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Emphasis on Role of Technology Sciences in Supply Side Reform of Science and Technology Innovation

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Abstract

The concept of technology sciences was proposed by Mr. Tsien Hsue-shen. It occupies a middle position in the chain of basic science and engineering technology innovation and plays a bridging role. For a long time, the concept of technology sciences has been rarely mentioned in China's science and technology policy making process, which to a certain extent has led China's science and technology policy to either favor the basic research or the engineering and technology, which is not conducive to the output of major scientific and technological innovations. It can also lead to the occurrence of the "neck jam" phenomenon. In response to the above problems, the key role of technology sciences in the supply side of science and technology innovation is expounded through literature review and case study. In addition, we construct a whole chain model of science and technology innovation with basic science as its source and technology sciences as its core. This study puts forward countermeasures and suggestions from three perspectives: knowledge, talents, and policy. Through the supply side reform of science and technology innovation, the whole chain of science and technology innovation is accelerated to provide a strong source of driving force for innovation.

Keywords

technology sciences; innovation; supply side reform

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Emphasis on Role of Technology Sciences in Supply-Side Reform of Science and Technology Innovation

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Abstract: The concept of technology sciences was proposed by Mr. Tsien Hsue-shen. It occupies a middle position in the chain of basic science and engineering technological innovation, playing a bridging role. For a long time, the concept of technology sciences has been rarely mentioned in China's science and technology policy making process, which to a certain extent has led China's science and technology policy to either favor the basic research or the engineering and technology. This is not conducive to the output of major science and technology innovations, causing the bottleneck problems. In response to the above problems, the key role of technology sciences in the supply side of science and technology innovation is expounded through literature review and case study. In addition, we construct a whole chain model of science and technology innovation with basic science as the source and technology sciences as the core. This study puts forward countermeasures and suggestions from three perspectives: knowledge, talents, and policy. Through the supply-side reform, the connection of the whole chain of science and technology innovation can be accelerated to provide a strong driving force for the innovation.
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Keywords: technology sciences; innovation; supply-side reform

In recent years, China has been leading the world in the fields of iron-based superconducting materials, quantum anomalous Hall effect, and multi-photon entanglement and has made great achievements in the fields of neutrino oscillation and stem cells, becoming a major contributor of high-quality papers in the world. However, China still lacks major original innovation achievements and has bottleneck problems. This means that the supply function of source knowledge from basic research has not been fully played, and the basic research can barely support science and technology innovation in key fields.

The gap between basic research and innovation, to some extent, is caused by the poor cognition and policy for technology sciences. For a long time, China's science and technology policy favors either the basic research or the engineering and technology, which is not conductive to knowledge supply of basic science for engineering technology, causing poor output of science and technology innovation. In view of the indispensable role of technology sciences in the whole chain of innovation, we explore the construction of knowledge supply chain with basic science as the source and technology sciences as the core. On the basis of the knowledge supply chain, this paper puts forward countermeasures and suggestions on talents cultivation, policy making, and financial investment, so as to provide policy enlightenment for improving the knowledge supply capacity of science and technology innovation.

1 Technology sciences and its role in science and technology innovation

1.1 Concept of technology sciences

Under the guidance of Professor Theodore von Kármán, Tsien Hsue-shen's thought of technology sciences was gradually formed in his research work of applied mechanics. In 1957, Tsien Hsue-shen published a paper On Technology Sciences [1] in *Chinese Science Bulletin*. In this paper, he proposed the concept of technology sciences. He points out that in the activities of engineering technology, it is necessary to integrate natural science and engineering technology and establish a new discipline—technology sciences, to overcome the limitations of experience. Technology sciences is based on natural science while is not natural science; it is derived from engineering technology while is not engineering technology. That is, technology sciences are an independent discipline between natural science and engineering

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technology, playing a bridging role. It is derived from the combination of the two and serves engineering technology. Natural sciences, technology sciences, and engineering technology interact with and support each other, which necessitate equal attention.

