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Planning for science: China's "grand experiment" and global implications

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China's rising capability in science, technology and innovation to a certain extent has to do with "a grand experiment" that started 15 years ago when the Chinese government released the National Medium and Long-Term Plan for the Development of Science and Technology (2006–2020) (MLP). MLP launched the indigenous innovation strategy and set goals to turn China into an innovation-oriented country. The junction when the old MLP phased out and a new MLP (2021–2035) will soon be introduced holds greater historical and practical significance for the Chinese and international scientific communities to make sense of planning for science. This paper reviews the progress achieved in implementing the MLP, analyzes the daunting challenges facing China to become an innovation-oriented nation, discusses the implications of planning science for the Chinese and international scientific communities, and speculates on what might be included in the new MLP.

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China's rising capability in science, technology and innovation (S&TI) to a certain extent has to do with "a grand experiment" that started 15 years ago (Cao et al., 2006). In early 2006, China's State Council, or the cabinet, released the National Medium and Long-Term Plan for the Development of Science and Technology (S&T) (2006–2020) (MLP). MLP launched the indigenous innovation strategy and set goals to turn China into an innovation-oriented country and the world's scientific power. The junction at which the old MLP phased out and a new MLP (2021–2035) will soon be introduced holds greater historical and practical significance for the Chinese and international scientific communities to make sense of planning for science.

Strategic actions and progress

While it is difficult if not impossible to assess the overall progress of such an incredible plan as MLP and capture its unequivocal outcomes, at least, it is possible to review whether MLP has achieved its main goals.

MLP's organization had been shaped at China's central government level through implementing strategic actions of the Central Committee of the Communist Party of China (CC CPC) and amending science, technology, and innovation (S&TI) related laws (see Fig. 1). China's state-led system positions a top-down approach with party-state as the key driver of S&TI development and emphasizes the central leadership and coordination. Amending the Law on S&T Progress and the Patent Law and formulating and implementing various policies and measures have facilitated the smooth fulfillment of the plan's relevant tasks. In addition, the country's S&T 5-Year Plans (FYPs) are vehicles for MLP's implementation. Particularly, the efforts to foster the indigenous innovation capability, as MLP stipulated, had been reinforced by the 11th, 12th, and 13th FYPs with specific programs written into respective FYPs and carried out accordingly (Appelbaum et al., 2016).

MLP defined a set of quantitative targets for China to achieve in 2020, including:

- increasing the nation's gross expenditure on R&D (GERD) as a percentage of GDP (GERD/GDP or R&D intensity) to 2.5%;
- increasing the contribution of S&T progress to economic growth (STP) to 60% or more;
- reducing the degree of dependence upon foreign technology (DFT) to 30% or less; and
- making China one of the top five countries in the world in terms of the number of invention patents granted to its citizens and citations of international scientific papers to its authors.

All except for the R&D intensity had been met in the final tally (Table 1). In 2020, China only managed to achieve a GERD/GDP of 2.4%, short of the 2.5% target, despite its rapidly rising R&D investment in the past 15 years. The contribution of S&T progress to economic growth (STP) reached 59.5% in 2019, representing a significant improvement over 40.9% in 2003; therefore, the STP target seems attainable. Although in 2016 the Chinese government stopped using the degree of dependence upon foreign technology (DFT), a pure Chinese creation, on its misleading nature, the indicator did decline to 31.2% in that year, attributing to rapid growth of domestic investment in R&D and shrinking foreign technology imports.[1] The number of Chinese triadic patents—patents filed with the U.S. Patent and Trademark Office, European Patent Office, and Japan Patent Office—had increased from 524 in 2005 to 5323 in 2018, elevating China's ranking from the 13th to the 3rd. Moreover, citations to Chinese international scientific papers have increased since 2006, leading to the rise of China's international standing from the 13th to the 2nd.

Meanwhile, China has consistently moved upward in international innovation league tables. Global Innovation Index (GII), for example, has seen an improvement for China to the 14th place in 2020 from the 29th in 2007 (Cornell University et al., 2020). Indeed, China has achieved most of MLP's targets while its national innovative capability has been on an accelerating and rising trajectory. However, it remains to be seen whether China has become a truly innovation-oriented nation as the achievement of MLP's quantitative targets and China's improvement in global innovation benchmarks such as GII do not quantify

