Postprint: A Study on Issues Concerning the Integrated Development of Innovation, Industrial, Capital, and Talent Chains

Authors: Nie Changhong, Zhao Feijie, Li Chuan, Chen Tong

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Abstract

The significance of promoting the deep integration of innovation chains, industrial chains, capital chains, and talent chains (hereinafter referred to as the "four chains") for high-quality economic development is self-evident. Its essence lies in reducing various barriers encountered when innovation elements flow across organizational boundaries, enhancing allocation efficiency, better leveraging enterprises' principal role in scientific and technological innovation, and strengthening the overall effectiveness of the national innovation system. Based on a systematic analysis of the integration issues of the "four chains" in China, this article proposes the following countermeasures and recommendations: (1) Promote systematic layout and systematic implementation of scientific and technological innovation policies; (2) Explore the establishment of "large-scale sci-tech intermediary institutions" and build decision-making mechanisms and market-oriented pricing mechanisms that conform to innovation laws; (3) Accelerate the formulation of implementation rules for the transformation of scientific and technological achievements and clarify the boundaries of responsibilities, rights, and interests; (4) Deploy and build the talent chain prospectively around the development needs of industrial chains and innovation chains; (5) Strengthen the supporting role of fiscal and tax policies in scientific and technological innovation; (6) Strengthen application scenario innovation to help improve market acceptance of domestically produced new technologies and new products.

Full Text

Preamble

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Authors: NIE Changhong[1],[2], ZHAO Feijie[1], LI Chuan[1], CHEN Tong[3]*

[1] School of Economics and Management, University of Chinese Academy of Sciences, Beijing 100190, China
[2] Science and Technology Innovation and Development Center, Chinese Academy of Sciences, Beijing 100190, China
[3] Academy of Mathematics and Systems Science, Chinese Academy of Sciences, Beijing 100190, China

Abstract

Promoting the deep integration of the innovation chain, industrial chain, capital chain, and talent chain (hereinafter referred to as the "four chains") is of self-evident significance for high-quality economic development. Its essence is to reduce the various barriers encountered when innovation elements flow across organizational boundaries, improve allocation efficiency, better leverage enterprises' principal role in scientific and technological innovation, and enhance the overall effectiveness of the national innovation system. Based on a systematic analysis of the challenges facing the integration of China's "four chains,"this article proposes the following policy recommendations: (1) promote the systematic layout and implementation of scientific and technological innovation policies; (2) explore the construction of "large-scale science and technology intermediaries" and build deliberative decision-making mechanisms and market-oriented pricing mechanisms that conform to innovation laws; (3) accelerate the formulation of detailed implementation rules for the transformation of scientific and technological achievements to clarify boundaries of responsibilities, rights, and interests; (4) deploy the talent chain in a forward-looking manner based on the development needs of the industrial and innovation chains; (5) strengthen the supporting role of fiscal and taxation policies in scientific and technological innovation; and (6) strengthen application scenario innovation to help improve market acceptance of domestic new technologies and new products.

Keywords: innovation chain, industrial chain, fund chain, talent chain, national innovation system

1. Connotation of "Four Chains" Integration

The essence of "four chains" integration is the effective allocation of innovation elements such as talent and capital. On the one hand, deepening social division of labor has made cross-organizational boundary flows of innovation elements increasingly frequent. However, due to varying degrees of market barriers, institutional barriers, information barriers, and administrative barriers, the allocation efficiency of innovation elements between organizations is often far lower than within organizations. On the other hand, understanding "four

chains" integration requires returning to the connotation of "integration" itself, which generally refers to different things merging into one entity and is commonly used to describe physical phenomena. In recent years, this term has also frequently appeared in the context of innovation economics. How can different production entities achieve integration? The key is to enable different entities to effectively allocate innovation elements through contractual behaviors under market mechanisms, thereby collaboratively advancing cross-organizational boundary innovation and improving innovation performance, provided that various barriers are reduced.

Furthermore, how should we measure the effectiveness of innovation element allocation? This article argues that such assessment should be conducted within the overall framework of the national scientific and technological innovation strategy, using whether it meets the "four orientations" requirement proposed by General Secretary Xi Jinping—"oriented toward the frontiers of world science and technology, oriented toward the main battlefield of the economy, oriented toward major national needs, and oriented toward people' s life and health" —to define the effectiveness of innovation element allocation in different sub-fields. The "four orientations" are not independent of each other but are interconnected and mutually supportive, collectively serving the overall goal of national economic and social development.

