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Abstract

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Keywords

technological sciences scientific and technological innovation “double cycle” self-reliance

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Build New Development Pattern of "Double Cycle" of Scientific and Technological Innovation

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Abstract: The CPC Central Committee proposed to speed up the formation of a new development pattern of the domestic and international double cycles, with the domestic cycle being the main body of this pattern. Facing a complex international and domestic situation, scientific and technological innovation being the core driving force, it is of urgent need to explore and build a new development pattern of "double cycle" to suit our national needs. Hence, under the guidance of Hsue-shen Tsien's thought on technological sciences and based on the original innovation function, secondary innovation function, and potential innovation function of technological sciences, this study puts forward the strategic idea of constructing a new development pattern of "double cycle" of scientific and technological innovation with technological sciences as the core. We hope that through the three strategic paths of domestic cycle, domestic and international double cycles, and international cycle, the "double cycle" of scientific and technological innovation will promote the economic "double cycle" and provide macro-strategic reference for China's scientific and technological self-reliance and integration into the international scientific and technological innovation pattern. **DOI:** 10.16418/j.issn.1000-3045.20210227101-en

Keywords: technological sciences; scientific and technological innovation; "double cycle"; self-reliance

It is pointed out at the meeting of the Political Bureau of the Central Committee of the Communist Party of China held on July 30, 2020 that "China still faces complex and severe economic situations with great instability and uncertainty that are likely to exist in the medium-long run and must be understood as a protracted war. China will speed up fostering a new development pattern in which domestic and foreign markets can boost each other, with the domestic market as the mainstay." It is clearly indicated during the 5th Plenary Session of the 19th Central Committee of the Communist Party of China held in October 2020 that "China will uphold the central role of innovation in its modernization drive and take self-reliance in science and technology as the strategic underpinning for national development."

In conjunction with the spirit of the recent series documents of the Central Committee, it can be assumed that scientific and technological (S&T) innovation is at the core of the new development pattern of the domestic and international double cycles, with the domestic cycle being the main body of this pattern (hereinafter referred to as the "double cycle"). Since the Sino-US trade frictions in 2018, the US has unreasonably suppressed Chinese high-tech enterprises. On the one hand, since China's S&T innovation is not well-grounded, China is not capable of strong independent innovation, especially originality, and the pattern of core technologies in key areas being enslaved to others has not fundamentally changed. On the other hand, the US frequently used its S&T advantages in the trade frictions to impose technological blockage on China, resulting in a prominent "hit in the throat."

General Secretary Xi Jinping pointed out that "only by holding these core technologies in our own hands can we truly grasp the initiative of competition and development and fundamentally safeguard economic security, national defense security, and security in other areas" [1]. At the same time, in the context of deep-going economic globalization, innovation resources are flowing faster across the world, and the economic and S&T ties among countries are getting closer. No country can solve all innovation challenges in isolation on its own. At the 9th collective study of the Political Bureau of the Central Committee held on September 30, 2013, General Secretary Xi expressed that "we should promote independent innovation from a higher starting point by deepening international exchanges and cooperation and making full use of global innovation resources, and work hand in hand with the S&T circles worldwide to make due contributions to addressing common global challenges."

It can be concluded that in order to play the role of S&T innovation in promoting the new development pattern of the economic "double cycle," we should first achieve the "double cycle" of S&T innovation. Specifically, in an open and shared international environment, key core technologies should be

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held in our own hands and also integrated into the overall pattern of global S&T innovation, making the "double cycle" of S&T innovation the endogenous driving force of economic "double cycle." Therefore, the process of forming a new development pattern of economic "double cycle" is promoted through the "double cycle" of S&T innovation. However, some basic concepts related to the "double cycle" of S&T innovation are not clear yet, including the connotation, constraints, and the mechanism and path of realization. These problems, if not solved, will not only affect the development of S&T innovation but also fundamentally affect the realization of economic "double cycle." To this end, this paper systematically tackled the basic problems related to the "double cycle" of S&T innovation. Additionally, the strategic concept of constructing the "double cycle" of S&T innovation under the guidance of Hsue-shen Tsien's thought on technological sciences is proposed to provide theoretical support and decision-making reference for the "double cycle" of S&T innovation.

