Report for the Innovation Centre Denmark in Shanghai (ICDK)

A New Model for Global Science and Innovation Infrastructure?

The Construction of Huairou Science City

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1. GLOBAL SCIENCE AND TECHNOLOGY GOING EAST?

> "*If the science superpowers are to avoid being left behind, they will need to step out of their comfort zones to keep up with the dynamism of the new players in this shifting landscape*"
>
> Nature, 2012[1]

In the last two decades, China has advanced from pursuing a science, technology and innovation (STI) policy of imitation, indigenous innovation and technological catch-up to becoming an inventor and "technology superpower" at the forefront of global science. China's central government has played a pivotal role in steering and providing the infrastructure for this transition from a manufacturing ("the world's factory") to an innovation-driven and knowledge-based economy. The rapid increase in funding for research and development (R&D) in China highlights this transition (see Figure 1).

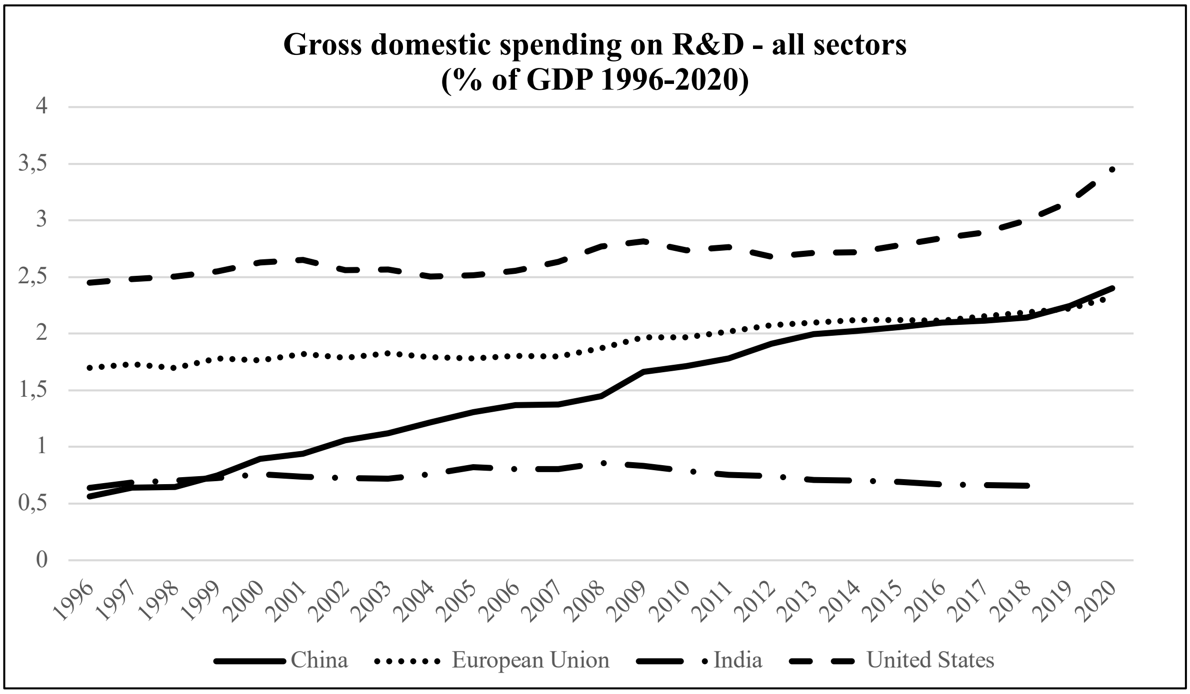

Figure 1. Spending on R&D. Source: World Bank Data.

Today, Chinese national R&D investment as share of GDP has surpassed the EU27 average while closing in on the United States (US). Figure 1 shows the development in national

[1] Jonathan Adams (2012). The Rise of Research Networks. *Nature* 490: 335-336.

spending on R&D in China compared to the US, the EU, and India in the period from 1996 to 2020. The GDP of the EU and China, respectively, were approximately USD 17 trillion in 2020, while the GDP of the US was USD 21 trillion and India USD 2.7 trillion. China's increased spending on R&D is well ahead of India's R&D investment, which has not increased at the same rate as its economic growth. This testifies to the significant role science and research has played in China's economic development over the past two decades.

China's increasing share of global R&D investments and innovation performance is reflected in the steady increase in Chinese international patents since 2000. Figure 2 shows the number of triadic patents filed by citizens in China, the US, and the EU. Triadic patents are registered in the EU, the US *and* Japan (i.e. the United States Patent and Trademark Office (USPTO), the European Patent Office (EPO), and the Japanese Patent Office (JPO)).

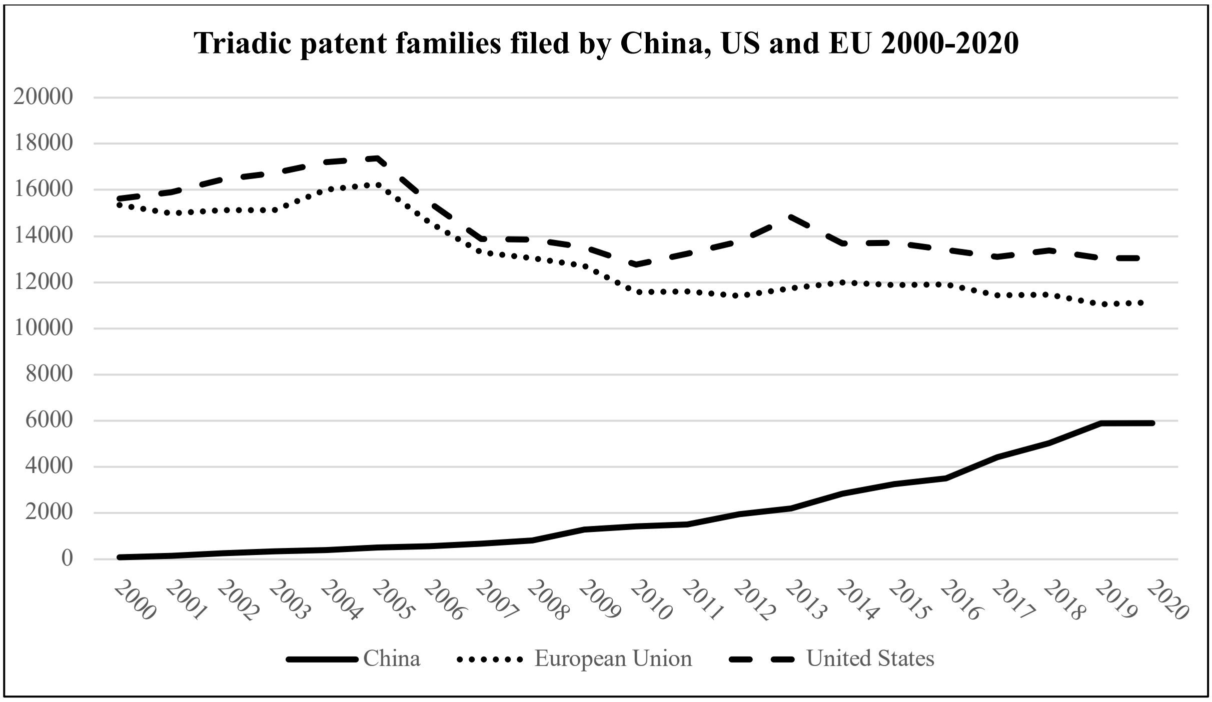

Figure 2. Triadic patents filed by Chinese residents. Source: OECD Stat. A patent family is a collection of patent applications covering the same or similar technical content.

For this reason, triadic patents often cover those inventions that the applicant expects would be of the greatest economic value. Triadic patents are, therefore, often used to assess a nation's technological and scientific position and productivity. The number of triadic patents registered by Chinese residents more than tripled between 2010 to 2020, from a total of 1,425 to 5,897.

China's growing share of global R&D investments and innovation performance is also reflected in the steady increase in patents currently in force in China (see Figure 3). In 2011, there were 696,939 nationally registered patents in force in China. This number had already doubled by 2015 (1,472,374). More than 3 million patents were in force in China in 2020.

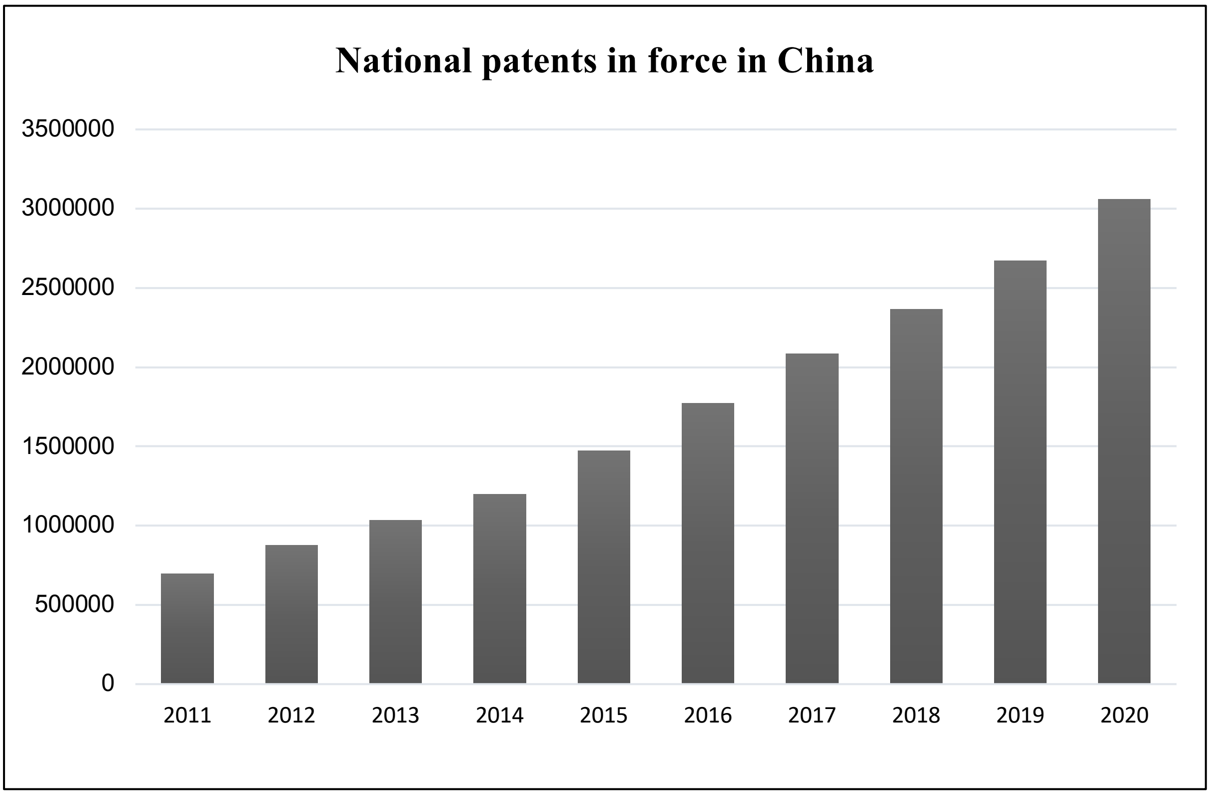

Figure 3. National patents in force in China. Source: WIPO Statistics Database.

