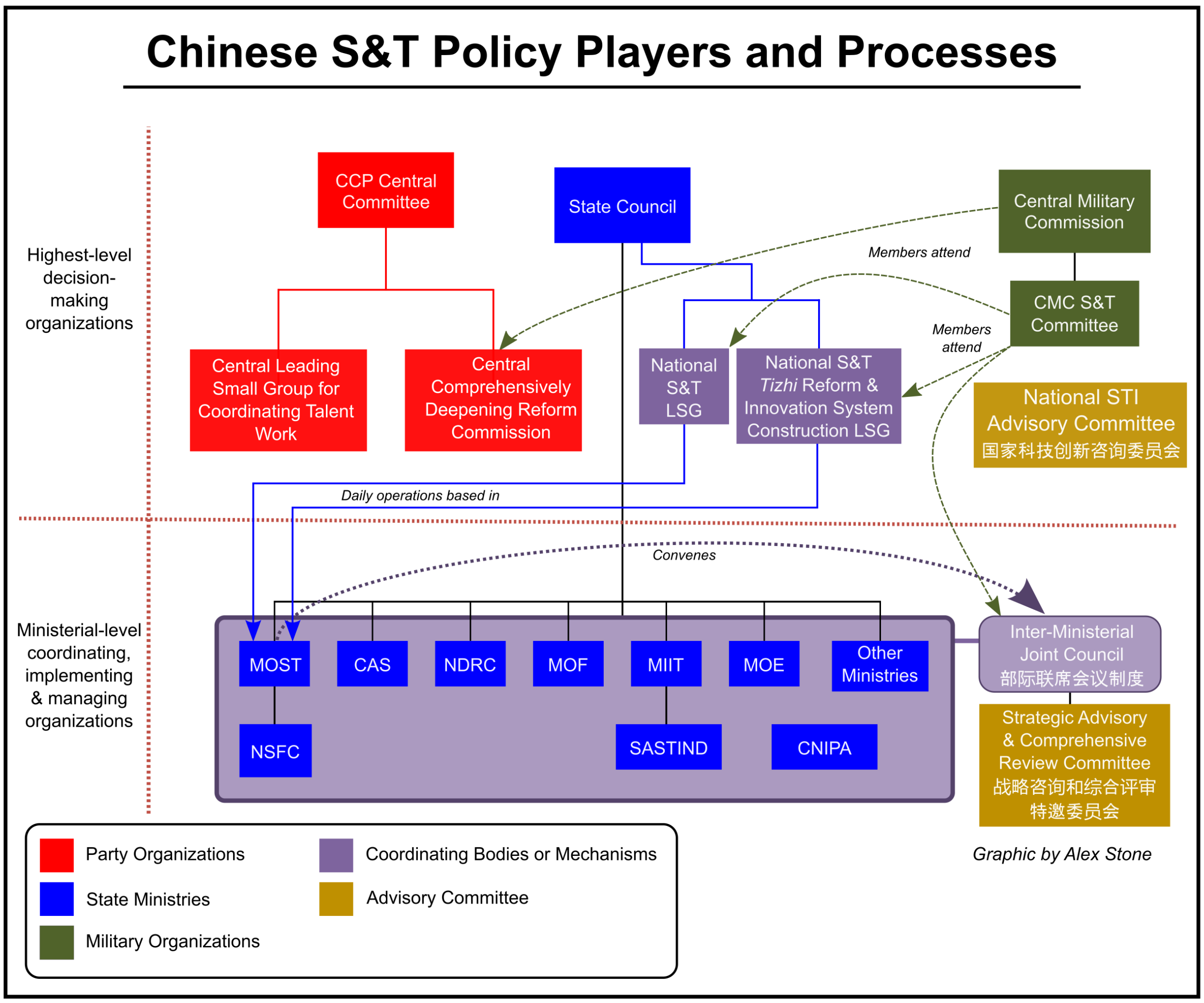
Reform Agenda STI Policy Areas (2015 Implementation Plan)
• Establish a market-oriented mechanism for technological innovation • Build a more efficient scientific research system • Reform talent training, evaluation, and incentive mechanisms • (Redacted [略] in public version) • Improve the mechanism to promote the commercialization of scientific and technological achievements • Establish a sound mechanism for enabling technological development through financial tools • Build a well-coordinated, innovative governance mechanism • Promote the formation of an open and innovative ecosystem characterized by deep fusion • Create a good environment that encourages innovation • Promote regional innovation and reform

Based on comments from top officials, MOST appears confident about the pace and progress of the S&T reform. Deputy Minister of Science and Technology Huang Wei [黄卫] indicated in 2017 that the S&T reform was on track. During a press conference in early 2017, Huang spoke of the "decisive progress" made in the latest round of reform. He highlighted the idea of a number of "new" and improved processes and mechanisms, including a new (S&T) planning system, a new (R&D) program generation mechanism, new management processes, and procedures, as well as an improved institutional environment conducive to innovation.[118] Huang added that the reform has fundamentally addressed the flaws of the S&T management system, which had been previously been described by many as "repetitious, dispersed, closed-off, and ineffective."[119] In an interview conducted over video during the 2021 Two Sessions [两会], China's main annual legislative meetings, Minister of Science and Technology Wang Zhigang further clarified that all 143 items on the to-do list had been completed, although he noted that certain problems remain and need to be addressed in the next round of reform.[120] Based on these comments, as well as the S&T policy priorities laid out in the 14th FYP, it can be inferred that although the S&T reform will likely continue, the new institutional arrangement, coordination mechanisms, and funding vehicles formed during the 13th FYP (which are the focus of section 2) will continue to be effective during the 14th FYP period.

Section 2. Policy Players and Processes

Having explained some of the unique features and policy rationales of the Chinese model of science, this section outlines the key players and processes involved in the formulation, coordination, and execution of China's national science policy. As a group of Chinese researchers noted in a 2017 journal article, existing Chinese scholarly research tends to focus on analyzing the policymaking and management system from a historical perspective, while very few studies discuss the current model of governance and even fewer lay out the organizational structure of the policymaking system.[121] The following graphic (fig.2) illustrates the central players and processes that shape China's national policy for science understood from piecing together a variety of sources .[122] It is organized into two levels: high-level decision-making organizations and lower level coordinating, implementing, and managing organizations. Section 2 follows this two-part structure. Minor organizational restructurings aside, the reform initiated after the 18th Party Congress (2012) focused on the creation of an "innovative governance mechanism" [创新治理机制] through the establishment of consulting bodies and communication channels, a development which is given considerable analytical attention in this section.[123]

Figure 2

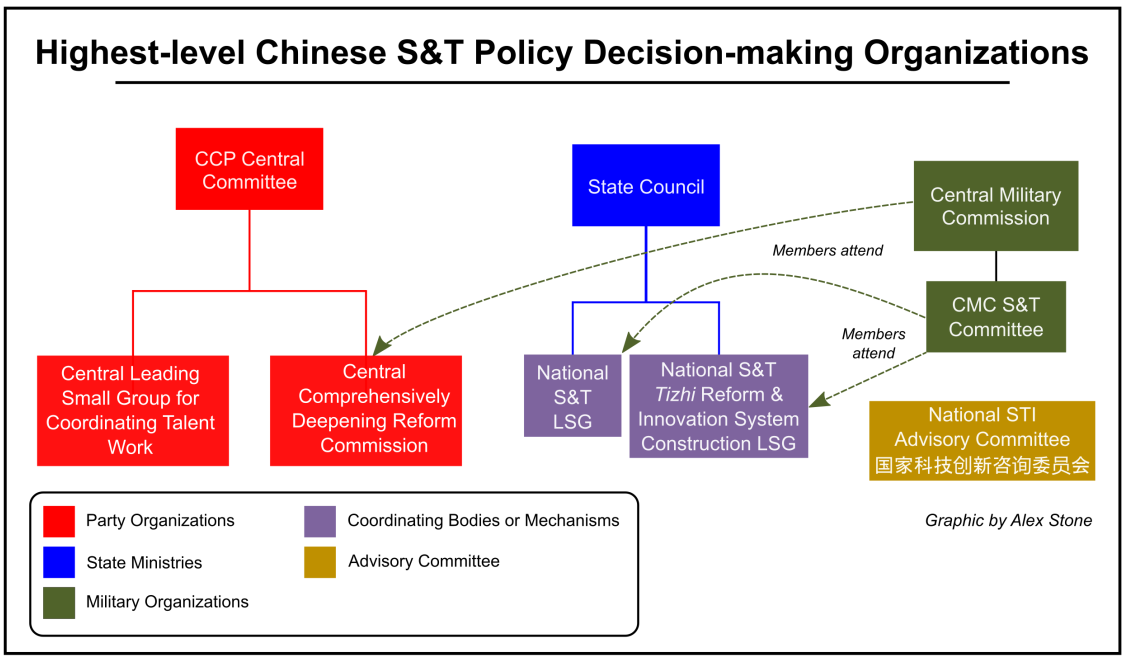


2.1 Players and Processes at the Highest-Level

As noted by the authors of *Beyond Sputnik*, "policy that affects the conduct of science, often results from broader public policy discussions, and from concerns that stretch far beyond the realm of science."[124] They note in the United States, the highest level of policy-making for science can include the president, with support from the President's Council of Advisors on Science and Technology (PCAST), Congress, as well as individuals and agencies involved in making decisions with major morale, social, economic, or political dimensions.[125]

In China, the CCP Central Committee and the State Council (with input from the National People's Congress) along with the Central Military Commission (CMC) represent the highest decision-making authorities who decide on all policy issues with the most significant impact and strategic implications. Coordinating bodies and taskforces created under the CCP Central Committee and the State Council for specific policy areas (often in the form of commissions, committees, or leading small groups [LSGs]), are also considered part of the highest policymaking authorities.

Figure 3



CCP Central Committee

Two taskforces under the CCP Central Committee oversee aspects of STI work:

- **The Central Comprehensively Deepening Reforms Commission** (CCDRC) exercises unified Party control over the design, planning, and coordination of all matters of reform. Major policy initiatives related to science and technology development, such as the 2015 Implementation Plan, are reviewed and approved by the CCDRC (and its predecessor the Central Comprehensively Deepening Reforms Leading Small Group).[126]
- **The Central Leading Small Group for Coordinating Talent Work** (CLSGCTW) [中共中央人才工作协调小组] was created in 2003 under the Organization Department of the CCP Central Committee. This LSG led the implementation of the National Medium- and Long-term Plan for the Development of Talent (2010-2020) and is responsible for the formulation and implementation of China's overseas talent

recruitment plans. The Director of the Central Committee Central Organization Department leads this LSG, with participation from 20 or more central and state ministries.

State Council

Two coordinating bodies [议事机构] under the State Council have significant STI responsibilities:

- **The National Science and Technology Leading Small Group** (hereafter referred to as the S&T LSG) was created in July 2018 under the State Council, replacing the former National S&T and Education LSG [国家科技教育领导小组]. Led by Premier Li Keqiang [李克强] and Vice Premier Liu He [刘鹤], the S&T LSG is the highest decision-making body responsible for developing and approving long-range S&T strategies, plans, important policies, programs, and other critical decisions about S&T development.[127]
- **The National S&T Tizhi Reform and Innovation System Construction LSG** [国家科技体制改革和创新体系建设领导小组] (hereinafter referred to as the S&T Tizhi Reform LSG) under the State Council. As its name suggests, this LSG, created in July 2012 and currently led by Vice Premier Liu He, leads all matters related to S&T Tizhi Reform.

Central Military Commission

The Central Military Commission and its subordinate organizations are connected to at least three of the four coordinating bodies. Xi Jinping, Chairman of the CMC, chairs the CCDRC, whose members include Xu Qiliang [许其亮], vice chairman of the CMC. Liu Guozhi [刘国治], director [主任] of the CMC S&T Committee, sits on both the National S&T LSG and the National S&T Tizhi Reform LSG.[128] Liu Sheng [刘胜], deputy director of the CMC Equipment Development Department (EDD), is a member of the National S&T Tizhi Reform LSG.[129]

Science of Science Policy

A common problem in science policy-making globally is that the top officials often lack the necessary scientific knowledge and technical background to make scientifically rigorous decisions, while scientists generally lack expertise in public policy making to provide the kind of input useful to policymakers. The issue is more severe in China's case due to the heavy involvement of its officials in the design of long-term STI development plans and specific research and development programs (discussed in section 1.3). Even though there have been some arrangements in place to increase the flow of ideas and suggestions to the central leadership,xxx existing mechanisms have been found insufficient in keeping pace with the rapid rate of scientific and technological development and Chinese scholars have called for the establishment of a unified and efficient national scientific and technological decision-making consulting mechanism directly supporting the central decision-making authorities.[130]

Senior leaders themselves have long been aware of this issue. The *PRC Science and Technology Progress Law* [中华人民共和国科学技术进步法] revised in 2007 stated a need to improve the rules and procedures for S&T policy-making, to give scientific and technological experts full representation in the process, to establish standardized consulting and decision-making mechanisms, and to promote scientific and democratic decision-making.[131] In his speech delivered in May 2018 to the academicians of CAS and the Chinese Academy of Engineering (CAE) , Xi Jinping again called for improving the S&T policy decision-making mechanism to accommodate input from high-level think tanks and other professional organizations.[132]

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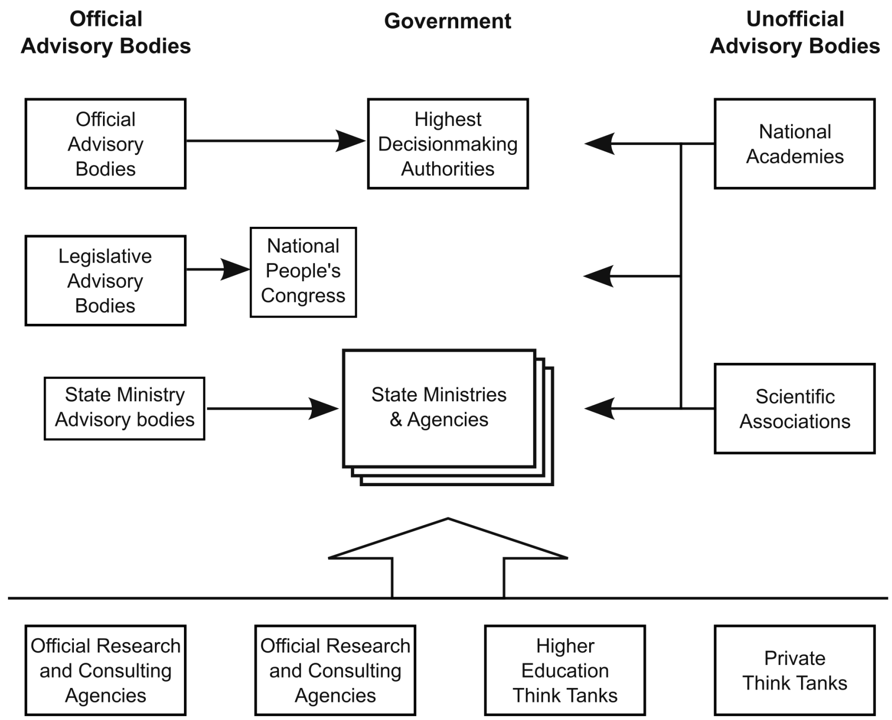
xxx Examples include the advisory role played by important organizations such as the Academic Divisions [学部] of the Chinese Academy of Sciences (CASAD) and the existing mechanism for the formulation and review of medium- to long-term S&T development plan.

