Driving Logic, Key Pathways, and China's Breakthrough in Building a World Science and Technology Power: A Postprint Based on Historical Examination of the United Kingdom, Germany, and the United States

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Date: 2023-12-03T00:00:00+00:00

Abstract

Building a world-class science and technology powerhouse constitutes China' s strategic development objective. Learning from others' experiences can provide valuable insights; conducting an in-depth analysis of the driving logic and key pathways of the United Kingdom, Germany, and the United States in building world-class science and technology powerhouses, and drawing lessons therefrom, holds significant reference value for China' s own endeavors. Empirical analysis reveals that the emergence of world-class science and technology powerhouses results from the joint action of six-dimensional innovation-driven logics: national policy innovation, educational reform innovation, talent team innovation, enterprise application innovation, independent scientific and technological innovation, and cultural construction innovation. The critical pathways encompass government-industry-academia-research collaboration, integrated development of education, science and technology, and talent, fusion of science and technology with the economy, complementarity between free innovation and organized innovation, and mutual promotion between basic research and applied research. China' s breakthrough path toward building a world-class science and technology powerhouse involves capitalizing on historical windows of opportunity, pursuing strategic advantages at the frontiers of science and technology, establishing collaborative innovation platforms, strengthening the foundation of basic research, addressing vulnerabilities of technological dependence, and removing bottlenecks in evaluation and application. Only through these efforts can China achieve scientific and technological self-reliance and strength, and ultimately build a world-class science and technology powerhouse with Chinese characteristics.

Full Text

Preamble

Citation Format: Bai Q. Driving logic, critical path and China's breakthrough in building a world power in science and technology—Based on historical survey of building a world power in science and technology by Britain, Germany, and the United States. Bulletin of Chinese Academy of Sciences, 2023, 38(10): 1447-1458, doi: 10.16418/j.issn.1000-3045.20230410001. (in Chinese)

English Citation: Bai Q. Driving logic, critical path and China's breakthrough in building a world power in science and technology—Based on historical survey of building a world power in science and technology by Britain, Germany, and the United States. Bulletin of Chinese Academy of Sciences, 2023, 38(10): 1447-1458, doi: 10.16418/j.issn.1000-3045.20230410001.

Abstract

Building a world science and technology powerhouse is China' s strategic development goal. As the Chinese proverb says, "stones from other mountains can be used to polish jade" —meaning we can learn from others' experiences. A deep analysis of the driving logic and critical paths behind Britain, Germany, and the United States in building world science and technology powerhouses offers valuable reference for China' s own efforts. Historical investigation reveals that the formation of a world science and technology powerhouse results from the combined effect of six innovative driving logics: national policy innovation, education reform innovation, talent team innovation, enterprise application innovation, independent scientific and technological innovation, and cultural construction innovation. The critical path lies in the synergy of government-industry-university-research collaboration, the integrated linkage of education, science and technology, and talent development, the fusion of technology and economy, the complementarity between free innovation and organized innovation, and the mutual promotion of basic research and applied research. China' s breakthrough path to building a world science and technology powerhouse requires seizing historical opportunity nodes, pursuing cutting-edge technological advantages, establishing collaborative innovation fulcrums, strengthening basic research foundations, addressing pain points of being constrained by others, and clearing application bottlenecks in evaluation systems. Only through these measures can China achieve technological self-reliance and strength, and build a world science and technology powerhouse with Chinese characteristics.

Keywords: world science and technology powerhouse, historical investigation, driving logic, critical path, China' s breakthrough

1. Historical Overview of Britain, Germany, and the United States Building World Science and Technology Powerhouses

1.1 Britain’ s Historical Path

Britain’ s journey to becoming a world science and technology powerhouse began with the emergence of outstanding scientists such as Bacon, Newton, and Boyle in the 16th century. Newton’ s classical mechanics and Boyle’ s chemical science established Britain as a world scientific center by the 17th century, laying the foundation for building a world technology powerhouse. In the 1620s, Britain’ s economic development level still lagged behind France’ s [2], but it pioneered the world’ s first modern patent law—the Statute of Monopolies (1624)—which granted patents to inventors, clarified private property rights, and encouraged technological innovation. In the 1660s, King Charles II chartered the Royal Society (1660), initiating the “institutionalization” of scientific organization, promoting scientific development, and fostering connections between its members and industry to facilitate science-industry interaction [3]. From the mid-17th century, Oxford and Cambridge reformed their classical traditions by placing “applied science teaching and research on a solid foundation of basic science” [4] and introducing mathematics and natural sciences into their curricula to “gain academic prestige” [5], thereby cultivating numerous scientific and technological talents for building a world technology powerhouse.