The number of scientific publications is a third important measurement in assessing a nation's innovation base and global performance. In 1999, China was the tenth largest contributer in terms of scientific publications, moving to fifth position in 2004 following the US, Japan, the UK, and Germany.[2] By 2016, China had surpassed the US in terms of scientific output measured by number of publications. China surpassed the EU in 2018 (see Figure 4 below).

[2] Ping Zhou and Loet Leydesdorff (2006). The Emergence of China as a Leading Nation in Science. *Research Policy* 35: 83-104, p. 85.

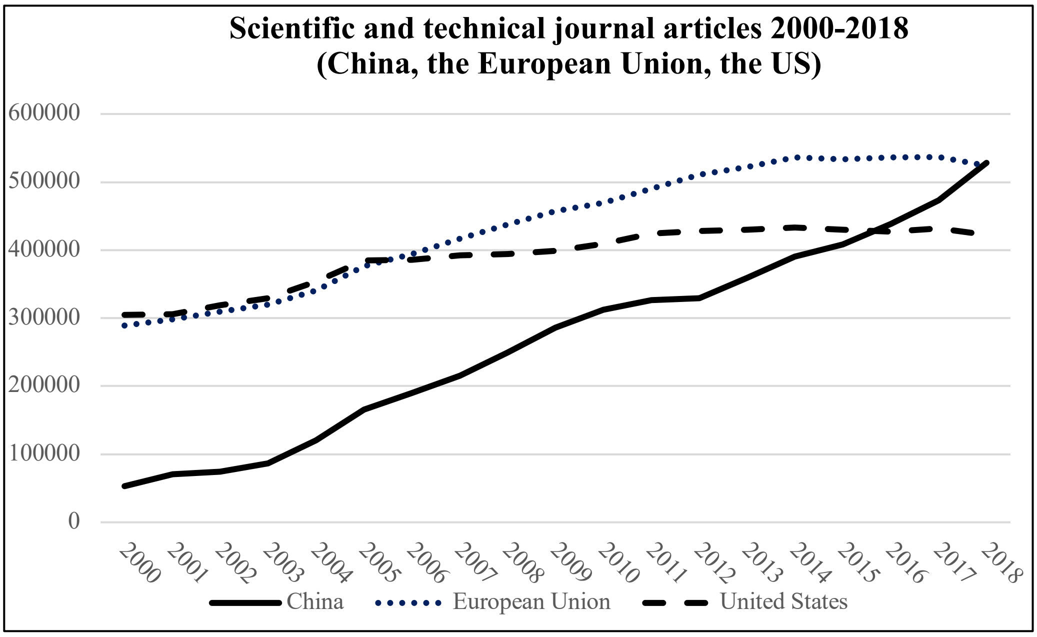

Figure 4. Scientific journal articles. Source: World Bank Data 2000-2018

Overall, these numbers show how the center of gravity for science, technology and innovation (STI) is moving east . The geography of global science has shifted from a bipolar world around the US-Europe axis to an increasingly multipolar world. China is in the lead of this development, with other Asian nations also closing in on the West in terms of scientific output. For instance, India surpassed in 2016 both the UK and Germany in terms of peer-reviewed scientific publications (Figure 5). The number of Chinese-authored scientific publications is four times higher than that of India. Notably, new locations are gaining strong competitive positions in an increasingly multipolar world of science, technology and innovation.

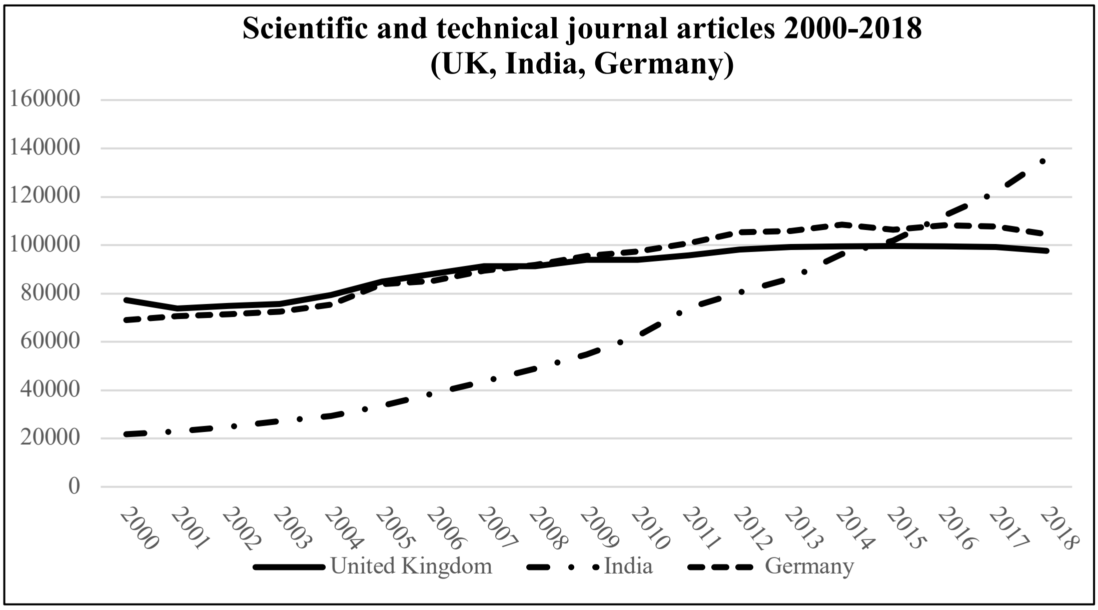

Figure 5. Scientific journal articles. Source: World Bank Data 2000-2018

Outline of the Report

This report maps the emergence of national science parks in China and tracks their role in China leapfrogging into a global lead position in science and innovation. It situates Chinese science parks in the transition from China as a fast follower to a path creator. The report evaluates this transition according to three levels of governance (global, national, and local). On a global level, China is rapidly closing in on lead nations in science and innovation (cf. **Section 1**). This position has been facilitated by an increasing investment in the establishment of science parks (see **Sections 2 and 3**), supported by large national investments and a strong positioning of science and technology in national policy-making, planning, and strategic programs since the beginning of the 1980s (cf. **Section 4**). The report illustrates these trends with the case of Huairou Science City in Beijing (**Section 5**). The final section (**Section 6**) outlines three science and technology areas (quantum science and -technology, nanoscience and -technology, and energy) to assess Chinese integration into global STI networks. These scientific and technological areas have recently been prioritized by Chinese policy-makers.

Primary data was collected from interviews with Chinese and Danish stakeholders, researchers, and policy-makers in China, as well as statistics from the Organisation for Economic Co-operation and Development (OECD), the World Bank, and the World Intellectual Property Organization (WIPO) on relevant research output indicators (e.g., patents and publications), and findings from the SDC Social Science project "Organizing Science: Global Science Parks in China", located at the Department of Organization (IOA), Copenhagen Business School. The report draws on long-term participant observation from the collaboration with UCAS over the past decade.

2. A BALANCED APPROACH TO ORGANIZING SCIENCE, TECHNOLOGY, AND INNOVATION

> "*If there is a Chinese approach to development, one place it is highly visible is in high-tech parks [science parks] with state funding*"
>
> Appelbaum et al., 2018[3]

Location – and co-location – plays a prominent role in China's progress towards a knowledge-based economy. In mapping out the emergence and significance of national science parks in China, **the report highlights how China has pursued a policy approach that combines a top-down mission-oriented innovation policy formulated and operationalized at the highest level of governance, with an awareness of agglomeration effects generated in spatial clusters of key stakeholders in the field of STI** (i.e., research institutes, government agencies, and firms). We use the case of the ongoing construction of Huairou Science City, which is part of Beijing's plan of becoming a "global science hub" by 2025, to demonstrate how China has made a national priority of becoming an *inventor* and a global science and technology superpower.

In 2020, *Nature* reported that Beijing had become the top science city in the world, followed by New York, Boston, San Francisco, and Shanghai. Together, these cities were referred to as the "world's science hotspots".[4] Nature's index was based on a combination of several indicators, including an expansion in R&D spending, the concentration of research institutions, research funding, number of researchers, availability of research facilities, and number of peer-reviewed scientific publications in high-ranked journals.

Beijing took this leading position in 2016, ten years after the launch of the strategic and ambitious Chinese 15-year plan for the development of science and technology, the Medium to Long-Term Plan for the Development of Science and Technology, 2006-2020 (MLP). Observers have dubbed the 2016 MLP 'China's "grand experiment"'[5]. The plan was the first to identify specific missions, guided by the principle of homegrown "indigenous innovation",

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[3] Richard P. Appelbaum, Cong Cao, Xueying Han, Rachel Parker, and Denis Simon (2018). *Innovation in China*. Cambridge: Polity Press.

[4] Nature Index, 'Nature Index's top five science cities, by the numbers', 19 September 2020; available online:

[5] Yutao Sun and Cong Cao (2021). Planning for Science: China's "Grand Experiment" and Global Implications. *Humanities and Social Sciences Communications* 8(1): 1-9.

to steer China into an innovation-oriented society and a knowledge economy at the frontier of global technological and scientific development (see Box 1).

Box 1. Strengthening Indigenous Innovative Capabilities

Confronted with the new international situation, we must have a greater sense of responsibility and urgency, by making S&T [science and technology] progress a major driving force for the economic and social development more conscientiously and resolutely. We must place the strengthening of indigenous innovative capability at the core of economic restructuring, growth model change, and national competitiveness enhancement. Building an innovation-oriented country is therefore a major strategic choice for China's future development

The Medium to Long-Term Plan for the Development of Science and Technology, 2006-2020 (preface)

To this end, the MLP listed concrete steps to strengthen China's STI policies and capacities, including increasing R&D investment as a percentage of national GDP to 2.5 percent. The aim was to reduce dependency on foreign technology to 30 percent (or less), and position China among the top five nations in the world in terms of citations in international scientific papers and patents granted to Chinese citizens. The direct results of this prioritisation are shown in figures 1 to 4 in section 1. The Chinese state-led system has adopted a top-down approach to realizing this **mission-oriented innovation policy** (see Box 2), based on central leadership and coordination, and facilitated by the 11th, 12th, 13th, and 14th five-year plans.