From a relatively macro perspective, deep integration of the "four chains" means that science and technology, industry, finance, and talent have formed a development pattern of synergistic complementarity, mutual empowerment, and overall optimization. The innovation chain comprises stages including basic research, applied research, technology development, and industrialization and commercialization of new products/processes, reflecting the transformation process from scientific value to technological value and then to economic value. The industrial chain refers to the chain-like process formed by various stages of final product production and processing. The capital chain encompasses the entire process of capital investment, operation, and recovery. The talent chain is a chain-like talent aggregate formed through the transmission and correlation of industrial knowledge, skills, achievements, and experience. Different dimensional supply-demand relationships and market-oriented connection mechanisms are the engines that drive the interconnection and deep integration of the "four chains" [Figure 1: see original paper].

2. Theoretical Analysis of "Four Chains" Integration

As technological progress accelerates and social division of labor deepens, scientific and technological innovation has gradually evolved into a complex process of continuous integration and iteration of internal and external organizational knowledge. The goal of "four chains" integration is precisely to promote high-quality economic development through scientific and technological innovation. From the perspective of participating entities, the "four chains" system consists of subjects such as government, enterprises, research institutes, universities,

and intermediary agencies. These subjects are located at different innovation links, possess differentiated innovation elements, and derive multi-level supply-demand relationships due to resource complementarity. “Four chains”integration refers to the evolution of the innovation chain, industrial chain, capital chain, and talent chain into a whole with synergistic and complementary functions under the action of market mechanisms and supply-demand relationships of input factors at various production stages.

“Four chains” integration involves a series of production activities: knowledge production activities on the innovation chain, product production activities on the industrial chain, capital appreciation activities on the capital chain, and labor appreciation activities on the talent chain, as well as practices linking various chains such as transformation of scientific and technological achievements and investment and financing [Figure 2: see original paper]. In knowledge production activities, there are two main initial input factors: R&D capital and R&D labor. R&D capital mainly comes from fiscal scientific research funds and social funds. This article adopts the definition of “social funds” from Nie Changhong and Ji Chaoxu’ s research, which defines “social funds” as the sum of various resources owned and controlled by socio-economic units other than the government that can be used for investment and reproduction. R&D labor comes from the labor input of scientific researchers in universities, research institutes, enterprises, and other institutions. The level of R&D output depends on the input levels of R&D capital and R&D labor. Through a series of practices such as experimental development and achievement transformation, R&D output forms technical elements that can enter enterprise production processes. In product production activities, input factors include technology, capital, labor, and other elements, while output forms include various products, with output levels depending on the input of various factors. Capital appreciation and labor appreciation activities are embedded within innovation chain and industrial chain activities.

Through effective allocation of innovation elements, heterogeneous innovation entities can be united to form a collaborative and efficient innovation network, enhancing innovation activity and inducing technological progress. Moreover, the flow of innovation elements can generate spillover effects, driving the diffusion and dissemination of innovation knowledge. The essence of “four chains” integration is the allocation problem of various elements such as capital, technology, and talent across different links and subjects. Due to the many allocation links and subjects, and the involvement of areas at the front end of the innovation chain where market failure easily occurs, “four chains” integration imposes higher requirements on the allocation of innovation elements.

3. Problems and Causes in “Four Chains” Integration

“Four chains” integration is closely related to macroeconomic background, social and cultural environment, policy synergy and consistency, decision-making orientation of innovation subjects, supply-demand relationships of scientific and

technological achievements, capital supply-demand relationships, and talent supply-demand relationships. Promoting "four chains" integration requires focusing on resolving supply-demand contradictions in various links. To further understand the current problems and causes of "four chains" integration in China, our research group invited 15 experts, scholars, and managers from research institutes, universities, industry authorities, and science and technology enterprises to conduct multiple in-depth discussions, generating approximately 200,000 words of interview records. Based on the interview results, China' s "four chains" integration currently faces the following problems.

First, the synergy and consistency of scientific and technological innovation policies are insufficient, and the institutional mechanisms for collaborative efforts among industry departments and regions need improvement. Various departments and industries have formulated numerous policies and systems to promote scientific and technological innovation. However, there are still phenomena such as relative absence of individual systems and policy conflicts, and the integrated layout of series systems related to finance, taxation, finance, state-owned asset management, public institution management, science and technology management, and achievement transformation needs strengthening. The resulting misallocation of innovation elements remains prominent. For example, to promote innovative development, some regions exhibit phenomena such as "disorderly talent attraction," "attracting without using," and "using for non-expertise purposes," which are not conducive to promoting "four chains" integration or enhancing the overall effectiveness of the national innovation system.