While still a work in progress, there have been two discernible lines of effort. The first involves the creation of a new committee positioned as the nation's highest-level decision-making and consulting organization with direct communication lines to the central leadership. The 2015 *Implementation Plan* called for the establishment of an organization called the National STI Advisory Committee (NSTIAC) [国家科技创新咨询委员会], whose role was envisioned as providing regular briefings to the Party Central Committee and the State Council on the latest trends in international scientific and technological innovation,[133] which, on paper, appears to function similarly to the U.S. President's Council of Advisors on Science and Technology. However, discussion related to this committee is largely presented in aspirational terms and there is only limited available information regarding its exact composition or operational status, suggesting it is a work in progress. The CCDRC approved a plan in February 2017 to design a national S&T decision-making consulting system [国家科技决策咨询制度] and mechanism for supporting the S&T decision-making needs of the CCP Central Committee. Some media reports about this plan highlighted the creation of a National S&T Decision-Making Advisory Committee [国家科技决策咨询委员会],[xxxi] which would not only provide timely suggestions on the difficult issues facing STI development, but also help policymakers keep abreast of global S&T advancements and provide insights on key issues affecting economic development and national defense.[134]

NSTIAC's position as the highest STI advisory body in China has made its staffing and functions a major topic of discussion in Chinese STI strategic consulting circles.[135] However, its significance relative to the Chinese Academy of Science, which had been long positioned as the nation's "highest S&T consulting body" is unclear. For example, a researcher with CAS's Institute for S&T Strategic Consulting [中国科学院科技战略咨询研究院] has argued that the creation of the new committee should by no means weaken the roles played by other organizations of similar functions, and proposed a framework for identifying the respective roles of these organizations (see fig.4).[136] Another group of CAS researchers proposed that the NSTIAC be co-chaired by renowned scientists selected by CAS and the CAE, with its office directly attached to the CCP Central Committee to enable routinized communication with the central decision-making authorities.[137] They further proposed that the members of the committee to be made up of Academicians elected by the two academies and directly appointed by the CCP Central Committee and the State Council, whose expertise covers the full range of natural sciences, engineering and technology, humanities and social sciences, interdisciplinary fields, and the industrial sector to directly serve the central decision-making.

xxxi It is not clear whether this is a separate committee, or another working title of the same committee as planned.

Figure 4 Suggested Framework of STI Advisory System



Source: Fan Chunliang, "Science Advice Institution for Policy Making and Think Tank Building," in Science and Society, 2017, 7(3): 79-93.

The second line of effort consists of the development of 50 to 100 of "specialized high-end think tanks" [专业化高端智库].[138] As of December 2020, a total of 29 think tanks are officially on the list of "national high-end think tank pilot program [建设试点]."[139] These think tanks cover a wide range of policy areas and can be divided into four categories based on their affiliations: 1) comprehensive research institutions directly under the Party Central Committee, the State Council, and the CMC; 2) professional think tanks housed in universities and scientific research institutions; 3) professional research institutions of state-owned enterprises; 4) other institutions under the guidance of the State Council or ministries.[140] STI policy as a broad topic is likely to be widely researched in most of these think tanks, along with routinized information collection, translation, and analysis of STI developments overseas, but the ones with a more specific S&T focus include:

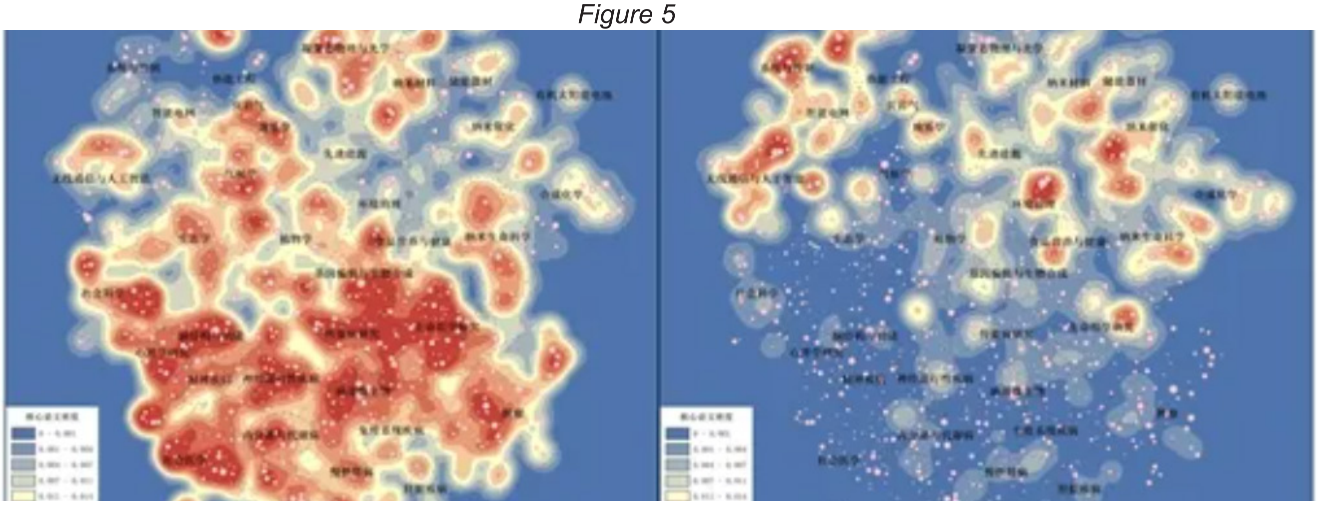
- Chinese Academy of Science and Technology for Development, MOST [中国科学技术发展战略研究院]
- Institute for S&T Strategic Consulting, CAS [中国科学院科技战略咨询研究院] [xxxii]
- Institute for Contemporary China Studies, Tsinghua University [清华大学国情研究院]

Notably, these think tanks are becoming increasingly adept at employing new technologies and big data analysis to inform decision-making. For example, CAS's Institute for S&T Strategic Consulting monitors China's scientific research landscape and released five studies on the subject employing big data analysis in 2009, 2012,

xxxii The English name listed on its website is the rather generic "Institutes of Science and Development," which differs from its original Chinese name and does not reflect its mission mandate. See http://www.casisd.cn/jggk/jgjj/.

2015, 2017, and 2021. The 2021 version, which reportedly used deep machine learning technology to identify research clusters, was released in April 2021.[141] The research team performed big data analysis on the most cited academic papers published between 2012 and 2017 in 10,223 emerging research areas and identified 97 clusters (trendy research areas). Based on information shared by the lead analyst Wang Xiaomei [王小梅] in an interview conducted with China Science Daily, their analysis is capable of identifying, at a national level, the most popular emerging research areas and identifying the extent and volume of Chinese scientific research in all existing research fields.[142] For example, this has allowed them to produce macro-level analyses comparing the U.S. and China, with some surprising results. Notably, that China's scientific research landscape perfectly complements the United States'. China's dominant research fields are mainly located on the upper right side of the scientific research diagram (see figure 5), covering nanotechnology, computers and engineering, and environmental sciences. China accounts for a relatively small share of the research fields in the bottom half of the diagram (medical sciences, social sciences, economy and business, biological sciences), where research from the United States dominates.

Figure 5

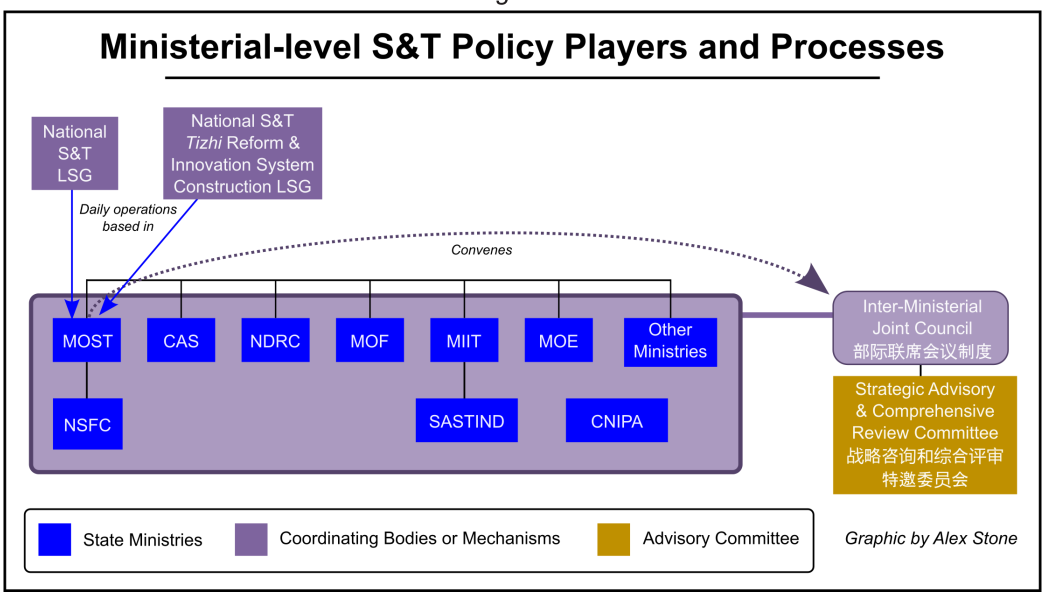


United States *China*

2.2 Players and Processes at the Ministerial Level

Organizations at the ministerial level implement the grand S&T strategies and plans approved by the central decision-making authorities. Unlike the United States, which adopts what Neal et al. describe as a "pluralistic" multiagency approach,[143] the Ministry of Science and Technology (MOST), as its name suggests, plays a /leading role in implementing S&T strategies and policies approved by the highest decision-making authorities and in managing S&T programs and projects funded by the central government. MOST's core mission mandates include formulating guidelines for the implementation of the innovation-driven development strategy, coordinating the allocation of scientific research resources, budgets, and funds, compiling guidelines for national R&D megaprojects, and supervising their execution, among others.[144] The offices for carrying out the day-to-day tasks for both the National S&T LSG and the S&T Tizhi Reform LSG also reside with MOST, with MOST Director Wang Zhigang serving as the office director.[145] MOST further expanded its portfolio to include responsibilities in drafting national basic research plans and crafting policies for recruiting foreign talents following its absorption of the National Natural Science Foundation of China (NSFC), the primary funding vehicle for basic and applied research in China, and the State Administration of Foreign Experts Affairs (SAFEA) in March 2018.[146]

Figure 6

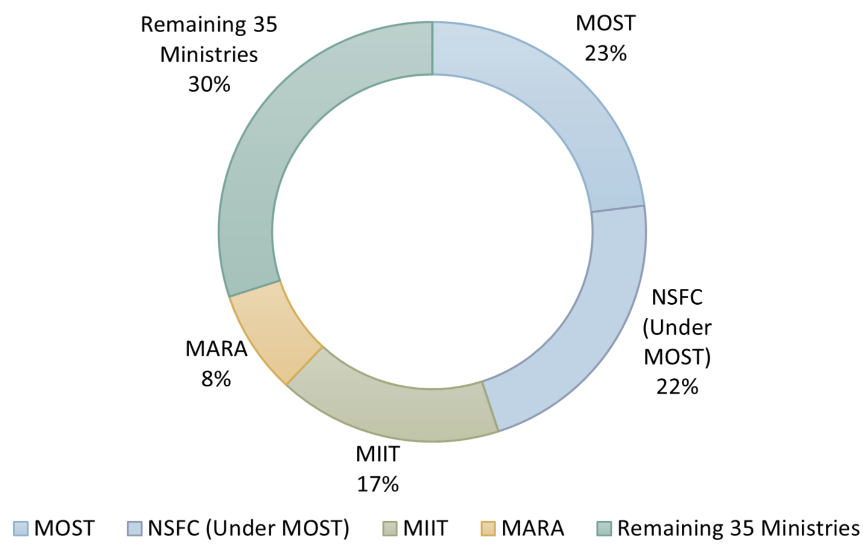


This centralized approach is even more evident when analyzing the central government's role in funding scientific research. According to DLUT's analysis of the finalized expenditure data from 2018, a total of 39 central departments (excluding CAS, which is considered a research performer in statistical analysis) were allocated funds for R&D in 2018. Among them, three departments—MOST, NSFC, and the Ministry of Information and Technology (MIIT)—accounted for over 60% of the total R&D spending, and their R&D expenditures are only increasing.[147] According to the DLUT team:[148]

- MOST manages close to 30 billion RMB in R&D funding. MOST channels most of its R&D funding to national megaprojects [重大专项]. NSFC, a close second, also manages a R&D funding budget of close to 30 billion RMB, which it invested entirely on basic research in 2018. The NSFC's subordination to MOST in 2018 further raises MOST's critical role in guiding and supporting scientific research.
- MIIT ranks third with 20 billion RMB mostly devoted to experimental development, followed by the Ministry of Agriculture and Rural Affairs (MARA) with 10 billion RMB channeled to megaprojects and experimental development.

Figure 7

Distribution of R&D Expenditure Among Central Departments (2018)



Ironically, reforms of MOST, including the subordination of NSFC to it have accomplished the exact opposite of what was recommended by scientists Rao, Lu, and Tsou in their 2005 *Nature* article. Noting the NSFC's efficiency and reputation for fairness in allocating research funds they argued that MOST should be reduced in importance and greater control be shifted to the NSFC. As Richard Suttmeier noted in his 2018 article, the subordination of NSFC to MOST was a controversial decision, as "members of the scientific community now fear that NSFC operations will succumb to the more applications-oriented, bureaucratic procedures of its new home ministry."[149]

The Ministry of Education (MOE) is another important player in supporting scientific research, investing 4 billion RMB into mostly basic research. Although its R&D budget is much lower than that of NSFC, MOE's core function is regulating and supporting the Chinese educational system. It manages and funds a group of the 75 most prestigious universities in China, most of which are China's top research universities. The Ministry guides and supports universities in their participation in national S&T programs and projects. It also promotes the development of the Chinese higher education system through initiatives such as the former "985" and "211" programs and the latest "Double First-Class University Plan."