Tsien Hsue-shen's thought of technology sciences surpasses Vannevar Bush's linear model of basic research and applied research which was popular in the 1950s as well as the Pasteur's quadrant model developed by Stokes. It is an advanced view on the interaction between science and technology. The thought of technology sciences has been fully embodied in the 1956–1967 National Scientific and Technological Development Plan (hereinafter referred to as the 12-Year Plan). With the guidance of this thought, the "Two Bombs, One Satellite" project has achieved great success [2,3]. Zhang Jinfu, former vice president of the Chinese Academy of Sciences [4], called Tsien Hsue-shen's thought as the way to strengthen China through technology sciences.

1.2 Innovation function of technology sciences

Liu [5] redrew the quadrant diagram of science and technology (Fig. 1) according to Tsien Hsue-shen's thought of technology sciences and Pasteur's quadrant model. He clarified the relationship among basic sciences, technology sciences, and engineering technology, as well as the function of technology sciences in innovation system.

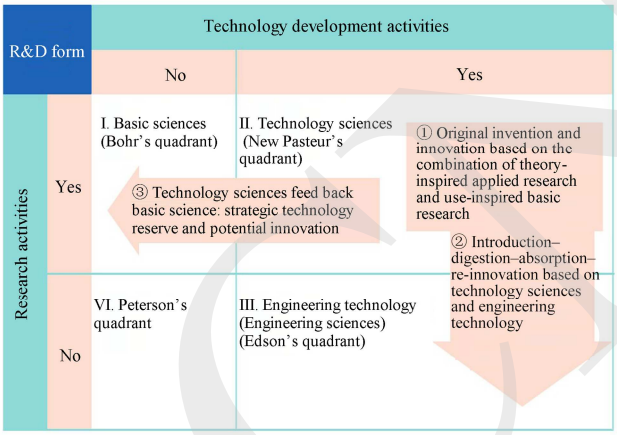

Fig. 1 The quadrant model of science and technology [5]

The four quadrants are named after four representative characters. The first quadrant is about basic sciences, exemplified by the work of Bohr, who is mainly engaged in pure basic research. The second quadrant is about technology sciences, exemplified by the work of Pasteur, who is mainly engaged in basic and use-inspired technological research. The third quadrant is about engineering technology, exemplified by the work of Edison, who is mainly engaged in the development of engineering technology. The fourth quadrant is mainly about the research activities exploring a specific phenomenon, such as Peterson's *Field Guide to Birds of Eastern and Central North America*. Among them, technology sciences (New Pasteur's quadrant) are in the second quadrant between the first and third quadrants. In addition to its original innovation function, technology sciences can boost engineering technology (secondary innovation function) and feed back basic sciences (potential innovation function).

(1) Original innovation function. In the frontiers of technology sciences, the combination of theory-inspired applied research with use-inspired basic research can help to make major breakthroughs and original invention of cutting-edge technology on the basis of technology sciences, and then realize the original innovation of frontier technology. Laser and Pasteur's innovative achievements on microorganisms are achievements of such original innovations.

(2) Secondary innovation function. Only by clarifying the basic principles of original technology, can we improve the structure and function, design and technology, and materials and processing, and finally realize the secondary innovation at the level of engineering science. Japan's duplicator and personal stereo are typical achievements of secondary innovations.

(3) Potential innovation function. If the laws summarized from the knowledge gained from engineering experience are consistent with those in the nature, technology sciences will promote or upgrading basic sciences. For example, engineering cybernetics is a pure technology science. Once being applied to biology, it can promote the development of biological science and technological innovation.