Box 2. Mission-Oriented Innovation

"Mission-oriented innovation establishes a clear outcome and an overarching objective for achieving a specific mission (e.g., setting clear goals and roadmaps towards carbon neutrality). As an example, setting an objective to dramatically reduce greenhouse emissions within a decade is a mission-oriented approach to innovation".

The Organisation for Economic Co-operation and Development (OECD)

This top-down approach, however, was complemented by **a bottom-up approach to organizing science and technology, underlined in the commitment in the 2006 MLP to "take full advantage of the important roles played by universities, research institutes, and national high-tech industrial parks in establishing regional innovation systems"**[6]. The

[6] The Medium to Long-Term Plan for the Development of Science and Technology, 2006-2020

Chinese approach to establishing science parks integrates economic and spatial planning in policy strategy, and combines top-down and bottom-up approaches to organizing STI. As such, the approach is **a balancing act between distinct institutional dynamics**. Indeed, "the development of Chinese science parks demonstrates a dual-directional capital switching between industrial production and land-based development"[7]. The mission to promote collaboration in research and innovation between multiple – public and private – stakeholders was restated in the 13th Five-Year plan (see Box 3).

Box 3: Innovation infrastructure in the 13th Five Year Plan

Enterprises, universities, and research institutes will be entrusted with building national technological innovation centers and we will support the development of corporate technology centers. We will give impetus to the open sharing of research infrastructure and innovation resources by institutions of higher learning and research institutes.

13th Five-Year Plan (2016-2020), Section 3: Infrastructure for Innovation

Policy-makers and researchers increasingly recognize that innovation is generated in interactive systems, and that innovation is best understood to unfold in ecosystems comprised of multiple players. These ecosystems are designed on logics of agglomeration and located in clusters and science parks (often referred to as research parks or science and technology parks). This emphasis on integrating multiple stakeholders to upscale the national innovation base has resulted in the introduction of new strategies to establish science parks in recent Chinese policy programs.

Whereas science parks were originally understood as pivotal for regional economic and industrial development and, therefore, placed under the administration of local and regional governments, the five year-plans that followed the 2006 MLP marked out science parks as a national concern. Science parks gradually became key to national strategic priorities and for realizing China's science and research policies and missions and strengthening its global position.

The first science park in China, the Beijing Experimental Zone for New Technology and Industrial Development (BEZ), was established in 1988 by the local government of Beijing. Today, BEZ is known as the Zhongguancun Science City – "China's Silicon Valley". Its main

[7] Kan Zhu, Fangzhu Zhang, and Fulong Wu (2022). Creating a State Strategic Innovation Space: The Development of the Zhangjiang Science City in Shanghai. *International Journal of Urban sciences*. Online First: DOI: 10.1080/12265934.2022.2132988. pp. 1-23, p. 7.

focus areas are electronics, energy, and biotechnology. Zhongguancun hosts several higher-learning institutions, such as Tsinghua University and Peking University, as well as research institutes, including those from the Chinese Academy of Science (CAS). The science park is also host to a range of Chinese market leaders such as LENOVO and Baidu, and several multinational corporations (e.g. Microsoft and Nokia). Zhongguancun achieved an average annual growth rate of 30 percent between 1988 and 2008.

In 2016, Beijing Municipality formally approved the construction of a new type of science park, dubbed a "national comprehensive innovation center". Huairou Science City is currently under construction, but is partly open to scientists for work in its laboratories. Located north of Beijing, the goal of Huairou Science City is to become the world's largest and most significant science park in terms of scientific and technological resources. In China's 14th and latest five-year plan (2021-2025), the plans for Huairou Science City were outlined as an important element of China's nationwide scientific and technological innovation platform (see Box 4).

Box 4: Extract from China's 14th Five-Year Plan

Section 4: Building a major scientific and technological innovation platform

Support Beijing, Shanghai, Guangdong-Hong Kong-Macao Greater Bay Area to form international science and technology innovation centers

Build comprehensive national science centers in Beijing Huairou, Shanghai Zhangjiang, Greater Bay Area, Hefei, Anhui, and support the construction of regional science and technology innovation centers in places where conditions permit

Strengthen innovative functions such as national independent innovation demonstration zones, high-tech industrial development zones, and economic and technological development zones

Appropriately advance the layout of major national scientific and technological infrastructures to improve the level of sharing and use efficiency.

China's 14th Five-Year Plan (2021-25)

The geographical concentration of research institutes, government agencies, and enterprises, and the institutional links and collaborations this concentration fosters, is captured in the concept of the **Triple Helix model** from science and technology studies.

The Triple Helix model differs from state-centered ("statist") models in which university and industry institutions are tightly controlled by government. In the statist model, government takes comprehensive leadership in developing projects and programs that institutionalize the relationship between universities and industry (see Figure 6).[8]

At the other end of the spectrum from the statist model is the "laissez-faire" model where each entity – government, industry, and university – is distinct and independent, and there is limited interaction. In the laissez-faire model, institutions may defend their territories to the detriment of knowledge flows between universities, private enterprises, and government agencies.

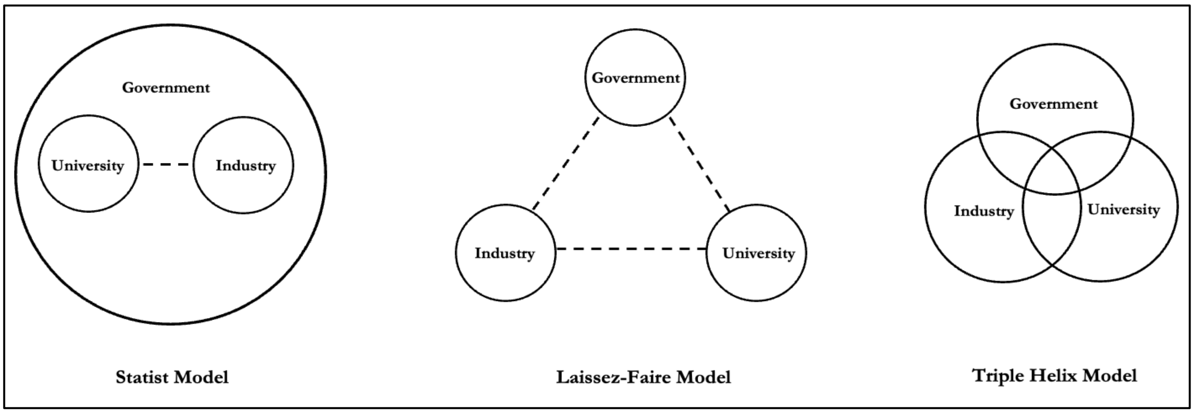

Figure 6. The Triple Helix

Science parks are a clear reflection of the Triple Helix model**.** While state intervention and leadership in organizing science, technology, and innovation have been influential in the Chinese approach to innovation (i.e., the statist model), the central government's emphasis on creating innovative hubs across, in particular, its eastern regions has generated what the Triple Helix literature refers to as "a knowledge infrastructure [of] overlapping institutional spheres, with each taking the role of the other and with hybrid organizations emerging at the interfaces"[9].

In the Chinese context, such hybrid organizations located in sites of spatial proximity (e.g., science parks) may include university spin-off firms and strategic alliances between firms, (national and foreign) academic research groups, and government laboratories that are encouraged but not necessarily tightly controlled by central government.

[8] See, Henry Etzkowitz & Loet Leydesdorff (2000). The Dynamics of Innovation: From National Systems and "Model 2" to a Triple Helix of University-Industry-Government Relations. *Research Policy* 29: 109–123.
[9] Ibid., p. 111

3. MAPPING THE ROLE OF SCIENCE PARKS IN INDUSTRIAL DEVELOPMENT

Defining Science Parks

At the global level, the number of science parks has rapidly increased since the establishment of the first science parks in the US in the 1950s. The most famous technology cluster probably remains Silicon Valley in California, known for its significant innovation output. Science parks have now become key nodes in the global STI infrastructure. More than 1000 science parks existed worldwide by the end of the 1990s.[10] In 2013, the European Commission reported that there were an estimated 366 science parks in EU member states, employing approximately 750,000 people across 40.000 organizations[11]. According to the US Department of Commerce, "Science parks are seen increasingly around the world as a means to create dynamic clusters that accelerate economic growth and international competitiveness"[12].

Several terms are used interchangeably to describe science parks, both in policy and scholarship. Science parks are often referred to as technology parks, science and technology parks (STPs, or S&T parks), science and technology industrial parks (STIPs), high-technology industrial parks, research parks, innovation parks, innovation centers, science cities, and techno-poles (mostly in the Francophone world). This report deploys the term "science park".

According to the OECD definition, "Science and technology (S&T) parks include a large variety of initiatives to stimulate the growth of high-technology employment and to encourage technology and knowledge transfer between universities and other research organisations and companies. S&T park objectives include: *i*) economic development (new technology-based firms, attracting new industries, etc.); *ii*) transfer of technology (between academia and industry); and *iii*) local benefits (job creation, cultural change, and image)"[13].

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[10] Dylan Sutherland (2005). China's Science Parks: Production Bases or a Tool for Institutional Reform? *Asia Pacific Business Review* 11(1): 83-104, p. 86.

[11] European Commission, Directorate-General for Regional and Urban Policy (2013). *Setting Up, Managing and Evaluating EU Science and Technology Parks, An Advice and Guidance Report on Good Practice*, October 2013, available online: https://ec.europa.eu/regional_policy/en/information/publications/studies/2013/setting-up-managing-and-evaluating-eu-science-and-technology-parks-an-advice-and-guidance-report-on-good-practice

[12] Hearing before the Committee on Commerce, Science, and Transportation, United States Senate (First Session), December 9, 2009; Statement made by Hon. John R. Fernandez, Assistant Secretary of Commerce, Economic Development Administration, U.S. Department of Commerce.

[13] Organisation for Economic Co-operation and Development (OECD) (2011). *Regions and Innovation Policy*, OECD Reviews of Regional Innovation. OECD Publishing, p. 195.

Accordingly, the parks' objectives are to become areas that promote scientific and technological development, e.g., through research and attracting technology-based companies. This is achieved by providing an innovation ecosystem that is conducive to knowledge-based work and R&D activities (see Box 5). Science parks – as innovation ecosystems and spatial clusters – are important sources of knowledge spillovers and technology transfers.

Box 5: Innovation Ecosystems and Spatial Clusters

"Innovation, knowledge creation and learning are all best understood if seen as the result of interactive processes where actors possessing different types of knowledge and competencies come together and exchange information with the aim to solve some – technical, organizational, commercial or intellectual – problems".