1 Connotation of the "double cycle" of S&T innovation

1.1 Historical background for the "double cycle" of S&T innovation

The proposal of the "double cycle" of S&T innovation is closely related to the current international and domestic situations. ① In recent years, the US Department of Commerce has frequently issued export control "entity lists" to sanction Chinese companies and scientific research institutions. In addition to Huawei in the firing line, the US Department of Commerce has extended its reach to China's higher education institutions. For example, Harbin Institute of Technology, Harbin Engineering University, Northwestern Polytechnical University, Beijing Institute of Technology, Nanjing University of Aeronautics and Astronautics, and Beihang University have been included in the sanctions list; Harbin Institute of Technology and Harbin Engineering University have been banned from using MATLAB software. ② The core of Sino-US trade frictions over the years is essentially high-tech competition. The US has repeatedly prohibited the export of high-tech products to China with the intention of causing a de facto "high-tech decoupling." ③ Since the reform and opening up, historic, holistic, and structural changes have taken place in China's science and technology sector. In terms of S&T input and output, China has become one of the world's leading countries in science and technology and gained the initial potential and conditions to break the S&T blockade imposed by the US.

1.2 Basic contents of the "double cycle" of S&T innovation

According to the basic logic of the economic "double cycle," the "double cycle" of S&T innovation can be generalized into the following three aspects.

(1) The construction of the domestic cycle is the mainstay. On the basis of good basic research, China strives to achieve a major "zero to one" breakthrough and form key core technologies with independent intellectual property rights. Through the integrated innovation of multiple subjects, the whole process chain of S&T innovation will be broken through and the initiative of industrial development will be grasped. Furthermore, such efforts are expected to provide better research support and more challenging research topics for scientific development and realize localized knowledge production, flow, diffusion, application, and reproduction.

(2) Domestic and international double cycles boost each other. China seeks to learn and utilize all outstanding basic science results, major original S&T inventions, and disruptive S&T products worldwide, and introduce external knowledge resources into the domestic cycle via R&D cooperation, technology licensing, and enterprise mergers and acquisitions. Through the integration and convergence of localized and external knowledge, the level of S&T innovation will be enhanced to better meet the needs of the global market.

(3) Actively integrating into the international cycle. "Independent innovation" and "self-reliance in science and technology" are never equivalent to self-imposed isolation, but rather the implementation of a more open, inclusive, reciprocal, and shared international S&T cooperation strategy. While learning advanced S&T achievements from developed countries, China will naturally become the object of study and research and integrate into the international cycle. As a responsible developing country, China should contribute to narrowing the S&T gap between developing and developed countries through the output and application of S&T achievements and enhance the overall level of global S&T development.

1.3 Key difficulties in the "double cycle" of S&T innovation

According to the basic contents of the "double cycle" of S&T innovation, three key difficulties need to be overcome based on China's current situation.

(1) The function of basic science research as the source has not been effectively fulfilled in the domestic cycle. As the source of innovation, basic science research plays the role of running water from the fountainhead in S&T innovation. However, the prerequisite for its free flow from the fountainhead to the engineering technology section and then yielding fruitful S&T innovation is that the intermediate "culverts" and "gates" are all unblocked. General Secretary Xi Jinping emphasized during the 24th collective study of the Political Bureau of the Central Committee on October 16, 2020 that "China should improve the rate and efficiency of transforming theoretical research results of quantum science and technology into practice and engineering," which implies

the earnest hope for the quick transformation of basic science results into original innovation.

(2) In the domestic and international double cycles, the "hit in the throat" problem directly affects the overall situation of China's S&T innovation. In the field of basic sciences, China has studied and cited extensive foreign classical literature and produced the world's largest number of scientific papers, of which the quality is improving year by year. The results, however, are not satisfactory for the original "zero to one" innovation and the solution to the "hit in the throat" problem. Constrained by the introduction and transformation of advanced foreign products in engineering technology for many years, China has never made a breakthrough or a qualitative leap in principles, only following the international frontier. Being in a "limited running" position, China is passive at every turn and unable to grasp the competitive advantage.