Second, the supporting role of science and technology intermediary agencies in promoting "four chains" integration needs further strengthening. (1) The construction of scientific and technological achievement transformation platforms needs to be enhanced. Currently, a large number of scientific and technological achievement transformation platforms suffer from serious homogenization, possessing information display functions but lacking project-level matching and negotiation functions, resulting in limited actual transformation effectiveness. (2) The support for innovation resources obtained by small and medium-sized enterprises is relatively insufficient. Due to lack of funds, space, equipment, talent, and technology, many scientific and technological achievements are difficult for SMEs to transform and implement. However, China' s public science and technology intermediary construction is relatively weak, making it difficult to provide effective support for SMEs. (3) The pricing mechanism for science and technology intermediaries needs improvement. As China' s scientific and technological achievement transformation market is still in its early development stage, the critical role played by science and technology intermediaries in the transformation process is not fully recognized, and both supply and demand sides have low willingness to pay intermediary fees, which is not conducive to the survival and development of science and technology intermediaries. (4) There is a large gap in transformation talent. The transformation of achievements requires specialized talents who understand both technology and the market to play a connecting and negotiating role. However, the shortage of interdisciplinary and

compound scientific and technological achievement transformation talents has become a pain point constraining the development of science and technology intermediary agencies and achievement transformation.

Third, there is a relative lack of detailed implementation rules for scientific and technological achievement transformation at different levels, and the phenomenon of "no basis for action" in transformation practice still exists. Achievement transformation is a key link in "four chains" integration. While laws and regulations such as the *Law of the People' s Republic of China on Promoting the Transformation of Scientific and Technological Achievements* have made principled provisions, specific implementation rules that can guide practice are still lacking. Most research institutes and universities have not yet formed implementable guiding clauses regarding organization and implementation of achievement transformation, distribution of transformation responsibilities, rights, and interests, and incentive and guarantee measures, making it difficult for transformation policies to truly land. Due to the lack of detailed rules, situations of "no basis for action" frequently occur in practice, and the phenomena of researchers and managers "not daring to transform" and "not wanting to transform" remain relatively prominent.

Fourth, the cohesion of talent in some fields or key technical links is insufficient, and the talent cultivation, evaluation, and utilization mechanisms need improvement. Although China enjoys obvious advantages in the total number of scientific and technological talents, structural contradictions are prominent, with a lack of world-class scientific and technological talents, and the construction of strategic scientists, leading talents, and excellent engineer teams is disconnected from the needs of the innovation and industrial chains. The matching between knowledge-oriented talent cultivation and demand-oriented industrial development is insufficient. On the one hand, the development of many "high-precision and shortage" fields requires talents with interdisciplinary knowledge reserves and comprehensive personal skills, but current discipline and specialty construction still cannot effectively meet these demands. On the other hand, the application orientation of university discipline settings needs strengthening, comprehensive talent cultivation needs enhancement, and enterprises' initiative in participating in talent cultivation is relatively limited. Moreover, under the current academic ecology, excessive linking of "hats," "projects," "titles," and "papers" to resources and interests, as well as disorderly competition for "hatted" talents among research institutes and universities, are not conducive to scientific and technological talents becoming scientific masters under normal academic growth patterns.

Fifth, the financing difficulty problem in the middle and late stages of the innovation chain urgently needs improvement, and multiple obstacles to capital entry need to be removed. The middle and late stages of the innovation chain mainly involve technology development, industrialization and commercialization of new products and processes, which are key links requiring effective synergy among multiple subjects to promote the transformation of technological value into eco-

nomic value. The commercial value of scientific and technological achievements is an important factor affecting financial institutions' participation in transformation. However, China' s current evaluation of the commercial value of scientific and technological achievements is weak, with relatively few specialized institutions engaged in scientific and technological achievement evaluation and commercial verification, and a severe shortage of compound talents who understand both technology and capital market operations, resulting in financing difficulties in the middle and late stages of the innovation chain and becoming a factor constraining "four chains" integration.

4. Typical Practices for Promoting "Four Chains" Integration

Promoting deep integration of the "four chains" is a systematic project. Focusing on several breakpoints and blockages mentioned earlier, this section correspondingly reviews typical domestic and international experiences to provide references for promoting deep integration of the "four chains."