New mechanism for managing funding vehicles and programs

The Ministry of Science and Technology's role in STI policy coordination was further enhanced in 2015 with the creation of a new coordinating mechanism in the form of an *Inter-Ministerial Joint Council for S&T Program Management* [科技计划管理部际联席会议]. Hailed as a significant breakthrough in China's S&T reform, the joint council, composed of a total of 31 government bodies, is charged with cross-agency coordination of STI development strategies and policies and making budgetary decisions regarding the centrally-funded STI programs. MOST is the primary convener [召集人] of the joint council, supported by the Ministry of Finance (MOF) and the National Development and Reform Commission (NDRC).[150] Important decisions reached by the joint council are usually submitted to the S&T Tizhi Reform LSG and the State Council for review and approval, although "particularly major issues" [特别重大事项] must be reported to the Party Central Committee.[151]

Table 4

Composition of the Inter-Ministerial Joint Council for S&T Program Management[152]			
Conveners [召集单位]			
Ministry of Science and Technology Convener [召集人]		Ministry of Finance Deputy Convener [副召集人]	National Development and Reform Commission Deputy Convener [副召集人]
Members [成员单位]			
MOE	MIIT	Ministry of Land and Resources	Ministry of Ecology and Environment
Ministry of Agriculture and Rural Affairs	Ministry of Transport	General Administration of Quality Supervision, Inspection, and Quarantine	Ministry of Housing and Urban-Rural Development
Ministry of Water Resource	National Health Commission	State Administration of Work Safety	National Radio and Television Administration
Ministry of Culture and Tourism	China National Intellectual Property Administration	Chinese Academy of Sciences	National Medical Products Administration
National Forestry and Grassland Administration	Academy of Engineering	China Earthquake Administration	National Natural Science Foundation of China
China Meteorological Administration	National Food and Strategic Reserve Administration	National Energy Administration	State Administration of Science, Technology, and Industry for National Defense
State Oceanic Administration	State Bureau of Surveying and Mapping	National Administration of Traditional Chinese Medicine	China Association for Science and Technology

In addition to the 31 bodies, the CMC S&T Committee (a critical body directing defense S&T programs) was also reported to have joined the *Inter-Ministerial Joint Council for S&T Program Management*, which was considered an important step in advancing the military-civil fusion strategy during the 13th FYP.[153] According to Zhang Xiaoyuan [张晓原], director-general of MOST's Department of Resource Allocation and Management [资源配置与管理司], while the military and other defense sector organizations had set up coordinating mechanisms, they were ad hoc or functioned as 'one-offs' for a specific project and lacked follow-up or coordination about next steps after the project was completed.

The joint council is further supported by three types of agencies, whose selection and composition are approved by the joint council itself. They include:

1) A Strategic Advisory and Comprehensive Review Committee [战略咨询与综合评审特邀委员会] composed of senior STI experts (see table below), who provide policy advice and support to the joint council.[154] The membership of this committee was publicized at its inception in June 2015, but no further updates appear to have been provided. The members are notably older, with an average age of 74

2) A group of public institutions [事业单位] acting in the capacity of "professional program management organizations" managing S&T programs primarily in the National R&D Plan [国家重点研发计划] category on behalf of the ministries. This change was intended to ensure that government departments no longer directly manage specific S&T projects and enhance the oversight role of experts and professional institutions.

3) A group of third-party organizations competitively selected to carry out performance evaluation of S&T

programs, the results of which would be used as an important basis to determine their funding status.

Table 5

Board of the Strategic Advisory and Comprehensive Review Committee (As of June 2015) [战略咨询与综合评审特邀委员会]*		
Name	**Age**	**Areas of expertise**
Committee Chair		
Xu Kuangdi [徐匡迪] †	83	Metallurgy, steel-making processes
Wang Dazhong‡ [王大中]	86	Nuclear energy, reactor design
Fang Xin [方新]	66	STI policy
Li Andong [李安东]	75	Former Deputy Director of the PLA General Armament Department (GAD) and former Director of the GAD S&T Committee
Li Jinghai [李静海] ‡	65	Mesoscale science, digital modeling, and simulation
Liu Xu [刘旭] †	68	Crop genetics
Qi Rang[齐让]	71	Politician (portfolio: population, resource, environment)
Chen Jia'er [陈佳洱] ‡	87	Nuclear physics, particle accelerators
Chen Yiyu [陈宜瑜] ‡	77	Hydrobiology
Xue Lan [薛澜]	62	Science policy, management, and innovation
* Membership may have changed without being announced. †:Academician of the Chinese Academy of Engineering (CAE) ‡:Academician of the Chinese Academy of Sciences (CAS)		

A core function of the joint council is to coordinate budgetary decisions regarding the centrally-funded STI programs. As noted in Section 1.3, restructuring initiated in 2014 has integrated the close to 100 centrally-funded S&T programs and funding vehicles[xxxiii] into five broad categories for streamlined management via an open and unified national S&T management platform operated by MOST.[155] The integration was achieved through abolishing, merging, and converting existing programs to significantly reduce the number of S&T programs in operation. The new funding categories and recent developments in each category are presented in the table below.

xxxiii These are programs that rely on competitive tendering of research proposals. This category does not include designated funds for central-level scientific research institutions and universities. See "Notice from the State Council on the Plan for Deepening the Reform of the Management of Centrally-Financed S&T Projects (Programs, Funds)."

Table 6

Centrally-financed STI Funding Vehicles and programs[156]	
New Pillars of Funding	**Details and Recent Developments**
National Natural Science Fund [国家自然科学基金]	The primary funding vehicle for basic research in natural sciences in China, operated by NSFC under the administration of MOST. NSFC operates 14 different funding programs.[157]In 2018, NSFC initiated a two-stage comprehensive reform plan to reorganize funding categories, improve evaluation mechanisms, and foster inter-disciplinary research to achieve "excellence in science" by 2027.[158]
National S&T Megaprojects [国家科技重大专项]	Characterized by enormous government investment and the national mobilization of R&D resources, these megaprojects focus on product models, industries, and technologies (civilian and military) that reflect the country's strategic intentions. Historically, scientific projects at this scale included programs such as the atomic bomb, ballistic missiles, satellites, manned space flights, and hybrid rice. This category currently includes the 16 national megaprojects outlined in the 2006 MLP and adds on top of that a new group of 16 megaprojects—termed "S&T Innovation 2030 Megaprojects" [科技创新2030重大项目] to be implemented between 2016 and 2030 (see Appendix 2 for detail).[159]
National Key R&D Programs [国家重点研发计划]	Under this category, various existing R&D programs administered by MOST, NDRC, MIIT, and other central government agencies were merged and integrated into one national plan. These included MOST's National High Technology R&D Plan (863), National Basic Research Program (973), among others. Programs in this category cover a wide variety of sectors and technological areas. While some address major scientific issues, the majority of the programs are application-oriented. According to MOST, a combination of "top-down" and "bottom-up" processes is adopted to identify funding areas in the National Key R&D Programs category for the 14th FYP period.[160] In early 2020, MOST, along with other relevant ministries, collected 16,000 major R&D needs [重大研发需求] from 67 central and local government units and more than 2,400 scientific research units. The information collected was then analyzed through consultation with the Strategic Advisory and Comprehensive Review Committee, senior expert panels, other government organizations, the scientific community, industry experts, etc., to arrive at the National Key R&D Programs 14th FYP, which was reviewed and approved by the Inter-Ministerial Joint Council. A combination of "top-down" and "bottom-up" processes are adopted to identify funding areas. An inter-ministerial joint council led by MOST makes the final funding decisions in consulting with the scientific community and industry experts.
Technology and Innovation Guidance Fund(S) [技术创新引导专项（基金）]	This category streamlined previous national funds operated by MOST, MOF, and NDRC into three major funds to guide and support technology transfer, commercialization, and growth of start-ups and SMEs.
Scientific Bases and Talent Programs [基地和人才专项]	This category aims to optimize the layout of China's scientific bases by streamlining the management of key national R&D facilities previously ran by MOST and NDRC. It is also designed to support the education, training, and research activities of S&E personnel and teams.

Section 3. The Research Base

Having examined the players and processes involved in science policymaking and funding of science, this section shifts the focus to the performers of scientific research in China. Over the past two decades, China's central government has invested heavily in the national scientific enterprise and infrastructure; planned, funded, and executed numerous R&D programs; and reorganized and reformed the policy formulation and implementation bureaucratic structure, processes, and mechanisms for the advancement of science and technology. During this same time period, China's science and engineering research base has made significant improvements in its performance in some major STI indicators, particularly in terms of its scientific research output. Beginning in the mid-2010s, China's strong performance in common indicators of scientific progress such as total R&D spending and journal and patent output led to a palpable shift in the perceptions and descriptions of Chinese scientific and technological achievements in the United States. For example, after the National Science Foundation (U.S.) revealed in a report that in 2016, China overtook the U.S. in terms of the total number of published scientific papers, various media reporting argued that China is poised to "outperform America in science"[161] or has the potential to "increasingly challenge American dominance of science."[162]

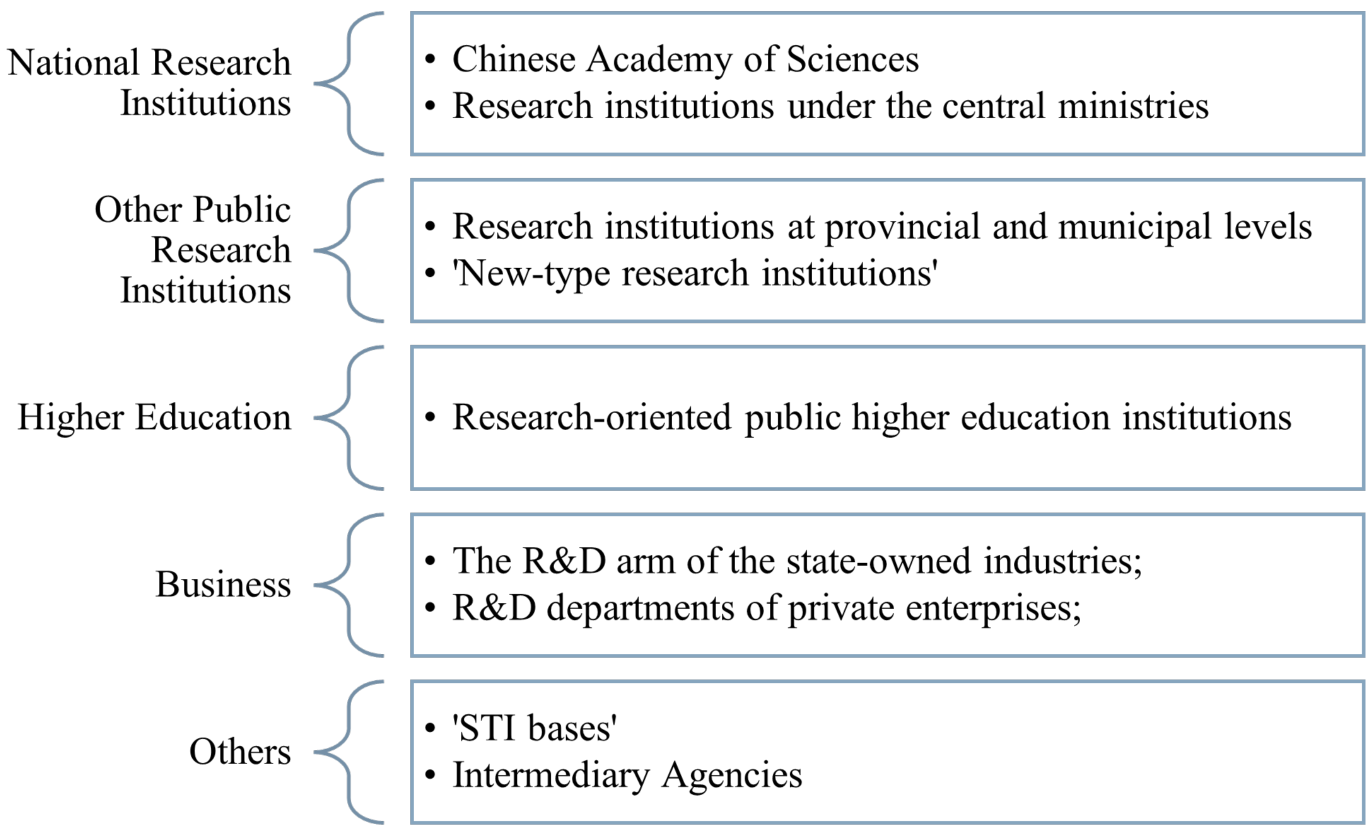
Official and public discourse in China surrounding these topics, however, takes a calmer tone. While acknowledging China's tremendous progress, they have questioned whether China's growth in scientific research output has translated into original, transformative discoveries or improved technological readiness. Xi Jinping's speech on China's STI development first delivered in 2018 was reposted in full in the CCP's leading official theoretical journal *Qiushi* in March 2021, right after the conclusion of the Two Sessions, for emphasis. According to Xi's assessment of the state of science and technology in China, it lacks vision, influence, innovation capability, sound institutional arrangement and mechanisms for resource allocation and STI governance, well-designed incentive policies to motivate China's large research base.[163] Further, despite the strong growth in R&D expenditure, China paid too little attention to basic research and has yet to make original, transformative scientific and technological breakthroughs.[164] Xi remarked that much work remains to be done to foster an institutional environment conducive to innovation.[165]

This section contextualizes this misaligned perception on Chinese science. It begins with an examination of the basic composition of China's science and engineering enterprise, followed by an analysis of its trends in R&D activities, with comparisons from the United States. Finally, it presents arguments about the quantity and quality of Chinese science output, focusing on three key science policy issues facing Chinese policymakers and STI stakeholders today. It calls attention to the limitations of traditional quantitative indicators as measures of scientific progress in China.

3.1 R&D Ecosystem at a Glance

The basic structure of China's science and engineering research base was shaped during the 1950s and 1960s. At the time, Scientific researchers were composed of five groups to include: the Chinese Academy of Sciences, higher education institutions, research institutions under various central ministries, research institutions under local governments, and defense R&D institutions.[166] Often referred to as the "five-route army (of R&D)" [五路大军], these institutions were entirely funded and operated by the government, entrusted to conduct research and development on programs with strategic implications. The business sector, particularly the private business sector, was absent for decades until Deng Xiaoping launched the economic reform program in 1978 to build a socialist market economy. While the R&D ecosystem evolved gradually over the next three decades to accommodate the rise of the business sector, both as an important source of R&D funding and as a performer, most of the government-owned, government-operated institutions remain as key performers of research and development. Figure 8 lists some of the key players in China's R&D ecosystem (trends in their R&D activities are examined in Section 3.2).

Figure 8: Key Players in China's R&D Ecosystem[xxxiv]



xxxiv The so-called 'new-type research institutions' [新型科研机构] are new organizations that cropped up in the last 10 years. A key characteristic of these new-type institutions is their management structure and diversified funding methods. They are considered leaner, capable, responsive, cutting-edge, and overall more efficiently managed than their wholly state-managed counterparts. Examples include the Research Institute of Tsinghua University in Shenzhen [深圳清华研究院], Shenzhen Innovation and Development Institute [深圳创新发展研究院], Shenzhen Institute of Advanced Technology [SIAT] [中科院深圳先进技术研究院], and Kuang-Chi Research Institute [光启研究院]. For more details, see Alex Stone and Peter Wood, "China's Military Civil Fusion Strategy," CASI, June 2020, https://www.airuniversity.af.edu/Portals/10/CASI/documents/Research/Other-Topics/CASI_China_Military_Civil_Fusion_Strategy.pdf, 83.

The "National Innovation Systems"

While the five-route army delineation still largely applies to China's R&D ecosystem, beginning in the early 2000s, the STI policy community began to research and adopt a new concept— "National Innovation Systems" (NIS) [国家创新体系]—(likely) heeding OECD's recommendations for employing systemic approaches in STI policymaking.[167] Reflecting changing realities, the *2006 MLP* put forward the goal of constructing and developing the "National Innovation Systems," defined as a social system led by the government that gives full play to the role of the market in allocating resources, and one in which all types of STI actors are closely linked and interacts effectively.[168] The *MLP* further proposed measures to develop five sub-systems where different elements of the NIS come into focus:[169]

- A *technology innovation system* with the business sector taking the lead, while at the same time fostering synergies between the business sector, academia, and research institutions;
- A *knowledge innovation system* led by research institutions and higher education;
- A military-civil integrated national defense science, technology, and innovation system;
- A *regional innovation system*, where (each region) has its own characteristics and advantages;
- A networked science and technology intermediary service system.