Entering the 18th century, a series of technological inventions and improvements—Kay’ s flying shuttle, Hargreaves’ spinning jenny, and Watt’ s steam engine—triggered the First Industrial Revolution, propelling Britain’ s economic takeoff and establishing it as a world technology powerhouse. However, after the mid-19th century, Britain missed the opportunity of the Second Industrial Revolution marked by electrical technology [6], gradually losing its advantage as a technology powerhouse.

1.2 Germany’ s Historical Path

Germany’ s path to building a world science and technology powerhouse originated with education reform. In the early 18th century, the Prussian government mandated compulsory primary education, and in the early 19th century pioneered modern higher education reform by establishing the University of Berlin in 1810—the first modern university in world higher education history that differed from both British liberal arts education and French engineering education [7]. The university made scientific research a core mission, playing a crucial role in Germany’ s scientific takeoff in the 19th century. Subsequently, Germany produced numerous world-class scientists and achieved many major scientific and technological accomplishments, gradually becoming a world scientific center. In particular, Liebig’ s organic chemistry and Siemens’ practical electric generator directly drove the Second Industrial Revolution, enabling Germany to successfully enter the electrical age [8]. During its world technology powerhouse construction, the government valued research personnel by directly providing salary guarantees from the state. In the 1870s, laws such as the Freedom of Movement Act created conditions for talent aggregation. Simultaneously, the government vigorously encouraged enterprises to attract outstanding scientists, established university research centers directly serving industrial production, emphasized the introduction, digestion, and innovation of foreign advanced technologies, enabling Germany to surpass Britain and France in building a world technology powerhouse by the latter half of the 19th century. However, during World War I and II, Germany gradually lost its technology powerhouse advantage due to the outflow of large numbers of scientists and other reasons.

1.3 The United States' Historical Path

Since its founding, the United States implemented the Patent Act (1790) and established the Patent Office (1802) to protect intellectual property and incentivize technological innovation. It enacted the Morrill Act (1862) to establish numerous applied state colleges to meet economic development needs, and passed the Immigration Act (1864) to attract and gather global talent to promote economic growth. In 1865, "its gross national product was still lower than that of Britain and Western European powers" [9], but the U.S. leveraged its abundant natural resources, seized the opportunity of the electrical technology revolution, and widely applied electricity to transform steel, automobile, and other industries through technological innovation, resulting in explosive GDP growth. By 1890, it achieved the world' s leading economic output [10] and surpassed Britain' s GDP in 1894 [11], becoming the world' s largest economy—a position it maintains today. In the 20th century, the United States attracted large numbers of European scientists, including Einstein, with its superior research conditions and attractive talent policies. These scientists not only conducted cutting-edge research but also participated in university teaching, training numerous outstanding scientific and technological talents. The number of American Nobel laureates began to exceed that of European countries [12], and the world scientific center gradually shifted from Germany to the United States in the 1930s. During World War II, the U.S. used a nationwide system to promote major breakthroughs [13], built a multi-agent collaborative innovation system [14], and organized the Manhattan Project, becoming the first country to possess nuclear weapons and establishing its leading position as a world technology powerhouse.

2. Driving Logic for Building a World Science and Technology Powerhouse

Examining the evolutionary history of Britain, Germany, and the United States in building world science and technology powerhouses reveals that despite different national conditions and circumstances, all three became world scientific centers in different historical periods and subsequently built world technology powerhouses, implicitly sharing innovation as the primary driving force.

