State-organized Research: Exploring China's Innovation Ecosystem Amidst the Shift of the World's Three Major Centers (Postprint)

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Abstract

The integrated and coordinated development of education, science and technology, and talent points the way for China's continuous advancement toward becoming a world science center, a world higher education center, and a world talent center (hereinafter referred to as the "three world centers"). Building upon the "three-stage" model of the national innovation ecosystem and considering the "centennial shift" transfer trend of the three world centers, along with the challenges and opportunities China faces in welcoming these centers, this article explicitly proposes the concept of "State-Organized Research" (SOR), arguing that the planned implementation of SOR in the present and future represents a crucial lever for China to seize the transfer of the three world centers. Finally, it offers several specific recommendations for implementing SOR tailored to China's current national conditions, providing unique intellectual support for the construction of China's national innovation ecosystem.

Full Text

State-Organized Research (SOR): Chinese Innovation Ecosystem to Meet Shift of World's Three Major Centers

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Abstract

The coordinated development of education, science and technology, and talent (ESTTI) has charted a clear course for advancing China toward becoming a world science center, a world higher education center, and a world talent center (hereinafter referred to as the "world's three major centers"). Drawing upon the "three-stage" model of national innovation ecosystems and analyzing the historical trend of these centers shifting approximately every century, along with China's current challenges and opportunities, this article proposes the concept of "state-organized research" (SOR). We argue that the planned implementation of SOR represents a crucial lever for China to welcome the shift of the world's three major centers. Finally, we offer specific recommendations for implementing SOR based on China's national conditions, providing unique intellectual support for building China's national innovation ecosystem.

Keywords: education-science-tech-talent integration (ESTTI); state-organized research (SOR); innovation eco-system (IES); world science center

1. Introduction

The 20th National Congress of the Communist Party of China dedicated a special chapter to "Implementing the Strategy of Revitalizing the Country through Science and Education and Strengthening Talent Support for Modernization," explicitly stating that "education, science and technology, and talent are the foundational and strategic pillars for building a modern socialist country in all respects" [1]. The report places education, science and technology, and talent in parallel, establishing an integrated "trinity" relationship and systematically outlining strategic deployments for advancing these three areas. This is of great significance for building the foundational and strategic support for modernization, opening up new fields and tracks for development, and continuously shaping new drivers and advantages. Constructing a world science center, a world higher education center, and a world talent center (hereinafter referred to as the "world's three major centers") represents an important goal of the integrated development strategy for education, science and technology, and talent in the new era, as well as a key lever for China to seize the historic opportunities presented by the new round of scientific and technological revolution and industrial transformation.

At present, China still faces shortcomings and weaknesses in critical core technology breakthroughs, cultivation of top-tier scientific talent, construction of high-level research universities and institutions, development of innovative enterprises, and attracting world-leading scientific talent. To address these challenges, we unequivocally propose the concept of "state-organized research" (SOR), hoping to use it as a lever to promote the integrated development of education, science and technology, and talent, and to welcome the shift of the world's three major centers. Scholars have already conducted extensive research on organized research [2-4]. Based on our previous research on national innovation ecosystems [5], we believe China is currently in the intermediate stage of national innovation ecosystem development. The enhancement of China's economic and scientific strength, coupled with urgent national strategic needs, requires the implementation of SOR through national will and power. This involves launching forward-looking and strategic national major science and technology projects, concentrating efforts on key technological fields, enhancing the level of organized research in research universities, and improving the national innovation ecosystem [4] to welcome the shift of the world's three major centers. Of course, the shift of these centers occurs on a century-long timescale, requiring persistent efforts across generations in education, science and technology, and talent to achieve the goal of becoming a top-tier innovative country by 2035 and a world science and technology powerhouse by 2050, establishing China as a major global center for science and innovation.

2. The "Three-Stage" Model of National Innovation Ecosystem and Implementation of SOR

The national innovation ecosystem encompasses both national system and innovation dimensions. Philosophically, it represents a synthesis and elevation of German classical economist Friedrich List's "national system" and Austrian-American economist Joseph Schumpeter's innovation theory. A national innovation ecosystem consists of a set of institutions established by a country to promote technological innovation. The key to improving its efficiency lies in refining institutional arrangements, actively promoting innovation-friendly policy supply, facilitating interaction and feedback among ecosystem components, and enhancing national institutions and incentive mechanisms for learning new technologies. The ecosystem's most important carrier is the interacting network or system aimed at promoting rational and efficient resource distribution among various actors. Government-industry-university-research collaboration constitutes the main elements of China's innovation ecosystem.

