Cross-border Symbiosis: The Technological Integration Revolution of Future Industries

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Abstract: Future industries, as the core carriers of the new round of technological revolution and industrial transformation, are essentially characterized by the reconfiguration of industrial forms and the innovation of value systems triggered by the cross-border integration of technologies. Based on the cross-disciplinary perspectives of technology philosophy, industrial economics and systems science, this paper dissects the internal logic, evolutionary path and symbiotic mechanism of technology integration in future industries, and explores the disruptive impact of cross-border integration on industrial boundaries, production factors, organizational forms and innovation ecosystems. The study found that technology integration, through knowledge spillover, factor recombination and functional complementarity, breaks the rigid boundaries of traditional industries and forms a symbiotic system where "technology - industry - society" is interembedded; Its evolution follows a progressive path of "single-point breakthrough - chain integration - ecological symbiosis", with the core driving force being the internal tension of technological iteration, the upgrading demands of market demand and the coordinated support of the institutional environment. Based on this, this paper constructs an analytical framework for the integration of future industrial technologies, providing a theoretical reference for understanding the laws of industrial transformation and promoting the construction of an innovation ecosystem.

Keywords: Future Industries; Technology Convergence; Cross-Border Symbiosis; Industrial Restructuring; Innovation Ecosystem

1. Introduction

Human society is entering a new stage of technological revolution characterized by "cross-border integration". Breakthroughs in frontier fields such as digital technology, biotechnology, new energy technology, and space technology are no longer confined to iterative upgrades within a single industry, but are showing a trend of deep integration across fields[1], disciplines, and scenarios. This fusion not only rewrites the traditional paradigm of technological innovation, but also gives rise to a number of forward-looking and strategic future industries, from AI-driven intelligent manufacturing to synthetic biogen-enabled green industries, from quantum computation-supported digital economy to nuclear fensing-led energy revolution. The rise of future industries is essentially the reconstruction of industrial ecosystems triggered by the cross-border integration of technologies[2].

Traditional industrial economics, based on the analytical framework of "clear industrial boundaries", has struggled to explain the evolution characteristics of "technology without boundaries[3] [4], industries without boundaries, and value without boundaries" in future industries. Driven by the convergence of technologies, the traditional divisions of agriculture, industry and services are gradually blurring, and the cross-border forms of "manufacturing + services", "digital + physical" and "biological + engineering" have become the mainstream of industries, forming a symbiotic pattern [5] [6]. This cross-border symbiosis is not merely a simple superposition at the technical level, but a systematic reconstruction of production factors[7], organizational models, and value logics. It provides new impetus for economic and social development, and poses new challenges to traditional industrial theories, innovation systems, and institutional designs.

This paper focuses on the core characteristics of "technology cross-border integration" in future industries, breaks through the boundary constraints of traditional industrial theories, constructs an analytical framework of "technology integration - cross-border symbiosis - industrial reconstruction", and enriches the connotations of industrial evolution theory and technological innovation theory. By dissecting the internal mechanisms and evolutionary paths of technology integration, it reveals the generation logic and development laws of future industries, providing a new theoretical perspective for industrial research from an interdisciplinary perspective. At the same time, it provides theoretical references for China to cultivate future industries and build an innovation ecosystem, and offers practical insights for policymakers to optimize industrial layouts, improve innovation support systems, and overcome barriers to cross-border integration.

This study will be conducted using a combination of literature research, logical deduction and interdisciplinary analysis. First, sort out the research results in related fields such as technology integration, future industries, and cross-border symbiosis, and clarify the core concepts and theoretical basis; Secondly, from the perspective of technology philosophy and systems science, analyze the internal logic and evolutionary stages of technology integration; Again, analyze the reconfiguration effect of cross-border symbiosis on future industries from four dimensions: industrial boundaries, production factors, organizational forms, and innovation ecosystems; Finally, construct a symbiotic system framework for the integration of future industrial technologies and propose corresponding development implications.