(3) In the international cycle, China's contribution to global S&T innovation is still inadequate. Although China has already produced internationally competitive products and services such as high-speed rail, 5G network, and electronic payment, the overall contribution to global S&T innovation is still inadequate. There is a lack of major S&T achievements like "a general theory of three-dimensional flow of turbomachines" proposed by Wu Zhonghua and "pioneering discovery of artemisinin concerning a novel therapy against malaria inspired by classical Chinese medicine literature" by Tu Youyou. For the improved influence of China's S&T innovation, efforts are needed in prominent scientific discoveries, major S&T inventions, original and important patents, and other aspects to provide more high-quality results for global S&T innovation.

2 Realization path of the "double cycle" of S&T innovation based on technological sciences

From the analysis in Section 1.3, there are three difficulties in S&T innovation, which can be solved based on the author's previous research [2] and Hsue-shen Tsien's thought on technological sciences [3]. Basic sciences cannot be directly applied to technological innovation, and it is difficult to obtain original innovation by relying on engineering technology themselves. Only the technological sciences have rich innovative functions and play a crucial role in forming the "double cycle" of S&T innovation. The innovation role of technological sciences can be summarized into original innovation function, secondary innovation function, and potential innovation function [2]. This functional positioning can provide a solid theoretical foundation and operational guide for the construction of the "double cycle" of S&T innovation.

2.1 Domestic cycle of S&T innovation

Based on the three innovation functions of technological sciences, the domestic cycle idea of S&T innovation is proposed with technological sciences as the core (Figure 1). As shown in Figure 1, the domestic cycle is composed of three paths.

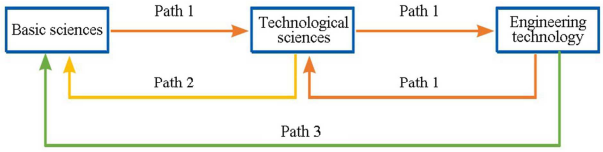

Figure 1 Idea of constructing the domestic cycle of S&T innovation

(1) Domestic cycle path 1: "basic sciences–technological sciences–engineering technology" and "engineering technology–technological sciences," which expresses the original innovation process of technological sciences. It involves two parts: ① To realize the localized flow of S&T knowledge through the path of "basic sciences–technological sciences–engineering technology" and keep key core technologies in our own hands; ② "Engineering technology–technological sciences," i.e., the problems extracted from engineering technology give rise to research on technological sciences, which in turn achieves innovation in engineering technology. The domestic cycle path 1 fully demonstrates the original innovation functions of technological sciences, i.e., original invention and original innovation combining theory-oriented applied research and application-oriented basic research. To illustrate the domestic cycle path 1 more clearly, its internal knowledge activities and subject activities are portrayed in depth in Figure 2. Figure 2 shows each key link and overall chain of knowledge activities and subject activities: ① Embarking on pure basic sciences, scientific principles and scientific discoveries are transformed into new technological principles, based on which we may produce prototypes and models or propose original invention proposals and finally transform them into product innovation or process innovation as needed by enterprises. ② From the needs of enterprises and markets, we may conduct application-oriented technological basic research, change the original innovation path that is initiated from the basic research section, and foster knowledge innovation to cater to the needs of enterprises and markets. The main features of this path are the presence of the knowledge supply chain for application-oriented basic research, which compensates for the shortcomings of the original linear model. The domestic cycle path 1 is essentially in full accord with what General Secretary Xi Jinping proposed in his speech at the symposium with scientists: "In one respect, basic research, in conformance with scientific discovery's own laws, requires curiosity to explore the world's mysteries. There is thus a need to encourage free exploration and full exchanges and debates. In another respect, basic research is driven by major S&T problems. That is, abstract theoretical questions are formed in the course of researching major applications and

then lead to explorations of scientific laws, with the result that basic research and applied research spur each other on" [4]. It is an accurate and in-depth interpretation of the spirit delivered by General Secretary Xi Jinping.