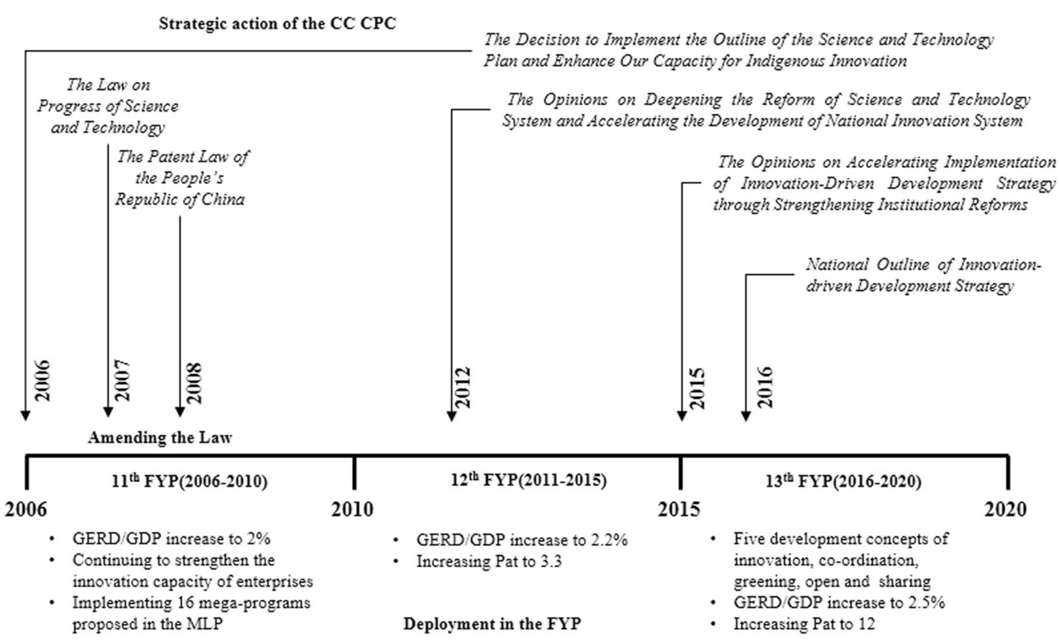

Fig. 1 Timeline of China's strategic actions relating to the MLP. Pat - the number of invention patents granted per ten thousand Chinese citizens. Source: Authors' research.

Table 1 The targets set in MLP and their fulfillment.

Indictors	MLP target	Fulfillment (year)
GERD/GDP	2.5%	2.40% (2020)
Contribution of S&T progress (STP)	60%	59.5% (2019)
Dependence of foreign technology (DFT)	Below 30%	31.20% (2016)
Invention patents granted to Chinese citizens	Top 5	3 (2018)
Citations to Chinese-authored papers	Top 5	2 (2018)

Sources: Authors' research.

China's national S&TI capability. Moreover, China still feels choked in some critical technologies such as semiconductors while the catch-up may take decades and future seems inherently uncertain.

Daunting challenges

Overspending on development. As the second largest R&D spender, China sees a level of GERD very close to that of the U.S. (in 2017, $496 billion, current PPP US dollars, about 23% of the global total for China versus $549 billion, or 25% of the global total, for the U.S.) (National Science Board, 2020). Although China didn't fulfill the R&D intensity target set for 2020, it has retained the momentum to help transform its economic structure and stimulate the next stage of economic and social development driven by technology and innovation.

The term R&D covers three types of activities: basic research, applied research and experimental development (OECD, 2015). However, in China, the share of GERD spent on basic research had been hovering at 5% for a couple of decades before finally reaching 6% in 2019, compared with 18.6% for the U.K. and 16.6% for the U.S. in 2018. Moreover, not only has proportion of the expenditure allocated to applied research been low and declining (11.3% in 2019, compared with 19.15% for U.S. in 2018) but the issue of the chronic imbalance in favor of experimental development has been largely ignored in policy. That is, China has overspent its R&D expenditure on development at the expense of scientific research—basic and applied, which may jeopardize the long-term prospect of the country's scientific, economic and social development.

Less government R&D spending led to less expenditure on scientific research at research-intensive universities and public research institutes that depend upon government for funding (Sun and Cao, 2014). Although MLP called on government to maintain its contribution to GERD at 40% between 2010 and 2020 (Jia et al., 2006, p. 49), in reality, between 2000 and 2019, governments decreased their contributions to GERD from about 40% to about 20% despite their rising funding. Governments have mistaken strengthening an enterprise-centered innovation system for their less contributions to GERD.

The orientation of China's S&T system reform toward S&T commercialization may have hindered the development of basic research, reflected in the preference of the government's R&D expenditure on applied research. Meanwhile, expenditure on experimental development is mainly funded and performed by enterprises, but their numbers may be doubtful. A study finds that more than half of the sample companies reported materially discrepant profit numbers to the local branches of the then State Administration of Industry and Commerce and the Ministry of Science and Technology so as to take advantage of government's incentives (Stuart and Wang, 2016). This indicates that the decline of government proportion in GERD is also partly attributed to government incentives and the fake data of enterprises.