2.1 National Policy Innovation Driving Logic

Britain' s policy innovation mainly manifested in using national policies to incentivize technological development and promote industrial revolution, such as enacting patent regulations, chartering the Royal Society, and encouraging the establishment of numerous civilian scientific and technological societies [15] to promote the integration of technology and industry. Germany' s policy innovation concentrated on systematic innovation in national-level education policies [16], particularly emphasizing "quality-based nation-building" and establishing a "dual system" education model to cultivate large numbers of applied technical talents. The United States' policy innovation primarily manifested in innovations to education, science and technology, and immigration policy systems. The implementation of the Morrill Act, Patent Act, and Immigration Act effectively created a "synergistic effect" for education development, technological innovation, and talent aggregation. Particularly, using a nationwide system to organize major scientific and technological breakthroughs to develop the atomic bomb first established the United States' leading position as a world technology powerhouse.

2.2 Education Reform and Innovation Driving Logic

Education is the foundation of building a science and technology powerhouse. A key driving logic enabling Britain, Germany, and the United States to successively build world science and technology powerhouses is education reform and innovation. All three countries cultivated scientific and technological talents and enhanced research levels through education reform, laying the foundation for becoming world technology powerhouses. Britain incorporated natural sciences into curricula at all school levels, and even the traditionally conservative Oxford and Cambridge reformed their aristocratic educational traditions—for example, Cambridge implemented high-standard mathematics honors degree examinations [17]. Germany incorporated science and technology education into curricula at all levels, cultivating large numbers of scientific and technological talents. The establishment of the University of Berlin particularly cultivated many world-class scientists. The United States successfully inherited and surpassed the essence of traditional European education by constructing a "localized" education system, creating departmental organizations and graduate schools in universities to cultivate large numbers of scientific and technological talents, enabling its higher education to rapidly catch up with Germany and laying a solid foundation for building a world technology powerhouse.

2.3 Talent Team Innovation Driving Logic

A first-class scientific and technological talent team provides human resource support for building a world science and technology powerhouse. One of the secrets of Britain, Germany, and the United States in building world technology powerhouses is attracting first-class scientific and technological talents through immigration policy innovation to serve national science and technology development strategies. The history of building world technology powerhouses is also a history of building world-class scientific and technological talent teams. Britain attracted large numbers of European craftsmen and technicians through "free movement" immigration policies and enacted numerous labor laws to protect the legitimate rights and interests of foreign workers [18]. The establishment of the Royal Society also brought together large numbers of scientific and technological talents for Britain. In the mid-to-late 19th century, Germany also introduced large numbers of skilled technical workers from Britain, Belgium, and other countries through immigration policies. By the early 20th century, Germany had ten times more engineers than England and Wales combined [19]. The construction of America' s scientific and technological talent team benefited from relaxed immigration policies and superior research conditions that attracted large numbers of European scientists, providing world-class talent support for building a world technology powerhouse.

2.4 Enterprise Application Innovation Driving Logic

Enterprises are the critical hub linking science and technology with the economy, playing a vital role in rapidly transforming scientific and technological achievements into real productive forces, deeply integrating innovation chains with industrial chains, and enhancing national overall innovation efficiency. Enterprise application innovation is an extremely important driving logic for Britain, Germany, and the United States to build world science and technology powerhouses. During the First Industrial Revolution, British textile, coal, metallurgy, and transportation enterprises rapidly applied steam power technology inventions to industrial production, replacing manual labor with machine production and greatly improving enterprise production efficiency. Statistics show that by 1850, Britain' s cotton textiles and steel production accounted for half of the world' s total, and coal production accounted for two-thirds, with "British industrial output accounting for 50% of the world" [20]. During the Second Industrial Revolution, German steel and transportation enterprises widely applied generator and internal combustion engine technologies to production transformation, enabling Germany to enter the electrical age first. American enterprises also widely applied electrical technology inventions to equipment innovation, business innovation, and process innovation, significantly enhancing scientific and technological competitiveness. Since the 1940s, the United States has gradually become the global leader in technological innovation trends.

2.5 Independent Scientific and Technological Innovation Driving Logic

The key to building a world science and technology powerhouse lies in independent scientific and technological innovation. Britain attracted large numbers of craftsmen and technicians from Italy and other European countries through immigration policies, bringing advanced technologies to Britain. On the other hand, Britain conducted re-innovation based on existing technologies–for example, Watt improved the steam engine through several key technological modifications. In 1856, based on British chemist Perkin' s artificial synthetic dye technology, Germany led in developing many chemical analysis instruments and electromagnetic instruments [21], enabling its chemical and electromagnetic industries to surpass Britain. The United States also experienced a process from learning and introduction to independent scientific and technological innovation. Between 1815 and 1918, more than 10,000 American youths flocked to German and British universities to learn advanced European technologies [22], and on this basis promoted technological improvement and re-innovation through various channels, enabling American scientific and technological independent innovation capabilities to surpass Germany and become the world' s number one science and technology powerhouse by the end of World War II.