2. Literature Review

Research on technology convergence. The concept of technology convergence was first proposed by Rosenberg (1963)[8], who argued that technology convergence is the blurring of technological boundaries caused by the intersection and infiltration of knowledge in different technological fields. Since then, scholars have expanded the study of technology convergence from different perspectives: from the perspective of technological evolution, Nelson and Winter (1982)[9]regarded technology convergence as an important form of technological paradigm shift, emphasizing the core role of knowledge spillover in convergence; From an industrial perspective, Pennings and Puranam (2001)[10]pointed out that technology convergence would break the boundaries of traditional industries and give rise to new industrial forms; In recent years, with the rise of digital technology, scholars have begun to focus on the integration model of "digital + physical", arguing that the intervention of data elements has shifted technology integration from "linear integration" to "ecological integration"[11]. Existing research has mostly focused on the integration phenomenon in a single technical field or specific industry, lacking a systematic analysis of the cross-border integration of multiple technologies in future industries.

Research on future industries. Future industries research began in the early 21st century, with early research mainly focusing on the industrialization prospects of emerging technologies such as nanotechnology and biotechnology[12]. In recent years, with the strategic layout of future industries in various countries, the focus of research has shifted to the characteristics, classification and development paths of future industries: Raju et al. is believed that future industries have characteristicssuch as technological frontier[13], scenario leadership, and ecological synergy; Some scholars categorize future industries into different types such as "technology breakthrough type" and "cross-border integration type"[14][15]; In research on development paths, scholars have emphasized the importance of government guidance[16][17], market-driven and the construction of an innovation ecosystem, but have not explored the internal mechanisms by which technology integration drives the evolution of future industries.

Research on cross-border symbiosis: Cross-border symbiosis originated from the theory of symbiosis in biology and was later introduced into the field of industrial economy. Gulati (1998)[18] defined industrial symbiosis as a cooperative relationship formed between different enterprises or industries based on complementary resources; In recent years, scholars have begun to focus on cross-border symbiosis in the context of technology convergence, arguing that this symbiosis is no longer a simple exchange of resources, but a "value co-creation" system based on technology synergy[19] [20]. Existing research has mostly focused on symbiotic relationships among enterprises, lacking an overall grasp of the industry-level cross-border symbiotic system.

In summary, the existing research has provided a theoretical basis for this paper, but there is still room for expansion in the following research: First, the multi-dimensional characteristics of future industrial technology integration need to be analyzed in depth; Second, there is a lack of systematic exploration of the cross-border symbiosis mechanism triggered by technology integration; Third, a multi-faceted analytical framework covering technology, industry and society has not been established. This article will focus on the above gaps.

3. The Internal Logic and Evolutionary Path of Future Industrial Technology Convergence

3.1 The Internal Logic of Technology Convergence

The logic of knowledge spillover: The essence of technology integration is the cross-domain flow and reorganization of knowledge[21]. Knowledge systems in different technical fields have differences and complementarities, and these differences and complementarities form the potential energy of knowledge spillover. For instance, when algorithmic knowledge of digital technology is combined with gene editing knowledge of biotechnology, it gives rise to the emerging field of digital biology; When the energy storage knowledge of new energy technology is combined with the in-orbit application knowledge of space technology, the space energy industry is formed. Knowledge spillover breaks the boundaries of knowledge in a single discipline and provides core technical support for future industries through the process of "knowledge intersection - knowledge reorganization - knowledge innovation".

Factor recombination logic: Technology integration drives the cross-border recombination of production factors[22], changing the factor allocation model of traditional industries. In traditional industries, production factors are mainly capital, labor and land, and factor flows are confined within the industry; In future industries, data, technology and knowledge are the core production factors, and the integration of technologies enables these factors to break through industrial boundaries and achieve cross-sectoral optimal allocation. Data, for example, becomes a universal factor of production across industries through the integration of digital technology with technologies in manufacturing, agriculture, healthcare and other fields; Technology elements, through cross-border integration, create a new model of element combination of "digital + biological + energy", giving rise to new industrial forms.