Ambitious mega-engineering programs. MLP selected 16 Mega-Engineering Programs (MEPs) and four Mega-Science Programs (with two more added later) as priorities for support (see Table 2). MEPs aimed to meet major national economic and social developmental needs focusing on core, common, and key technologies of major strategic products. These programs reflected China's efforts to mobilize and concentrate resources on big and important areas, as well as the country's transition from focusing on the development of individual technology to the integration of the efforts of the entire S&TI system.

In fact, various countries have organized mega-programs such as the U.S. War on Cancer and Japan's Very-Large-Scale Integrated Circuit (VLSI) program in integrated circuits. Moreover, China's MEPs bear a remarkable similarity to them, as China, a developmental state, likes to use the model for achieving long-term interests or public policy goals relative to market-oriented economies (Appelbaum et al., 2011).

Chinese policymakers have continued to calibrate the expectation of what is possible for the model. In 2016, the 13th FYP for S&TI introduced a series of similar programs, "S&TI 2030-Mega-Programs," covering energy, information, aerospace, manufacturing, transportation, materials and other fields. Apparently, these programs have been built on MLP's then ongoing MEPs and will be integrated into its successor to 2035.

The extraordinary scale and scope of the MEPs have made it difficult for us to track their progress. In general, MEPs have driven the development of relevant industries. In 2009, the Chinese government launched Strategic Emerging Industries (SEI) programs as a response to the global financial crisis. There was significant sectoral overlap between MEPs and SEIs and most MEPs led to a subsequent SEI program. In addition, the mega-programs of high-definition Earth observation systems and manned aerospace and Moon exploration promoted the development of satellites and their applications.

International experience suggests that the mission-oriented mega-program model is only appropriate for R&D programs dominated by government agencies with public actors being end-users while the programs have a clearly defined specific goal. With a specific goal and involving the public sector, certain integrated MEPs such as large passenger aircraft and the aforementioned two programs have made remarkable progress. However, some others have not as they did not specify a concrete goal and involved the private sector. These programs functioned as a coordination for funding, with many different research projects contracted out to domestic companies and research institutes (Naughton, 2021, p.53). For example, the IC MEP was closely related to the development of the semiconductor industry but China's IC trade deficit has more than doubled since 2005 (Ernst, 2015). The U.S.–China trade friction has further restricted Chinese firms such as ZTE and Huawei from accessing to the most sophisticated chips from foreign MNCs. This is also the case for the MEP of core electronic components, high-end generic chips, and basic software.

Besides, some exploratory programs such as MEPs of drug innovation and development and control and treatment of AIDS, hepatitis, and other major diseases had goals that were too broad, thus making progress assessment more difficult. In fact, these programs were less likely to be completely successful.

Reforming the national S&T programs still not smooth. In 2006, when the MLP started, there were two types of national S&T programs (NSTPs) in China: basic programs and MEPs.

Table 2 Mega-programs in MLP (2006–2020) and S&TI 2030.

Mega-Programs in MLP (2006–2020)	S&TI 2030 Mega-Programs
Mega-Engineering Programs	Mega-Engineering Programs
1. Core electronic components, high-end generic chips, and basic software	1. Innovative seed industry
2. Extra large-scale integrated circuit manufacturing and technique	2. High-efficiency use of green coal
3. New-generation broadband wireless mobile telecommunications	3. Smart grid
4. Advanced numeric-controlled machinery and basic manufacturing technology	4. Space-terrestrial information network
	5. Big data
5. Large-scale oil and gas exploration	6. Intelligent manufacturing and robots
6. Large advanced nuclear reactors	7. Advanced materials research and their applications
7. Water pollution control and treatment	8. Comprehensive environmental improvement in Beijing, Tianjin, and Hebei
8. Genetically modified new-organism variety breeding	
9. Drug innovation and development	9. Health security
10. Control and treatment of AIDS, hepatitis, and other major diseases	10. A new-generation of artificial intelligence (added later)
11. Large aircraft	
12. High-definition Earth observation systems	
13. Manned aerospace and Moon exploration	
Mega-Science Programs	Mega-S&T Programs
1. Protein science	1. Aero-engines and gas turbines
2. Quantum research	2. A deep-sea space station
3. Nanotechnology	3. Quantum communication and quantum computing
4. Development and reproductive biology	4. Brain science and brain-inspired intelligence
5. Stem cell (added later)	5. National cyber security
6. Climate change (added later)	6. Deep space exploration and probe orbit service maintenance systems

Note: The MLP (2006–2020) identified 16 Mega-Engineering Programs but only made 13 programs public.
Sources: Authors' research based on the MLP and China's 13th 5-Year Plan.