2.6 Cultural Construction Innovation Driving Logic

Britain, Germany, and the United States all attach great importance to innovation culture construction in their processes of building world science and technology powerhouses. Britain's success in building a world technology powerhouse benefited from its pioneering establishment and implementation of patent protection systems that created a scientific and technological innovation culture, greatly stimulating national enthusiasm for scientific and technological innovation. To this day, Britain continues to intensify innovation culture construction through policy guidance, issuing "Building Our Industrial Strategy" and "Industrial Strategy: Building a Britain Fit for the Future" in 2017 to incentivize seizing world science and technology frontiers and maintaining its world technology powerhouse status. Germany' s construction of a world technology powerhouse involved a systematic engineering approach to scientific and technological innovation culture construction, from compulsory education to cultivate innovation awareness, to vocational education advocating "craftsmanship spirit," to founding the University of Berlin in pursuit of research excellence. This innovation culture not only integrated scientific and technological innovation pursuits into the national education system and enterprise production processes but also into daily national life [23]. The United States' success in building and maintaining its world technology powerhouse status benefits from the influence of its adventurous spirit and pragmatist culture on scientific development [24]. From the arrival of the first immigrants to North America, through independence and westward expansion, American citizens have demonstrated "novel and creative spirit" [25].

3. Critical Paths for Building a World Science and Technology Powerhouse

Building a world science and technology powerhouse is a systematic project involving organic linkage of multiple agents, interaction of multiple factors, and collaborative driving of multiple logics, among which lie hidden critical paths for generating world science and technology powerhouses.

3.1 Government-Industry-University-Research Collaboration

From the perspective of world technology powerhouse construction mechanisms, the processes of Britain, Germany, and the United States involved a "quadruple helix" innovation mechanism composed of government, industry, universities, and research institutions. Through functional complementarity and interactive roles, they formed scientific and technological innovation networks that collaboratively promoted world technology powerhouse construction. In this innovation network, national or local governments represent the administrative chain, playing roles in overall coordination, policy support, and resource supply; enterprises represent the industrial chain, playing roles in market demand orientation, achievement application and transformation, and market development; universities and research institutions represent the academic chain, playing roles in knowledge innovation and technology research and development. During collaborative innovation, the administrative, academic, industrial, and technological chains conduct timely factor exchange and functional complementarity. For example, during World War II, the United States' Manhattan Project organized through a nationwide system brought together government, numerous enterprises, multiple universities, and multiple research institutions to form a collaborative innovation mechanism of administrative, industrial, academic, and technological chains, successfully developing the atomic bomb and establishing America' s status as a world nuclear power. This exemplifies government-industry-university-research collaboration as a critical path for building world technology powerhouses.

3.2 Integrated Linkage of Education, Science and Technology, and Talent

World technology powerhouse construction involves multiple agents, levels, and factors, with education, science and technology, and talent playing fundamental, critical, and strategic supporting roles. None of these three can be absent in building a world technology powerhouse. The integrated linkage of education, science and technology, and talent is another successful path for Britain, Germany, and the United States. Britain achieved transformation from classical to modern education through reform, not only cultivating large numbers of scientific and technological talents but also attracting talent from around the world, producing numerous major scientific research achievements, and achieving integrated linkage of education, science and technology, and talent, thereby becoming a world scientific center and leading the First Industrial Revolution. Germany exemplifies using education reform to promote scientific and technological innovation and gather outstanding talents. The creation of modern universities not only led to breakthroughs in Liebig' s organic chemistry, Schwann' s cell theory, and Planck' s quantum hypothesis but also attracted large numbers of American international students and gathered talents, creating an integrated linkage effect of education, science and technology, and talent, subsequently becoming a new world scientific center and building a world technology powerhouse. The United States implemented the Patent Act, Morrill Act, and Immigration Act, providing policy guarantees for scientific and technological development, education innovation, and talent aggregation, successfully achieving integrated linkage of education, science and technology, and talent through institutional innovation and realizing catch-up and surpassing. Historical facts prove that integrated linkage of education, science and technology, and talent is an indispensable critical path for building a world technology powerhouse.