(2) Domestic cycle path 2: "technological sciences–basic sciences," which refers to the process of technological sciences repaying basic sciences. Hsue-shen Tsien [3] pointed out with foresight that the research results in technological sciences, if analyzed and further improved, could become a part of natural sciences. A remarkable example here is engineering cybernetics, which is summarized from the practice of automatic control. In nature, it evolves into biological cybernetics. As technological science, cybernetics can profoundly contribute to the development of biology, a basic science discipline, and fully embody the repaying function of technological sciences to basic sciences.

(3) Domestic cycle path 3: "engineering technology–basic sciences," which denotes the role of engineering technology in the development of basic sciences. Historically, in the field of astronomy, the emergence of telescopes and gravitational detection devices has spawned more discoveries of new astronomical phenomena and accelerated the progress of astronomy. In the field of atomic physics, the electron-positron collider and other large-scale scientific devices have caused a more profound understanding of the microscopic world. In the field of medicine, the continuous upgrading of medical equipment has deepened human understanding of life, and advances in basic medicine have been generated thereof. The three paths described in Figure 1 illustrate the general idea of constructing the domestic cycle of S&T innovation: Through efforts in basic sciences and engineering technology, new technological principles, models, prototypes, original inventions, etc. are formed in the key link of technological sciences so as to achieve the ultimate goal of innovation in engineering technology. Additionally, the development of technological sciences and engineering technology can in turn promote the development of basic sciences, thereby forming the power source for a new round of circulation. Supposing China can independently complete the above-mentioned paths, we will keep key core technologies in our own hands through patent applications, technological secrets, industrial connections, and other industry–university–research cooperation. Moreover, the development of basic sciences is continuously promoted by naturally existing feedback relations (Figure 2), and the domestic cycle of S&T innovation can continue to run by reinforced market demand orientation.

2.2 Domestic and international double cycles of S&T innovation

Figures 1 and 2 illustrate the innovation chain of "basic sciences–technological sciences– engineering technology" from the perspective of the domestic cycle. Expanding the horizon to an international perspective, we can draw the idea of constructing domestic and international double cycles of S&T innovation based on the secondary innovation function of technological sciences, which also contains three paths (Figure 3).

(1) Path 1 of domestic and international double cycles: "foreign engineering technology–domestic technological sciences–domestic engineering technology," which provides a new idea of learning, digesting, absorbing, and re-innovating advanced foreign engineering technology based on the secondary innovation function of technological sciences. In the past, the study of foreign advanced technologies often fell into the cycle of "introduction–falling behind–reintroduction–falling behind again," mainly because the technical principles of advanced foreign technologies were not figured out, making improvements and re- innovation impossible on their bases. In the future, we should figure out the technical principles of advanced foreign technologies at the level of technological sciences and strive to upgrade the technical principles, in hope of improving the innovation level of engineering technology in China on the new technological track.