Additional policy guidance for the construction of the NIS was introduced in 2012 (which also saw the creation of the National S&T Tizhi Reform and Innovation System Construction LSG under the State Council) and 2016.[170] Policies were generally designed to: 1) strengthen the business sector's role as the pioneer of innovation; 2) promote cooperation and integration between and amongst the business sector, public research institutions, and higher education; 3) promote cooperation and integration between the defense and civilian innovation system; 4) build up regional innovation hubs centered on the respective areas of local STI actors.[171] In addition to the traditional performers of R&D, beginning in the mid-2010s, the so-called national STI bases [国家科技创新基地] have also been included as a key component of the NIS. Under the umbrella term national STI bases, a variety of existing national-level laboratories and other science and engineering centers were reorganized and reclassified into three categories listed below.[172]

Table 7

National STI Bases[173]

Types of National STI Bases	Core Components	Mandate
Science and Engineering [科学与工程研究]	National Laboratories [国家实验室] State Key Laboratories [国家重点实验室]	Carry out strategic, cutting-edge, and forward-looking research and development activities centered on strategic, national objectives.
Technology Innovation and Commercialization [技术创新与成果转化]	National Engineering Research Centers [国家工程研究中心] National Technology Innovation Centers [国家技术创新中心] National Clinical Research Centers [国家临床医学研究中心]	Carry out research and development on cross-sector and engineering technologies to support economic and social development.
Foundational Support [基础支撑与条件保障]	National Science and Technology Resource-Sharing Service Platforms [国家科技资源共享服务平台] National Field Scientific Observation and Research Stations [国家野外科学观测研究站]	Discover the laws of nature, catalogue field research data, and provide resource-sharing services that benefit the public.

While policymakers intended for development of the NIS to be "basically completed" by 2020,[174] the development of NIS appears to remain a work in progress. In a 2018 journal article, Chen Jin [陈劲], director of Tsinghua University's Research Center for Technological Innovation [清华大学技术创新研究中心], argues that the development of the NIS and its subsystems suffers from serious shortfalls when compared against China's overarching goals for STI development.[175] According to Chen, the "technology innovation system" and the "regional innovation" system have yet to achieve the kind of outcome intended by the *MLP*, citing issues such as a lack of actionable roadmaps for development, the underdeveloped role of state-owned companies, and homogenized buildup of regional innovation centers.[176] Chen also pointed to a lack of a clear division of responsibilities (basic research, applied research, experimental development, engineering, commercialization of technologies, etc.) amongst the various actors within the NIS.[177] The basic research ecosystem, in particular, is one of the weakest links. Further, he argues that policy supporting education and its coordination with STI development have been seriously neglected in the design of the NIS. Chen judged the lack of top-notch innovative talents resulting from this neglect has been hurting Chinese innovation.

Scholars in influential positions have also proposed new frameworks for the development of the NIS. For example, Mu Rongping [穆荣平], director of CAS's Center for Innovation and Development [中国科学院创新发展研究中心], argued in a July 2018 *People's Daily* article for the adjustment and optimization of the NIS, proposing the development of new sub-systems including the national security innovation system, national research, and experimental development system, national industry innovation system to substitute or complement existing sub-systems.[178] With the 14th FYP calling for the continuous improvement of the NIS to enhance its effectiveness,[179] further adjustment in its design and reorganization can be expected during the 14th FYP period.

The "National Strategic S&T Enterprise"

Perhaps to prioritize and refocus efforts in the development of NIS, beginning in the mid-2010s, the phrase "national strategic S&T enterprise" [国家战略科技力量] began to take center stage. Even though Xi Jinping had been referencing this term even since taking the helm, its popularity soared in late 2020. Unlike the NIS, which is an all-encompassing concept covering all STI actors, the 'national strategic S&T enterprise' represents the cream of the crop in the NIS.[180] According to Xi, the national strategic S&T enterprise is primarily composed of national laboratories [国家实验室],[xxxv] national research institutions, leading [高水平] research universities, leading [领军] STI firms.[181] He added that these organizations should shoulder the mission of advancing China's self-reliance in science and technology on their own initiatives without prodding [自觉履行].[182] At the annual Central Economic Work Conference [中央经济工作会议] held in December 2020, China's top economic policy-makers put the "strengthening of the national strategic S&T enterprise" at the very top of their economic policy agenda for 2021. In his speech to prominent scientists and engineers delivered in May 2021, Xi stated that "the (outcome) of global S&T competition rests on the national strategic S&T enterprise."[183] The 14th FYP released in March 2021 also suggests that policy measures in the near future will focus on developing and improving this segment of the NIS.[184] Even though Xi only used vague qualifiers such as "high level" and "leading," an educated guess can be made as to the makeup of this fairly selective group of institutions (see table 8).

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xxxv China is in the middle of a complete revamping of its laboratory system. It currently has four National Laboratories, including the Beijing Electron Positron Collider, National laboratory for Marine Science and Technology (Qingdao), National Synchrotron Radiation Laboratory (Hefei), and Lanzhou Heavy Ion Accelerator National Laboratory (housed at the Heavy Ion Research Facility in Lanzhou). Some of the ones that were previously filed under this designation have been downgraded to either national R&D centers or state key laboratories. The 14th FYP indicated plans to build more national laboratories in the areas of quantum information, photonics and micro- nanoelectronics, network communications, artificial intelligence, biomedicine, and modern energy systems.

Table 8

The National Strategic S&T Enterprise[185]		
Core Component	**Likely Candidates**	**Highlights of Xi's Mission Mandate**
National Laboratories	China is in the middle of a complete revamping of its laboratory system. It currently has four National Laboratories[xxxvi] but has plans to build more in the areas of quantum information, photonics and micro-nanoelectronics, network communications, artificial intelligence, biomedicine, modern energy systems during the 14th FYP Period (2021-2025).[186]	National laboratories [国家实验室] should closely follow global S&T development trends, and yield more strategic, critical, and major scientific and technological achievements. National laboratories should (work) in concert with the state key laboratories [国家重点实验室], and form a highly effectively national laboratory system with Chinese characteristics.
National Scientific research institutions	• Chinese Academy of Sciences • Research institutions under state ministries	National research institutions should be guided by national strategic needs, focus their efforts on solving major scientific and technological problems that have hindered China's national development, speed up the construction of cradles of original innovation and accelerate breakthroughs in critical technologies.
Leading research universities	• MOE-managed universities • MIIT-managed universities • CMC-managed universities • Double First-Class universities	Leading research universities should become the driving force of basic research and S&T breakthroughs. They should align themselves with national strategic goals and strategic tasks, and strive to imbue academic disciplines, research, and discourse with Chinese characteristics.
Leading STI firms		Leading STI firms should form cross-sector innovation bases where they can collaborate closely, carry out research and development in cross-sector technologies, improve China's baseline industrial capability and industrial chain modernization level.

xxxvi The four official national laboratories include: Beijing Electron Positron Collider, National laboratory for Marine Science and Technology (Qingdao), National Synchrotron Radiation Laboratory (Hefei), and Lanzhou Heavy Ion Accelerator National Laboratory (housed at the Heavy Ion Research Facility in Lanzhou).

3.2 Trends in Research and Development Activities

Having outlined the key players in China's NIS, this section highlights trends in research and development activities performed by three main users of R&D funding: public research institutions, higher education, and business.[xxxvii]

Public Research Institutions

A Significant Share of the Chinese Government's R&D Funding is Channeled to Public Research Institutions.

According to data released in the China Science and Technology Statistical Yearbook series, the number of research institutions in China has remained above 3,000 in recent years, among which around 700 are centrally-funded.[187] Even though centrally-funded research institutions only account for roughly 20 percent of the total, they employ over 70 percent of the R&D personnel in China and play instrumental roles in China's scientific advancement.[188][xxxviii] Among the 700 centrally-funded research institutions, the Chinese Academy of Sciences (CAS) is the largest national research institution for the natural sciences. As The world's largest research organization,[189] CAS is a public institution under the State Council. CAS operates 11 research academies, over 100 research institutes, three universities, 130 labs and engineering centers, 270 field observation stations, and is leading the construction and development of over 30 large national S&T facilities. CAS employs a workforce of 71,000 people and has more than 77,000 graduate students studying in its universities and institutions.[190] Public research institutions [公共研究机构] like CAS rely on government investment for sustaining daily operations and for a large share of their R&D spending. In 2019, government investment supported 85% of R&D performed in public research institutions.

National research institutions such as CAS and the Chinese Academy of Engineering have always been considered the central government's strongest ally in research and development. Chinese leaders have traditionally relied heavily on government-funded and operated institutions, whose political identity [政治成分] it can trust, to conduct research and development on programs with strategic implications. CAS alone, for example, led 87.7% of the R&D programs during the *Twelve-Year Plan*.[191] In a speech delivered during his visit to the Chinese Academy of Sciences in July 2013, Xi Jinping described CAS "a (branch of the) national strategic S&T enterprise that the Party, the nation, and the people can rely on and trust."[192] The "trust" Xi emphasized is not just in CAS's research capabilities, but also in its "red genes" [红色基因], a phrase commonly used to describe a legacy of ideological purity and loyalty to the CCP. According to Xi Jinping, research and development activities in national research institutions will continue to be guided by national strategic needs, with a focus on solving major scientific and technological problems that have hindered China's national development.

For these reasons, the Chinese government channels a significant share of total R&D funding to public research institutions (57%) compared with other sectors. Higher education, for example, receives 24%, and business only 16%.[193] Due to the principal role in scientific research played by public research institutions, the efficiency and effectiveness of these organizations are crucial to advances in Chinese science. However, public research institutions suffer from the problem of low efficiency due to the fact that they operate in a similar manner to government agencies or state entities, which are known to suffer from problems of low efficiency

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xxxvii The OECD also delineates private non-profits as a 4th main performer of R&D; however, this category does not apply to China.

xxxviii It is unclear whether the various defense research institutions, many of which *operate* as public institutions, are included as public research institutions in statistical reporting. Additionally, many defense research institutions under the state-owned defense conglomerates previously classified as public institutions are undergoing ownership reforms (launched in July 2017) to be corporatized.

due to guaranteed funding and the lack of competition. According to Xue Lan [薛澜], a science policy expert and member of the Strategic Advisory and Comprehensive Review Committee, there is significant room for improvement in this area, particularly with regard to the stalled public institution reform [事业单位改革] which has been negatively impacting the development of knowledge-intensive fields.[194]

Higher Education

R&D performance in higher education is concentrated in a selective group of universities funded and managed by central and state ministries.

China has a total of around 3,000 institutes of higher education [高等学校]. Among them, close to 2,000 universities report R&D activities.[195] Chinese higher education primarily relies on the government and, to a lesser extent, the business sector for R&D funding. The share of government-funded R&D performance in higher education increased from 58% in 2008 to 67% in 2018, while the share funded by business declined from 35% to 27% in the same period.[196][xxxix] The lack of diversified funding schemes and the decline in funding from the business sector means that the Chinese government must maintain or boost its current level of investment to ensure China's future scientific advances.

A large share of the R&D investment from the government and the private sector supports a small and highly selective group of leading public research universities funded and managed by the central and state ministries.[xl] According to data from 2018, among the 1,994 universities that reported R&D activities, 52% of total R&D expenditures were channeled to MOE universities,[xli] which themselves account for less than four percent of the total. In all, just 5.81 percent of 1,994 universities received 71% of total funds for R&D.[197] That means 94.19% of universities had to share 29% of the government R&D funding. The government's sizable investment allocated to public research institutions thus comes at the expense of higher education.[xlii] Due to their status as public universities, these universities are also unable to make up for funding shortfalls through higher tuition costs. These data suggest that high quality research is overwhelmingly likely to come from this selected group of universities. As the authors of *Beyond Sputnik* pointed out, the level of science conducted is largely determined by the amount of funding made available to researchers in universities, national laboratories, government agencies, and industries.[198] According to recent analysis by CAS's Science and Technology Strategic Consulting Institute, 81.4% of the highly cited papers produced by Chinese researchers were supported by some form of government funding.[199]

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xxxix R&D funding from the government (central, local, as well as the defense arm) through competitive tendering of research proposals is often referred to as "vertical funding" [纵向经费], while those from the private sector is referred to as "horizontal funding" [横向经费].

xl In contrast with the United States, where private universities outperform public universities.

xli The Ministry of Education manages and funds a group of 75 most prestigious universities in China, most of which are China's top research universities.

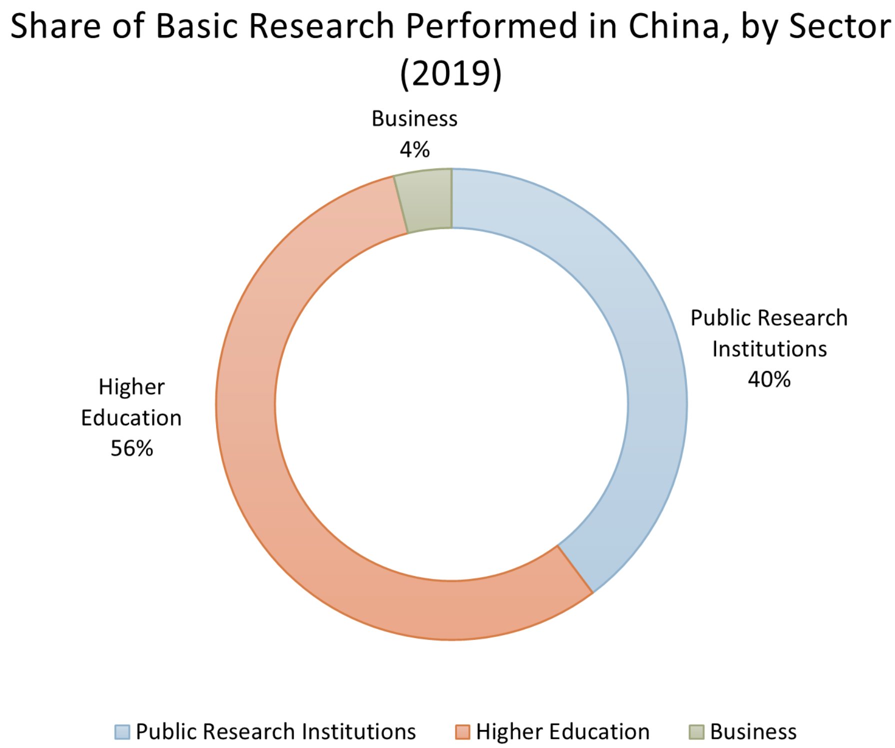
xlii By contrast, higher education made up 51 percent of federally funded R&D performance in the United States. See National Science Board, "The State of U.S. Science and Engineering 2020," National Science Foundation, 15 January 2020, https://ncses.nsf.gov/pubs/nsb20201/preface

Business

Majority of scientific research performed by public research institutions and higher education; business R&D dominated by experimental development.

Analysis of trends in China's R&D spending between 1995 and 2019 by the DLUT team shows that the majority of scientific research activities (basic and applied research) are consistently performed by two types of organizations: public research institutions and higher education. According to *S&T Daily*, higher education, public research institutions, and the business sector spent 72.22 billion RMB, 51.03 billion RMB, and 5.08 billion RMB, respectively, on basic research, meaning that public research institutions and higher education together accounted for 96% of basic research performed in 2019 (see figure below).[200] These trends suggest that the funders and performers of basic and applied research in China have largely remained the same for decades. That is to say, the central and local governments continue to fund most of the scientific research, and government-funded and government-operated institutions are still the nation's largest performer of scientific research.