3.3 Integration of Scientific and Technological Innovation with Economic Development

The close integration of scientific and technological innovation with economic development is an inevitable path choice for building a world technology powerhouse. Britain, Germany, and the United States built world technology powerhouses through various pathways promoting this integration. During the First Industrial Revolution, Britain connected scientific organizations with industry, promoting science-industry integration to some extent (for example, members of the Lunar Society in Birmingham, Manchester, and other manufacturing areas actively promoted the application of scientific knowledge in industry and technological innovation). During the Second Industrial Revolution, Germany established national chemical research institutions (1877) and national mechanical research institutions (1879) to directly serve industrial development. Simultaneously, the government vigorously encouraged enterprises to attract outstanding scientists to promote close integration of science and technology with industrial economy. In the late 19th and early 20th centuries, the United States also established various research institutes and industrial laboratories nationwide to promote close integration of scientific research and production, transforming it from a backward agricultural country to an industrial powerhouse in the second half of the 19th century. Clearly, the close integration of scientific and technological innovation with economic development is another common path for Britain, Germany, and the United States to build world technology powerhouses.

3.4 Complementarity Between Free Innovation and Organized Innovation

In handling the relationship between free innovation and organized innovation, Britain, Germany, and the United States have no unified model—sometimes emphasizing market-driven spontaneous free innovation, sometimes emphasizing organized innovation led by national strategic needs. Before building a world technology powerhouse, throughout almost the entire 19th century, Americans were keen on "inventing gadgets," and enterprises spontaneously introduced advanced technologies from European countries. However, since the 20th century, the United States has strengthened the construction of an "institutionalized" national innovation system, such as the Manhattan Project. Before and after World War II, Germany had both free innovation and organized innovation coexisting. Since the 21st century, although Britain, Germany, and the

United States have continuously strengthened science and technology planning, increased investment, and promoted international scientific and technological cooperation [26] to maintain and strengthen their world technology powerhouse status, respecting the laws of scientific and technological innovation activities and adhering to the complementarity of effective markets and capable governments remains their most fundamental science and technology policy. Clearly, building a world technology powerhouse requires both fully respecting the inherent logic of scientific development and actively responding to the logic of national strategic needs, making the integration and complementarity of the two another critical path.

3.5 Mutual Promotion of Basic Research and Applied R&D

The mutual promotion of basic research and applied R&D is another critical path to building a world technology powerhouse. First, basic research triggers technological innovation and promotes applied R&D. Britain, Germany, and the United States all promoted technological R&D innovation through basic research innovation during their world technology powerhouse construction, thereby empowering industrial revolutions. For example, 18th-century research in thermophysics and gas theory promoted steam engine improvement, driving the First Industrial Revolution; Liebig' s organic chemistry in Germany promoted innovation in German chemical industrial technology, enabling German chemical industry to dominate the Second Industrial Revolution. Second, applied R&D drives basic research and promotes original theoretical innovation. For instance, the demand for steam engines to improve production efficiency greatly promoted the development of thermodynamics in the 18th-19th centuries, especially the discovery of the first and second laws of thermodynamics. Therefore, emphasizing the coordinated development of basic research and applied R&D—continuously increasing investment in basic research to promote original innovation while using applied R&D to drive basic research—is another critical path to building a world technology powerhouse.

4. Valuable Lessons for Building a World Science and Technology Powerhouse

The above analysis yields many beneficial insights for building a world technology powerhouse. However, one question deserves deeper investigation: Why was Britain surpassed by Germany, and why was Germany subsequently surpassed by the United States? Clarifying this question provides valuable lessons for China' s current efforts to build a world technology powerhouse.