Our research group, from a complexity science perspective, argues that national innovation ecosystems are not static but continuously evolve through self-learning and systemic evolution under internal mechanisms, exhibiting dynamic "three-stage" characteristics [5] [Figure 1: see original paper].

Stage A (Elementary): Spontaneous Market Behavior Stage. In this stage, influenced by market mechanisms, innovation enterprises, universities, and research institutes spontaneously form industry-university-research collaboration mechanisms based on their respective interests. When the national innovation ecosystem is immature, industry-university-research collaboration emerges as a bottom-up, passively demand-driven process, gradually forming scattered collaboration patterns. Universities and research institutes transfer technologies to innovative enterprises, which commission R&D from universities and institutes, but these relationships fail to form an orderly complex system, with government remaining detached from specific collaborations. Scientific and technological innovation in this stage typically lacks domestic and international competitiveness, and national innovation policies are often inadequate.

Stage B (Intermediate): Strong Government Action Stage. As national comprehensive strength increases, a collaborative government-industry-university-research innovation system is initially established. To cope with foreign technological competition, especially in key core technologies related to national security, it becomes necessary to establish a government-led national innovation ecosystem. This is because mature systems for technological innovation diffusion have not yet formed, and government-led promotion of collaborative innovation is the most direct and efficient approach. In this stage, government occupies the core position in the national innovation ecosystem while playing a strong linking role, carrying universities, research institutes, and innovative enterprises to form a triple helix structure. Numerous major science and technology projects, programs, large-scale scientific facilities, and overall national innovation resource layouts rely on state power for advancement, making government an indispensable core element of the innovation system.

Stage C (Advanced): Government-Guided, Market-Led Innovation Freedom Stage. As the national innovation system matures and scientific and technological strength continuously improves, with increasingly refined innovation policy environments, the triple helix structure of the national innovation ecosystem continues to ascend. Government direct intervention in innovation entities gradually decreases, shifting instead toward strategic planning for medium- and long-term scientific and technological innovation. Meanwhile, technological innovation enterprises, universities, and research institutes become more functionally powerful, possessing stronger international competitiveness. The ability to cultivate and attract scientific and technological talent at all levels continuously strengthens, fostering mature market-led platforms and achieving a new round of "realm of freedom" operation in the national innovation ecosystem.

Based on preliminary assessment, China is currently in Stage B (Intermediate) of its national innovation ecosystem. The current state of China's innovation ecosystem, its scientific and technological strength, and the contradictory relationship with meeting national strategic needs imply that China must accelerate the construction of a science and technology powerhouse and achieve high-level scientific and technological self-reliance through state-led SOR, ultimately realizing the transition from Stage B to Stage C.

3. Historical Trend of "Centennial Shift" of the World's Three Major Centers and China's Opportunities

3.1 Historical Trend of "Centennial Shift" of the World's Three Major Centers The world's three major centers are essentially isomorphic and should be considered holistically within the strategic vision of integrating education, science and technology, and talent.

1. **World Science Center.** Generally, when a country's total scientific achievements in a specific period exceed 25% of the world's total during the same period, that country is considered a world science center [8]. A world science center possesses world-class strategic scientists and innovation teams, world-class universities, research institutions, and discipline systems, as well as world-leading large-scale scientific facilities and basic research infrastructure.
2. **World Higher Education Center.** This refers to a location at the center of the global education system, representing a concentration of higher education systems with strong world influence or even serving as a model for global higher education. It is primarily manifested through scientific and technological achievements, high-level talent output, and educational system innovation [9,10].
3. **World Talent Center.** The determination of a world talent center mainly depends on the concentration of world-class scholars and outstanding (international) students—the country with the highest concentration is the world talent center [11].

As shown in Table 1 , from Italy to the United States, the transfer of the world's three major centers exhibits an approximate "centennial shift" trend. In the future, the world three major centers may evolve into a pattern of multiple coexisting centers, with comprehensive centers and specialized disciplinary centers developing side by side [11-13]. With continuously improving comprehensive national strength and high-level national attention, China faces valuable opportunities to build the world's three major centers.

3.2 Possibility Analysis of China Welcoming the Shift of the World's Three Major Centers Based on the typical characteristics of the world's three major centers, we conduct a comparative analysis of relevant indicators from major innovative countries worldwide and examine China's current difficulties and opportunities in building these centers.