First, coordinate multiple types of domestic innovation subjects and build an innovation ecosystem covering vertical innovation chains and horizontal multi-subjects. In 2014, the United States established Manufacturing Innovation Institutes, which aim to ensure America' s global leadership in advanced manufacturing by establishing public-private partnership networks that promote large-scale cooperation among industry, academia, and federal laboratories in technology, supply chains, and workforce development. The network subjects include the U.S. Departments of Commerce, Defense, and Energy; 16 manufacturing institutes established by these three departments; and NASA, the National Science Foundation, the Department of Health, Department of Agriculture, Department of Education, and Department of Labor. The practices of Manufacturing Innovation Institutes are instructive: (1) Laws come first to strengthen top-level design. The United States has basically completed the top-level design for intelligent manufacturing development by issuing three acts: the *Revitalize American Manufacturing and Innovation Act of 2014*, the *National Network for Manufacturing Innovation*, and the *United States Innovation and Competition Act of 2021*, while establishing specialized departments to coordinate various subjects involved in the *National Network for Manufacturing Innovation*. (2) Adopt a public-private partnership (PPP) operation model. Participating subjects include government, research institutions, local universities and community colleges, venture capital institutions and incubators, and manufacturers, with clear division of labor and pragmatic cross-institution cooperation, ensuring efficient operation of the entire innovation network. The practice of U.S. Manufacturing Innovation Institutes demonstrates that building an innovation ecosystem and strengthening synergistic complementarity among various subjects are effective ways to promote deep integration of the "four chains."

Second, rely on science and technology intermediary agencies to conduct R&D demand research and achievement transformation, and promote the flow of tech-

nical elements into production departments. Science and technology intermediary agencies are important subjects promoting the integration of innovation and industrial chains. At the practical level, the operation model of Belgium' s Collective Research Centers (CRCs) is worth learning from. CRCs are non-profit institutions with both R&D functions and science and technology intermediary functions, mainly providing services to member companies, including: technology advisors visiting enterprises to collect technical demand information, studying the possibility of improving enterprise processes, selecting R&D models compatible with enterprise capabilities, and promoting R&D activities based on enterprise technical demands. They also disseminate research results information from universities and research institutions, and provide technological innovation suggestions to member companies based on their own knowledge when visiting member enterprises. They conduct technology transfer and other activities to accelerate the diffusion of new technologies. The CRCs case demonstrates that science and technology intermediary agencies play an important linking role in promoting "four chains" integration.

Third, invite terminal enterprises in the industrial chain to participate in research topics to achieve seamless connection between scientific research and achievement transformation. The premise for basic and applied research outputs to effectively support industrial development is that research teams refine research questions according to industrial development needs. Inviting enterprises to participate in R&D plans is an effective approach. For example, Finland' s second largest lake (Water Lake) was once severely polluted. To address this, the local government invited the University of Helsinki to conduct research on water quality monitoring methods. Since the research required measuring relevant trace elements in water, and commercially available sensors at the time could not meet these requirements and needed to be co-developed with enterprises, the research team invited a well-known local sensor manufacturer to participate in the project establishment and subsequent research. The Water Lake case achieved a triple win for government, university, and enterprise: for the government, it solved water quality monitoring methods, equipment, and subsequent monitoring issues; for the university, it completed research tasks while also completing achievement transformation; for the enterprise, it gained opportunities to understand market demand and timely launched new products. The Water Lake case demonstrates that strengthening cooperation between universities/research institutions and enterprises at the basic and applied research stages is an optional path to promote "four chains" integration.

Fourth, construct a social fund-supported basic research model based on industry-academia-research strategic cooperation to help transform basic research achievements. The Dalian Institute of Chemical Physics (DICP), Chinese Academy of Sciences, is a comprehensive research institution combining basic research, applied research, and technology transformation, with the development characteristic of driving disciplines through tasks. For a long time, DICP has promoted a large number of achievements transformation through industry-academia-research strategic cooperation with local governments

and enterprises, playing an important role in alleviating the supply-demand contradiction of petrochemical products in China. For example, in 2004, DICP cooperated with social funds on the methanol-to-olefins project, achieved substantive progress in 2010, and officially operated the project in 2014, adding 2.8 million tons/year of olefin production capacity and 6 billion yuan in economic benefits. Drawing on research by Nie Changhong and Ji Chaoxu, the key for DICP to attract social fund support for basic research lies in: scientists and entrepreneurs have established a foundation of mutual trust—entrepreneurs believe scientists' achievements are beneficial to enterprise development and have strong investment willingness; scientists have confidence in enterprise development and are willing to select research topics according to enterprise needs; the effective docking between scientists' academic research leadership motivation and entrepreneurs' market competition leadership motivation 促成了 industry-academia-research strategic cooperation. The complementary synergy of resource advantages between DICP and enterprises 促成了 the R&D, transformation, and implementation of the methanol-to-olefins project.

5. Policy Recommendations

Promoting deep integration of the "four chains" is of great significance for resolving the primary and secondary contradictions currently facing industrial chain development. Based on the preceding analysis, we propose six recommendations.