Harald Bathelt, Anders Malmberg, & Peter Maskell (2004).

In this report, we draw on the definition of science parks provided by the International Association of Science Parks and Areas of Innovation (IASP) (see Box 6). This definition provides a set of criteria, including specialized professionals, a culture of innovation, and institutional cooperation between university and industry, as reflected in the Triple Helix model.

Box 6: Definition of "Science Parks"

A science park is an organisation managed by specialised professionals, whose main aim is to increase the wealth of its community by promoting the culture of innovation and the competitiveness of its associated businesses and knowledge-based institutions.

To enable these goals to be met, a Science Park stimulates and manages the flow of knowledge and technology amongst universities, R&D institutions, companies and markets; it facilitates the creation and growth of innovation-based companies through incubation and spin-off processes; and provides other value-added services together with high quality space and facilities.

IASP website (https://www.iasp.ws/our-industry/definitions)

Mapping Science Parks

In situating and assessing the role of science parks in Chinese public policies and programs intended to promote China as a "global science superpower", this report applies the framework of "mission-oriented innovation" developed by Professor in Economics of Innovation and Public Value, Mariana Mazzucato. Mission-oriented innovation suggests that public policies related to science, technology, and innovation should be designed to directly address long-term societal challenges and promote the technological upgrading that is required to address these challenges. According to Mazzucato, systemic changes to meet societal challenges are contingent on cooperation between multiple stakeholders representing government, industry, civil society, and university. Indeed, "the development of contemporary Chinese science parks should be studied against the expanding state guidance for technology upgrading"[14].

To effectively address long-term societal challenges, it is important that governments and other public policy actors, such as regional and international organizations, select a number of high-impact missions to focus on. Examples of such missions are industrial development, poverty alleviation, climate change, health, and an aging society. Short-term and isolated approaches to systemic societal challenges have proven inadequate. Missions should be "measurable, ambitious, and time-bound targets that have the potential to become one of the most significant vehicles for change"[15].

China's recent pledge to reach peak carbon dioxide (CO_2) emissions before 2030 and achieve carbon neutrality by 2060 is an example of a mission-oriented innovation policy. To achieve the mission of mitigating climate change, China has set the ambitious target of increasing the share of non-fossil energy consumption by 20 percent by 2025, 25 percent by 2030, and in excess of 80 percent by 2060. Concrete actions include the lowering of energy consumption by 13.5 percent from the 2020 level by 2025, the capacity of wind and solar power to reach over 1,200 gigawatts and the coverage rate of forest to reach 25 percent by 2030. This mission is at the same time ambitious (China is currently the biggest emitter of carbon dioxide), measurable (concrete targets are set), and time-bound (carbon neutrality by 2060).

A core concept in Mazzucato's framework on mission-oriented innovation is the "**entrepreneurial state**"[16]. The concept suggests that the state is the main agent behind innovation policies and advances, as opposed to private and independent entrepreneurs, and large companies. Private actors, in turn, often capitalize upon the efforts of risk-taking governments in solving grand societal challenges that require massive investments in science and technology. These investments are made in the early stages of the innovation process, when

[14] Kan Zhu, Fangzhu Zhang, and Fulong Wu (2022). Creating a State Strategic Innovation Space: The Development of the Zhangjiang Science City in Shanghai. *International Journal of Urban sciences*. Online First: DOI: 10.1080/12265934.2022.2132988. pp. 1-23, p. 7.

[15] Organisation for Economic Co-operation and Development (OECD). Website of the Observatory of Public Sector Innovation on "Mission-Oriented Innovation": https://oecd-opsi.org/work-areas/mission-oriented-innovation/

[16] Mariana Mazzucato (2013). *The Entrepreneurial State: Debunking Public vs Private Sector Myths.* London: Anthem Press.

private enterprises often perceive investment as high risk. Public investments are therefore directed into large top-down R&D policy schemes that create new markets for innovative firms. Mazzucato suggests that entrepreneurial states often play a market-creating role, particular shaping new markets in, for instance, renewable energy and quantum technology where the risks of market failure are high.

Chinese innovation policies over the last decade have reflected Mazzucato's framework. The Chinese state has acted as an "entrepreneurial state" in being the main agent in developing and consolidating the nation's innovation system. China has explicitly adopted a mission-oriented policy, most recently with the 2006 MLP and the 11^{th}-14^{th} Five-Year Plans. In brief, China's innovation capacity is fostered by the dual efforts of state and market. The central government acts as the institutional enabler and market regulator in an increasingly firm-centered innovation model. Plans and strategies have set measurable goals for Chinese universities in general and the Chinese Academy of Sciences (CAS) and the University of Chinese Academy of Sciences (UCAS) in particular.

4. CHINA'S MISSION-ORIENTED INNOVATION DEVELOPMENT

Public policies and central planning have played an important role in China's ambition to achieve scientific and technological advances and, more recently, to move to the frontiers of global science. China's mission-oriented policy approach to innovation has over time been operationalized through five-year plans and key policy programs. These programs and plans have initiated important paradigmatic changes in the organization of science, technology, and innovation (see Box 7).

Box 7: Public Policy Plans & Programs (Science, Technology, and Innovation)	
Imitation	**1949**: Chinese Academy of Sciences (CAS) established
	1956: Twelve-Year Plan (1956-67), Development of Science and Technology
	1978: Deng Xiaoping launches the Four Modernizations program
	1979: US-China Agreement on Cooperation in Science and Technology
	1982: National Key Technology R&D Program
Innovation	**1986**: Spark Program
	1986: National High-Technology R&D Program (the 863 Program)
	1986: National Natural Science Foundation of China (NSFC)
	1988: Torch Program
	1992: Sino-Russia Science & Technology Cooperation Agreement
	1997: National Basic Research Program (the 973 Program)
	1998: EU-China Science & Technology Cooperation Agreement
	2006: Medium to Long-Term Plan for the Development of Science and Technology
Invention	**2013**: Xi Jinping President of the PRC (reappointed in 2018 and 2022)
	2013: "Made in China 2025" Initiative
	2015: Tu Youyou becomes the first Chinese Nobel laureate
	2016: National strategy for building National Comprehensive Innovation Centers
	2016-20: 13th Five-Year Plan (first FYP under the Xi Jinping administration)
	2021-25: 14th Five-Year Plan (innovation highest priority for national development)

The 1988 Torch Program established China's first science parks and the pivotal National Medium and Long-Term Plan for the Development of Science and Technology (2006–2020).

This plan (MLP) spearheaded China's transition from following a science and technology catch-up strategy centered on imitating extant technologies embodied in, for instance, (imported) final products, to adopting a mission-oriented innovation policy. In China, this mission oritentated policy is based on the principle of homegrown, "indigenous innovation" to reduce dependency on foreign technologies and has been reflected in a rapid and steep increase in R&D investment.

Recently, China has established a strategy to build large-scale national innovation centers (including the Huariou Science City). This strategy has resulted in large investments in advanced national laboratories and basic science, to position China as a "world science superpower" attractive to foreign talents and international research networks and funding. This strategy should be undersood in the context of three distinct periods in Chinese STI policy characterized by: (1) imitation; (2) innovation; and (3) invention (see Box 7).

Imitation: 1950s to mid-1980s

The first period (**imitation**) stretches from the beginning of the 1950s to the mid-1980s. Here, Chinese public policy and planning targeting science and technology were mainly centered on "catching up". During the time of Deng Xiaoping (1978-1989), formulating and implementing science and technology policies became a policy priority, in the belief that a strong science and technology base was essential for economic growth. Science and technology became one of Deng Xiaoping's so-called "Four Modernizations" (next to agriculture, industry, and defense), reflecting a programmatic approach to consolidate and align socialism with economic modernization – a key aspect of Deng Xiaoping's "Reform and Open Door" agenda.

During the Deng presidency, the policy-making structure for science and technology was established and guided by the aim of integrating science and technology into planned economic acitivity. The National Planning Outline for Science and Technology Development (1978-85) identified 108 research projects to be pursued within eight key science and research fields: Agriculture, energy, materials, computer, laser, space, high-energy physics, and genetics. To this end, it outlined four main goals to be achieved by 1985:

1. Catch up with the advanced economies in important science and technology fields
2. Increase the number of science and technology professionals to 800,000
3. Establish up-to-date research centers
4. Complete a nation-wide system of science and technology

Imitation was largely carried out by reverse engineering; a "mode of technological development strategy that entails the acquisition of technological principles by autopsying final (typically, imported) products"[17]. Applied science was emphasized during this first phase of reforming the country's science and technology system. The Chinese Academy of Sciences (CAS) followed a strategy of "one academy, two systems" according to which a smaller group of researchers would focus on basic science, whilst the majority of research personnel would engage in applied science that would benefit the economy directly.

To catch up with and close the technological gap to advanced industrialized countries, China introduced the Key Technologies R&D Program in 1982, followed by the Spark Program in 1986. These two programs were launched to promote the transfer of advanced applied technologies to rural areas.

The 863 Program, formally the High Technology Research and Development Plan, was launched in 1986. This also aimed ot narrow the gap between indigenous and advanced foreign technologies. Administered by the Ministry of Science and Technology, the program focused mainly on applied science. It identified eight major areas of national priority for catching up: biotechnology, space technology, information technology, laser technology, automation technology, energy technology, new materials, and ocean technology. The plan was subsumed within China's overarching ambition to spur industrial development and limit reliance on foregn technology in a shift from low-technology manufacturing to high-technology production.

Innovation: 1980s to 2010s

The subsequent period of **innovation** wass shaped by the launch of the Torch Program in 1988 which sought to develop new high-tech industries, train a talented workforce, and promote international cooperation by establishing high-tech development zones (HTDZs). Indeed, the establishment of HTDZs was identified in the Torch Program as the key means to accelerate the development of Chinese high-technological industries. Designed to foster bottom-up innovations, HTDZs, and science parks more generally, were identified as significant to the development of a national innovation system. This correlates with the strategy of mission-oriented innovation policy in Mazzucato's framework, according to which "successful

[17] Jong-Hak Eun, Keun Lee, and Guisheng Wu (2006). Explaining the "University-Run Enterprises" in China: A Theoretical Framework for University-Industry Relationship in Developing Countries and Its Application to China. *Research Policy* 35(9): 1329-1346, p. 1340.

innovation policy combines the need to set directions from above with the ability to enable bottom-up experimentation and learning"[18]. The policy approach was further consolidated in the 2006 MLP, which emphasized the role of science parks in creating an innovation base for science and technology and reducing dependency on foreign technologies.