With steady and continuous public finance, the basic programs included five components administrated by some 30 government agencies:

- the National Key Basic Research Program ("973") including Mega-Science Programs under MLP and the National Naturel Science Foundation of China (NSFC) Program;
- the National High Technology R&D Program ("863");
- the National Key Technology R&D Program (keji gongguan);
- the newly-established National S&T Infrastructure Platform Program; and
- other policy-oriented S&T programs.

The basic programs provide public S&T goods, covering a wide range of S&T areas and requiring long-term and stable funding. Mission-oriented MEPs are set up around the national strategic goals. The reform of S&T program in 2006 highlighted the role of MEPs in NSTPs. For a period, China had decentralized the distribution of its central R&D spending. However, the funding system suffered from a lack of top-level design and unified planning, ineffective coordination, and a lack of transparency in funding distribution and accountability in spending (Sun and Cao, 2014).

To solve these problems and in response to the desire for further reform proposed by the scientific community, in 2014, the State Council decided to reorganize NSTPs into five types:

- the NSFC Program;
- MEPs managed by twelve ministries along with the military, two provinces, three state-owned enterprises, and one university (Naughton, 2021, p.53);
- National Key R&D Programs;
- Special Fund for Guiding Technology Innovation; and
- Special Fund for S&T Bases and Talent.[2]

Of these five, the National Key R&D Programs, the largest, integrate the 973 Program and Mega-Science Programs under MLP; the 863 Program; and the National Key Technology R&D Program; the Industrial Technology R&D Fund, a policy program that used to be under the National Development and Reform Commission (NDRC) and Ministry of Industry and Information Technology (MOIIT); and Special Funds for research in public sectors managed by 13 central government agencies, and so on.

Aiming to solve the problems of the lack of unified planning, ineffective coordination, and program overlapping, NSTPs did reshape the public funding system (Fig. 2). However, the reform has turned out to be not that simple and smooth. For example, the National Key R&D Programs aim to link basic research, applied research, and development research, as well as accelerating the transformation and commercialization of achievements. Yet, it is impossible for a project supported by the programs to complete all these tasks within three to 5 years stipulated by program guidelines. Such arrangements may end up weakening basic research and orienting most projects toward application and short-termness. More importantly, the reform may not fundamentally change the way that government funds the NSTPs.

Indeed, how to spend R&D expenditure in an accountable and efficient way, how to differentiate NSTPs for their functions, and how to define the orientation and the mode of operation over each type of the programs are still unsettled. Therefore, responding to the maladaptation between the current national challenges and the government funding system for R&D would motivate further reform of national funding system. Similar problems in other countries have prompted funding experiments funding as well. For example, the U.S. intends to establish APPA-Health and ARPA-Climate to replicate the success of its Defense Advanced Research Projects Agency (DARPA) model and to accelerate the pace of breakthroughs (Collins et al., 2021).

Controversy around attracting overseas talents. To tackle the "brain drain" phenomenon and indeed the talent shortage that has nagged China in the reform and open-door era, at the end of 2008, the Organization Department of the CC CPC began to implement a new overseas high-level talent program (also known as the "Thousand Talents Program," TTP). The program

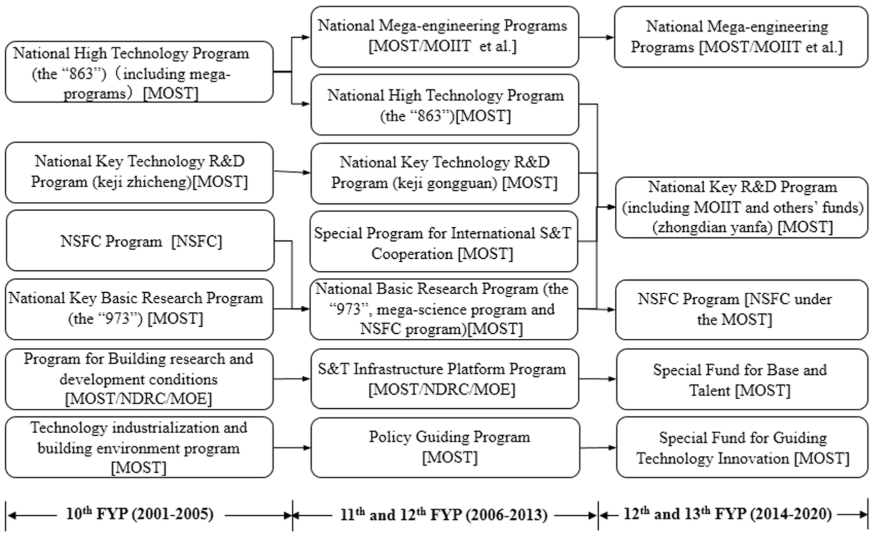

Fig. 2 China's Reform for National S&T Programs between 2006 and 2020. Each panel provides the names of programs and the main government agencies in charge of the programs. MOST - Ministry of Science and Technology; NSFC - National Natural Science Foundation of China; NDRC - National Development and Reform Commission; MOE - Ministry of Education; MOIIT - Ministry of Industry and Information Technology. Source: Authors' research.