1.3 The bridging role of technology sciences

Among three functions of technology sciences, the original innovation function undoubtedly plays a crucial role in the current science and technology innovation. Laser is a typical case of original innovation based on technology sciences. The theoretical basis of laser is the hypothesis of stimulated emission proposed by Einstein in 1916. In 1958, the American physicists Townes & Schawlow published the paper "Light Amplification by Stimulated Emission of Radiation," in which they proposed the realization principle of stimulated emission and established a model of laser machine which was then applied for a patent. Maiman at the Hughes Aircraft Company produced the first ruby laser. The work of Einstein, Townes & Schawlow, and Maiman falls into the categories of basic sciences, technology sciences, and engineering technology, respectively. Townes & Schawlow transforms Einstein's basic theory into technical principles that can be directly applied to engineering technology, playing a bridging role. According to this case, technology sciences serve as a bridge in the innovation chain with basic science as the source, enabling the transformation of the basic research results (basic sciences) to original innovation achievement (engineering technology) and thus connecting the whole chain of science and technology innovation (Fig. 2).

2 Absence of the thought of technology sciences affects science and technology innovation

Due to various reasons, the scientific community, the government, and the public have not fully understood the nature and function of technology sciences. The concept of technology sciences, as well as the particularity of the policies, organizations, and management related to technology

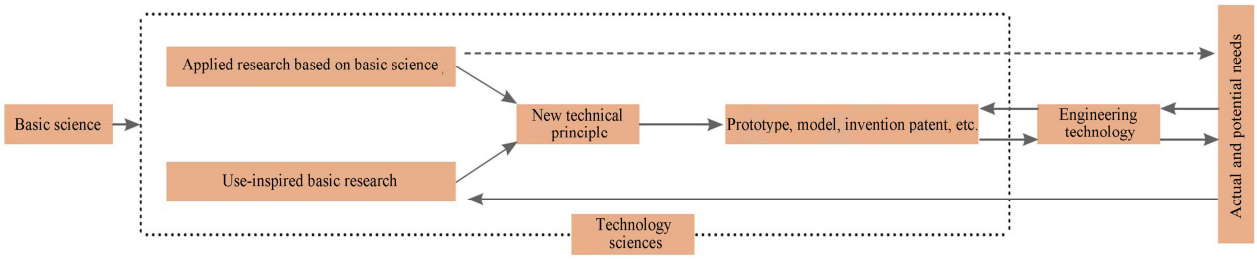

Fig. 2 The innovation chain of basic sciences–technology sciences–engineering technology

sciences, remains unclear [7]. This cognitive absence directly affects the construction of the national innovation system and the policy making of science and technology.

2.1 The role of basic research is difficult to be fully played

Since China implemented the strategy for innovation-driven development, science and technology innovation has been playing a key role in the construction of an innovative country [8]. Science and technology innovation extends the previous innovation activities mainly oriented towards engineering practice to basic sciences. The scientific findings and theories from basic research activities supply knowledge for engineering technology to foster innovative achievements.

However, we should not assume that a good job in basic research will definitely lead to innovation results, which is neither in line with the principles of technology sciences nor with practical experience. In history, the Soviet Union was a country with strong ability of basic research. However, due to the disjunction between research and market demand, the basic research could not sufficiently support technology innovations required by the market, which finally led to the continuous decline of its science and technology innovation capacity. In contrast, its long-time competitor, the United States, not only attaches importance to the innovative source function of basic research but also focuses on the combination of basic research achievements with market demand. The research institutions, and/or with enterprises in the United States, have developed a large number of innovative models of theoretical and disruptive technologies, which has fostered the surging of original innovative achievements. Laser, atomic energy, semiconductors, integrated circuits, penicillin, streptomycin, polymerase chain reaction (PCR), and giant magnetoresistance are all major inventions and innovations based on technology sciences.

2.2 Deviation in the orientation of academic research

For a long time, the evaluation criterion of Chinese academic circle is the number of published papers. As a result, the academic staff have a biased understanding of research and focus on publishing papers instead of promoting the application of basic research achievements to the market. Therefore, cutting-edge achievements of technology sciences and major original innovative achievements are insufficient. This explains why the number of published papers of China has ranked the second in the world while the innovation capacity cannot reach the top level.