4.1 Avoid Missing Opportunities Due to Conservatism

Britain, Germany, and the United States all seized major historical opportunities of industrial revolutions to build world technology powerhouses. Britain and Germany respectively seized the First and Second Industrial Revolutions, while the United States seized the Second Industrial Revolution. However, why was Britain later surpassed by Germany and the United States? An important reason is that after achieving great success in the First Industrial Revolution, Britain became conservative and complacent, preferring to obtain huge profits from its vast colonies rather than spending enormous costs to update technological equipment. In contrast, unified Germany implemented heavy industry priority policies through strong central authority, forcing large amounts of capital into railways, transportation, and other industries, promoting rapid heavy industry development and surpassing Britain' s economic output before World War I. The United States implemented a series of domestic social and economic reform measures during the Second Industrial Revolution, allowing science and technology originally germinated in Britain to take root, blossom, and bear fruit in America, achieving breakthroughs in cutting-edge fields and gaining competitive advantages. For Britain, seizing the First Industrial Revolution opportunity was crucial to building its world technology powerhouse, while missing the Second Industrial Revolution opportunity was a major reason for losing its world dominance. Clearly, opportunities are fleeting and time-sensitive. Building a world technology powerhouse must seize major historical opportunities.

4.2 Avoid Slow Application and Transformation

The close connection between innovation chains and industrial chains is an inherent requirement for building a world technology powerhouse. Britain, Germany, and the United States all built world technology powerhouses by emphasizing the timely transformation of scientific and technological achievements into productive forces. Why was Britain surpassed by Germany and the United States? One reason was slow application and transformation, with science and technology disconnected from industry. In the early 19th century, Britain had leading scientific achievements in physics and chemistry but failed to utilize them in time. These achievements, "neglected in Britain" [27], were widely applied in German industry, enabling Germany' s economic strength to rapidly surpass Britain. It was not until being severely damaged by Germany in World War I that Britain realized the importance of timely transformation and application of scientific achievements. This provides another lesson for China: the intensity of scientific and technological achievement transformation and application must be increased and accelerated to build a world technology powerhouse with strong scientific and technological capabilities.

4.3 Avoid Lagging Institutional Reform

Building a world technology powerhouse must derive vitality from institutions and momentum from reform. Pioneering institutional reform according to the needs of the times to release innovation vitality and enhance innovation momentum is both the successful experience of Britain and Germany in building world technology powerhouses and an important reason for their subsequent loss of leading positions, as well as the secret for latecomer America to surpass

Europe. Britain' s pioneering patent protection system was closely related to its becoming a world technology powerhouse. Germany' s pioneering education system reform was closely related to its becoming a new world technology powerhouse. America' s systematic institutional reforms in law, education, science and technology, and talent were closely related to its becoming the new world leader. Historical facts repeatedly prove the importance of pioneering institutional reform for building a world technology powerhouse. This provides another lesson for China: we must grasp key institutional reforms to provide institutional guarantees for building a world technology powerhouse, effectively enhancing the overall efficiency of the national innovation system and building a world technology powerhouse as soon as possible.

5. China' s Breakthrough in Building a World Science and Technology Powerhouse

China' s construction of a world science and technology powerhouse must follow the inherent logic of building world technology powerhouses while basing itself on national conditions and following a path with Chinese characteristics. From a national conditions perspective, China is building a world technology powerhouse under socialism with Chinese characteristics. From an advantages perspective, China has the socialist institutional advantage of concentrating resources to accomplish major tasks. From a foundation perspective, China has "effectively stimulated innovation and entrepreneurship vitality from all sectors" [28] through reform, and "scientific and technological strength has achieved leapfrog development" [29], but there remains a large gap from world technology powerhouses, especially the United States [30]. "The foundation of scientific and technological innovation is not yet solid, innovation levels still show obvious gaps, and in some fields the gap has not narrowed but rather expanded" [31]. Based on the above analysis and China' s actual situation, this paper proposes that to build a world technology powerhouse with Chinese characteristics as soon as possible, we must both coordinate overall planning and systematic advancement while targeting weaknesses for key breakthroughs.