intended to attract from the world within 5 to 10 years about 2000 leading scientists and professionals, mostly ethnic Chinese, below the age of 55. Two years later, an affiliated program for young talents was introduced targeting overseas scholars 40 years old or younger. Indeed, talents recruited into the programs have significantly contributed to the development of their affiliated institutions by publishing more and higher impact papers at the international level, extending new research areas, and uplifting overall performance of the domestic scientific community (Cao et al., 2020).

However, China is still experiencing a serious shortage of high-end academics and other professionals and witnessing a new exodus of leading scientists, which may greatly undermine its efforts to build an innovation-oriented country, the MLP's main goal. Even the high-profile Thousand Talents Program with enormous prestige and benefits attached has failed to achieve its goal as a significant number of the position holders have not returned to China on a fulltime basis as expected (Zweig and Wang, 2013; Sun et al., 2017; Zweig, et al., 2020). Moreover, the program has become internationally controversial. Amid recent tensions with China, the U.S. government especially targeted U.S.-based scholars and high-tech professionals, quite a number of whom have not been frank with their involvement in the program (Zweig et al., 2020).

Both developing and developed countries have used "brain circulation" strategies. Not only has China halted its talents recruitment programs in the U.S. and some other countries, it has also had difficulty sending students and scholars, especially in some high-technology fields abroad. This will undoubtedly have negative impacts on China's technological learning and catch-up (Tang et al., 2021). Overseas talent recruitments may need to pay attention to the issues of transparency, research integrity and ethics, and intellectual property protection and avoid the part-time "double dipping" phenomenon (JASON, 2019).

Meanwhile, many overseas-educated Chinese students, especially the best and brightest, remain in and contributed their wisdom to the countries where they have studied. While international collaboration inevitably involve them, it is necessary to make proper institutional arrangements so as to prevent conflicts of interests and commitment from happening (Zweig et al., 2020).

Implications of the Chinese "grand experiment"

China has delivered an unnerving and rousing performance in science, technology, and innovation in the past 15 years. China's planning experience has caused the attention of the world scientific community and S&TI policymakers.

Planning—a way of S&T governance. China has a long history of formulating FYPs for national economic and social development (since 1953) and FYPs usually include an S&T component. The MLP to 2020 was particularly inspired by the Long-term Plan for the Development of Science and Technology (1956–1967), or the 12-year plan, the most celebrated of China's past S&T plans, which not only laid the foundation for modern science in China but also has been recognized as an important milestone in S&T planning (Cao et al., 2006). Corresponding to China's FYPs for economic and social development, the Ministry of Science and Technology leads the formulation of FYPs for S&T development, which are important vehicles for MLP's implementation.

In fact, several developed countries also have adopted the practice of planning S&T development, albeit not necessarily in the Chinese approach. For example, since 1996, Japan has drawn up S&T basic plans every 5 years, overseen by a cabinet-level office, according to its Science and Technology Basic Law enacted in 1995. Now, the country is working on its 6th Science and Technology Basic Plan. S&T Basic Plans in South Korea and Framework Programs in the EU have some planning characteristics. In addition, the American Academy of Arts and Sciences (2014) proposed the introduction of a more strategic, long-term approach toward S&T policymaking at the federal level as a way of restoring the vital role of research.

But applying Goodhart's Law that "when a measure becomes a target, it ceases to be a good measure" (Varela et al., 2014), measuring China's S&TI capability by MLP's targets might be problematic. For example, China has increased its payments for the use of foreign intellectual property (IP) significantly from US$ 6.63 billion to US$ 37.78 billion between 2006 and 2020, while its receipts increased from US$ 200 million to US$ 8.5 billion in the same period. Indeed, China's average annual growth rate of IP receipts is faster than that of IP payments and China still runs a larger IP deficit in 2020 although it seems to have fulfilled MLP's goal of reducing foreign technology dependence as implied.

As a latecomer, China needs more foreign technologies including IP in developing its industry and moving toward the international frontier. China is also the world's second largest R&D spender but its large amount of R&D activities have not generated enough technologies and IP for usage in its industrial development. Therefore, the country still has to spend a significant amount of its money acquiring foreign IPs, which is not included in R&D expenditure.[3]

Similar problems exist in other countries, where government's planning targets are not being met on time. For example, the Lisbon strategy stipulated investing 3% of EU's GDP on R&D by 2010, but the majority of its Member States remained far from the target by 2020.