First, strengthen top-level design and promote the systematic layout and implementation of scientific and technological innovation policies. Strengthen the supporting implementation of policies in science and technology, finance, taxation, and other fields. Regularly compile industrial chain demand lists, refine key scientific questions, clarify technology development goals, and integrally allocate innovation resources such as funds, talent, projects, platforms, and policies in basic research, achievement transformation, and other links. Follow innovation laws, systematically plan development goals and key tasks of the innovation chain, give play to the government' s guiding role in innovation resource allocation, continuously optimize the innovation ecosystem, and promote coordination among enterprises, research institutes, financial institutions, and other subjects in R&D, production, capital, and talent links.

Second, explore the construction of "large-scale science and technology intermediaries," build deliberative decision-making mechanisms and market-oriented pricing mechanisms that conform to innovation laws, and provide a sound ecosystem for deep integration of the "four chains." Take market-oriented operation as the starting point, pool and integrate innovation resources such as talent, capital, platforms, and policies, reduce market barriers, information barriers, institutional barriers, and administrative barriers in the flow of elements, and improve allocation efficiency. Actively attract various innovation subjects to settle in, explore the construction of commercial operation models for large-scale science and technology intermediaries, improve innovation revenue distribution

mechanisms, and strengthen the cultivation and protection of new practices, models, and business forms.

Third, accelerate the formulation of detailed implementation rules for the transformation of scientific and technological achievements, clarify boundaries of responsibilities, rights, and interests, and promote solutions to the problems of "not wanting to transform," "not daring to transform," and "not knowing how to transform." Strengthen the supporting connection between implementation rules and systems in fiscal and taxation, finance, state-owned asset management, public institution management, and science and technology management. Improve mechanism design, promote the implementation of relevant systems, appropriately increase flexible provisions, and encourage various innovation subjects to formulate achievement transformation systems adapted to their actual development conditions within policy-permitted scope. Form interdisciplinary and cross-industry transformation teams, focus on existing scientific and technological achievements, conduct communication and docking oriented toward enterprise needs, and promote batch transformation and implementation of scientific and technological achievements.

Fourth, deploy the talent chain in a forward-looking manner based on the development needs of the industrial and innovation chains. Improve the industry talent demand forecasting and shortage talent information release mechanism, establish an interdisciplinary talent cultivation mechanism, encourage enterprises and institutions to jointly build productive training bases and industrial talent training bases, and vigorously cultivate and utilize strategic scientists. Optimize the resource allocation methods for major science and technology projects, establish cross-organization allocation mechanisms for key technology leading talents, and carry out collaborative innovation based on various innovation subjects. Focus on the "four orientations" and establish an evaluation system conducive to scientific and technological talents concentrating on research.

Fifth, strengthen the supporting role of fiscal and taxation policies in scientific and technological innovation to help improve the level of achievement transformation and industrialization. Optimize the beneficiary screening mechanism for R&D expense super-deduction policies to form a tax policy support system covering the enterprise growth and innovation lifecycle. Improve mechanisms for special fund support and social fund support, and further leverage the advantages of new R&D institutions in solving common technology problems in industrial development. Clarify the differentiated positioning of different types of funds: for government guidance funds, establish a comprehensive evaluation system to guide them to allocate funds to fields and links with great potential, long cycles, and high risks; for social venture capital funds, improve financing service models such as bank-government coordination and investment-loan linkage, and encourage financial institutions to expand financing channels for achievement transformation.

Sixth, strengthen application scenario innovation and use government procurement and major project organization and implementation as starting points to

help increase the market share of domestic new technologies and new products. Support relevant departments to take the lead in exploring scenario innovation and provide a user base for technology iteration and upgrading. For new technologies and new products, establish flexible supervision and negative list management mechanisms to create a sound environment that encourages innovation and tolerates failure. Encourage various subjects to participate in innovative scenario construction, actively build an integrated scenario market, create an integrated platform, widely link various subjects, track the practical effects of scenario innovation, and form precise enterprise profiles.

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Author Biographies

NIE Changhong, Director of the Science and Technology Innovation and Development Center, Chinese Academy of Sciences (CAS), and Researcher and Ph.D. Supervisor at the School of Economics and Management, University of Chinese Academy of Sciences. Main research fields: science and technology finance, macroeconomics, and industrial policies. E-mail: chnie@stidc.ac.cn

CHEN Tong, Postdoctoral Fellow at the Academy of Mathematics and Systems Science, Chinese Academy of Sciences. Main research fields: science and technology policy, transformation of scientific and technological achievements, industrial relocation, and macroeconomic analysis. E-mail: chentong2022@amss.ac.cn

*Corresponding author

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