5.1 Seizing Nodes: Grasping Major Historical Opportunities

Seizing major historical opportunities leads to prosperity, while missing them not only causes development stagnation but may also exact painful costs—modern China has profound historical lessons in this regard. History repeatedly warns us that failing to recognize, respond to, or seek change before major historical opportunities will result in missing an entire era. Timing-wise, each scientific and technological revolution occurs approximately every 100 years. Currently, the world is at a critical period of a new round of scientific and technological revolution, and whoever seizes this major historical opportunity will occupy future initiative. Since the 21st century, countries that have already built world technology powerhouses—Britain, France, Germany, and the United States—have all introduced relevant policies from national strategic levels to seek strategic initiative and maintain and strengthen their existing positions. Facing fierce international scientific and technological competition, China must seize the time node of this new round of scientific and technological revolution. How to seize this major historical opportunity? First, we must have adequate mental preparation and establish a sense of urgency, crisis, and mission. Second, we must have key grasping points—namely, major original innovations, breakthroughs in key core technologies, and transformation and application of scientific and technological achievements—to win development initiative and gain strategic advantages.

5.2 Pursuing Victory Points: Forward-Looking Planning for Scientific and Technological Frontiers

As a latecomer facing comprehensive U.S. high-tech blockade and suppression, China must achieve breakthroughs by deeply studying "victory-winning" strategies to achieve "asymmetric" catch-up and surpassing. As *The Art of War* states, "What enables the wise sovereign and the good general to strike and conquer, and achieve things beyond the reach of ordinary men, is foreknowledge." Scientific and technological competition is a "war without smoke." Only through forward-looking planning and advanced layout can we occupy future scientific and technological commanding heights. Therefore, in the coming period, the state must strengthen scientific forecasting and strategic assessment based on insights into scientific and technological development trends, and forward-plan for world science and technology frontiers for the next 50 or even 100 years. For example, what disruptive technologies that could change the world might emerge in the future? Where might the commanding heights of future world scientific and technological competition be? Currently, the prospects of a new round of scientific and technological revolution are becoming increasingly clear. We must not miss opportunities in fields such as brain science, gravitational waves, and dark matter that could become future scientific and technological competition frontiers. Therefore, while encouraging free scientific and technological innovation, we recommend using this national institutional reform opportunity to establish a strategic committee for scientific and technological frontiers under the newly formed Central Science and Technology Commission, composed of strategic scientists specializing in frontier research. This would provide decision-making consultation for the state to make advanced deployments in strategic layout, policy systems, and support conditions, helping China win strategic advantages in future scientific and technological competition.

5.3 Building Fulcrums: Improving Collaborative Support Networks

Building a world science and technology powerhouse is a systematic project that requires systematic thinking, strengthening force fulcrums, and optimizing support layouts to effectively enhance overall scientific and technological innovation efficiency. Based on China's actual situation, we recommend using "one foundation, three pillars, and four forces" as entry points to consolidate fulcrums for world technology powerhouse construction. First, cultivate "one foundation" deeply. Materially, China has world-leading major scientific and technological infrastructure, but problems such as "insufficient innovation culture leadership" [32] remain, requiring focused cultivation of innovation culture soil. Second, consolidate "three pillars." Education, science and technology, and talent are the three "cornerstone pillars" of building a world technology powerhouse—removing any one makes the structure unstable. However, for a long time, the three have been segmented by administrative boundaries, with institutional designs focusing on one aspect at the expense of others, lacking linkage mechanisms and insufficient supporting synergy. We need to strengthen overall coordination and horizontal integration to enhance "collaborative effects." Therefore, we recommend strengthening inter-departmental coordination at the national level to enhance consistency in institutional goals, synergy in actions, and complementarity in functions among education, science and technology, and talent systems, promoting optimization and maximization of the integrated education-science-technology-talent institutional system. Third, coordinate "four forces." Although China has established a national strategic scientific and technological force system with national laboratories, national research institutions, high-level research universities, and leading scientific and technological enterprises as the main body, their different affiliations and administrative segmentation prevent them from forming a collaborative innovation strategic force system, making it difficult to respond to complex and sharp international scientific and technological competition in a timely manner. Therefore, we recommend strengthening the functions of the Central Science and Technology Commission, enhancing policy coordination, optimizing the force system, ensuring coordinated linkage of key systems, and comprehensively enhancing the overall effectiveness of the strategic scientific and technological force system.