The state—a double-edged sword. The state-led S&TI development and planning could be a double-edged sword. Such a model is advantageous in its ability of mobilizing substantial resources to meet specific national goals; or the state could mobilize the country's entire resources on programs of strategic importance. However, as noted, this model is not a cure for all S&T challenges. There is the need to delicately balance the role of the state and the market in innovation.

Utilizing the "whole-of-the-nation system" (juguo tizhi) to mobilize and concentrate resources, China has taken full advantage of the benefits as a latecomer and achieved the catch-up with developed countries in certain technological areas. The "whole-of-the-nation system" is most suitable for a few state-led sectors with clear goals, such as high-speed rail and large passenger aircraft. However, such a system does not always work as it often fails in consumer-centered sectors (e.g., the automobile industry) and in areas where there is no leader to follow. It is less effective and efficient in market-oriented or exploratory fields without clear goals.

In market-oriented economies, government intervenes as an autonomous self-regulating order through investing in R&D, especially basic research, out of the market failure concern (Mowery, 2009) and through nurturing a fair, open, and competitive environment. The notion of "entrepreneurial state" also argues that state needs to take risk and create a highly networked R&D system for national goods over a medium-to-long-term time horizon (Mazzucato, 2013).

In China's transition from a centrally planned economy to a socialist market economy, the state's main focus remains S&T and innovation-driven economic development. On the one hand, the state is omnipresent and determines the market being part of the state-centered order (Fang, 2010). The state operates the S&T and innovation system and allocates S&T resources. However, it doesn't always work.

During the global financial crisis, China dramatically increased direct government intervention on industrial development, as part of a massive stimulus program, to mitigate its negative effects on both emerging sectors and hard-hit traditional industries, but largely ignored the more fundamental issues of the reform of its S&T system. Afterward, most developed economies dialed back their stimulus efforts, while China still consolidated its industrial policy initiatives (Naughton, 2021). The direct government intervention distorted the market-oriented mechanism, which otherwise could expand the potential contribution to S&T progress. As a result, China's total factor productivity, a global benchmark for economic efficiency and innovation, has experienced a significant slowdown in growth, from 3.51% in the 10 years before the global financial crisis to 1.55% in 2008–2017 (The World Bank and Development Research Centre of China's State Council, 2019).

On the other hand, the state needs to allow for the autonomous operation of the scientific community and the true market orientation for enterprises in innovation. For example, He Jiankui's gene-edited baby scandal in 2018 relates to one of the most critical issues in research ethics, procreative ethics, and medical practice. The project did not go through an ethical review process and He applied the gene-editing technology to human assisted procreative medicine in a hospital. None of these had been known to government departments or the scientific community before He made them public. In 2019, He was jailed for 3 years for illegal medical practices and illegal gene editing is written into Chinese Criminal Law in 2020. Indeed, while laws regulate the behaviors of scientists, research ethics and integrity should be within the purview of the scientific community.

Similarly, government intervention should not substitute the market economy. The intervention may distort incentives. For example, firms may increase patenting to take advantage of the subsidies offered by local governments (Eberhardt et al., 2017); academics may publish more insignificant papers that carry significant weight in performance evaluation. Now, aware of such distortions, the central government has taken action to correct overemphasis on publications, titles, credentials, and awards in the evaluation of scientists and institutions, and will abolish patent subsidies soon.

Governance: overcoming the asymmetric structure. As the world's second largest economy, after the U.S., China has been now growing its economy at a slower pace than in earlier decades. Along with structural issues, such as export-oriented growth and insufficient domestic consumption, the economy has been further perturbed by a disruptive, prolonged trade dispute with the U.S. since 2018. The trade dispute has spilled over into issues that may undermine China's efforts to become an innovation-driven nation and a world's S&T power. Sources of the tensions include high-tech competition, technology transfer, IP protection and the Thousand Talents Program. There is real risk of decoupling between the two countries in technology and talent. In fact, the decoupling rhetoric has originated from mutual suspicions between China and the U.S. when a rapidly rising nation is perceived to challenge the incumbent power, which wants to maintain its supremacy in economic, technological and geopolitical terms.

In order to achieve the ambition to become an innovation-oriented country, China has to overcome its asymmetric governance system between the omnipresent state and other actors including universities, research institutions and enterprises that are significantly less powerful. Or, there needs a balance between government, market and the research community. The state-led innovation system may allocate resources through a less market-based mechanism and may lead to a less autonomous research community. Under these circumstances, China needs to modernize its governance structure by diversifying participants, rather than depending solely on the state, appropriately balancing power structure of the participants, and making the research community self-organized.