Figure 9



The business sector, consisting of around 130,000 industrial companies of scale that report R&D activities,[201] is now the leading source of R&D funding (76%) in China. Total business R&D spending jumped 55 times from 30 billion RMB in 1995 to nearly 1.7 trillion RMB in 2019. However, 96 percent of the business sector's R&D funding is intramural, directly supporting R&D performance by businesses.[202] Furthermore, while contributing to the vast majority of China's enormous growth in total R&D expenditures over the years, the proportion of basic and applied research conducted by the business sector has in fact declined. In 2019, only 0.3 percent of the business sector's R&D performance is for basic research, and applied research only accounted for 3.31%.[203] In other words, the business sector in China only devoted 3.61% to scientific research (basic and applied research) in 2019. By contrast, 21% of the R&D performed by the business sector in the United States in 2018 is for scientific research.[204] While China's total R&D expenditure has skyrocketed over the past 20 years, the business sector, a significant contributor to this growth, has been overwhelmingly focused on experimental development at the expense of scientific research. As Huawei Technologies founder and CEO Ren Zhengfei noted in a 2019 interview, scientific research is an essential driver to Huawei's development, and China's tech giants such as Huawei and Baidu have the means and resources to operate and sustain their own research academies which employ hundreds of mathematicians, physicists, chemists, and engineers devoted to scientific research.[205] However, he pointed out that the large base of small and medium-sized enterprises often lack both in-house scientific research capabilities as well as communication and cooperation channels with universities.

Figure 10

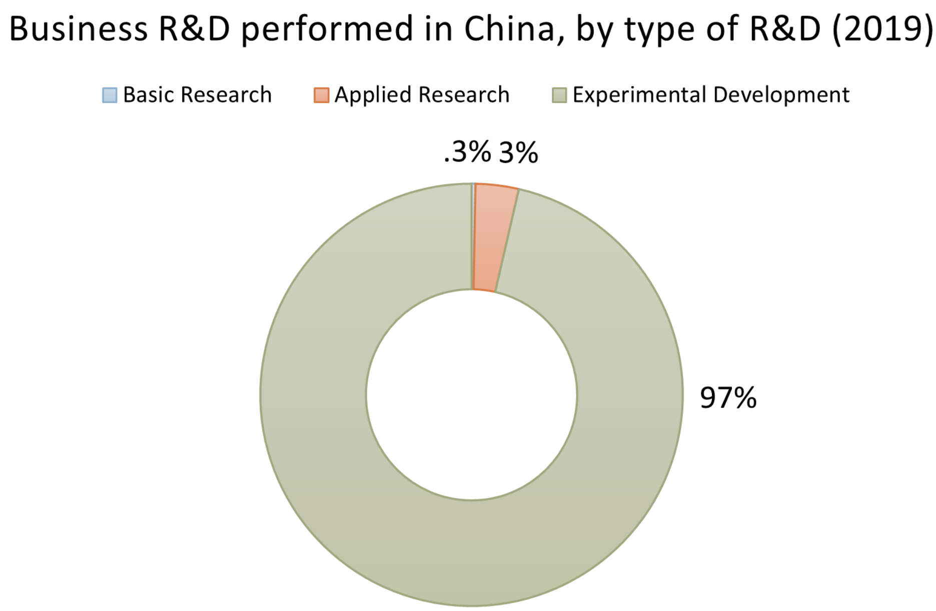
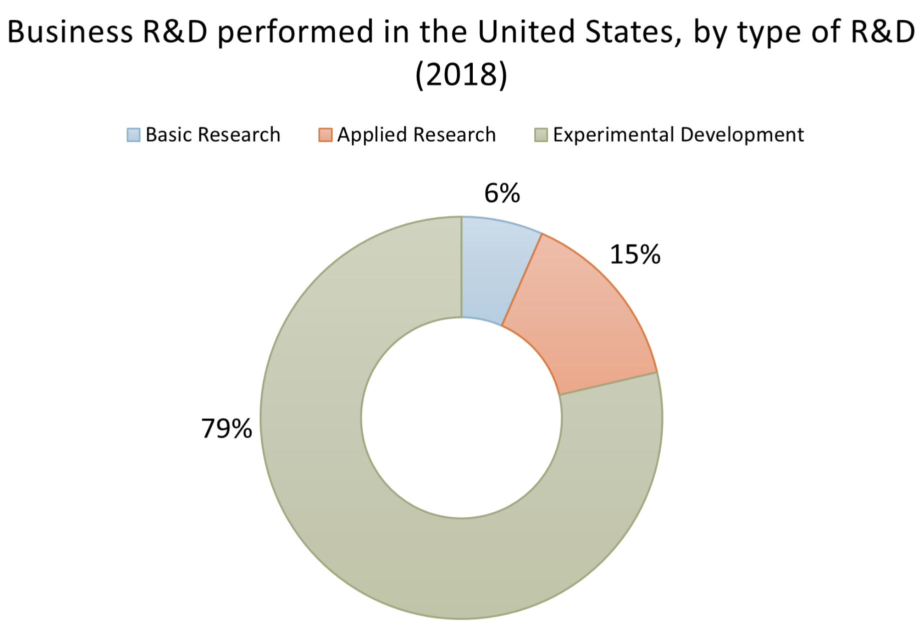


Figure 11



3.3 Assessing output

During the past decade, China's science and engineering research base made significant improvements in its performance in some of the major STI indicators. The *2006 MLP* set the goal of China becoming one of the top five countries globally in terms of the "number of patents granted (to citizens/nationals) [本国人发明专利年度授权量]" and "(total) citation count of scientific publications (by citizens/nationals) [本国人国际科学论文被引用数]" by 2020. Chinese researchers completed both goals ahead of schedule in 2015 and 2017, respectively. In terms of patent numbers, the latest data shows that China ranks number one in the world, with 452,804 and 399,878 patents granted in 2019 by patent office and origin, respectively, in 2019.[xliii] In terms of publication citations, publications in international journals by Chinese researchers between January 2007 and October 2017 were cited 193.35 million times, surpassing the U.K. and Germany to take second place in the world.[206] Furthermore, according to the U.S. NSF:[207]

- "China's science and engineering (S&E) publication output has risen nearly tenfold since 2000, and as a result, China's output in terms of absolute quantity now exceeds that of the United States."
- "China increased its production of peer-reviewed S&E articles by eight percent annually between 2006 to 2016, compared to only 1% in the U.S. In 2016, China surpassed the U.S. in publications of S&E research papers. In 2018, China accounted for 21% of the worldwide refereed S&E publications, below the EU (24%) but ahead of the U.S. (17%)."
- "Between 2000 and 2016, China's index of highly cited articles more than doubled, from 0.4 to 1.1 (compared through the representation of its articles among the world's top 1% of cited articles, normalized to account for the size of each country's pool of S&E publications)."

These common indicators appear to suggest that China's rapid growth in R&D spending over the past two decades have yielded significant improvements in both the quantity and quality of Chinese research output, which in turn has led to the perception of China's rise as a formidable competitor in global scientific leadership. However, there have been heated debate on the limitations and drawbacks of these traditional indicators as measures of scientific progress among Chinese leaders and stakeholders in the STI community. In March 2018, Shi Yigong [施一公], a CAS academician, structural biologist, and dean of the School of Life Sciences at Tsinghua University, revealed his concerns about the prospects of the Chinese scientific research community in an interview with the Liberation Daily's Shanghai Observer [上观新闻].[208] As one of the first groups of scientists who returned to China as part of the Thousand Talents Plan recruitment effort, Shi gave up a position with Princeton University and renounced his U.S. citizenship in 2011—a move that added to his already considerable clout and influence.[209] According to Shi, rather than making him proud, China's success in exceeding the United States in terms of scientific paper counts instead left him more concerned about the state of their competition, going so far as to say that China had produced too many "garbage papers" [垃圾文章] and was simply publishing for publishing's sake. Clearly troubled by the growing popularity of quantitative research assessment metrics, Shi hinted that they could be easily manipulated: "… These core STI indicators - the number of papers, the number of citations, the impact factors of journals[xliv] - can be artificially raised. I think everyone knows what I mean," adding

xliii The United States ranked second, with 354,430 and 309,644 patent grants by office and origin, respectively. See Alex He, "What Do China's High Patent Numbers Really Mean?" Centre for International Governance Innovation, 20 April 2021. https://www.cigionline.org/articles/what-do-chinas-high-patent-numbers-really-mean/

xliv Impact Factor (IF) is "a measure of the frequency with which the "average article" in a journal has been cited in a particular year or period." See "The Clarivate Analytics Impact Factor," accessed May 2021, https://clarivate.com/webofsciencegroup/essays/impact-factor/.

that "A country like China could easily raise the values of these indicators." He cautioned the S&T community to not conflate publication counts with scientific research capability and called for the improvement of China's research assessment system.[xlv]

Shi has been joined by other voices such as Lu Bai [鲁白], a world-renowned Chinese neuroscientist and an outspoken figure on China's national science policy issues,[xlvi] who shared similar insights in a March 2021 article.[210] Lu noted the limitations of indicators such as R&D intensity, workforce size, and S&E publication output in measuring a nation's STI capabilities. Lu argued that, as far as scientific research is concerned, to be a global scientific powerhouse requires a country to meet three key criteria: make transformative scientific discoveries that change the world; gather a large number of top scientific minds; and exhibit a cultural environment conducive to stimulating extraordinary scientific discoveries. Lu judged the current state of China's indicators as far from meeting these criteria and urged the promotion of measures that could actually advance original, transformative discoveries. Wang Yangzong [王扬宗], professor of the University of Chinese Academy of Sciences, offered another perspective on how to evaluate China's lack of transformative scientific discoveries. According to Wang, a good indicator for measuring breakthroughs in original innovation is through an examination of the award list of the biennial Chinese National Natural Science Award—the First Prizes, in particular. Tellingly, no First Prizes were awarded in 2004, 2005, 2007, 2008, 2010, 2011, and 2012. Wang further noted that although they have been awarded every year since 2013, there have only been a very small number of recipients, and of those some have been mired in controversy.[211]

Perhaps more troubling is the low rate of conversion of scientific breakthroughs to practical applications. In 2019, Wang Yiming [王一鸣], deputy director of the Development Research Center of the State Council revealed that China's "transfer and conversion rate" of technology born out of research and development funded by the government [财政资金支持的技术成果转移转化率] is less than 10%, far lower than average of 40% to 50% in developed nations.[212] Wang did not explain how these numbers are calculated, and some Chinese scholars have pointed to a lack of agreed-upon definition and method for statistical analysis for this indicator. However, other researchers have drawn similar conclusions based on their own calculations, which employ more precise definitions and methods of statistical analysis. An analysis performed by Renmin University researcher Shen Jian [沈健] suggests China's technology commercialization rate (non-business) is even lower than the official number (see table 9).[213] Additionally, according to a recent report from a Canadian think tank, in the eyes of a Chinese patent expert, "only 10 percent of China's patents have market value and that probably 90 percent of them are 'trash.'"[214]

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xlv It is worth noting that there is a global focus on determining better research assessment methods as seen by the San Francisco Declaration on Research Assessment (DORA), which presented problems with using metrics such as the impact factors and stated that there is "a pressing need to improve the ways in which the output of scientific research is evaluated by funding agencies, academic institutions, and other parties." See https://sfdora.org/

xlvi Dr. Bai Lu is currently a tenured Professor in the School of Pharmaceutical Sciences at Tsinghua University. http://www.sps.tsinghua.edu.cn/en/team/team/2016/1230/97.html.

Table 9

Comparison of Chinese and U.S. Success in Converting S&T Research Results[215]		
Indicators	**China**	**United States**
"Patent commercialization rate [专利转化率]" (Used as a proxy for technology conversion rate)	6%	50%
"Patent commercialization efficiency [科技成果转化效率]" (Defined as the ratio of the number of patents used (i.e., adopted and applied by enterprises) to the total number of patents	6%	100%

The low conversion rates of technologies and patents are particularly disconcerting for Chinese science policymakers. First of all, this calls into question how much government investment in scientific research has translated into practical gains. The low conversion rates indicate a remarkably low rate of return on investment for the Chinese central and local governments, which together spent 1.1 trillion RMB supporting broad STI development in 2019 and 454 billion RMB on research and development. Secondly, these numbers suggest a critical failure in policies designed to enhance the synergy between science and innovation systems, which was a priority of the *2006 MLP*. The lack of progress in this area suggests that much work remains to be done before this innovation system can serve as the "primary means for China to enhance the nation's indigenous innovation capability" as envisioned by the *2006 MLP*.

Lü Jian [吕建], a CAS academician and the dean of Nanjing University, summarized China's dilemma in its STI development succinctly in an interview from 2020. According to Lü, the central issues that policymakers should address can be analyzed along three dimensions:

- **A pair of contradictions [一对矛盾]:** In terms of common indicators, China's S&E publication numbers, citation counts, and number of patent applications filed are all among the highest in the world; however, (in Lü's own assessment) it ranks somewhere near the twentieth place in terms of its innovation capability.
- **Two weaknesses** [两个软肋]: 1) lack of self-sufficiency in critical technologies; 2) lack of Nobel Prize winners.
- **Two deviations** [两个偏差]: value (treating academic titles and the number of publications as the objective of scientific inquiry) and behavior (restlessness and an eagerness for instant success and quick profits).

Comments such as these suggest that while China has seen significant growth both in terms of input into the research base (i.e., R&D spending) and output from the research base (i.e., S&T publications), the output has yet to translate into the *gains* desired by the policy makers and the scientific community at large. At its core, the *2006 MLP* reflected the Chinese leadership's view that China's STI endeavor was a battle that needed to be fought simultaneously on three fronts: 1) self-reliance in generic, cross-sector technologies urgently needed in most industrial sectors, 2) self-reliance in core technologies critical to economic and national security, and 3) original and transformative scientific breakthroughs and cutting-edge technologies that can bring strategic advantages to China in the long run. Given the frequency with which terms such as "lack of original innovation," "chokepoint technologies [卡脖子技术]", and "technology self-sufficiency [科技自立自强]" dominate recent discussions and official STI policies, the overarching goal of achieving self-sufficiency and original innovation capability appears yet out of reach.

In the central leadership's calculus, China's continued struggle in bringing out original discoveries and innovation and the nation's lack of breakthroughs in critical technologies are two glaring weaknesses that cast a long shadow over China's prospects of achieving self-sufficiency and its goal of joining the front rank of innovative nations by 2035 and becoming a true *S&T Great Power* by 2050. As noted by Xi Jinping in his May 2021 speech referenced earlier in this report, the low efficiency [效能] of the STI system and the low return [效益] derived from the output of the STI system are long-standing issues that require intensive effort to overcome.