The focus on science parks, in particular following the 1988 Torch Program administered by the Ministry of Science and Technology, provided an important space for bottom-up experimentation and learning. The Torch Program aimed to support the commercialization of research results with applied science forming the basis to, "develop high-tech industries by promoting the commercialization of S&T achievements, the industrialization of R&D results, and the internationalization of high-tech industries"[19]. In the mid-1980s, a number of researchers affiliated to universities and research institutes located in Beijing's Zhongguancun district founded small-scale enterprises to commercialize research results. Most of these enterprises were engaged in electronics and located on the same street in Zhongguancun, coined "Electronics Street". Zhongguancun became a high-technology center. Following the Torch Program, it was formally nominated an HTDZ (i.e., a science park).

A central aim of the Torch Program was to ensure that these newly established high-tech zones, or science parks, would constitute an innovation ecosystem conducive to high-tech innovation and international collaboration and investment. High-tech enterprises within the science parks would enjoy preferential treatment in terms of state subsidies and tax rebates. The 2006 MLP retained this emphasis on top-down planning combined with bottom-up experimentation and learning. It rested on a belief in the merits of the Triple Helix model and sought to foster close institutional ties and spatial proximity between actors possessing different types of knowledge and competencies. The implementation of the MLP became an important focus in subsequent five-year plans, ultimately leading to a new policy paradigm centered on invention.

The ambition of the MLP was to advance and consolidate China's scientific leadership by 2020, and make China a technology exporter, and, notably, a "world science and technology superpower" by 2050. To channel this ambition, the MLP introduced the concept of **indigenous innovation.** This concept would serve to reduce China's reliance on foreign technologies and scientific achievements and enable China to "leapfrog"to a position of international

[18] Mariana Mazzucato (2017). "Mission-Oriented Innovation Policy: Challenges and Opportunities", UCL Institute for Innovation and Public Purpose Working Paper (September 2017), p. 3.
[19] Torch Program (2011). *National High-Tech Industrial Zones in China*. Ministry of Science and Technology, Torch High Technology Industry Development Center. People's Republic of China, p. 2

technological and scientific leadership. The MLP conceptualized indigenous innovation as consisting of three types of innovation: (1) genuinely original innovation from increased investments in basic science and national key laboratories and research facilities; (2) integrated innovation, by which existing technologies are fused together in new and innovative ways; and (3) re-innovation, defined as improving upon or assimilating imported technologies.

According to the MLP, the following objectives should be met by 2020:

1. Increase R&D investment as a percentage of national GDP to 2.5 percent
2. Reduce dependence on imported foreign technology to no more than 30 percent
3. Raise contributions of technological advances to economic growth above 60 percent
4. Position China among the top five nations in the world in scientific citations

In line with the mission-oriented innovation framework, the MLP identified a set of priority areas and programs. These included 11 key areas, such as energy, environment, health, and urbanization (all related to national needs); eight fields of "frontier technology" (i.e., applied science projects); 13 "engineering mega-projects", such as "new-generation broadband wireless mobile telecommunications" and "water pollution control and treatment"; and four basic science megaprojects within reproductive biology, protein science, quantum research, and nanotechnology (see Box 8 below).

To realise the strategy of indigenous innovation, the 2006 MLP policy framework included tax incentives, the strengthening of intellectual property rights protection (especially of China-based patents and inventions), the strengthening and diversification of funding for science and technology, and concrete policies for the recruitment of research talent from abroad and the fostering of talent at home through public investments in education.

The principle of indigenous innovation resulted in several new strategies targeting innovation and industrial development. China's Thousand Talents Program launched in 2007 to attract and recruit scientists (in particular of Chinese nationality) from prestigious research environments abroad reflects this change in policy. Adopted in 2015, the "Made in China 2025" industrial plan aims to position China as the global leader in manufacturing high-quality and high-technology products within ten advanced technology and equipment fields (including information technology, new materials, and space and aviation). To meet this goal, R&D would become more indigenized and no longer rely on foreign R&D knowledge and investment. Chinese firms would receive preferential treatment through loans, subsidies, and tax rebates.

Box 8: Science Programs Identified in the MLP	
Key Areas	
Agriculture Energy Environment Information technology Manufacturing National defense	Population & health Public securities Transportation Urbanization & urban development Water & mineral resources
Science Megaprojects	
Reproductive biology Protein science	Quantum research Nanotechnology
Frontier Technology	
Advanced energy Advanced manufacturing Aerospace and aeronautics Biotechnology	Information Laser New materials Ocean
Engineering Megaprojects	
Advanced numeric-controlled machinery and basic manufacturing technology Control and treatment of AIDS, hepatitis, and other major diseases Core electronic components, high-end generic chips, and basic software Drug innovation and development Extra large scale integrated circuit manufacturing and technique Generally modified new-organism variety breeding High-definition Earth observation systems Large advanced nuclear reactors Large aircraft Large-scale oil and gas exploration Manned aerospace and Moon exploration New-generation broadband wireless mobile telecommunications Water pollution control and treatment	

Invention: 2010s – today

The evolution of Chinese STI policy-making has recently entered a phase centered on **invention**. By the launch of the 13th Five-Year Plan (2016-2020), ten years after the 2006 MLP goals were formulated, China had climbed from a 29th to the 14th position in the Global Innovation Index (GII) and surpassed the US in scientific publications. The Global Innovation Index is published by the World Intellectual Property Organization (WIPO) and consists of approximately 80 indicators to rank the innovation capabilities of world economies. Indicators include, for instance, expenditure on education and patents by origin. In 2022, China ranked 11th on the GII, following Denmark in 10th position.

Since 2019, China has been developing the follow-up plan to the 2006 MLP, the new 15-year MLP (2021-2035) which has not yet been released. However, recent speeches by President Xi Jinping suggest that China is set on the path of original, basic and "big science". At the opening of the Communist Party's 20th congress in Beijing in October 2022, President Xi Jinping declared that China must "regard science and technology as our primary productive force, talent as our primary resource and innovation as our primary driver of growth"[20]. This is evident in the increasing policy emphasis and expenditure channeled to basic science and talent development. The congress report further underlined that China was determined to "expand science and technology exchanges and cooperation with other countries"[21].

The current 14th Five-Year Plan (2021-2026) emphasizes the importance of advancing innovation in science and technology to strengthen economic development and growth. Among other things, it commits to an annual increase in China's R&D investment of more than seven percent. In a speech on the role of science and technology in the 14th Five-Year Plan period, Xi Jinping stressed that investment in basic science and the development of China's national laboratory system were imperative for achieving the goals set out in the new plan: "Amid fierce international competition, unilateralism, and protectionism, we must work out our own way to upgrade, become more innovative, and make more breakthroughs from scratch"[22] (see Box 9).

Box 9: Basic research is the fountainhead of the whole scientific system

"We must aim at the global S&T frontiers, seize upon the major trends, make a good "first move", lay a solid foundation, reserve the long-term, be willing to sit on the bench, dare to be a planter and well-digger, and achieve forward-looking basic research and leading original results as major breakthroughs, laying a solid foundation for building China into a world S&T superpower"

Xi Jinping, March 2021

Xi Jinping added that universities, colleges, and research institutes should play an even more important role in expanding the nation's innovation base. This recently resulted in increased

[20] Quoted in Smriti Mallapaty, "What XI Jinping's Third Term Means for Science", Nature, 27 October, 2022: https://www.nature.com/articles/d41586-022-03414-z

[21] Ibid.

[22] Quoted in Liu Zhen, "Xi Jinping Calls on Science to Solve the Big Problems Choking China", South China Morning Post, 13 September, 2020: https://www.scmp.com/news/china/science/article/3101376/xi-jinping-calls-science-solve-big-problems-choking-china

investment in new and larger cross-disciplinary research facilities and national key laboratories to promote "big science". These big-science national laboratories (also mentioned in the 14th Five-Year Plan), managing large-scale research infrastructures (RIs), are placed under the central government and not individual universities and research institutes. Large-scale RIs have been key to the success of national laboratories world-wide. For example, the Brookhaven National Laboratory, home to several RIs and supported by the U.S. Department of Energy, has produced seven Nobel Prize-winning discoveries since 1947. Large-scale RIs are defined as "large scientific instrumentation, facility, and equipment clusters that require large investments and complex engineering and networking efforts; they are usually recipients of funding by national or supranational bodies and shared by communities of scientists"[23]. They are important for attracting top talents and international research groups and funding. RIs include, for instance, the world's largest particle accelerator, the Large Hadron Collider (LHC), located in the European Organization for Nuclear Research (CERN) in Switzerland and the European Spallation Source (ESS) located in Lund, Sweden. In China, CAS has been responsible for the construction and management of the majority of large-scale RIs.[24] Among Chinese RIs are Five-hundred-meters Aperture Spherical Telescope (FAST), located in Guizhou, and the Shanghai High Repetition-rate X-ray Free Electron Laser and Extreme Light Facility (SHINE) – both among the world's largest RIs. With the constructon of the Huairou Science City, central government is concentrating resources on establishing large-scale, big-science RIs.

Within the context of the US-China trade war, which triggered a reassertion of the concept of indigenous innovation, Xi Jinping has noted that Chinese scientists should be "patriotic and innovative". At the same time, a key concern in bolstering the nation's innovation base during the 14th Five-Year Plan period is to create a competitive and attractive environment for international scientists. According to the President, "We will gradually allow international science and technology organizations to set up in China, allow foreign scientists to work in Chinese science and technology institutions, and make China a free arena for open global cooperation in science and technology"[25].

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[23] Beatrice D'Ippolito and Charles-Clemens Rüling (2019). Research Collaboration in Large Scale Research Infrastructures: Collaboration Types and Policy Implications. *Research Policy* 48: 1282-1296, p. 1292.

[24] See, Lili Qiao, Rongping Mu, and Kaihua Chen (2016). Scientific Effects of Large Research Infrastructures in China. *Technological Forecasting & Social Change* 112: 102-112; Xiyi Yang, Xiaoyu Zhou, and Cong Cao (2023). Remaking the Chinese Academy of Sciences. *Science* 379(6629): 240-243.

[25] President Xi Jinping, quoted in Liu Zhen, "Xi Jinping Calls on Science to Solve the Big Problems Choking China", South China Morning Post, 13 September, 2020:

The evolution of priorities in Chinese science, technology, and innovation policy plans and programs through the three phases of imitation, innovation and invention is illustrated in Figure 7. It shows how STI priorities changed over time from a concern for establishing an educational system to support early industrial development to building a nation-wide innovation system supporting China’s integration into, and extraction of technological know-how from global innovation networks. This has over time been achieved by, among other things, political support and investment in industrial clusters and the early science parks within the Torch program. In the current policy paradigm, focus has shifted towards being at the forefront of global science, technology and innovation. An important means in realizing this ambition is the construction of large-scale research infrastructures, attractive to local and international top talents and research funding, managed by national laboratories under the central government, and located within the next generation of science parks in China, that is, “National Comprehensive Innovation Centers” (such as the Huairou Science City).