Functional complementarity logic: Different technological fields have their own functional advantages and application limitations, and technological integration achieves a synergy effec of "1+1>2" through functional complementarityt[23]. Digital technology has an advantage in data processing and intelligent decision-making, but lacks the ability to be implemented in physical scenarios; Physical technologies such as manufacturing technology and engineering technology have the advantage of physical implementation, but lack efficiency and flexibility; Biotechnology's strength lies in the regulation of life processes, but it lacks precise control means. Technology integration, through the complementary functions of "digital technology empowering physical technology" and "biotechnology combined with engineering technology", compensates for the limitations of a single technology and forms a full-scenario technology capability covering "virtual - physical - life".

Demand-driven logic: The upgrading of market demand is the external driving force for technology integration[24]. With the development of the economy and society, human demands for production and life have shifted from "quantity satisfaction" to "quality improvement", and from "single function" to "comprehensive experience". Such demand upgrades cannot be met through the upgrading of a single technology or industry. For example, the demand for "healthy living" has driven the integration of digital technologies such as intelligent monitoring, biotechnologies such as precision medicine, and medical technologies such as minimally invasive treatment, forming the precision health industry; The demand for "green development" has given rise to the integration of new energy technologies such as renewable energy, digital technologies such as intelligent dispatching, and manufacturing technologies such as green production, building a green and low-carbon industrial system.

3.2 Evolutionary Paths of Technology Integration

Technology convergence in future industries is not achieved overnight but follows a progressive evolutionary path of "single-point breakthrough - chain integration - ecological symbiosis", with distinct characteristics and core tasks at each stage.

Single-point breakthrough stage: The initial stage of technology integration, with the core feature being the breakthrough progress of a single frontier technology and attempts at cross-domain applications[25]. In this stage, technological breakthroughs in areas such as quantum computing, gene editing, and nuclear fusion become the "tipping point" of technological fusion and start to permeate related fields. The emergence of large models, for example, indicates a breakthrough in AI technology, first with single-point application attempts in areas such as healthcare, education, and manufacturing, forming initial fusion forms such as AI healthcare and AI education. The core task at this stage is to verify the industrialization of the technology and solve the "technical feasibility" problem. The scope of integration is narrow and the depth is shallow, and a systematic integration model has not yet been formed.

Chain integration stage: The development stage of technology integration, with the core feature being the chain-like integration of multiple cutting-edge technologies and the reconstruction of the industrial value chain[26]. Based on the application verification of single-point technologies, technologies from different fields begin to form "technology chains" and are systematically integrated around specific industrial scenarios. For example, in the intelligent vehicle industry, AI technologies such as autonomous driving, new energy technologies such as power batteries, digital technologies such as Internet of Vehicles, and manufacturing technologies such as intelligent production form a complete technology integration chain, reconfiguring the value chain of R&D, production, sales, and services in the automotive industry. The core task of this stage is to build a "technology-industry" integration chain, solve the "industry fit" problem, and expand the integration scope from the application of a single technology to the entire industrial chain, forming an integrated industrial form with scale effect.

Ecological symbiosis: The mature stage of technology integration, with the core feature being the ecological integration of multi-domain technologies and the formation of a "technology-industry-society" symbiotic system. On the basis of chain integration, technology integration breaks through the boundaries of a single industry to form a cross-industry and cross-field technology ecosystem that is deeply adapted to social demands[27][28], institutional environments, and cultural values. For instance, the integration of digital technology, biotechnology, new energy technology and space technology has created the "Smart Earth" ecosystem, covering smart cities, precision agriculture, green energy, space exploration and many other fields, achieving a symbiotic relationship between industrial development and social progress. The core task of this stage is to build a cross-border symbiotic system, solve the problem of "system synergy", and integrate from the technological and industrial level to the social level to form a symbiotic ecosystem that evolves and innovates continuously.