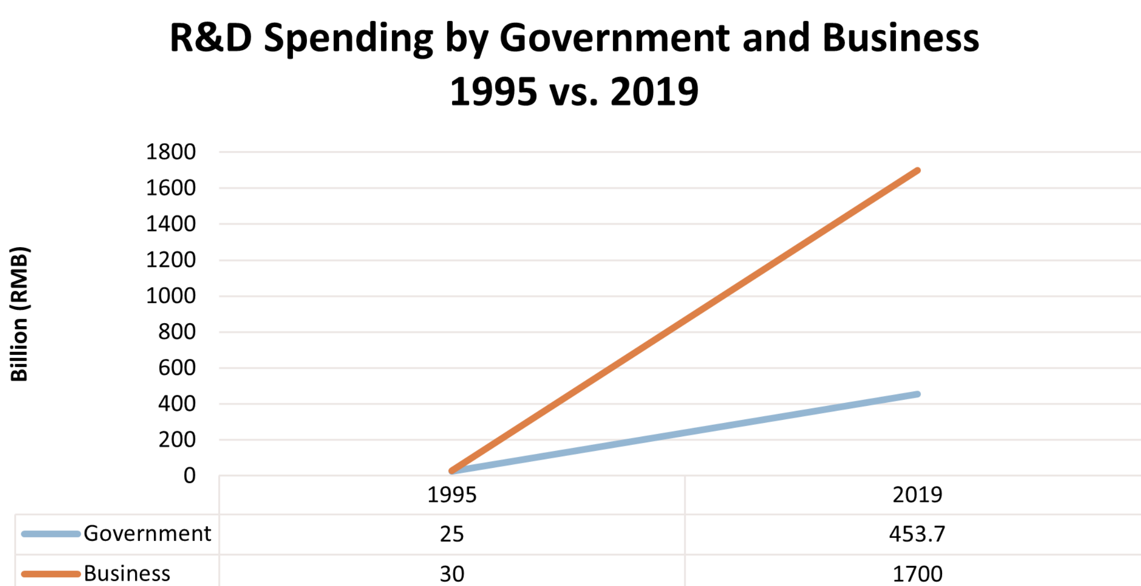
What Went Wrong?

A multitude of factors could have resulted in this conundrum; however, many in the science policy circle and the larger scientific community have taken aim at two particular possible culprits. The first issue concerns China's proportionally low spending on scientific research for the past two decades. The second issue centers on the incentive structure where simple quantitative metrics play outsized roles in the assessment of individual researchers and institutions, which has led to unintended consequences with serious implications for China's STI development.

Proportionally Low Spending on Scientific Research

As described in Section 3.2, China's business sector is almost entirely focused on experimental development, making scientific research disproportionally dependent on government investment in China. According to analysis from 2020, the Chinese government consistently funds most basic research (90%). Scientific research has not tracked with the sizable growth of the business sector, which has far outpaced growth in R&D spending by the government (see Figure 12).

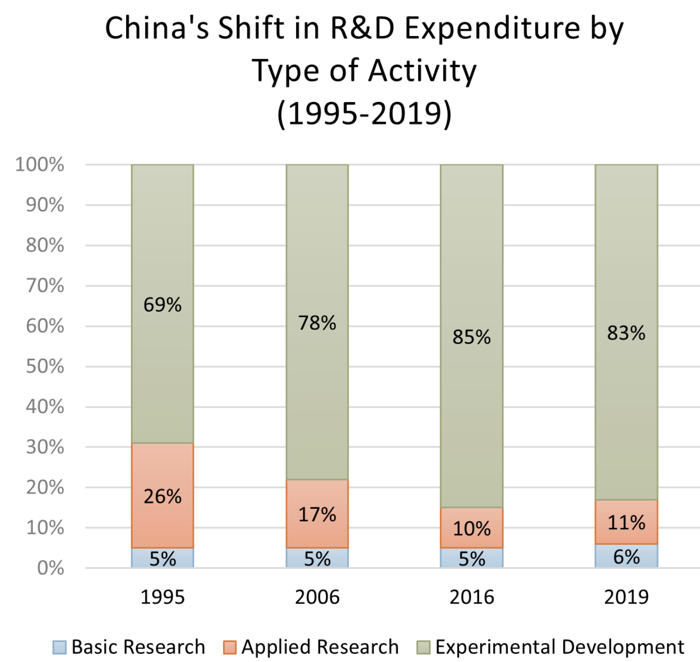
Figure 12



In an article from 2014, DLUT Professor Sun Yutao [孙玉涛], an expert on China's STI funding and budgeting policies, and Professor Cao Cong [曹聪], an expert on Chinese STI policies with the University of Nottingham in Ningbo, noted the rapid decline in the share of basic and applied research spending as a percentage of total R&D expenditure between 1995 and 2014. They argue that the smaller proportion of spending on scientific research (hovering around 16%), compared with an average of 35% in many developed nations, could jeopardize China's ambition to become an innovative country.

Sun and Cao were particularly concerned about the decline of applied research as a proportion of the total R&D performed. According to them, although China's government R&D expenditure continued to support primarily applied research, society-wide trends in R&D spending had shifted from applied research to downstream experimental development. They argue that this may be attributed to the fact that China's innovation policy overemphasizes development and high-tech industries at the expense of scientific research. Applied research, they note, serves as a critical link in the R&D process, the decline of which would adversely impact China's ambition to become an innovative country. Since the publication of their article in 2014 the trends they identified have continued. As shown in fig.13, between 1995 and 2018, the majority of R&D expenditures were channeled toward experimental development, with China's basic research funding consistently accounting for merely 5% of the total R&D funding, and only tipped up to 6% in 2019. Applied research funding meanwhile fell from 26% to 11%. The 2017 *OECD Economic Survey of China* drew similar conclusions, noting that China's uneven distribution of R&D investment at the expense of investment in basic and applied science contributed to it lagging behind other nations in original innovation.

Figure 13



Comparing data from 2018 (the latest year for which data from both countries are available), scientific research (basic and applied science) accounted for 36% of the total U.S. R&D expenditure in 2018, whereas the latest number in China from 2019 was at 17% (see fig.14 and fig.15).[xlvii] In nominal terms, total estimated U.S. basic and applied research expenditures in 2018 were $211.5 billion. Total Chinese basic and applied research expenditures in 2018 were 328.13 billion RMB (roughly $51 billion), meaning that the United States outspent

xlvii U.S. data: "Total estimated U.S. R&D expenditures in 2018 (the most recent year for which data are available) were $580.0 billion. Of this amount, $96.5 billion (16.6%) was for basic research, $115.0 billion (19.8%) was for applied research, and $368.5 billion (63.5%) was for development." See, "U.S. Research and Development Funding and Performance: Fact Sheet," Congressional Research Service, 24 January 2020. https://fas.org/sgp/crs/misc/R44307.pdf; Chinese data: "In terms of activity types, national basic research funding is 109.04 billion yuan; applied research funding is 219.09 billion yuan." "Statistical Communiqué on National Science and Technology Expenditures in 2018" [2018年全国科技经费投入统计公报], National Bureau of Statistics, 30 August 2019. http://www.stats.gov.cn/tjsj/zxfb/201908/t20190830_1694746.html

China on basic and applied science by roughly four to one in 2018.[216] According to OECD data, basic research expenditure accounted for 0.49 percent of total U.S. GDP ($21.43 trillion) in 2018, whereas Chinese basic research expenditure accounted for 0.12 percent of China's GDP ($13.89 trillion) from the same year.[217]

Figure 14

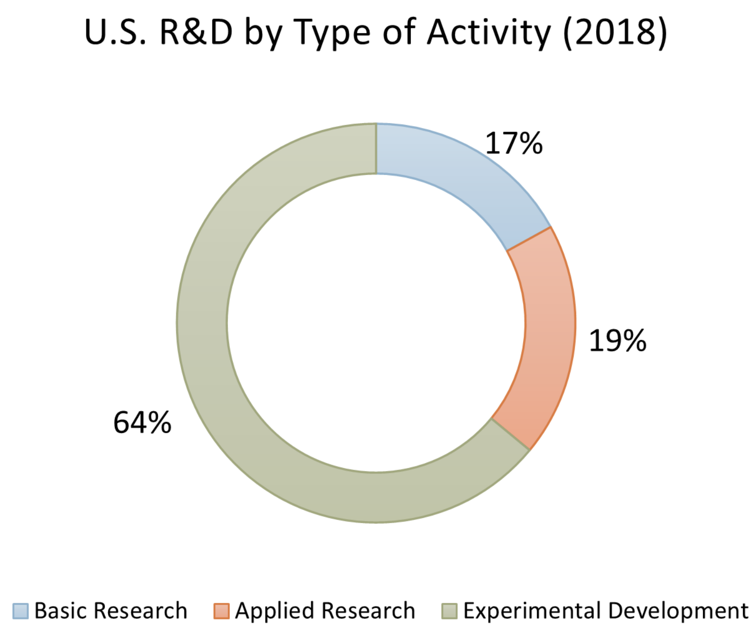
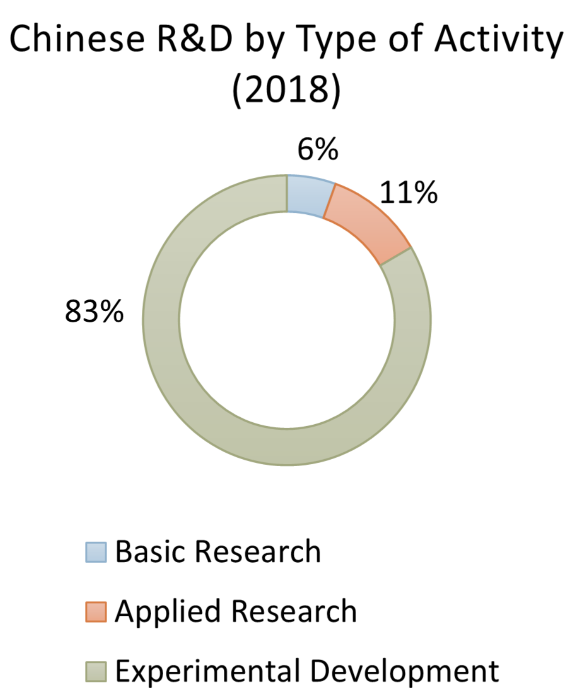


Figure 15



The problem of proportionally low investment in scientific research caught the attention of senior leaders in 2018, which led to a series of policy measures issued by the State Council and MOST aimed at strengthening basic research for "'0' to '1' innovation."[xlviii][218] These policy measures likely contributed to the 1 percent increase in share of basic research (from 5% to 6%) and applied research (from 10% to 11%) funding in 2019. The 14th FYP has pledged to boost the share of basic research spending to 8% by 2025.[219] During his visit to the NSFC on 19 July 2021, Premier Li Keqiang's [李克强] comments gave this policy issue an even greater sense of urgency. As Li put it, "we have arrived at a critical moment where we must rally loudly [大声疾呼] for the strengthening of basic research."[220] Commenting on the need to strengthen support for math and other disciplines of the natural sciences, Li remarked that many of China's chokepoint technology problems are ultimately a reflection of its inadequacy in basic scientific research.[221]

Based on recently released policy documents, the State Council is hoping to enhance basic research through the introduction of a more diversified funding mechanism with active participation from sources outside of the central government. In addition to pledging significant increases in centrally-financed support for basic research, the State Council also called for "guiding and encouraging investment in basic research by local governments, enterprises, and other private sources."[222] MOST has formulated a *Basic Research Ten-Year Action Plan (2021-2030)* [基础研究十年行动方案(2021—2030)] to systematically guide and support the development of emerging, weak, or unpopular disciplines, as well as to promote cross-fertilization of disciplines and interdisciplinary research.[223] Notably, the decline in applied research continues to be overlooked as a policy priority.

xlviii The term "'0' to '1'" is used to refer to original, transformative breakthroughs, although it appears to have come from American entrepreneur and investor Peter Thiel, who coauthored the 2014 book *Zero to One: Notes on Startups, or How to Build the Future* with Blake Masters.

'SCI Supremacy'

While the decision to reinforce basic research is a development welcomed by the scientific community, which has long called for such a move,[xlix] this measure alone might not be sufficient in improving China's original innovation capability and delivering the kind of policy outcomes desired by the central leadership. The Chinese scientific community has identified a number of serious problems as resulting from the failing incentive structure, which the Chinese science policymakers must effectively address to achieve desired outcomes.

To evaluate the research output of scientists for completion of a degree, faculty recruitment, advancement, award of grants, etc., China, like many other countries, has been relying on quantitative research assessment metrics since the mid-1980s.[l] Quantitative assessment metrics,[li] due to their simplicity and objectivity, are widely adopted internationally in government funding agencies, research institutions, and higher education to aid their decision-making for promotions and grant authorizations. However, they are often adopted in combination with several other qualitative measures such as the peer-review process. For example, noting that most of the funding agencies in the United States use some form of competitive peer-review process for awarding research funds, the authors of *Beyond Sputnik* wrote:[224]

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xlix More than 80 percent of the principal investigators surveyed by NPG for their White Paper said that China should devote more funding to basic research. See Nature Publishing Group, "Turning Point: Chinese Science in Transition," I.

l In 1986, Professor Gong Changde [龚昌德], the head of the Department of Physics at Nanjing University, introduced the Science Citation Index (SCI) to China while serving as the leader of a promotional board review team. That year, less than a decade after the seminal 1978 National Science Conference, China had already made major breakthroughs in many technological fields, and researchers often reported their work as "nationally leading" and "internationally advanced." Gong believed that these statements were not objective and that the number of publications in domestic first-class academic journals was not a good indicator for world-class research. After testing various metrics Gong settled on SCI, a citation index edited and published at that time by the American Institute of Scientific Information, as the primary indicator to consider for promotion. By the late 1980s, major scientific research projects such as the "863 Program" were underway, but administrators struggled with the difficult problem of finding qualified research units to take on these projects. A simple and clear evaluation system that directly reflected the strength of scientific research units was needed. At that time, the efforts at Nanjing University were in full swing, and the results proved to be remarkable. The Beijing Metrology Academy subsequently borrowed the practice from Nanjing University and included the number of papers published on the SCI and the number of papers cited as important indicators in its evaluation system. Many universities and research institutes across the China then followed suit. See "Gong Changde (who) Introduced SCI (to China) and Pushed Chinese Scientific Research to the World" [龚昌德：引入SCI 推中国科研走向世界], accessed August 2019. https://www.newscctv.net/tap2cdn/video/activities/videoG/vinfo/V201809010013.html; "Academician Gong Changde: Scientific Romantic" [龚昌德院士：科学的浪漫主义者], "China Scientists Annual Conference" [中国科学家年会], accessed July 2021. http://www.cnice.org/h-nd-5961.html.

li Commonly adopted quantitative methods for measuring research output and impact takes the form of citation metrics (or bibliometrics), working under the assumption that citations provide an objective indicator of the impact of research on subsequent work. Citation impact can be measured based on article-level, author-level, or journal-level bibliometrics. Examples include the journal impact factors (IF) for academic publications and the H-Index that measures the quality and quantity of individual researchers. In order to evaluate the research impact of an institution or a country, the common approach is to aggregate the same indicator by institution or country.

"Each agency has its own criteria it asks panel reviewers to use in scoring proposals. For example, some of the criteria both NSF and NIH use include significance (does the study address an important problem? how will scientific knowledge be advanced?); approach (are the design and methods well developed? are problem areas addressed?); innovation (are there novel concepts or approaches? are the aims original and innovative?); investigator (is the investigator appropriately trained?); and environment (does the scientific environment contribute to the probability of success? are there unique features of the scientific environment?)."