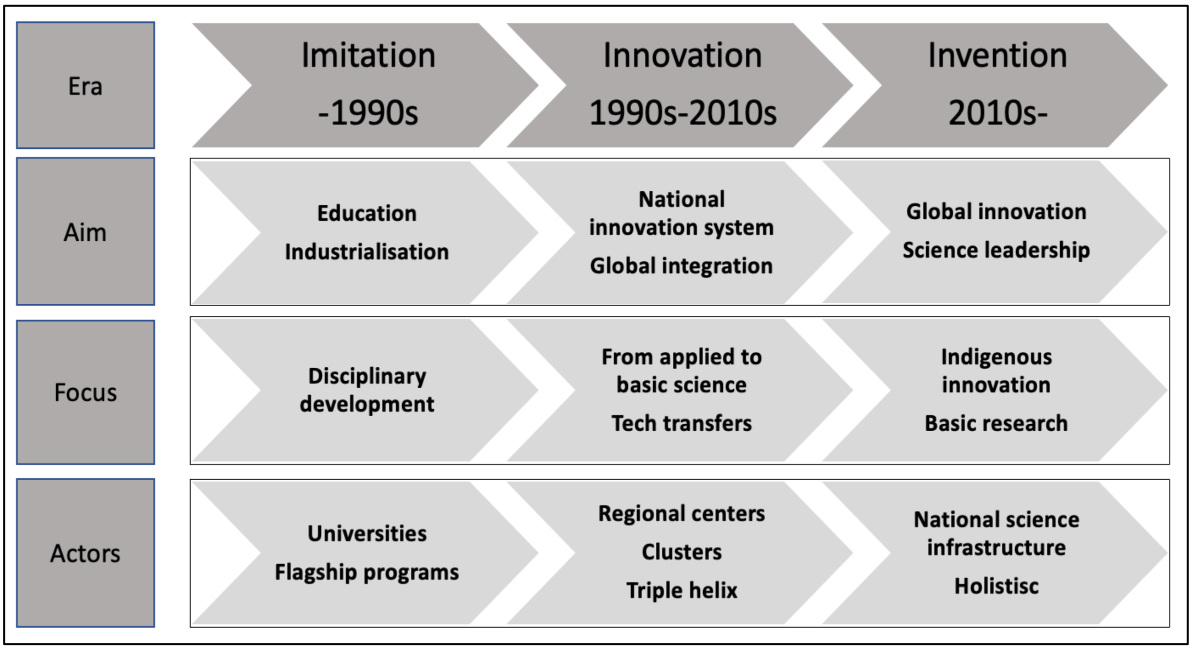

Figure 7: The Evolution of China’s STI Policies

https://www.scmp.com/news/china/science/article/3101376/xi-jinping-calls-science-solve-big-problems-choking-china

5. SCIENCE PARKS IN CHINA – INNOVATION BY DESIGN

The first science park in China, the Zhongguancun Science Park in Beijing, was established in 1988. By the end of 1992, the Chinese government had already approved over 52 state-level science parks (officially referred to as high-tech industrial development zones, HTDZs, under the Torch program). This number reached 53 in 1997 with the establishment of the Yangling Agricultural Technology Park in the western province of Shaanxi, and 54 in 2007 when the Ningbo Science Park was established in Zhejiang province.[26] In the period from 1992-2000, the number of firms in science parks tripled, labour productivity quadrupled, and science parks' share of host cities' industrial output increased from two percent to almost 33 percent.[27]

Central government recommited to the establishment of state-level science parks in the early phase of the 11th Five-Year Plan (2006-10). As a result, the number of science parks increased to 89 in 2012, and almost doubled in the period from 2012-2016 to 168.[28] Today, there are 173 national science parks in China, comprising the central component of China's national innovation system.[29] They have all been established under the Torch program and within the jurisdiction of the Ministry of Science and Technology and its Torch High Technology Industry Development Center.

In 2021, Chinese science parks contributed to 13.4 percent of the country's GDP, according to the China's Ministry of Science and Technology.[30] Firms have to obtain a certificate from the Ministry of Science and Technology to enter the parks on the condition that their products are of a "high- and new-technology nature". Additionally, firms have to spend at least three percent of sales on R&D to gain entry. In exchange, science parks offer a range of incentives, including exemption from corporate tax for two years for new firms, license waivers for the important materials and components required s to produce high-tech goods for export, and assistance with registration of intellectual property. The Suzhou Industrial Park close to Shanghai has pursued

[26] Haiyang Zhang and Tetsushi Sonobe (2011). The Development of Science and Technology Parks in China, 1988-2008. *Economics* 5: 2011-6
[27] Albert Guangzhou Hu (2007). Technology Parks and Regional Economic Growth in China. *Research Policy* 36(1): 76-87, p. 78.
[28] Richard P. Appelbaum, Cong Cao, Xueying Han, Rachel Parker, and Denis Simon (2018). *Innovation in China*. Cambridge: Polity Press, p. 123
[29] Zhang Zhihao, "High-Tech Zones Lead Innovative Growth Over Past Decade", China Daily, 15 September, 2022: https://www.chinadaily.com.cn/a/202209/15/WS63228081a310fd2b29e77be6.html
[30] Ibid.

a strategy of attracting large-scale foreign R&D investment and multinational firms (see Box 10).

Box 10: Suzhou Industrial Park

The Suzhou Industrial Park (SIP) was established in 1994 in the Jiangsu province, located in the city of Suzhou 20 minutes by highspeed train from Shanghai. The park was established and jointly developed by the Chinese and Singaporean governments. Today, it is managed by the China-Singapore Joint Steering Council. The initial purpose of the park was to create the best conditions – in terms of infrastructure and services – for foreign investors in China. To meet this purpose, the early development of the park was shaped by Singapore's strategy of attracting multinational corporations. The large majority of corporations located in the park are foreign. It was listed on the Shanghai Stock Exchange in 2019. It hosts several high-tech industries, such as nanotechnology, artificial intelligence (AI), and biomedicine and -technology. The park is home to several universities, including Suzhou University, Renmin University of China (Suzhou Campus), and Xi'an Jiaotong-Liverpool University.

State-level science parks in China's eastern regions are located along the coast in the main cities of Beijing, Shanghai, Shenzhen and Qingdao. In central and western China, science parks are located in, in particular, Chengdu, Wuhan, and Xi'an. This spatial distribution of science parks follows the general distribution of industrial and technological resources and capabilities across China.

Chinese Science Parks: Integrating Economic and Spatial Planning

Chinese science parks have followed the same development as East Asian science parks in general. A recent (2022) study suggests that in East Asia, science parks represent the developmental state in pursuing an economic development policy of proactive planning. As a result, East Asian science parks can be understood as centrally planned and cultivated innovation spaces "due to the visible participation of state actors and state-organized resources"[31].

This is in contrast to the world's first science parks established by universities in the West. Stanford University founded the Stanford Research Park in 1951, which became an important part of Silicon Valley. The Cambridge Science Park was established in 1971 by the University of Cambridge's Trinity College. These university parks were significant in consolidating the research status of the founding universities and strengthening their ties to industry through technology transfer and commercialization. An important motivation was also to raise revenues from the universities' landholdings. This suggests a more spontaneous, and less planned, approach to creating innovation spaces by university entrepreneurs and private ventures, with little or no state involvement.

Box 11: Regional Comparison of Science Parks

In a 2011 study on "Regions and Innovation Policy", the OECD noted: "The science parks, high-tech quarters and innovation centers of Anglo Saxon countries are usually of much more modest scale and ambition. In the United States, quite large geographic areas may be included, but the degree of planning beyond that of restrictive zoning is small. In northern Europe and Scandinavia, sites are always small, and the incubator unit for new firms is the dominant model. Such sites may be elements of larger technology complexes at the urban scale, and in some cases are parts of new towns".

In East Asia, science parks have tended to be larger, promoted by central government and more integrated into national development strategies. This is distinct strategy from science parks in the West. In East Asia, science parks have largely been configured as policy tools for centrally planned national strategies. For example, the establishment of science parks in China in the 1990s was guided by China's approach to economic reform, emphasizing decentralization, marketization, and globalization. With decentralization, local governments focused

[31] Kan Zhu, Fangzhu Zhang, and Fulong Wu (2022). Creating a State Strategic Innovation Space: The Development of the Zhangjiang Science City in Shanghai. *International Journal of Urban Sciences*. Online First: DOI: 10.1080/12265934.2022.2132988. pp. 1-23, p. 4.

increasingly on local economic development, which involved improving local business environments through, for instance, industrial park development. Second, the establishment and management of East Asian science parks are closely related to urban development, in particular in terms of redistributing land value appreciation and balancing land use between industrial, residential, and environmental functions (Huairou Science City is a clear case of such a balancing act). Whereas urbanization is usually assessed as an external condition that motivates innovation activities, science parks in East Asia, and in China in particular, are often designed to institutionally support urban development tasks. "East Asian science parks have gradually shifted from industrial agglomerations and production sites toward mega urban projects"[32]. The development of science parks in China has followed the same pattern as in other East Asian nations. Where science parks originally were perceived as means to commercialize universities' science and technology assets and therefore to simply fulfill universities' commercialization strategies, they are increasingly conceived as important means for regional and national development and catch-up, including the promotion of national technology development and international competitiveness. Beginning in the early 2010s, and initiated in particular by the MLP plan, Chinese central government regained its power in controlling and constructing high-tech zones, science parks, and other strategic innovation spaces. The establishment of the Zhangjiang Science City in Shanghai (see Box 12) and the Huairou Science City in Beijing are two prominent examples of a new type of science park.

Box 12: The Zhangjiang Science City

The future Zhangjiang Science City is located in the Pudong area east of the city of Shanghai. The aim is to upgrade the Zhangjiang Hi-Tech Park (established in 1992) into a science park and expand the area to cover 94 square kilometers. Currently under construction, the project was initiated in 2016 when the Zhangjiang Science City became part of the Chinese central government's strategy to build a handful of strategically placed National Comprehensive Innovation Centres. An important part of this transition is the development of large research facilities funded by central government. According to *Nature*, the Zhangjiang Science City "boasts one of the country's most established biotechnology hubs"[1]. As of November 2022, Zhangjiang hosts more than 18,000 companies and 440 R&D institutes, including R&D centers of the world's largest pharmaceutical and biotech firms. In 2021, the Shanghai city government announced plans to develop the science city into an "internationally influential innovation center" in biomedicine by expanding the industry cluster in Zhangjiang and encouraging R&D investment by offering subsidies. As envisioned by the central government's 2016 strategy on "National Comprehensive Innovation Centres", Zhangjiang will develop into a so-called "science city".