4. Cross-Border Symbiosis: The Core Effect of Future Industrial Technology Integration

The cross-border symbiosis triggered by technology integration not only changes the paradigm of technological innovation, but also has a disruptive impact on industrial boundaries, production factors, organizational forms and innovation ecosystems, forming the core characteristics of future industries.

4.1 The Blurring and Reconstruction of Industrial Boundaries

Traditional industrial boundaries form rigid divisions based on "product attributes", "production processes", and "technical features", such as the tripartite division of agriculture, industry, and services, as well as the subindustry classification within manufacturing. Technology integration breaks these rigid boundaries through cross-border symbiosis, creating a new form of "industry without boundaries"[29].

Reconfiguration of industrial classification: Technology integration has rendered traditional industrial classification standards ineffective, giving rise to a large number of "cross-border industries" and "integrated industries"[30]. For example, "digital agriculture," which combines agricultural technology, digital technology and biotechnology, belongs neither to traditional agriculture nor to the digital industry; "Biomanufacturing" integrates biotechnology, manufacturing technology, and new materials technology, crossing the boundary between the bioindustry and manufacturing. This cross-border integration has given rise to new dimensions of industrial classification, shifting from "product-oriented" to "technology integration-oriented" and "scene demand-oriented".

Reorganization of industrial value chains: Traditional industrial value chains show linear characteristics, with unidirectional flows from R&D, production, sales to services; The cross-industry symbiosis driven by technology integration has shifted the value chain from "linear" to "web-like", with the value chains of different industries interweaving and empowering each other[28]. For example, the value chain of the new energy vehicle industry not only includes vehicle research and development and production, but also integrates the value chain of power batteries in the new energy industry, autonomous driving in the AI industry, Internet of vehicles in the digital industry, and charging services in the energy industry, forming a cross-industry value network.

The reshaping of the industrial competition pattern: The breaking of rigid industrial boundaries has shifted industrial competition from "intra-industry competition" to "cross-industry competition" and "ecological competition". Traditional enterprises' competitors are limited to those within the same industry, while enterprises in future industries will have to face cross-industry competitors from different industries[31]. For example, traditional car companies' competitors include not only other car companies, but also technology companies such as Huawei and Apple, new energy companies, etc. The core of the competition has shifted from "product competition" to "ecosystem competition", forming a pattern where those who can build a more complete technology integration ecosystem gain a competitive advantage.

4.2 Cross-Border Flow and Upgrading of Production Factors

Technology convergence has driven the cross-border flow and form upgrade of production factors[32], creating a new system of production factors centered on "data-technology-knowledge" and changing the traditional factor allocation model.

The upgrading of factor forms: Traditional production factors are mainly tangible ones such as capital, labor and land, while the production factors of future industries are mainly intangible ones, presenting the characteristics of "datafication", "technologicalization" and "knowledgeization". Data, as a new type of factor of production, penetrates into various industrial fields through technological integration and becomes the core driving force for the improvement of total factor productivity; Technology and knowledge are no longer auxiliary factors attached to other factors, but have become independent factors of production, directly involved in value creation.

Transboundary flow of factors: Technological integration breaks down the industrial and geographical boundaries of factors of production, enabling free flow across industries and regions. Data, for example, flows efficiently across industries through the integration of digital technology with manufacturing, agriculture, healthcare and other fields; Technology elements are freely allocated among enterprises, universities and research institutions through cross-border cooperation and industry-university-research collaboration; Knowledge elements are shared and reorganized globally through open innovation platforms.

Enhanced factor allocation efficiency: Cross-border symbiosis has formed a factor allocation model of "factor sharing - complementary advantages - collaborative innovation", significantly enhancing factor allocation efficiency. Through technology integration, factor resources from different industries complement each other, avoiding duplicate investment and waste of resources; The cross-border flow of factors has led to the concentration of resources in high-efficiency areas, achieving the optimal allocation of factors; The collaborative innovation of factors creates a synergy effect of "1+1>2", which boosts total factor productivity.