However in China's case, quantitative metrics such as the number papers published in Science Citation Index (SCI) indexed journals, impact factor of the journals, etc., have become the most-highly weighted factors—and in many cases the only factors—for evaluating the academic performance of researchers and professors. According to *Turning Point*, when asked to list the "main factors tend[ed] to be used for researcher assessment" in their affiliated institutions, 88% of the PIs surveyed by the NPG listed "impact factor of journals in which papers are published" and 78% noted "number of SCI papers."[225] By contrast, only 14% of the PIs mentioned "teaching quality" as an important factor used in the evaluation of their institutions.[226]

The phenomenon in which the Chinese scientific research community pays undue emphasis to SCI papers is known as the 'SCI Supremacy' [SCI至上] problem (also referred to as 'Publication-Only (Evaluation)' [唯论文] or 'SCI Strange Circle' [SCI怪圈]). As Tian Hui [田辉], professor with China's National Institute of Education Sciences [中国教育科学研究院], pointed out in an article comparing assessment processes and practices across different countries, the number of academic publications in reputable journals is an important reference indicator for the evaluation of university faculty staff in all countries, but the phenomenon of "publication-only evaluation" is less common worldwide.[lii][227]

'Publication-only evaluation' has given rise to many problems plaguing the research base. First and foremost, a reliance on quantitative indicators such as citation metrics as the only criteria for evaluation risks conflating research quality with research impact. As a group of researchers from the Nordic Institute for Studies in Innovation, Research and Education argued, "research quality is a multidimensional concept, where plausibility/soundness, originality, scientific value, and societal value commonly are perceived as key characteristics."[228] According to them, citations reflect aspects of scientific impact and relevance with important limitations, and, more importantly, there is no evidence that citations reflect other key dimensions of research quality.[229]

Secondly, the incentive structure under 'SCI Supremacy' is not necessarily conducive to innovation. In a 2018 survey of scientists and engineers across China's S&T workforce conducted by the China Association for Science and Technology in support of the evaluation of the *2006 MLP*, an astounding 93.7% who have published academic papers agree that their primary motivation for publishing is to meet requirements for promotion.[230] These indicators are also highly weighted in the screening process for the numerous "talent titles [人才称号],"[liii] status symbols also known as "hats [帽子]" that indicate a researcher's academic influence and which have a direct impact on the resources available to a researcher, their compensation as well as for their parent department and institution.[231] Bao Yungang [包云岗], executive director of Research Center for Advanced Computer Systems,

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lii Although there is evidence to suggest that similar problems are more prevalent in other nations than Chinese analysts perceive them to be. For example, the San Francisco Declaration on Research Assessment (DORA) called attention to problems with using metrics such as the impact factor and stated "a pressing need to improve the ways in which the output of scientific research is evaluated by funding agencies, academic institutions, and other parties." See: https://sfdora.org/.

liii "Talent titles" are obtained through various talent recruitment programs [人才计划] run by central and local governments, or by being awarded certain well-known research grants.

Institute of Computing Technology, Chinese Academy of Sciences, commented on the obsession with quantitative metrics and status symbols in an interview from December 2020.[232] According to Bao, many scholars take on the mindset that a scientist's career trajectory follows one route only: publish papers, get "hats," publish more papers, get more "hats," so on and so forth.

Table 10

Most Coveted "Hats"	
Titles	**Agency**
Academician [院士]	CAS, CAE
National Science Fund for Distinguished Young Scholar [国家杰出青年科学基金/杰青]	NSFC
Cheung Kong/Changjiang/Yangtze River Scholar Program [长江学者奖励计划/长江]	MOE and Li Ka Shing Foundation
Thousand Talent Program [千人计划/千人]	CLGCTW

There have also been reports on Chinese higher education and research institutions handing out cash bonuses for individual research papers ranging from a few thousand RMB to several hundred thousand depending on the impact factor of the journals. For example, Chongqing University policy stipulated that an individual paper published in journals *Science*, *Nature*, or *Cell* will be awarded 600,000 RMB.[233] This widely-adopted practice in China prompted *Nature* to publish an article in July 2017 with the strongly worded title *Don't Pay Prizes for Published Science*, which argued against the practice of handing out prizes for a single publication that is not yet proven and warned that the practice is "probably not good" for research in the long run.[234]

An even more serious problem is widespread research misconduct and fraud. In 2017, longstanding practices of academic dishonesty, misconduct, and fraud exploded into public view due to high-profile cases such as the retraction of 107 research papers in *Tumor Biology*, a Springer Nature cancer journal. According to *Nature* reporting, "The articles were retracted because their reviews had been fabricated, and many papers had been produced by paper mills."[235] In the wake of this scandal, the Ministry of Science and Technology has pledged to exercise "zero tolerance" against academic misconduct; however, whether these measures to curb academic wrongdoing will be effective remains to be seen. As noted by the same *Nature* article, numerous measures had been introduced since as early as 2006 to address the issue, but many have not been strongly enforced.[236] In a speech delivered in April 2019 at Zhejiang University, CAS academician and Tsinghua University physicist Zhu Bangfen [朱邦芬] pointed out that China faces an "unprecedented" academic integrity crisis both in terms of the prevalence of the practice and the severity of the transgressions.[237] Zhu acknowledges that academic misconduct is a worldwide issue, but he argues that Chinese officials and the legal system's track record of mishandling these cases make the problem more serious in China's case. Zhu offered numerous examples of practices involving academic dishonesty, including:[238]

- The common occurrences of plagiarism in coursework in higher education, even in top research universities such as Tsinghua
- Letters of recommendation are one of the most valued evaluation methods in the academic world globally; however, many letters of recommendation and evaluations in China are drafted by the applicants themselves
- Many claims about significant scientific research breakthroughs in Chinese media are exaggerated or simply untrue

- The selection and evaluation process for many of the most coveted academic titles (such as those listed in Table 10) suffer from ethical violations (i.e., calling in favors or using personal connections)
- Outsourcing writing papers to third parties (commercial companies) or ghostwriters

Yang Wei [杨卫], CAS academician, former director of the NSFC, and former dean of Zhejiang University, provided an even more comprehensive list detailing 14 different forms of academic misconduct and fraud practiced by Chinese researchers:[239]

1. Plagiarism
2. Fabrication
3. Falsification: altering data and making false claims
4. Ghostwriting: papers written by third parties
5. Repeated publication: publishing the same research in multiple journals or replicating a journal article published in one language in another
6. Improper attribution: attribution without contribution, contribution without attribution
7. Conflicts of interest: Positively portraying technology or advancements in which the author has an undisclosed financial stake or which was sponsored by involved entities
8. Lobbying: attempts to influence reviewers through personal connections
9. Academic dictatorship: using academic clout to exert control over a certain academic field and suppress potential opponents
10. Improper citation
11. "Ghost citation:" increasing citations through fake authors or ghost journals
12. "Ghost reviewers:" fabricating reviewers or journals
13. Irreproducibility
14. Ethical misconduct: violation of internationally observed ethical constraints

According to Yang, China has in fact made some progress in addressing these problems. He noted that in 2010, China accounted for 4,117 of 5,040 articles retracted worldwide, but the number has been falling since then, although its retraction rate is still 1.5 to 1.6 times higher than the world average.[240] Yang has said in recent years his concern has also shifted to moral and ethical issues in science (such as human gene-editing) that he perceives as more complicated and difficult to address in China's case due to insufficient interest, research, and policy attention into this area.[241]

"The Place You Do Not Want to Be"

A side effect less examined—an evil more banal by appearance than blatant fraudulent behavior—is the aggregation of efforts in "hot-topic" areas where researchers believe offer much better prospects of getting published. According to neuroscientist Lu Bai, China's failing incentive structure gave rise to a strong sense of opportunism in the Chinese academia, where some researchers are particularly skilled at sniffing out opportunities for promotion. Instead of focusing on their own areas of research, these scientists expend their energy chasing after hot topics, branding themselves as a stem cell expert one day and a neuroscience expert the next.[242] Trendy topics and research areas with a low barrier of entry in particular tend to attract an aggregation of researchers who produce a large number of papers that cite each other frequently. Responses on academic and job forums point to the disciplines of Biomedical Engineering, Chemical Engineering, Environmental Science and Engineering, Materials Science and Engineering [生化材环] as areas particularly impacted by this practice.

Wen Zhenhai, a CAS chemist, told *Nature* reporter Sarah O'Meara that "Junior researchers must survive the intense competition for funding, so we have to pursue hot topics of research, even though that means our work might not be innovative and [might] overlap with others'."[243] This statement is corroborated by numerous responses regarding the state of the field given by Chinese scientists on various internet forums.[244] For example, in the field of materials science,[liv] there is a tacit understanding that the following fields are to be pursued if one wants to get published: nanomaterials, two-dimensional materials such as graphene, and energy storage materials such as perovskite, among others. These research areas are so popular as to attract many researchers outside the field of chemistry, chemical engineering, and materials science to pivot their research focus. However, many of these clusters die out because those ideas are neither original nor plausible. At the same time, research on advanced traditional materials and core strategic materials, as outlined in *Made in China 2025* plan, has failed to receive enough research and development efforts from Chinese scientists because researchers knew that it is much harder to publish in those "more traditional" areas.

Posts on forums suggest that some members of the research community have successfully cracked the publication "code" and developed a readily applicable routine: 1) identify a trending topic area published in *Science* or *Nature*; 2) read the original text and citations; 3) tweak the chemical composition and characterization properties; 4) purchase equipment, or sometimes, equipment and lab experiments are not necessary as there are pieces of software that could conveniently change parameters and conduct simulations; 5) publish "while [the topic] is still hot."[245] This practice is known as "water dumping [灌水]," [246] which literally means pouring water into a container, an internet term that was originally used to describe the behavior of posting inundating a BBS forum with a large amount of useless or meaningless information. Researchers now use this term to describe the act of publishing for publishing's sake, an act that dilutes the quality of the publications.

Some may argue that the utilitarian nature of the approach does not negate the possibility of quality research and strokes of genius rising out of those papers. A hallmark of the 'water dumping' practice, however, is the complete lack of consideration of use. To take a given material from basic science research to the production line requires at least five stages: (1) lab research and experimentation; (2) experimental factory trial; (3) production line trial (also referred to as "middle testing"); (4) factory trial; and (5) factory production. Every stage is indispensable, and it is not easy to achieve the transition from laboratory to pilot test to industrial production. Several responses noted that their research in academia or research institutions never bothered to consider the myriad of factors involved in stages 3-5, such as cost efficiency and processing techniques. Researchers joked that they spent more time tweaking images in research papers to make them more visually appealing than considering how a type of material might benefit a certain industry. This mentality can have particularly harmful effects. As one researcher wrote on an online forum:[247]

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liv A MOST report in 2017 noted that China (excluding Taiwan and Hong Kong) became the world's biggest producer of scientific papers in the field of materials science as far back as 2005. The same source also indicates that the number of material science papers in the Science Citation Index (SCI) reached 114,734 between 2011 and 2015, 2.17 times that of the United States, and 5.18 times that of Japan. [科技部关于印发《'十三五'材料领域科技创新专项规划》的通知], 14 April 2017, http://www.most.gov.cn/mostinfo/xinxifenlei/fgzc/gfxwj/gfxwj2017/201704/t20170426_132496.htm.

"The state of the field in China's materials research circle is partly influenced by the United States, where there are many influential researchers that are ethnically Chinese that have a particularly strong voice and influence in the fields of nanomaterials, etc. Many in the Chinese materials R&D workforce are also cultivated in this circle. Therefore, the evaluation system for publishing and reviews, and even the academic circle at large has formed an ecosystem that is inextricably linked to each other. Besides publishing an insane number of articles, how much contribution has this system made to the development of advanced materials in China's industrial sector?

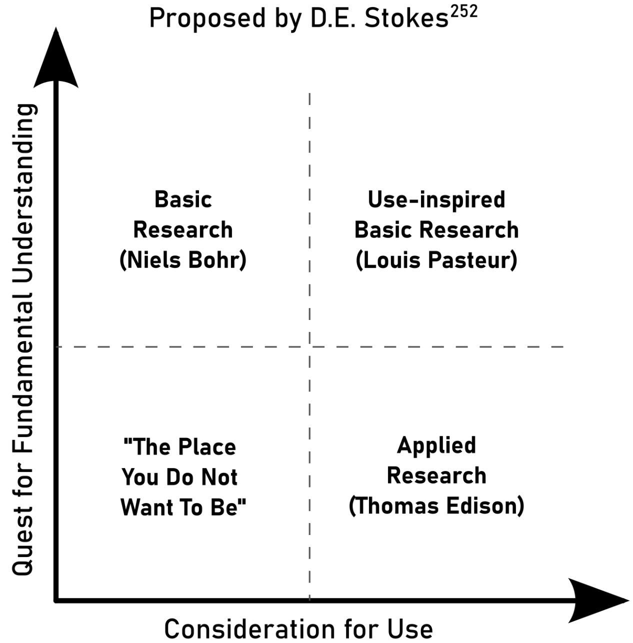
One contribution this circle did make, though, is to Japanese companies that produce transmission electron microscopes (TEM) by purchasing piles of TEMs that run in the millions. By the way, why is China heavily dependent on imports for high-performance electron microscopes and other precision instruments? One of the most important reasons is that the indigenously developed materials just won't cut it, so precision cannot be achieved."

Encouraging this kind of behavior in academia has real-world implications for when scientists and engineers leave academia for the broader workforce. A common theme among anecdotes shared by master's and Ph.D. graduates in chemical engineering and materials science engineering who spent the majority of their time in school writing research papers about materials currently in vogue, such as graphene, is that they found themselves ill-prepared for the jobs at chemical plants or materials manufacturers. A sentiment shared by these concerned researchers is that for a country like China that has yet to achieve innovation-based growth, that is in dire need of advancement not only in frontier research but also in "core, key technologies," having large groups of researchers chasing hot topics in the name of advancing basic science is becoming a price the nation cannot afford to pay.

This sentiment, in fact, converges with the concerns of the central leadership, who have long emphasized the practical application value of scientific research. It is somewhat ironic then, that two groups with the same goals instead arrived at a place neither wanted to be. Rather than achieving the optimal outcome of developing practical applications in the course of pursuing purely scientific questions, a segment of the Chinese research community appears to be failing to do either. This conundrum is perhaps best illustrated by the quadrant model of scientific research proposed by D. E. Stokes in his book from 1997 (see Figure 16). The vertical axis asks whether the work involves a "quest for fundamental understanding" and the horizontal axis asks whether the work involves "considerations of use."[248] The lower right-hand cell represents the objective of China's national science policy since the founding of the PRC till the early 1990s. The upper right-hand cell, which Stokes described as including "basic research that seeks to extend the frontiers of understanding but is also inspired by considerations of use,"[249] is a perfect match for the policy goals of the current leadership. However, the flawed incentive structure has resulted in some portion of China's research output slipping into the lower left-hand cell, driven by things other than a quest

Figure 16

Quadrant Model of Scientific Research Proposed by D.E. Stokes[252]



for fundamental understanding and with no consideration of use. Stokes did not name the cell, but offered up the German idea of *Wissenschaft*[250] as a fitting example. Some scientists, however, have jokingly named the cell "the place you do not want to be," [251] a description the Chinese leaders and researchers would probably agree with.