[32] Ibid., p. 5.

Huairou Science City: A National Comprehensive Innovation Center in Beijing

Huairou Science City and the Zhangjing Science City are both part of the national strategy for building **National Comprehensive Innovation Centres** (*guo jia zong he ke chuang 28hong xin*), initiated by the State Council in 2014 and officially launched in 2016. This strategy was further developed in the 13th Five-Year Plan of National Strategic Science Infrastructures, promulgated by the National Development and Reform Commission in January 2017 (see Box 13).

> **Box 13: National Development Reform Commission 2017**
>
> "…construct a number of the National Comprehensive Innovation Centers with international impact [in] Beijing, Shanghai, Hefei and other areas where facilities are concentrated […] To become an important node in global innovation networks, frame the platform foundation of the national innovation system, and promote spillover effects for regional innovation-driven development […]. Overall, to serve the national strategic interests in major scientific and technological tasks, promote breakthroughs in original innovation and basic research, and conquer the challenges in core and key technologies. Above all, to strengthen China's voice in international science and technology competition".

According to the State Council, the strategy aims at "**establishing a national innovation system with Chinese characteristics**" to "improve the level of economic and social development and international competitiveness" in order to reach the goal of becoming a "world science and technology innovation power by 2050".

To this end, the infrastructure for an innovation-driven economy should be improved, including the construction of national laboratories of a quality that would make them internationally competitive, "large-scale cross-disciplinary research platforms", and "a comprehensive, high-level international science and technology base" together with "world-class scientific research centers" across four large cities (see Table 1 for details). The implementation of the national strategy was placed directly under the central government, as opposed to local or regional governments.

City	Entitlement date	Local innovation spaces	Area	Strategic emerging industries
Shanghai	Feb 2016	Zhangjiang Science City	94 km²	Integrated circuit Biotech Artificial intelligence
Hefei	Jan 2017	Binhu Science City	102 km²	Quantum information science New energy Artificial intelligence
Beijing	May 2017	Huairou Science City	101 km²	New material Energy conservation and environmental protection industry Biotech
Shenzhen	March 2020	Guangming Science City	99 km²	Information industry Biotech New materials

Table 1. Planned National Comprehensive Innovation Centers in China[33]

The construction plan for Huairou Science Park was included in the 13th Five-Year Plan for Beijing in January 2016, and formally approved by Beijing Municipality in November 2016. It is located in Beijing's northern Huairou district and part of Beijing's "Urban Master Plan" (2016-2035), named "Three Cities, One Area". The plan's stated ambition is to turn the capital of China into an international high-tech and scientific center. The three science cities are Huairou Science City, the Zhongguancun Science City, and the Future Science City located in the Changping District**.**

The Huairou Science City is envisaged to be fully operational by 2035 (though several research facilities are already open for researchers and students). It is planned to span more than 100 square kilometers, and host 16 large-scale, cross-disciplinary RIs (e.g., a High Energy Photon Source), almost 50.000 researchers, and the main campus of the University of Chinese Academy of Sciences (UCAS). The Beijing municipal government alone has committed to spend USD 2.27 billion on this major science infrastructure project. The construction of Huairou Science City incorporates the construction of a high-speed train connection to Beijing

[33] Source: Kan Zhu, Fanzhu Zhang & Fulong Wu (2022). Creating a State Strategic Innovation Space: The Development of the Zhangjiang Science City in Shanghai. *International Journal of Urban Sciences* (online first): 1-23, p. 9.

center, new schools and high-schools, residential areas, and the expansion of the area’s tourism and health system (such as a new research hospital).

The Huariou Science City covers the five major scientific areas of space science, material science, earth system science, life sciences, and intelligent science (see Figure 8), and includes researchers from a variety of universities and institutes in and around Beijing. A large number of CAS research institutes will be located in the science city, such as the National Space Science Center, the Institute of Nanoenergy and Nanosystems, the Institute of High Energy Physics, the Institute of Electronics, and the Institute of Chemistry.

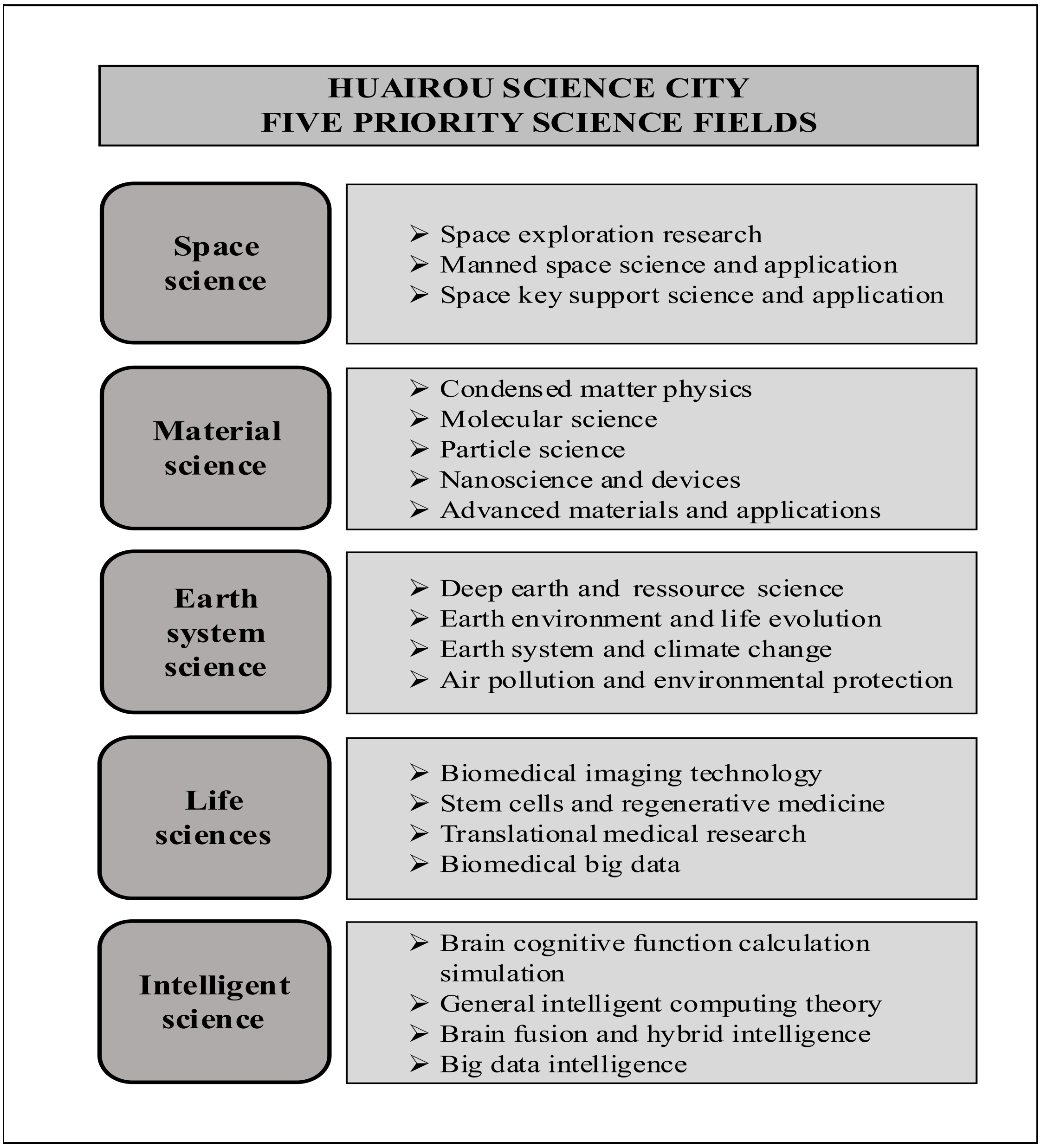

Figure 8. Major Priority Areas of Huairou Science City

To support these five scientific areas institutionally, the Chinese central government will establish a number of "national laboratories", managed by different universities (e.g., Peking University and Tsinghua University) and research institutes (CAS), and located in the Huariou Science City. In the 13th Five-Year Plan, it was stated that, "a number of national laboratories should be set up in major innovation fields". National laboratories are established by the Ministry of Science and Technology and ultimately placed under the control of the central government.

Whereas existing national laboratories in China (referred to as "state key laboratories" in the Chinese innovation system) often are single-purpose, the multi-purpose comprehensive national laboratories are cross-discplinary, and embrace several research fields. Together with the establishment of new large-scale RIs, they are oriented towards "big science" and major scientific breakthroughs (see Figure 9, next page).

Today, there are more than 500 state key laboratories, mainly located in the Beijing area. Half of these key laboratories are affliated with universites and research institutes, with the other half linked to state-owned enterprises. The larger, cross-disciplinary national laboratories are more explicitly oriented towards national strategic needs, such as public health and national security, are granted more resources and facilities than other university or industrial laboratories, with the intention to expand both basic and applied sciences.[34]

[34] See, Jane Qiu (2016). Building National Laboratories to Meet China's Development Challenges. *National Science Review* 3: 387-391.

Project	Institute
Material genome research platform	Institute of Physics, CAS
Clean Energy Materials Testing Diagnostics and R&D Platform	Institute of Physics, CAS
Advanced light source technology research and development and test platform	Institute of High Energy Physics, CAS
Advanced experimental platform for advanced carrier and measurement technology	Institute of Mechanics, CAS
Space Science Satellite Series and payload development test support platform	National Space Science Center of CAS
International Meridian Science Program Headquarters	National Space Science Center of CAS
High-energy synchrotron radiation source supporting comprehensive experimental building and user service building	Institute of High Energy Physics, CAS
Interdisciplinary Research Platform for Interdisciplinary Science and Process Simulation	Institute of Engineering, CAS
Brain cognitive mechanism and brain-computer fusion cross-disciplinary research platform	Institute of Biophysics, CAS
Electromagnetic ejection microgravity experimental device platform	Center for Space Application Engineering and Technology, CAS
Beijing Molecular Science Interdisciplinary Research Platform	Institute of Chemistry, CAS
Light element quantum material cross platform	Peking University
Beijing Laser Acceleration Innovation Center	Peking University
Air-ground integrated environment awareness and intelligent response research platform	Tsinghua University

Figure 9. National Laboratories and Cross-Research Platforms in the Huairou Science City

6. CHINA'S INTEGRATION IN THE GLOBAL SYSTEM OF INNOVATION

With the establishment of science parks and the evolution of policies targeting science, technology and innovation, China has developed capacities in accordance with the five-year plans. The most recent one aims at the cutting-edge in technology fields such as artificial intelligence, quantum information, integrated circuits, life and health, neuroscience, biological breeding, aerospace science and technology, and deep sea. In this section, we briefly zoom in on three scientific and technological fields where China is rapidly moving towards a lead position in the global system of innovation. These are quantum science and technology, nanoscience and technology, and energy.