4.3 Networking and Synergy of Organizational Forms

The organizational structure of traditional industries is mainly hierarchical and bureaucratic, emphasizing vertical management and internal collaboration; The cross-industry symbiosis driven by technology integration has transformed the organizational form towards networking, collaboration and platformization, forming a cross-organizational and cross-industry collaborative innovation system.

Blurring of organizational boundaries: Technology integration has broken down the organizational boundaries of enterprises[33], creating new organizational forms such as "open organization", "virtual organization", and "ecological organization". Enterprises are no longer closed entities, but rather form close partnerships with other enterprises, universities, research institutions, and users through technology integration, building interconnected organizational networks. For example, in the smart car industry, car companies form collaborative organizations with technology companies, component companies and charging service companies through technology integration to jointly promote the development of the industry.

Platformization of organizational models: Platform organizations will become the core form of future industrial organizational forms, achieving cross-organizational and cross-industry resource integration and collaborative innovation through technology platforms. Platform organizations have the characteristics of "decentralization", "openness" and "synergy", which can break the constraints of hierarchy and promote the free flow of elements and the release of innovative vitality[34]. For example, industrial Internet platforms integrate various entities such as manufacturing enterprises, software enterprises, and service providers, and achieve optimal allocation of production resources and collaborative optimization of production processes through technological integration; The synthetic biology platform brings together biotech companies, research institutions, users, etc., forming a chain of collaborative innovation from technology research and development to industrial application.

Synergistic organizational collaboration: Cross-border symbiosis drives organizational collaboration from "linear collaboration" to "networked collaboration", forming a multi-subject, multi-dimensional, multi-level collaborative innovation system. Supported by technology integration, organizational collaboration is no longer confined to supply chain collaboration between upstream and downstream enterprises, but extends to the entire value chain links such as R&D, production, sales, and services; The subjects of collaboration are no longer limited to enterprises, but include various entities such as universities, research institutions, governments, and users; The way of collaboration is no longer limited to offline cooperation, but rather real-time collaboration that integrates online and offline through digital technology.

4.4 Openness and Co-Creation of the Innovation Ecosystem

Technology integration has driven innovation ecosystems to shift from "closed" to "open" and "symbiotic", forming cross-domain, cross-subject, and cross-regional innovation ecosystems that provide sustained impetus for future industrial development.

The first is the diversification of innovation entities: the traditional innovation ecosystem is centered around enterprises, with universities and research institutions serving only as supporting entities; The innovation ecosystem of future industries breaks the boundaries of entities and forms an innovation network[35] with the collaborative participation of multiple entities - enterprises - universities - research institutions - governments - users - investors. Enterprises, as the core carriers of technology industrialization, are responsible for transforming technological achievements into market products; Universities and research institutions provide support for cutting-edge technology research and development and basic research, and are the "source of knowledge" of the innovation ecosystem; The government creates a favorable environment for the innovation ecosystem through policy guidance, institutional supply and public services; Users are deeply involved in the innovation process, from demand creation, product design to trial feedback, becoming "co-creators" of innovation; Investors, through capital empowerment, provide financial support for technology research and development and industrialization, accelerating the implementation of innovation results. The collaborative participation of multiple entities has enabled the innovation ecosystem to form a closed-loop system of "knowledge production - technology research and development - industrial application - market feedback - iterative innovation".

The second is the sharing of innovation resources: technology integration breaks down barriers to innovation resources and promotes their development towards openness and sharing[36]. At the technical level, open source technology platforms have become important carriers for future industrial innovation. By opening up algorithms, codes, and technical standards, global sharing of technology resources such as open source AI platforms and open source databases for synthetic biology has been achieved, lowering the threshold for innovation and enabling small and medium-sized enterprises and individual innovators to participate in cutting-edge technological innovation. At the hardware level, the construction of shared laboratories, pilot platforms, and networks for sharing large scientific research instruments and equipment avoids repetitive investment and improves the utilization efficiency of scientific research resources; At the knowledge level, the popularization of academic open access platforms and industry knowledge bases has facilitated the cross-disciplinary flow and reorganization of knowledge, providing a rich knowledge reserve for innovation. The sharing of innovation resources has shifted the innovation ecosystem from "single-point innovation" to "group innovation", significantly enhancing innovation efficiency and quality.