3.2.1 Significantly Enhanced Competitiveness of Top Research Institutions and Research Universities in Recent Years

From an overall national ranking perspective, China's Nature Index score ranks second only to the United States, with the largest increase among the top 10 countries. China and the United States form the first tier with absolute advantages, while Germany, the United Kingdom, Japan, and others constitute the second tier. In the field of global basic scientific research, China is becoming a scientific powerhouse on par with the United States [14].

Regarding top research institutions, the 2022 Nature Index Annual Tables show that China has 26 institutions among the global top 100, with the Chinese Academy of Sciences ranking first globally, surpassing world-leading institutions such as Harvard University, the Max Planck Society, and the French National Centre for Scientific Research.

In terms of high-level research universities, the number of Chinese universities in the global top 100 increased from 6 to 12 between 2019 and 2023, with overall rankings rising rapidly: Tsinghua University and Peking University entered the global top 20; the University of Hong Kong and Chinese University of Hong Kong entered the top 50; Fudan University, Shanghai Jiao Tong University, Hong Kong University of Science and Technology, Zhejiang University, University of Science and Technology of China, and Hong Kong Polytechnic University entered the upper-middle tier of the global top 100; and Nanjing University and City University of Hong Kong joined the top 100 (Table 2). In 2023, the number of Chinese universities in the global top 100 exceeded that of the United Kingdom and Germany, though the gap with the United States remains significant (Table 3). Moreover, the rankings of Tsinghua University and Peking University still show clear gaps compared to top Anglo-American universities such as Oxford and Harvard.

In terms of disciplinary strength, ESI (Essential Science Indicators) data released in January 2023 show that Chinese universities have 2,054 disciplines in the global top 1% (an increase of 54) and 243 disciplines in the global top 0.1% (an increase of 5). China has established disciplinary advantages in chemical engineering, metallurgical engineering, instrumentation science, and aerospace engineering. In chemical engineering, Chinese universities occupy half of the global top 10; in metallurgical engineering, the proportion is nearly 40%; in instrumentation science, Chinese institutions almost monopolize the global top 10; and in aerospace engineering, the proportion in the global top 100 is nearly 25%. However, in world-class disciplines, China still has significant gaps compared to higher education powerhouses like the United States. The overall number of advantageous disciplines in Chinese universities remains far lower than in the United States and the United Kingdom, with no discipline ranking first globally, while the United States and the United Kingdom have 26 and 15 disciplines ranked first, respectively (Table 4).

3.2.2 Noticeably Improved Scientific Research Strength, but Still Significant Gaps with Developed Countries, Especially the United States

China's overall scientific research strength has noticeably improved, ranking in the first tier globally in high-quality papers and patent outputs, but still lags behind the United States. In 2021, China published 2,045 papers in 18 top-tier global science and technology journals (with citation counts exceeding 100,000 and impact factors exceeding 30 in 2021), accounting for 6.37% of the world total and ranking second globally, though still nearly half that of the United States. From 2011 to 2021, China produced 1,808 hot papers (cited in the top 0.1% of their disciplines), accounting for 41.7% of the global total and surpassing the United States for the first time. China produced 49,900 highly cited papers (cited in the top 1% of their disciplines), but this still trails the United States' 78,500 [15]. In terms of publications in *Science*, *Nature*, and *Cell*, the quantitative and qualitative gaps with the United States are rapidly narrowing, though a "qualitative gap" remains [16].

China's PCT (Patent Cooperation Treaty) patent applications have steadily ranked first globally, with an average annual growth rate of 29.93% from 2013-2020, far exceeding the United States, United Kingdom, France, and other major innovative countries in both volume and growth rate (Table 5). However, China has fewer than 500 PCT patents per 10,000 enterprise researchers, and its triadic patent families are less than 20% of those of the United States and Japan [17]. China also faces a massive intellectual property deficit, with intellectual property royalty service trade revenue of 76 billion RMB and expenditure of 302.3 billion RMB in 2021, resulting in a deficit of 226.3 billion RMB [18].

China still has significant gaps with major innovative countries in basic research investment intensity. In 2021, China's basic research funding accounted for 6.09% of total R&D expenditure, compared to 16.44% in the United States, 18.28% in the United Kingdom, 22.67% in France, and 14.67% in South Korea. China's basic research investment intensity was only 0.12%, compared to 0.50% in the United States, 0.32% in the United Kingdom, 0.50% in France, and 0.68% in South Korea.