The state-led innovation system is also less effective in making macro-level coordination. The state is not one entity within itself but is made up of many departments and agencies with their own interests that might be in conflict with each other. China's State Leading Group on Science &Technology has not fully functioned coordinating agencies at the macro-level. The Ministry of Science and Technology (MOST) oversees S&T affairs, but it is only one ministry among many within the State Council and probably a weak one in terms of clout (Cao et al., 2013). Besides, S&T budget is directly appropriated from the Ministry of Finance (MOF).

Less effective macro-level coordination remains a major challenge, although it has been improved through the reform of funding system in 2014 and state institutions[4] in 2018. MOST started to convene a new Inter-Ministerial Joint Committee (IMJC) in 2014, with participation from the MOF and other agencies whose administrative ranks seemingly are the same (Cao and Suttmeier, 2017). After the 2018 reform, MOST absorbed the State Administration of Foreign Experts Affairs (SAFEA), which was previously under the Ministry of Human Resources and Social Security, and the independent National Natural Science Foundation of China (NSFC). The merger consolidated the role of the ministry in administering China's R&D programs but not necessarily in the S&T budgeting and other functions. It seems that the absence of the functional equivalent in China of a national science advisory system to coordinate S&T affairs between agencies (Cao and Suttmeier, 2017), although China called for establishing such a system for science decision-making in as early as 2017.

Outlook for the new MLP

China has been developing a new MLP (2021−2035) since 2019. While it is still unknown what it will embody, the Outline of the 14th 5-Year Plan (2021−2025) for National Economic and Social Development and the Long-Rang Prospects through the Year 2035 offers a glimpse of it and its possible impacts on China's S&TI trajectory.

The outline of the 14th FYP points out that China will "adhere to the core position of innovation in China's overall modernization and take S&T self-reliance and self-improvement (zili ziqiang) as the strategic support for national development." In order to fulfil China's ambition to become a leading innovative country by 2035, the outline stipulates four main tasks: "strengthening the nation's strategic S&T power," "improving the technological innovation capability of enterprises," "stimulating the innovative vitality of talent," and "refining S&T innovation institutions and mechanisms." The next MLP is likely to develop along these lines.

S&T "self-reliance and self-improvement". The new MLP will place more emphasis on S&T "self-reliance and self-improvement." On the one hand, "self-reliance and self-improvement" is a continuation of the concept of developing self-generating capabilities, from "self-reliance" (zili gengsheng) in the Maoist era to indigenous innovation (zizhu chuangxin) in the MLP (2006–2020) to "self-reliance and self-improvement" now. On the other hand, it is a response to the post-2018 U.S. government's tightening of its exports to China of advanced components and equipment, especially semiconductors and the equipment to manufacture advanced electronics devices.

For long-term development, China is convinced that S&T self-reliance and improvement can support and sustain its industrial development and meet its needs in national security and people's livelihood. Just as strengthening "indigenous" innovation raised concerns abroad over the emergence of "techno-nationalism" and its implications for China's future economic openness (Serger and Breidne, 2007), emphasis on S&T self-reliance and improvement might lead to similar concerns. China would have to adopt more market-oriented approach instead of using government subsidies and other administrative measures to promote the upgrading of manufacturing industry. Accordingly, governments have withdrawn their subsidies for new energy vehicles.

In light of the new concept of S&T "self-reliance and self-improvement" and against the anti-globalization headwind, there is need to dissipate two misunderstandings. One is to equate self-improvement and self-reliance with autarky or an unwillingness to open to the outside world. China has taken full advantage of and benefited enormously from the opportunities offered by globalization. China has witnessed rapid increases in the share of publications with international collaboration from 15% in 2000 to 20% in 2015. The U.S., the U.K., Australia, and Canada are China's most important partners, among which the U.S. accounted for 45% of joint publications (Shashnov and Kotsemir, 2018). Unfortunately, Sino-U.S. collaborative papers that peaked in 2020 may start to decline (Armitage, 2021).

It is very unlikely that China will ever close its door in technological and economic development. The 14th FYP proposes actively promoting openness and cooperation in S&T so as to "further integrate China into global innovation networks" and "promote international S&T cooperation in global epidemic prevention and control, public health, clime change and so on." In addition, China has provided the world with a bigger market for manufacturing and consumption. As the tension between China and the U.S. won't be ease anytime soon, the challenges lie in cultivating open innovation and integrating China more deeply in the global innovation network. China's new development blueprint and innovation-driven development will bring more opportunities to the world. In particular, China and the U.S. need to work together, which is crucial to the global S&TI development and overcoming common challenges such as climate change and the spread of infectious diseases. The other is to overemphasize indigenous innovation while ignoring the ultimate purpose of innovation, namely, the creation of new technologies and products with international competitiveness.