Third, symbiosis of the innovation mechanism: Cross-border symbiosis has given rise to an innovation mechanism of "collaborative innovation - risk sharing - benefit sharing", forming a deeply bound symbiotic relationship[37][38] among various entities in the innovation ecosystem. In terms of collaborative innovation, different entities, based on the demand for technological integration, form cross-disciplinary innovation consortia around specific innovation goals to jointly carry out technological research and development and industrialization breakthroughs, such as the integrated innovation consortium of quantum computing and artificial intelligence, the collaborative research and development platform of nuclear fusion and new energy storage, through resource complementarity and technological synergy, Overcome technical bottlenecks that are difficult for a single entity to break through; In terms of risk sharing, the innovation uncertainty and high investment risks brought about by technology integration are dispersed through the joint participation of multiple entities. Enterprises, governments, and investors share R&D risks and market risks together, reducing the innovation pressure on a single entity. In terms of shared benefits, the proceeds from innovation are distributed among multiple entities based on contribution, forming a benefit distribution mechanism of "who innovates, who benefits; the more you contribute, the more you benefit", which stimulates the innovation enthusiasm of all types of entities. This co-biochemical innovation mechanism has endowed the innovation ecosystem with the ability to self-evolve and continuously iterate.

5. The Real Challenges of Future Industrial Technology Integration and Cross-Border Symbiosis

Technology integration-driven cross-border symbiosis brings revolutionary opportunities for future industrial development, but in practice, it still faces practical challenges at the technical, institutional, and social levels, which restrict the in-depth advancement and full release of innovation efficiency of cross-border symbiosis.

5.1 Technical Level: Integration Barriers and Synergy Dilemmas

The lack of unified technical standards: The development paths and technical systems in different technical fields vary, resulting in the fragmentation of technical standards[39]. For example, interface standards in the digital technology field, testing standards in the biotechnology field, and safety standards in the new energy technology field lack unified norms, which leads to problems such as "interface incompatibility", "poor data flow", and "system incoordination" in cross-domain technology integration, such as the integration of industrial Internet and medical devices due to inconsistent communication protocol standards, Resulting in the inability to transmit and share data in real time; The integration of synthetic biology and smart manufacturing is difficult to automate the production process due to differences in technical standards. The lack of uniformity in technical standards increases the cost of technology integration and reduces integration efficiency.

Core technology "choke point" : Future industry technology integration relies on breakthroughs in cutting-edge core technologies[40], but some core technologies in areas such as high-end chips are still monopolized by a few technologically advanced countries[41], and China is facing a "choke point" predicament. The lack of core technologies has left the technology integration of China's future industries temporarily at the "peripheral integration" level, making it difficult to achieve deep technology system integration, such as the integration of AI large models and biopharmaceuticals, due to the reliance on imported high-end computing power chips, which leads to limited model training efficiency; The integration of new energy vehicles and the Internet of Vehicles has affected the safety and reliability of autonomous driving due to the insufficiency of core sensor technology.[42] The shortcomings in core technologies have restricted the level and quality of cross-border symbiosis.

Insufficient technological collaborative innovation capacity: Technological integration requires cross-disciplinary knowledge integration and technological collaboration[43], but the current innovation system in China still has problems of disciplinary segmentation and disconnection between industry, academia and research. Research in universities and research institutions is mostly focused on a single discipline, lacking interdisciplinary research teams and platforms; Enterprises' technological research and development is mostly centered around their own business, and collaborative innovation with universities and research institutions is mostly superficial cooperation, failing to form deep technological integration and knowledge sharing. The lack of collaborative innovation capabilities in technology makes it difficult for cross-domain technology integration to form an innovative synergy and to fully exert the synergy effect of technology integration.