To solve this problem, the Ministry of Science and Technology, National Development and Reform Commission, Ministry of Education, Chinese Academy of Sciences, and National Natural Science Foundation of China have jointly formulated the Plan for Strengthening Basic Research from 0 to 1, in the hope of enhancing innovation capacity through strengthening basic research. This plan conforms to the thought of technology sciences and makes it clear that solving the problems intermediate between basic research and original innovation is in the category of academic research, and even more important academic research. The basic research from 0 to 1 can produce not only papers but also invention patents, prototype, model, and other theoretical achievements. However, due to the lack of the guidance of technology sciences, the concept and the logicality of operation means in this plan remain unclear. Specifically, the connotation and extension of basic research, the way of application of basic research achievements into market, and the way of talent training are not defined.

2.3 It is difficult to solve the bottleneck problems

In recent years, China's research in engineering science and technology has reached the top level in the world. China has a strong international competitiveness in engineering fields such as roads and bridges, marine drilling platforms, large ships, and high-speed railways. In the field of engineering machinery, a number of key technologies and products in the manufacturing of engineering equipment have emerged, such as shield tunneling machine, road roller, and crane. Nevertheless, bottleneck problems still exist in core components and parts and high-end material manufacturing.

Bottleneck problems appear because of the weak capacity of original innovation. Most innovations focus on the improvement and integration. Efforts should be made to address the major problems in the fields of engines, integrated circuits, high-end components, and advanced materials through a new joint mechanism. In particular, attention should be paid to the protection and application of scientific and technological achievements. After all, there are historical lessons

such as Wu Chung-Hua's three-dimensional flow theory of turbomachinery [①]. We should clearly realize that in the context of science and technology innovation, the improvement of engineering technology can no longer fully meet the needs of the market and national development. China should devote to making major technological breakthroughs based on new technical principles to improve international competitiveness.

3 The framework of supply-side reform of science and technology innovation based on technology sciences

Technology science plays an important role in the chain of science and technology innovation, which can provide demand side including enterprises and the market with direct and effective knowledge supply. To solve the problem of insufficient knowledge supply, we should emphasize the role of technology sciences in the supply-side reform of science and technology innovation (Fig. 3). The reform framework takes technology sciences as its core and involves knowledge, talents, and policy. Therefore, the supply-side reform can be conducted from the following three aspects: knowledge supply, talent supply, and policy supply.

3.1 Knowledge supply reform: constructing a knowledge supply chain of science and technology innovation based on technology sciences

The core of national innovation system construction and innovation-driven development strategy is to construct and form innovation supply chain to promote technological innovation of enterprises. Since basic research is the source of science and technology innovation, we should give full play to the intermediary role of technology sciences in the discovery–innovation system and build a knowledge supply chain: basic science–technology sciences–innovation, which will supply high-quality knowledge that meets demand.

This knowledge supply chain contains two paths of knowledge activities. ① Starting from pure basic science, we can transform scientific principles and discoveries into new technical principles to produce prototypes and models or put forward original invention schemes, and finally transform them into innovative products or technologies for enterprises. ② Starting from the demand of enterprises and the market, we can carry out use-inspired basic research to alter the original innovation path initiated from the basic research and carry out knowledge innovation. This path supplements the use-inspired basic research to the chain, which complements the deficiency of the original linear model. At the same time, it changes the previous idea that takes basic research as the supply side of science and technology innovation. Instead, it includes technology sciences as a source of knowledge supply into the supply side. This shortens the distance between the knowledge supply and the demand of enterprises and the market. It can realize the rapid and effective docking between knowledge supply chain and industrial supply chain, and ultimately provide products and services that are more in line with the needs of consumers as well as the economic and social development.