Arguably, the prospects of Chinese science partially depend on national science policies that can enable the part of the research base mired in the practice of 'water dumping' to make the leap from the lower-left cell into the upper right. In a speech at the Ninth National Congress of the Chinese Association of Science and Technology in May 2016, Xi Jinping made a cryptic remark about the S&T workforce: "Science and technology workers must write their papers on the soil of the motherland and apply S&T achievements to the great modernization endeavor." In May 2018, in another address to CAS and CAE academicians, Xi stated that China is still short on high-level innovative talents, especially leading talents in science and technology, and criticized the existing talent assessment method for placing sole emphasis on papers, professional ranks, and academic degrees.[252]

Five months after Xi Jinping's speech, the Ministry of Science and Technology, the Ministry of Education, the Ministry of Human Resources and Social Security, the Chinese Academy of Sciences, and the Chinese Academy of Engineering jointly issued a notice on the MOST website pledging to "clean up" the practices of placing an overemphasis on "papers, professional titles, academic degrees, and awards."[253] The PLA joined this drive in May 2019, with the publication of an article in its official newspaper *PLA Daily* titled "Military Research Should Guard Against 'SCI Worship [SCI崇拜]'".[254] The article criticized some military academies and research institutes that have also taken citation analysis-based metrics as an authoritative indicator for evaluating the capabilities of researchers. "SCI worship" in the civilian field results in the loss of scientific and technological resources, but when applied to defense S&T research, it could put the nation's combat capabilities at risk, the article warned, concluding that "protecting military scientific research achievements is paramount."[255]

Case Study: A Materials Science Researcher's Success against All Odds

This case study, involving a recent high-profile development related to China's hypersonic weapons program, perfectly encapsulates many issues discussed in Section 3.3. While ultimately a success story, the following case reveals many structural issues with China's R&D ecosystem and illustrates the difficulties researchers encounter in their attempt to take bench research to the production line.

A daily news program on Hunan TV [湖南卫视] aired in April 2019 profiled Professor Fan Jinglian [范景莲], an expert in high-temperature material science from Central South University in Hunan province whose team had developed a light-weight refractory metal matrix composite material [轻质难熔金属基复合材料] that can sustain prolonged use under temperatures as high as 3,000 degrees Celsius (5,430 Fahrenheit). The report specifically mentioned that the material has been widely used in cutting-edge technology fields such as hypersonic flight vehicles and missiles. This news story was subsequently picked up by multiple media outlets, including SCMP and Janes. Fan's CSU personal page gives away little, but a snapshot of her academic and research career can be pieced together based on a *Hunan Daily* news report from 2018, Fan's Baidu Baike page, and some archived web pages.

Fan currently leads refractory metal research at the Powder Metallurgy Research Institute (粉末冶金研究院/PMRI) of Central South University (CSU). The PMRI houses the State Key Laboratory for Powder Metallurgy [粉末冶金国家重点实验室] and the Defense State Key Laboratory for Lightweight and High Strength Structural Materials [轻质高强结构材料国防科技重点实验室]. Fan received her Ph.D. from CSU in 1999, and her Baidu page noted that she worked for a U.S.-based company called Injectamax Corp after graduation and that she was a "national high-level visiting scholar"[lv] in the United States in 2002. It was unclear when Fan returned back to CSU, but she was with PMRI when it was involved in a materials research project for hypersonic flight vehicles

lv It is unclear from available information where she was based during this period.

around 2009. The majority of the researchers favored carbon-based materials for this application. For instance, Fan's teacher, CAE academician Huang Boyun [黄伯云], led a team of researchers who designed and fabricated an ablation-resistant carbide (Zr0.8Ti0.2C0.74B0.26) coating material suitable for use on hypersonic vehicles.[256]

Fan, however, approached the problem differently than her peers. She used a type of nanocomposite technology to "hybridize" high-temperature ceramics and refractory metals. "Hybrid" ceramics and refractory metals allow the material to have both the high melting point and low-density properties of ultra-high temperature ceramics and at the same time and the malleability of metals. The material developed by Fan has been applied to the leading-edge hot end components of hypersonic vehicle(s) and high-energy solid rocket motor of air-to-air missile(s) and air-to-ground missile(s), making it the only material selected for key high-temperature components of many national high-tech projects and models.

Multiple external factors might have contributed to Fan's success, including: her academic education from CSU, a highly ranked materials science university; her mentorship from CAE academician Huang Boyun [黄伯云]; the funding she received from national defense S&T research programs; the lab facilities she had access to at CSU; and her overseas experience. However, based on Fan's own personal account of the event, her success is more a testament to her courage in overcoming institutional bias and perseverance despite the lack of support at every stage of research and development.

According to *Hunan Daily*, Fan proposed this idea as far back as 2006. But when she presented her idea to S&T authorities in Beijing, they considered her a joke and a charlatan of sorts. "Don't listen to this woman. She talks a good talk, but she's bluffing. What she proposed probably will not work." Fan was not easily discouraged. After she returned to Changsha, she screened dozens of different processing techniques and rented a high-temperature sintering furnace using her own money, and conducted hundreds of experiments. She was able to produce quality samples in 2012 but failed to find a single company or factory willing to take on the task of mass-producing this material. Fan Jinglian raised 1 million RMB from the core laboratory staff, rented a private facility, and began experimenting with small batch production.

Fan found more substantial backing from a High-tech Zone in Ningxiang (a county-level city in Hunan) [宁乡高新区] which offered 10 million RMB worth of funds and government loans to build a factory. Changsha Weina Kunchen New Materials Co., Ltd. (长沙微纳坤宸新材料有限公司) was thus founded with Fan Jinglian as the Chairman of the board. By 2017, Fan's new company had been certified by the military and begun prototyping products in three major categories. The report also noted that Fan Jinglian's research was not accompanied by acclaim scientists typically receive by publishing in international journals because Fan had mostly engaged in work on major national defense projects, meaning that many of the results could not be published publicly. In her interview, Fan told the reporter, "Our knowledge should be translated into the wealth of society and the nation, and serve our country's needs." The motivation and desire to help the country through one's work was perhaps what Xi Jinping had in mind when he called on scientists to "write their papers on the soil of the motherland."

Conclusion

Since the dawn of the modern era Chinese leaders have placed their faith in the advancement in science as a path to national security, prosperity, and power. At the turn of the last century, Qing scholars and scientists began a campaign of national salvation through advancement in science. After the founding of the RPC, Mao Zedong ordered the nation to "march toward science." China's current leader Xi Jinping has closely linked his narratives of Chinese national rejuvenation and the "China Dream [中国梦]" with China's leadership in science and technology, wants China to become the global center for scientific research. At the same time, as noted in this study, China's quest for scientific advancement has oftentimes been a proxy for its techno-nationalist pursuits. Since the founding of the PRC, technology policy has a much clearer trajectory of development. The overemphasis on technology policy comes at the expense of science, which as a policy field has always been operating under the shadow of technology. The consequences of the neglect are evident by the government's proportionally low investment into scientific research and delays in responses to address some of the serious issues of its S&E research base.

The 13th FYP period marked a turning point for China's national science policy. Chinese policymakers, recognizing insufficient policy attention paid to scientific research heretofore, have begun to adopt a much more targeted approach toward science. Policymakers have drafted detailed Implementation Plans for supporting basic research and have pledged a significant increase in funding for the next five years. They have also begun to address problems with the nation's faulty evaluation mechanism for researchers and the many menaces this mechanism had created. More policy moves in this area are expected during the 14th FYP. The S&E research base is in urgent need of fixing its incentive structure to free researchers from a severe case of "publish-or-perish," the side effects of which have suppressed the tremendous potential of its research base. Successful policy moves in these areas have a chance of quelling some prevalent harmful publishing practices and improving the overall quality of Chinese research. More Chinese research making the leap from the undesirable bottom left corner into the Pasteur's Quadrant, where scientific pursuits marry both a quest for the "truth" and considerations for practical applications, would benefit not just the Chinese research community but also science in general. These changes will in turn enhance China's prospects of achieving its STI development objectives envisioned by senior leaders.

The Chinese political system is adept at initiating reforms and making policy adjustments, and these changes could have significant, positive impacts on Chinese science. However, some of the more deep-seated institutional issues leading Chinese scientists have identified as adversely impacting Chinese science are unlikely to be addressed, as those issues travel beyond the realm of science policy into Party politics. Chinese Communist Party leaders have long deemed the Party's leadership in science an absolute priority, despite evidence that it prevents freedom of inquiry and channels valuable time and energy away from research to political activities. Leading Chinese scientists have argued that the arbitrary and boundless power of the government and government officials has prevented a true merit-based competitive incentive environment from taking root. Their proposition of freeing science and the scientific community from Party and bureaucratic influence has been actively ignored. The ruling Party likes to take credit for progress in Chinese science, frequently describing breakthroughs as being owed to correct leadership of the Party or the inherent strength of the Chinese system. Of course, this progress is more often the result of individual Chinese scientists who are often poorly compensated infrequently recognized for their work, and whose achievements happen in spite of tight political controls and onerous bureaucratic procedures. It is therefore critical not to lose sight of these strengths and weaknesses in the Chinese model of science that simple comparisons of STI indicators do not reveal. Even though the advance of Chinese science has stunned the world, leading Chinese scientists continue to look to the U.S. model of science, protected by liberal democracy values, and its research enterprise, "free to pursue the truth wherever it may lead," as sources of inspiration.

Ultimately, human capital is at the heart of great power competitions in science, and U.S. science policy, while fully reflecting national security concerns, must be designed to attract and retain brilliant minds. As Xi Jinping himself has stated, the outcome of the global S&T competition rests on the national strategic research enterprise.

Appendixes

Appendix 1: Distinctions between national science, technology, and innovation policies

Science policy, technology policy, and innovation policy [lvi]			
	Science Policy	**Technology Policy**	**Innovation Policy**
Policy Focus	"…allocating sufficient resources to science, to distribute them wisely between activities, to make sure that resources are used efficiently and contribute to social welfare. Therefore, the quantity and quality of students and researchers receives special attention."	"The objectives of technology policy are not very different from those of science policy but – at least to begin with – it represented a shift from broader philosophical considerations to a more instrumental focus on national prestige and economic objectives."	"Intellectual property right protection; diffusion, use and marketing of new technologies."
Part of the innovation system in focus	"… universities, research institutions, technological institutes and R&D-laboratories. Science policy is both about the internal regulation of these parts of the innovation system and about how they link up to the environment – not least to government and industry. However, strengthening this linkage becomes even more crucial in technology and innovation policy."	"…the attention moves from universities toward engineering and from the internal organization of universities toward how they link to industry. Technology policy may go even further and include the commercialization of technologies, but then we approach what we will call innovation policy."	"… the focus of policy moves from universities and technological sectors, as in science and technology policies, toward all parts of the economy that have an impact on innovation processes."
Primary policy instruments	"…budgetary decisions on allocating funds to public research organizations, such as universities, and subsidies or tax relief for private firms."	Public procurement; Direct economic incentives in terms of subsidies and tax reductions; Supporting research at universities; A combination of sector or technology specific economic incentives with more or less protectionist trade policy.	"Innovation policy pays special attention to the institutional and organizational dimension of innovation systems, including competence building and organizational performance."

lvi Excerpted or summarized from Bengt-Åke Lundvall and Susana Borrás, "Science, Technology, and Innovation Policy," in Jan Fagerberg and David C. Mowery eds., The Oxford Handbook of Innovation, September 2009. https://doi.org/10.1093/oxfordhb/9780199286805.003.0022

Appendix 2: Basic framework of 2006 Medium to Long-term Plan for the Development of Science and Technology (2006-2020)[257]

Guiding Principles	Interpretation	Proposed Courses of Action
"Indigenous innovation" [自主创新]	"Indigenous innovation" [自主创新] calls for the enhancement of three types of innovations: original innovation [原始创新] integrated innovation [集成创新] re-innovation based on assimilation and absorption of imported technologies [引进消化吸收再创新]	Deepen the S&T system reform by improving relevant policies and measures Increase S&T investment Strengthen the buildup of S&T talents Develop a National Innovation Systems
"Leapfrogging int priority fields" [重点跨越]	"Leapfrogging in priority fields" [重点跨越] places emphasis on the act of prioritization [有所为有所不为] to concentrate efforts and resources in key areas deemed critical to the national economy and security.	Implement 16 special megaprojects that are in line with national objectives: 1. Advanced numerically-controlled machine tools and basic manufacturing technology 2. Control and treatment of AIDS, hepatitis, and other major diseases 3. Core electronic components, including high-end chip design and software 4. Extra large-scale integrated circuit manufacturing 5. Drug innovation and development 6. Genetically modified organisms 7. High-definition earth observation systems 8. Advanced pressurized water nuclear reactors and high-temperature gas cooled reactors 9. Large aircraft 10. Large-scale oil and gas exploration 11. Manned space, including lunar exploration 12. Next-generation broadband wireless telecommunications 13. Water pollution control and treatment 14-16. Three unannounced projects, thought to be classified. Likely candidates include: the Shenguang inertial confinement fusion laser project; the second-generation Beidou satellite navigation system; near space vehicle (hypersonic vehicle) technology project.

Guiding Principles	Interpretation	Proposed Courses of Action
"Enabling cross-sector development" [支撑发展]	"Enabling development" [支撑发展] refers to breakthroughs in broadly-applicable cross-sector technologies [共性技术] with potential for value creation across a broad range of industries and applications to better serve the nation's economic and social development.	Identifies 11 priority fields [重点领域] for economic and social development, from which 68 priority areas [优先主题] with potential to achieve technical breakthroughs in the near term were listed.
"Leading the future" [引领未来]	"Leading the future" [引领未来] represents a vision that investment in frontier technologies [前沿技术] and basic research [基础研究] will spur future economic growth and social development.	Selects 27 areas in eight cutting-edge technological fields, and 18 basic scientific issues as priorities. It also proposes to implement four major scientific research programs.

Appendix 3: Chinese National S&T Megaprojects

2006 MLP Megaprojects	S&T Innovation 2030 Megaprojects
1. Advanced numerically-controlled machine tools and basic manufacturing technology 2. Control and treatment of AIDS, hepatitis, and other major diseases 3. Core electronic components, including high-end chip design and software 4. Extra large-scale integrated circuit manufacturing 5. Drug innovation and development 6. Genetically modified organisms 7. High-definition earth observation systems 8. Advanced pressurized water nuclear reactors and high-temperature gas cooled reactors 9. Large aircraft 10. Large-scale oil and gas exploration 11. Manned space, including lunar exploration 12. Next-generation broadband wireless telecommunications 13. Water pollution control and treatment 14. Three unannounced projects, thought to be classified. Likely candidates include: the Shenguang inertial confinement fusion laser project; the second-generation Beidou satellite navigation system; near space vehicle (hypersonic vehicle) technology project.	1. Aero engines and gas turbines 2. Deep-sea space station 3. Quantum communication and computing 4. Brain science and brain-inspired intelligence 5. National cyberspace security 6. Deep space exploration and spacecraft on-orbit service and maintenance system 7. Seed industry independent innovation 8. Clean and efficient use of coal 9. Smart grid 10. Space-Earth Integrated Information Network 11. Big Data 12. Intelligent manufacturing and robotics 13. R&D and application of new critical materials 14. Environmental management the Beijing-Tianjin-Hebei region 15. Health 16. Artificial intelligence 2.0

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