5.2 Institutional Level: Lagging Boundary Constraints and Rules

Rigid constraints of the industrial regulatory system: The traditional industrial regulatory system was formulated based on clear industrial boundaries, emphasizing "industry-specific regulation" and "territorial regulation", while the cross-border integration of future industries breaks the traditional industrial boundaries, leaving the existing regulatory system in a predicament[44] [45] where "regulatory vacuum" and "regulatory overlap" coexist. On the one hand, for the emerging industries formed by the integration of digital technology and biotechnology, the existing regulatory system lacks clear regulatory subjects and regulatory standards, resulting in some innovative achievements being difficult to industrialize due to the inability to obtain regulatory licenses; On the other hand, for cross-industry integration forms such as smart cars and industrial Internet, multiple regulatory authorities act independently, and regulatory rules conflict with each other, increasing the compliance costs for enterprises. The rigid constraints of industrial regulatory systems have become institutional obstacles to the cross-industry symbiosis of technology integration.

Inadequate adaptation of the intellectual property system: Technology integration brings new challenges to intellectual property protection, and the existing intellectual property system is difficult to adapt to the innovative characteristics of cross-border symbiosis[46]. First, it is difficult to define the scope of protection of intellectual property rights. The innovative achievements formed by technology integration often involve multiple technical fields, and the traditional patent classification system is difficult to accurately define their scope of protection, resulting in frequent intellectual property infringement disputes; Second, the ownership of intellectual property rights and the distribution of benefits are complex. Multiple entities in cross-disciplinary innovation consortia jointly participate in technology research and development, and there is a lack of clear rule basis for the division of ownership and the distribution of benefits of intellectual property rights, which can easily lead to conflicts of interest; Third, the transformation mechanism of intellectual property rights is not smooth. Intellectual property rights formed by technology integration are often highly specialized and complex, and existing intellectual property trading platforms lack professional assessment and transformation services, making it difficult for intellectual property rights to be transformed into real productive forces.

Fragmentation of the policy support system: Currently, China's policy support for future industries is mostly focused on a single technology field or specific industry, lacking systematic policy support for technology integration and cross-border symbiosis[47]. In terms of policy formulation, policies issued by different departments have their own focuses and lack synergy. For example, policies issued by the science and technology department focus on technology research and development, policies issued by the industrial department focus on industrial development, and policies issued by the financial department focus on financial support. There is a lack of effective connection among policies, making it difficult to form a policy synergy. In terms of policy content, policy support is mostly focused on traditional means such as research and development subsidies and tax incentives, and there is insufficient support in areas such as the formulation of technical standards, the construction of innovation ecosystems, and the establishment of cross-border collaborative platforms, which cannot meet the development needs of technology integration and cross-border symbiosis.

5.3 At the Social Level: Cognitive Bias and Inadequate Adaptation

Lagging social cognition: The public and some practitioners' perception of future industrial technology integration remains at the level of "technology superposition", and they fail to fully recognize the systemic changes brought about by cross-border symbiosis[48]. Some enterprises simply interpret technology integration as "introducing new technologies", ignoring the integration of the technology system and the transformation of the organizational model, resulting in technology integration being superficial; The public has cognitive biases and fears about the new industrial forms brought about by technology integration, such as artificial intelligence and synthetic biology; Low acceptance of the application of new technologies, such as resistance to gene-edited foods and distrust of autonomous driving, has affected the marketing and industrialization process of new technologies. The lag in social perception has created social resistance to the integration and symbiosis of technologies.