Regarding large-scale scientific facilities, although China has formed clustering effects, the gap with the United States remains substantial. By 2020, China had built 22 major scientific facilities [19], with notable clustering effects in Beijing, Shanghai, and Hefei. The United States, however, has deployed a batch of world-leading large-scale scientific facilities in high-energy physics, nuclear physics, astronomy, energy, nanotechnology, ecological environment, and information technology, totaling approximately 60 facilities [20]. Compared to the United States, China not only has fewer major scientific facilities but also has fewer world-leading or unique facilities, fewer institutionalized research programs relying on these facilities, and lower levels of international collaboration [21].

3.2.3 Abundant Talent Resources but Lacking Top Teams; Incomplete Innovation Ecosystem

As of 2022, China's talent resources totaled 220 million people, with R&D personnel exceeding 6 million person-years, ranking first globally for many years. The 2022 Global Innovation Index shows China ranked 11th, successfully joining the ranks of innovative countries. However, China still lacks world-class strategic scientists and innovation teams, and its innovation ecosystem remains imperfect. For instance, the number of Nobel Prizes in science, Fields Medals, Turing Awards, and other prestigious awards is extremely disproportionate to China's talent resources. In terms of Nobel Prizes in science (as of 2021), China has only one native laureate (Tu Youyou), with an awardee ratio of 0.71 per 10 million population, compared to 377 in the United States, 130 in the United Kingdom, and 108 in Germany, with ratios of 11.54, 19.53, and 13.13 per 10 million, respectively. Japan, also in East Asia, has 28 Nobel laureates with a ratio of 2.20 per 10 million, while Sweden and Switzerland each have over 25 laureates with ratios exceeding 25% [9]. Additionally, the World Bank's *Doing Business 2020* report shows China's business environment ranking improved from 91st in 2012 to 31st in 2020 among 190 economies, but still lags behind South Korea, the United States, the United Kingdom, Germany, and others [22]. In 2020, only 10.56% of Chinese citizens possessed scientific literacy, far below the 20%-30% level in major developed countries [23].

4. Measures for Implementing SOR to Coordinate Construction of the World's Three Major Centers

4.1 Strengthen Systematic Layout of National Strategic Scientific and Technological Forces to Shape "Asymmetric" Advantages in International Competition National strategic scientific and technological forces serve as the "national team" for building a science and technology powerhouse, the "ballast stone" for national security, the "guiding star" for frontier exploration, and the "seeder" for emerging industries. Our research group proposes four recommendations:

1. **Systematically plan the systematic layout of national strategic scientific and technological forces through top-level design.** We recommend exploring the establishment of a National Strategic Scientific and Technological Force Construction Advisory Committee under the unified leadership of the Central Science and Technology Commission, with participation from top strategic scientists as technical leads and central/local government departments and research institutes. This committee would lead the design of roadmaps and implementation plans for the systematic layout of national strategic scientific and technological forces at the national level.

2. **Accelerate the construction of international science and technology innovation centers and comprehensive national science centers.** Accelerate the development of the Beijing, Shanghai, and Guangdong-Hong Kong-Macao Greater Bay Area international science and technology innovation centers, and strongly support the construction of comprehensive national science centers in Shanghai Zhangjiang, Anhui Hefei, Beijing Huairou, and the Greater Bay Area to create drivers for high-quality development.

3. **Appropriately advance the construction of national major science and technology infrastructure to support high-level scien-**

tific and technological self-reliance.** Consolidate the foundational and strategic platform base for national scientific and technological innovation, seize the commanding heights of long-term and overall scientific and technological strategy, improve the full-cycle management mechanism for construction, operation, and evaluation of major science and technology infrastructure, promote open sharing of major facilities, and provide support for core technology breakthroughs and industrial innovation development.

4. **Pilot first to explore best practices for systematic layout of national strategic scientific and technological forces.** Drawing on China's experience in establishing special economic zones, support national laboratories in exploring "science and technology innovation special zones" in terms of policies and institutional mechanisms. Explore management systems, assessment and evaluation mechanisms, research innovation models, incentive and distribution mechanisms, talent policies, and platform construction for national strategic scientific and technological forces under a new type of national system, summarizing successful experiences in serving the "Four Orientations."