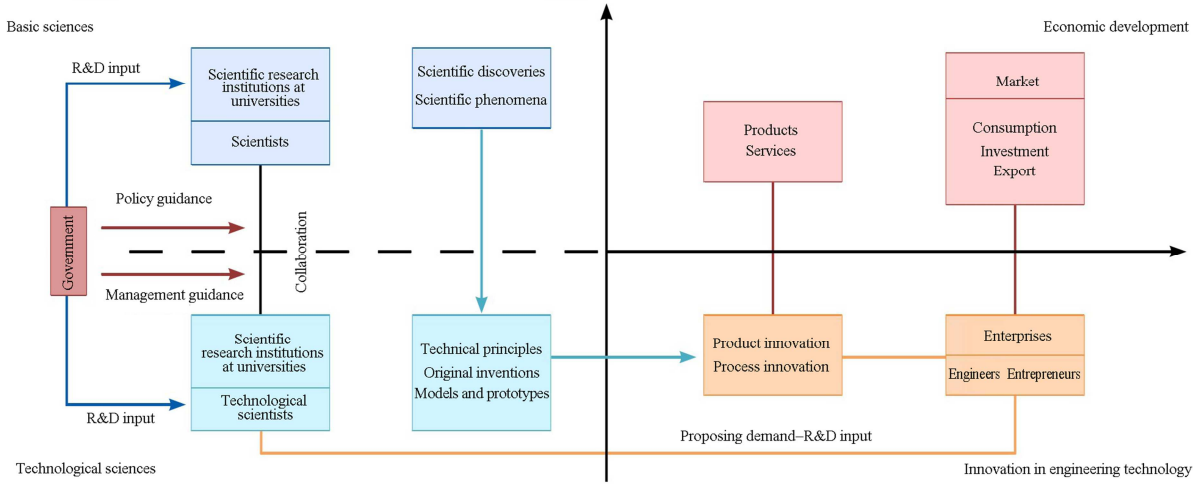

Figure 2 Activity chart of the main body of domestic cycle with technological sciences as the core

(2) Path 2 of domestic and international double cycles: "foreign technological sciences–domestic engineering technology," which gives a new idea of promoting the innovation level of engineering technology in China based on the achievements of foreign technological sciences. Taking Marconi's wireless communication technology as an example, it was initially achieved in Italy and the UK, but finally became a reality in the US. Then there is the case of penicillin, whose achievements in basic sciences and technological sciences originated in the UK. However, it was eventually industrialized and produced by a pharmaceutical enterprise in the US. The results of technological sciences, although protected by patents and other forms of intellectual property rights, are in their infancy, and the patent thicket has not yet been formed, leaving us with considerable space and time to exploit them. As a counter-example, the technological science results of Wu Zhonghua and Tu Youyou in China have been used by foreign countries for many years without compensation due to the lack of patent protection at that time.

(3) Path 3 of domestic and International double cycles: "foreign basic sciences–domestic technological sciences–domestic engineering technology," which offers a new idea of using the outcomes of foreign basic sciences in all aspects to improve China's innovation level in engineering technology from the source [5]. Since basic sciences possess the natural characteristics of openness and sharing, there are few barriers to learning and utilization. For example, Einstein's theory of stimulated emission proposed in 1916 was transformed into technological science results by Townes and Schawlow in 1958 and then guided Maiman to successfully build a ruby laser in 1960. It exemplifies the transformation of the results of basic sciences into engineering technology. Inspired by the work of foreign counterparts, Chinese scientists made the first laser early in 1961, fully demonstrating the extensive and undifferentiated source role of basic science results.

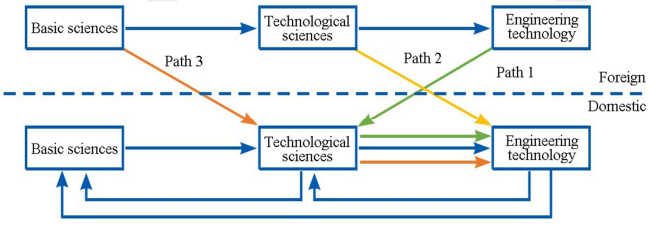

Figure 3 Idea of constructing domestic and international double cycles of S&T innovation

2.3 Integration into the international cycle of S&T Innovation

By reversing domestic and foreign positions in Figure 3 to form Figure 4, the direction of knowledge flow can be reversed, showing the feasibility and possibility of China's active integration into the international cycle of S&T innovation. This means that while making full use of both domestic and foreign resources, China's advanced S&T achievements are also regarded as resources and thus become the knowledge base for the innovation activities of foreign subjects. This not only embodies China's contribution to global S&T innovation but also is an inevitable outcome of China's deep involvement in the international cycle.

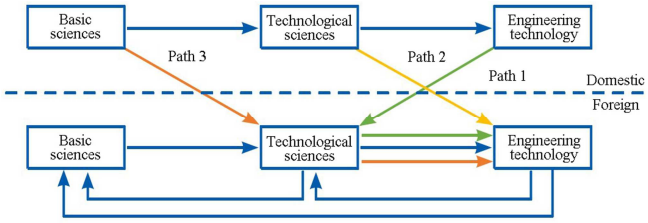

Figure 4 Idea of integrating S&T innovation into the international cycle

3 Measures and recommendations

In order to implement the construction framework of the "double cycle" of S&T innovation, we propose three measures and recommendations that take into account China's conditions.