Quantum science and technology

Quantum computing and communications have become important science and technology fields. Media report on a "quantum race" between nations and companies to gain leadership in the quantum technology field. Quantum communication is key to creating more secure networks for transmitting data globally, preventing hacking and cyberattacks. Quantum computers are not only extremely fast and effective (e.g., in terms of data speed) compared to conventional computers, but can solve previously impossible problems. This has major implications for a host of different industries. Quantum comuters are also a high national priority as they can ultimately break encryption and be a significant element of national security systems (as well as providing financial and private data protection).

Box 13: Quantum technology

The first revolution in quantum physics at the beginning of the 20th century enabled interventions such as the transistor and laser, laying the foundations for computer chips and the GPS. The "second quantum revolution", currently unfolding, concerns new technologies to store, process, and transmit information globally.

The US and China are the main global players in developing quantum technology. In 2019, Google announced quantum supremacy with its invention of Sycamore, a quantum computer, that could solve a given problem in 200 seconds. The same problem would take the world's fastest supercomputer 10,000 years to solve. Sycamore is the result of a research collaboration between Google and a team of physicists at the University of California, Santa Barbara. In the same year, the US Congress passed the National Quantum Initiative Act, which committed the

US Government to provide USD 1.2 billion to fund quantum physics research over a period of five years. The Act established a National Quantum Coordination Office tasked with coordinating collaborations between universities, the private sector, and the government.

China is currently funelling a high level of investment into the development of capacity within quantum technologies. The recent five-year plan pushed the advance of Chinese research on quantum computers, quantum communication, and metrology by identifying quantum technologies as a strategic scientific research field. China launched the Micius satellite in 2016, which established an ultrasecure link between two ground stations in China and Austria. In September 2017, the first unhackable video conference took place between the Chinese and the Austrian research teams, using the Micius satellite and quantum cryptographic keys. The Micius itself was developed by a group of Chinese researchers at the University of Science and Technology of China, led by Professor Pan Jianwei. The same research team developed and tested in May 2021 the "Zu Chongzi", a superconducting quantum processor, which is said to be a million times faster than Google's super computer Sycamore.

By 2020, Chinese enterprises and research institutes comprised 13 of the 15 largest patent holders in quantum communication in the world, making "China the epicentre of quantum communication"[35]. In the lead was the Japanese firm Toshiba with 36 patents, followed by the Chinese enterprise, Ruban Quantum Technology, with 22 patents. Among the Chinese patent holders are CAS in third position, Huawei Investment & Holding, Chengdu University of IT, and Southeast University.[36] While China holds the majority of patents across the full spectrum of quantum technology, the US is in the lead on quantum computing with 312 patents distributed across five different enterprises (IBM as the largest patent holder has 96 patents, followed by Microsoft, Intel, MagiQ Technologies, and Google). Chinese patent holders in quantum computing include Beijing University of Post & Telecom, South China Normal University, Quantumctek, Anhui Qasky Quantum S&T, and University of S&T of China. Together, they hold 252 patents.[37]

[35] KPMG (2020). *Quantum Technology in Denmark: The Case for Danish Investment in Quantum Technology (Report)*. Copenhagen, November 2020; available here: https://assets.kpmg/content/dam/kpmg/dk/pdf/dk-2020/11/Quantum-technology-in-Denmark.pdf (p. 26).
[36] Ibid.
[37] Ibid.

Nanoscience and technology

Nanoscience (i.e., the study of structures and materials on an ultra-small nanoscale) and nanotechnology have the potential to revolutionize a host of different areas and industries, including manufacturing, the environment, and healthcare. Indeed, "nanotechnology is one of the core areas of technology competition among developed countries in the 21st century and plays a supporting and leading role in social, economic, and technological development"[38]. Nanoscience and technology were included in China's 2006 MLP as a "science mega-project" and a key component in the "Made in China 2025" initiative. Both strategies committed to large public R&D investments, as well as encouraged private – international and national – R&D investments in expanding the field of nanoscience and technology. Since, the Chinese nanotechnology industry has been developing rapidly, boosted by considerable state funding, and legislative and regulatory support.

The most important location in China's nanoscience and tech infrastructure is the "Nanopolis" in Suzhou. To date, this nanotech industrial zone is the largest in the world. It hosts several multinational companies and Chinese start-ups in nanotechnology. The leading Chinese universities within nanoscience and technology include Peking University, Nanjing University, and University of Science and Technology of China. CAS is one of the leading national research institutes in nanoscience and technology, together with the Suzhou Institute of Nano-Tech and Nano-Bionics (SINANO).

Among significant breakthroughs led by Chinese research teams is the development of a new nanoparticle in 2020. The nanoparticle can be used in the treatment of gene-related disorders as well as specific types of cancer, such as brain, liver, and lung cancer. Another breakthrough in nano-research is the invention of a new nanomaterial by a research team at the CAS Institute of Chemistry, located in the Huariou Science City. This new nanomaterial can be used effectively to eliminate large amounts of liquid pollution and emissions from chemicals used in printing ink, which is perceived as a major threat to human health. This invention inscribes itself into China's ambition to be at the forefront of green transition.

The US is also a leading force in the field of nanoscience and technology. In 2000, the US Government launched the National Nanotechnology Initiative to coordinate its national research and increase its public spending in the field. The relationship between China and the

[38] Yijie Cheng, Yun Liu, Wei Fan, Zhe Yan, & Xuanting Ye (2019). Triple Helix on Globalization: A Case Study of the China International Nanotech Innovation Cluster. *Information Development* 35(2): 272-289, p. 272.

US in nanoscience and technology has been labelled a race and a competition (similar to their lead positions in quantum science).[39] According to Statnano in 2021 more than 42 percent of the world's nanotechnology publications were by Chinese researchers, compared to 11.5 percent US-authored publications. This amounts to more than 85,700 Chinese nano research articles in 2021. In the last decade, almost 14 percent of all Chinese scientific articles have been within nanoscience and technology.[40]

Energy

International agreements on climate goals almost all include the reduction of greenhouse gas emissions to set targets. The green transition is highly dependent on an energy transition. Such an energy transition relies on a combination of renewable energy and the development of new energy technologies. China is by far the largest emitter of carbon dioxide accounting for 30 percent of the global emissions in 2020. Per capita emissions are considerably lower than most countries but - although the curve is flattening - energy consumption is on the rise due to industrial development. Hence, technologies relevant to energy transition are a high priority in Chinese national policies. China is also the largest market for renewable energy and, currently, the country with most renewable energy installed.

New technologies to allow for more renewable energy in the energy mix relate to storage technologies (e.g., Power-to-X) that aim to build capacity to align production of energy with consumption of energy. Power-to-X is one of the technologies currently being developed and tested across the globe. China is in the lead in the construction of Power-to-X facilities using hydrogen for storing energy. The recent Medium and long-term plan for the development of the hydrogen energy industry (2021-2035), together with the 14th Five-Year Plan (2021–2025) identify hydrogen as one of the six frontier areas.

As part of the effort to clean air in large cities, China has positioned itself in the lead in developing trucks and buses to run on hydrogen (also for use in the construction industry). This is known as "grey" hydrogen. However, the expertise developed comes with the potential to shift to clean energy sources and move into "green hydrogen" as renewable energy sources increase.

[39] See, for instance, Haiyan Dong, Yu Gao, Patrick J. Sinko, Zaisheng Wu, Jianguo Xu, & Lee Jia (2016). The Nanotechnology Race Between China and the United States. *Nano Today* 11(1): 7-12.

[40] Statnano, "Top 20 Countries in Publishing Nano Articles in 2021", 7 January 2022. https://statnano.com/news/70227/Top-20-Countries-in-Publishing-Nano-Articles-in-2021

Among energy technologies for the future, fusion energy has great potential but is still in an early phase of development. China's fusion project, EAST, with its expected total costs of more than USD one trillion is used to test the International Thermonuclear Experimental Reactor (ITER) technologies under construction in France. ITER is a global network and a joint project between the US, the UK, the EU, India and China. It is expected to start operating in 2025. In December 2021, the EAST Tokamak fusion reactor set the world record of 1056 seconds. Although a promising technology that would provide clean and safe energy by splitting hydrogen into helium at ultrahigh temperatures, the energy used for this process is so far higher than the energy produced. However, expectations for the future are high.

CONCLUSION

Over recent decades, China has gradually developed a national model for positioning itself at the frontier in global science, technology and innovation infrastructure. This model – comprised of various centrally planned innovation policy programs, plans, and strategies – has been developed through the three phases of imitation, innovation, and more recently, invention.

Throughout this development, science parks have increasingly become a matter of national strategic priority. This strategic prioritization follows from recognition of the importance of top-down, mission-oriented innovation policy combined with increasing awareness that innovation and knowledge production are best achieved in institutional envirioments of co-location where actors possessing different types of knowledge and expertise coordinate and exchange know-how. Science parks provide such institutional locations and spatial clusters conducive to innovation, scientific breakthroughs, and technology transfers between government, industry, and university.

The recent strategy of building large-scale National Comprehensive Innovation Centers – such as the Huairou Science City – testify to the ambition of leapfrogging China to leapfrog to a position of a "world science and technology superpower" by 2050, as envisioned in the 2016 MLP. Science parks are now a direct national – and not only local or regional – priority among Chinese policy-makers. This is demonstrated by a commitment to increase investment in establishing multi-purpose and interdisciplinary national laboratories that expand the scientific reach of eixisting state laboratories and provide large-scale RIs. In the context of these major changes in China's nation-wide laboratory system, financial resources and research capacities are increasingly being redirected towards basic science.

China's approach to bolstering its national innovation system can best be understood as a balancing act between a top-down mission-oriented approach, fuelled by China acting as an entrepreneurial state, and a bottom-up approach, characterized by what the science and technology literature refers to as the Triple Helix model. The approach has already resulted in several significant outputs, including important advances in fields such as quantum and nano technologies, increased public R&D expenditure, higher levels of scientific publication, and larger numbers of invention patents.

The Chinese case, at the same time, demonstrates that the world of science and technology has become more multipolar and more interconnected. This portentss a future where the building of capabilities to orchestrate and organize across multiple geographical locations and institutional sites becomes increasingly relevant for Danish university researchers, knowledge intensive companies, and foreign representations.