Strengthening strategic S&T forces. The new plan will emphasize strengthening China's strategic S&T forces. The 14th FYP has four sections on the issue: "consolidating and optimizing S&T resource allocation," "strengthening original and leading S&T research," "unrelentingly strengthen basic research," and "establishing major technological innovation platforms." The 14th FYP further proposes "increasing government spending on basic research" and especially "increasing funding for basic research to 8% of GERD" in the plan period.

The nation's strategic S&T forces include world-class universities, research institutes and innovative enterprises. To start, it is necessary to clarify the division of labor between universities and research institutes and overcome significant overlapping and even redundancy in their respective missions although certain level of overlapping and redundancy is necessary to avoid systematic malfunction. In particular, research-intensive universities should focus on basic research and talent training, R&D institutes are oriented to applied research, and the Chinese Academy of Sciences be restructured, at least in part, to become fully publicly funded national laboratories to take on missions of solving nation's strategic S&T problems.

Obviously, developing strategic S&T forces has to be examined against the competition between China and the U.S. China will rely on the national strategic S&T forces to build world-class comprehensive innovative platforms at national laboratories, national scientific research centers and national technological innovation centers. According to the 14th FYP, China will formulate an Outline on Actions for Strengthening China through Science and Technology to improve the "new whole-of-the-nation system" (xin juguo tizhi) under a socialist market economy, achieve breakthroughs in key and core technologies, and improve overall efficiency of the innovation system. In its transition from imitation to innovation, China needs to transform the state-led to the enterprises-centered innovation system, and balance the power between the government and the market, turn out more innovative enterprises in emerging industries through technological exploration and entrepreneurship.

Although policymakers have been proclaiming the need to establish national laboratories, there has not been much progress or even any detail of such organizations. While the establishment of "new" national laboratories will also be a key area to watch regarding the ongoing reform of the S&T system, these national laboratories, which will be part of the strategic S&T forces, need to have clearer mandates in prioritized areas of national development rather than just reorganize or even rename existing ones. From 2021 to 2025, China is likely to set up national laboratories in several major innovation fields, perhaps quantum information, photons and micro-nano electronics, network communications, artificial intelligence, biomedicine, modern energy systems and others.

Optimizing the structure of the S&TI system. The S&TI system is the foundation of the S&T and innovation enterprise. The new plan will endeavor to optimize the structure of the S&TI system guided by "the strategic needs of the state," as the 14th FYP specifies. S&T development needs to cater to major national demands of economic and social development, such as sustainable growth, innovation-driven development, innovative society, healthcare, aging population, carbon neutrality, among others. As these issues involve different aspects of S&TI, it is necessary for the new MLP to properly handle the relationship between research and development, between government and the market. The new plan is expected bolster structural quantitative indicators, such as the share of basic research expenditure, as mentioned, and government's contributions in GERD.

It is no longer appropriate to apply the technocratic thinking to science and innovation. Weak research capability is still a major constraint for China to be more innovative and to achieve breakthrough in key technological fields. As science flourishes contingent on government support, individual initiatives, and an autonomous research community, the new plan should propose strengthening basic research funding, research ethics and an increasing important role of the research community.

To be truly innovative, China should pursue a bottom-up innovation policy and improve the market-oriented system. This becomes especially critical as China is fast approaching the frontier of international science and the top-down approach is fast losing its glamour. This explains why the 14th FYP proposes "encouraging enterprises to increase investment in R&D" and "forming an enterprises-cantered and market-oriented innovation system, which deeply integrates enterprises, universities, research institutes and users."

China needs to improve its innovation ecosystem. In reaching the international frontier of research and tackling key and core technologies, China may learn from the sector-oriented decentralized model in the U.S., considering setting up more relatively independent funding agencies in health and energy under the NSTPs. Indeed, it might be the time to reconsider the proposal of establishing a new National Institute of Health to be responsible for biomedical and health research.

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Notes

1 A private communication with an analyst at the Chinese Academy of Science and Technology for Development, a think tank of the Ministry of Science and Technology, in 2019. DFT was defined as expenditure on importing foreign technology / (GERD + expenditure on importing foreign technology).

2 The last three programs are mainly under the administration of the Ministry of Science and Technology (MOST).

3 In 2019, China's GERD is RMB 2.2 trillion (about US$ 320.98 billion), and IP payment is US$ 34.37 billion, or some 10% of the R&D expenditure.

4 In 2018, the CC CPC decided to deepen the reform of both the Party and state institutions and issued the Scheme on Deepening Reform of Party and State Institutions.

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