(1) Attaching importance to the role of technological sciences in the "double cycle" of S&T innovation. ① Efforts should be made to strengthen the publicity of the ideas of technological sciences, clarify the vital role of technological sciences in original innovation, digestion, absorption, and re-innovation, and deepen the understanding of scientific circles, governments, enterprises, and other relevant personnel on the connotation contained in the ideas of technological sciences. ② We should intensify the theoretical research and practical summary of S&T innovation with the ideas of technological sciences, and deepen the particular understanding of the policies, the organization and management of technological sciences. ③ Measures should be taken to clear up the difference and connection between basic sciences and technological sciences and clarify the harm to S&T innovation brought by the lack of the ideas of technological sciences. ④ We should emphasize and implement the spirit of a series of documents such as *Several Opinions of the State Council on Comprehensively Strengthening Basic Science Research* and *Work Plan for Strengthening Basic Research "from zero to one"* based on the ideas of technological sciences.

(2) Strengthening the construction of specialized policies and organizations related to technological sciences. It is necessary to guide and manage the construction of the "double cycle" of S&T innovation at the macro-management level, ensure the smooth flow of the knowledge supply chain for S&T innovation with technological sciences as the core, and guarantee the active, standard, and synergistic behavior of innovation subjects. ① In guidance documents such as the 14th Five-Year Plan for national S&T innovation, we should re-affirm the critical position of technological sciences in building a great power in science and technology and stress

the strategic role in the national S&T development and the improvement of independent innovation capability. ② The guiding principles and subject guidelines for supporting technological science research should be defined in science and technology projects such as the National Natural Science Foundation of China and the National Key R&D Program of China, and the support for technological science research should be built up in terms of financial investment. ③ We can gather the superior resources of the Department of Basic Research and the Department of High and New Technology of the Ministry of Science and Technology as well as the Department of Science, Technology and Informatization and the Department of Higher Education of the Ministry of Education and other relevant departments to reinforce the guidance and management of the development of technological sciences.

(3) Promoting the integration and innovation of multiple subjects with technical scientists as a bridge. In line with the operation of the knowledge innovation supply chain, a synergistic mechanism of S&T innovation subjects should be constructed, which is centered on the cultivation and use of technological scientists (corresponding to scientists and engineers). ① It is essential to drive scientists, inventors, and even entrepreneurs to collaborate, taking the cultivation and use of technological scientists as a grip. ② We should promote the synergistic innovation of scientists, inventors, and entrepreneurs, discover and encourage the commanding leaders in S&T innovation who incorporate styles of "scientists–inventors–entrepreneurs." ③ Enterprises can establish their innovation institutes, recruit high-level talents, and provide generous treatment or even equity; ④ Relying on the "National Technology Innovation Center" under construction by the Ministry of Science and Technology, we should support the development of technological sciences and profoundly conduct comprehensive and regional research on technological sciences.

4 Conclusion and outlook

In retrospect, Hsue-shen Tsien's thoughts on technological sciences that are fully reflected in the *Long-range Plan for Scientific and Technological Development 1956–1967* have achieved great success in the "Two Bombs, One Satellite" project. They were referred to as "the way to make China a powerful country in technological sciences" by Zhang Jinfu [6]. In the innovation chain with basic sciences as the source, technological sciences can act as the bridge and intermediary to allow basic research results (basic sciences) to be finally transformed into original innovation results (engineering technology). Therefore, the whole chain of S&T innovation is connected. Moreover, supplemented by the learning and absorption of advanced foreign S&T achievements centered on technological sciences, the general framework of China's "double cycle" of S&T innovation is constructed. The ideas of technological sciences still have immense theoretical value and practical significance even to this day [7], which can provide insight into the construction of the "double cycle" pattern of S&T innovation in China.

Indeed, the construction idea of the "double cycle" of S&T innovation proposed in this paper is still a macroscopic theoretical idea. Although corresponding measures and recommendations are provided for the framework of the idea, efforts should be made to achieve concrete results in practice and refine operable and implementable policies to ensure the smooth operation of China's "double cycle" of S&T innovation and ultimately lay a solid foundation for establishing the economic "double cycle" pattern.

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