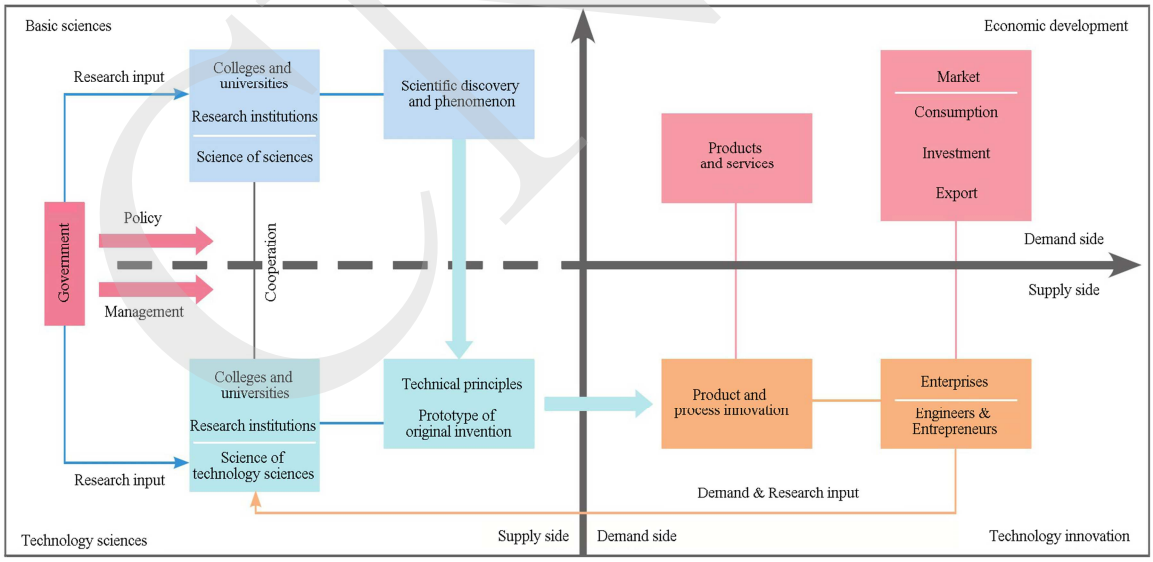

Fig. 3 Supply-side reform of science and technology innovation based on technology sciences

① In the 1950s, Wu Chung-Hua put forward the three-dimensional flow theory of turbomachinery, which was called Wu's theory by international peers. This theory was widely applied in advanced aero-engine design. The spey engine produced by Rolls-Royce in the UK benefits from this theory. In the 1970s, China introduced the Rolls-Royce spey engine, and Wu Chung-Hua participated in the technical improvement.

3.2 Talent supply reform: building a collaborative innovation mechanism centered on technical scientists

In the 1950s, Tsien Hsue-shen began to explore the cultivation of technical scientists at the University of Science and Technology of China [1]. In order to realize the translation between engineering technology and natural science theory, technical scientists should not only master the method of mathematical modeling but also extract the demand of enterprises and the market from engineering technology (and conduct theoretical research by employing natural science research results and engineering practice experience) [9].

Efforts should be made to establish a collaborative mechanism of science and technology innovation which centers the cultivation and utilization of technical scientists. Scientists, inventors, and entrepreneurs should cooperate to provide intellectual support for the operation of the knowledge supply chain for science and technology innovation and to realize the integration of innovation activities and knowledge as well as the integration of intellectual support and knowledge support.

It is necessary to promote the collaborative innovation of scientists, inventors, and entrepreneurs. Leading talents and strategic scientists who can act as all the three characters (scientists, inventors, and entrepreneurs) and transform technologies for application should be fostered. The popular development mode of technology sciences is to push technology sciences to enterprises and make enterprises support the research of technology sciences, which can be exemplified by Bell laboratory in the United States [10]. Many enterprises in China are also trying this mode. They are establishing their own innovation research institute, recruit top-level talents, with preferential treatment and stock right. The collaborative model of scientists, engineers, and entrepreneurs has begun to take shape, a typical representative of which is the Alibaba DAMO Academy. However, these spontaneous efforts are not enough. It is still necessary for the state to lay out industrial departments, establish research and development centers of industrial technology sciences, and shoulder the responsibility of supporting the development of technology sciences.