4.2 Establish National Strategic Scientific and Technological Topics and Implement a Global "Open Competition" System Through SOR, strengthen medium- and long-term planning, forward-looking judgment, and top-level design for China's scientific and technological development. Select a group of world-class scientists from domestic and international sources to collectively establish a list of major topics reflecting the "Four Orientations" and concerning national security and people's livelihood. Based on China's development strategies and scientific foundations, form a group of forward-looking, original, systematic, and strategic problem domains and problem sets to support long-term, high-risk, difficult, and promising strategic scientific plans and projects. Guide national strategic scientific and technological forces and innovative leading enterprises to "compete for the list" and "race horses" around these topics, implementing collaborative 攻关 for major scientific and technological tasks and determining the direction and priorities of scientific and technological innovation. Through SOR, coordinate and promote the integrated development of higher education, scientific and technological innovation, and talent cultivation, achieving frontier cross-integration and integration of science, fundamentals, and engineering to form future-oriented integrated advantages in education, science and technology, and talent. Use national will and capabilities to solve deep-level, principled, and mechanistic problems that constrain key generic technological innovation and industry-university-research transformation, achieving efficient operation of a collaborative innovation system where "the state sets topics, enterprises propose problems, research universities and organizations provide solutions, and markets and other organizations evaluate results."

4.3 Accelerate Enhancement of Scientific and Technological Innovation Capacity of High-Level Research Universities to Meet National Major Needs Building a world higher education center requires comprehensively enhancing the scientific and technological innovation capacity of high-level research universities and fully leveraging their role as the main force in basic research and a vital force in major scientific and technological breakthroughs. Our research group proposes three recommendations:

1. **High-level research universities should break free from the constraints of "Four Only" and "Five Only"** (referring to evaluation systems overly focused on specific metrics) **and discipline assessments**, adhering to the "Four Orientations" to conduct organized, designed, closed-loop, and replicable research.
2. **Focus on building high-level national scientific and technological innovation platforms.** Accelerate the construction of a distinctive, cross-integrated, open, and shared scientific and technological innovation platform system centered on national laboratories, national key laboratories, and provincial/ministerial key laboratories. Actively explore innovations in platform construction institutional mechanisms and operation management models, including internal operation management models for national-level scientific and technological innovation platforms within universities.
3. **Optimize allocation of research forces and resource sharing, promote transformation of university research achievements, and build a full-chain research talent cultivation system.** Achieve comprehensive and coordinated development in scientific research, platform construction, talent cultivation, management operation, and social services.

4.4 Improve the Talent Policy System by Combining Independent Cultivation with Active Recruitment Chinese research universities and research institutes face prominent issues such as "looking at hats" (titles), "counting papers," "competing for titles," "setting age limits," and resulting problems of "competing for connections," "engaging in operations," and "comparing titles." Some universities and research institutions engage in vicious "talent wars" and "talent flowing southeast" to improve international rankings, representing "stock" transfer rather than "incremental" improvement. Moreover, China's talent policies remain insufficiently attractive to top strategic scientists and innovation teams, with top talents in various global fields rarely developing in China.

Our research group proposes four recommendations:

1. **Establish mechanisms for cultivating and recruiting strategic scientific and technological talent, exploring "recommendation systems" and "career systems."** Break single, linear talent evaluation sys-

tems and change traditional methods of determining personnel by projects and determining projects by titles. Instead, select personnel according to research directions, determine projects by personnel, and fully empower researchers. Implement forward-looking and reserve major science and technology projects for strategic scientists, scientific and technological leaders, outstanding young talents, and non-consensus talents to help them achieve independent topic selection, free exploration, and independent innovation.

2. **Strive to make STEM (science, technology, engineering, mathematics) education the golden 招牌 of Chinese higher education.** High-quality advancement of new engineering and outstanding engineer cultivation programs will enhance the attractiveness of Chinese universities to high-level international students in STEM fields.
3. **Strengthen integration of theory and practice to discover and cultivate national strategic scientific and technological forces and talent through application.** Through SOR, forge talent echelons and groups including chief scientists, chief engineers, research backbones, young talents, and graduate students.
4. **Build an open innovation ecosystem and participate in global science and technology governance.** Actively design and lead international big science plans and projects, establish globally-oriented scientific research funds, actively integrate into the global innovation network, participate in global science and technology governance, fully grant national strategic scientific and technological forces the autonomy to cultivate and recruit world-class talent, form a globally competitive open innovation ecosystem, and help China build the world's three major centers.

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Note: Figure translations are in progress. See original paper for figures.