5.4 Strengthening the Foundation: Extraordinary Strengthening of Basic Research

In recent years, world technology powerhouses such as Britain, France, Germany, the United States, and Japan have maintained high-level basic research investment intensity, with the United States steadily increasing [33]. For China, since the 18th Party Congress, R&D funding intensity has maintained rapid growth for 10 consecutive years, rising from 1.91% in 2012 to 2.44% in 2021, higher than the EU average of 2.20% but still significantly lower than the United States (3.45%), Germany (3.14%), Japan (3.27%), and South Korea (4.81%). In terms of basic research share in enterprise R&D funding, developed European and American countries are all above 5%, while China is only 0.5%, hovering at a low level for a long time [34]. Clearly, China' s basic research still faces shortcomings of insufficient overall investment [35] and particularly low social investment, especially enterprise R&D funding, with "weak capacity to supply sources supporting economic and social development" [36], constraining world technology powerhouse construction. In view of this, we recommend "extraordinary" strengthening of basic research from the national level. First, implement a "baseline+" extraordinary investment plan, which means raising total basic research funding to the "baseline" level on par with the United States, then adding national fiscal investment in some scientific and technological frontiers and key fields to ensure absolute total investment surpasses the world' s number one technology powerhouse. Second, establish an extraordinary fiscal support mechanism for enterprise R&D investment through substantial tax reductions, multiplied fiscal subsidies, and other methods to encourage enterprises to significantly increase R&D investment and enhance enterprise independent scientific and technological innovation capabilities.

5.5 Addressing Pain Points: Overcoming Key Core Technologies

The "ceiling" currently facing China' s scientific and technological innovation is that "some key core technologies are constrained by others," with high external technology dependence, particularly in key basic materials, high-end specialized chips, terminal processors, and advanced testing equipment that have long relied on imports. This has become a pain point in building a world technology powerhouse. China must learn from this painful lesson and concentrate on tackling these challenges. First, we need "big ideas" to solve the conceptual problem of "independent innovation," fundamentally abandoning dependency consciousness and unswervingly following the path of independent innovation with Chinese characteristics. Second, we need "big actions" to solve the problem of how to walk this path well. We must give full play to the socialist institutional advantage of concentrating resources to accomplish major tasks, focus on pain point issues, gather multiple forces, organize major breakthroughs, and achieve key breakthroughs. Third, we need "big vision" —key core technologies must be constantly renewed. Advanced technologies are relative: advanced at one time may become backward later. Therefore, we must both maintain independence and keep a global perspective, walking well the path of international scientific and technological cooperation and innovation.

5.6 Clearing Blockages: Innovating Evaluation and Application Mechanisms

Institutional smoothness brings vitality, and mechanism smoothness brings efficiency. Since the 18th Party Congress, the national level has intensively issued a series of policy documents on reforming the scientific and technological evaluation system and mechanism. However, due to multiple factors such as thinking inertia and resource and interest distribution, the development of scientific and technological undertakings still faces blockages in scientific and technological evaluation systems and achievement transformation and application. The former manifests as academic-oriented evaluation orientation and singular standards, while the latter manifests as scientific and technological achievements remaining in studies and laboratories, making it difficult to produce knowledge "spillover effects" and timely transformation into real productive forces. Reforming the scientific and technological evaluation mechanism to clear achievement transformation and application blockages is urgently needed. First, establish and improve a diversified scientific and technological evaluation mechanism. For different types, natures, and characteristics of research such as basic research, applied research, and development research, establish a classified evaluation standard system to overcome the "one-size-fits-all" evaluation standard problem. Second, vigorously promote the transformation and application of scientific and technological achievements. The key is to facilitate close connection between innovation chains and industrial chains, giving full play to the dual driving roles of "capable government" and "effective market," smoothing channels between science and technology and the economy, and promoting deep integration of science and technology with the economy.

Building a world science and technology powerhouse is the only way to achieve the great rejuvenation of the Chinese nation. The long-suffering and indomitable Chinese nation has stood at a new historical starting point, facing new major historical opportunities. We must deeply learn from modern China' s historical lessons, adhere to innovation as the primary driving force, improve strategic thinking, establish innovative thinking, and maintain systematic thinking. We must both follow the multiple innovative driving logics of world technology powerhouse generation and learn from the critical paths of world technology powerhouse construction, creatively transforming and applying them. Only then can we forge a path with Chinese characteristics to build a world technology powerhouse, revive the nation, and benefit humanity.

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Responsible Editor: Wen Yanjie

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