3.3 Policy supply reform: making science and technology innovation policies oriented to technology sciences

Among the four key programs of basic research in China, the major research program and the special fund for research of scientific apparatus mainly focus on pure basic research. Major science frontiers, interdisciplinary projects, and key basic research projects for future economic and social development take applied basic research and industrialization into account. Our understanding and emphasis on technology sciences in these projects are still inadequate. With the thought of technology sciences, we should reconsider the requirements of knowledge supply chain and innovation actors to adjust the existing funding policy and management system.

It is suggested to emphasize technology sciences from all aspects and highlight the role of technology sciences in the construction of a science and technology power as well as in the development of national science and technology and the improvement of independent innovation capacity. Independent management departments, strategic planning, and capital investment should be provided for technology sciences. Meanwhile, a special talent cultivation and distribution system needs to be built to cover the important fields of technology sciences. It is necessary to provide policy guidance and management services for the supply-side reform of science and technology innovation from the government level, so as to ensure the smooth operation of the knowledge supply chain of the innovation centered on technology sciences, as well as the active, standard, and coordinated behaviors of innovation actors.

4 Conclusions

General Secretary Xi Jinping has pointed out that basic research is the source of the whole scientific system, and we should aim at the science frontiers, …, to achieve major breakthroughs in cutting-edge basic research and leading original achievements, …, connect applied basic research with industrialization, and promote the precise docking of innovation chain and industrial chain [11]. Therefore, we should learn the current trend of science and technology development and give full play to the source role of the basic research and the intermediary role of technology sciences to form the whole-chain innovation pattern, promote the smooth operation of the chain, and truly implement the innovation-driven development strategy.

On the basis of Tsien Hsue-shen's thought of technology sciences, this paper puts forward countermeasures and suggestions for the supply-side reform of science and technology innovation from three perspectives: knowledge, talents, and policy. However, since the reform involves all aspects, its framework, operation mechanism, and implementation need to be further discussed in detail. We hope this paper can attract attention to technology sciences and its function in the science and technology innovation, and arouse Tsien Hsue-shen's thought of technology sciences which has been proved to be effective in the leapfrog innovation practice of the "Two Bombs, One Satellite" project. Such reform will facilitate the response to the challenge of the fourth industrial revolution dominated by intelligent manufacturing and bioengineering.

References

1 Tsien H S. 论技术科学. Chinese Science Bulletin, 1957, 8 (3): 97–104 (in Chinese).

2 Feng Z J, Zhang N C. 技术科学研究的重要作用. Science Research Management, 1980, 1 (1): 9–19 (in Chinese).
3 Jiang Y P. 钱学森与技术科学. Shanghai: Shanghai People's Publishing House, 2015 (in Chinese).
4 Zhang J F. 让科学精神永放光芒—读《钱学森手稿》有感. Complex Systems and Complexity Science, 2006, 3 (2): 77–81 (in Chinese).
5 Liu Z Y, Chen Y. New Pasteur's quadrant: New paradigm of high-tech policies. Chinese Journal of Management, 2007, 4 (3): 346–353 (in Chinese).
6 Yang Z K, Liu Z Y, Liang Y X. The technological sciences trend of the achievements' nature of the Nobel Prize for natural science awards: Since the 21st century. Studies in Science of Science, 2016, 34 (1): 4–12 (in Chinese).
7 Zheng Z M. 从钱学森的技术科学思想谈起. Study Times, 2017-12-27 (05) (in Chinese).
8 Literature Research Center of the CPC Central Committee. 习近平关于科技创新论述摘编. Beijing: Central Party Literature Press, 2016 (in Chinese).
9 Chen Y, Song C, Liu Z Y. What is the engineering sciences? Studies in Science of Science, 2020, 38 (1): 3–10 (in Chinese).
10 Yang Z K, Liang Y X. 从基础研究中获得原始创新. Study Times, 2016-01-07 (07) (in Chinese).
11 Xi J P. 在中国科学院第十九次院士大会、中国工程院第十四次院士大会上的讲话. People's Daily, 2018-05-29 (02) (in Chinese).

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