Mismatch of talent structure: Technology integration requires compound talents who have both cross-disciplinary knowledge reserves and collaborative innovation capabilities, but the current talent cultivation system is difficult to meet this demand[49]. In the education system, the discipline Settings of universities are still dominated by traditional discipline classification, and the construction of interdisciplinary majors and interdisciplinary platforms lags behind, resulting in students having a single knowledge structure and lacking cross-disciplinary thinking and collaborative innovation ability; In the talent evaluation system, the existing evaluation criteria mostly focus on academic achievements or technological breakthroughs in a single field, with insufficient recognition of cross-disciplinary innovation achievements and collaborative contributions, making it difficult to encourage talents to participate in cross-disciplinary integration and innovation; In terms of the talent mobility mechanism, the barriers to talent mobility across fields and industries have not been completely broken down, and talent resources are difficult to be freely allocated among different fields, resulting in a shortage of compound talent supply.

The digital divide and the issue of equity: The industrial transformation brought about by technological integration may exacerbate social division and inequality[50] [51]. On the one hand, the integration of digital technology and advanced manufacturing technology has driven the automation and intelligence of production, which may lead to the replacement of some traditional jobs and the risk of unemployment for low-skilled workers, exacerbating the polarization of the job market; On the other hand, the development of future industries depends on high-quality resources such as digital infrastructure and high-end talents, and there are differences in the ability of different regions and groups to access these resources, which may lead to a further widening of the "digital divide" and "technology divide". Such as the gap between developed and underdeveloped regions in the layout of future industries, and the inequality between high-income and low-income groups in enjoying the benefits of new technology applications. If these problems are not properly addressed, they will affect social stability and restrict the sustainable development of cross-border symbiosis.

6. The Realization Path of Future Industrial Technology Integration and Cross-border Symbiosis

In response to the above challenges, it is necessary to build a coordinated implementation path at the technical, institutional and social levels, break down integration barriers, improve institutional guarantees, optimize the social environment, and promote the cross-border symbiosis of future industrial technology integration to a deeper level and a higher level.

6.1 Technical Level: Build a Collaborative Innovation System to Break through Integration Barriers

Promote the collaborative formulation of technical standards: Establish a cross-departmental and cross-field coordination mechanism for technical standards, with government guidance, industry associations taking the lead, and enterprises participating, to formulate unified technical interface standards, data sharing standards, and security specification standards. For key areas such as the integration of digital and physical technologies, and the integration of biotechnology and engineering technologies, cross-domain standard-setting working groups will be formed to accelerate the development and promotion of key technical standards. Such as developing communication protocol standards for industrial Internet and medical devices, safety control standards for synthetic biological production processes, etc. Encourage enterprises to participate in the formulation of international technical standards, convert China's technological innovation achievements into international standards, and enhance China's say in the global technical standards system.

Tackle core technology weaknesses: Implement the "Future Industry Core Technology Breakthrough Plan", focus on key "bottleneck" areas such as quantum computing, high-end chips, key materials, biomanufacturing, and nuclear fusion, form cross-disciplinary and cross-enterprise innovation consortia, and carry out concentrated breakthroughs. Increase investment in basic research and support universities and research institutions in conducting cross-disciplinary basic research to provide theoretical support for breakthroughs in core technologies; Improve the mechanism for the transformation of scientific and technological achievements, establish a full-chain transformation platform of "basic research - technology development - industrial application", and accelerate the application of core technological achievements; Strengthen international cooperation in science and technology, introduce advanced foreign technologies and high-end talents, and enhance China's independent innovation capacity in core technologies through "introduction - digestion - absorption - re-innovation".

Build cross-disciplinary collaborative innovation platforms: Integrate the innovation resources of universities, research institutions and enterprises to build a number of national cross-disciplinary collaborative innovation platforms, such as the "digital + biological" integrated innovation platform and the "new energy + space technology" collaborative research and development center. The platform focuses on the key common issues of technology integration and provides one-stop services including technology research and development, pilot-scale transformation, testing and certification; Establish a cross-disciplinary talent exchange mechanism, encourage universities and enterprises to jointly cultivate compound talents, and support researchers to move and work part-time across different fields; Promote open source innovation models, build open source technology platforms and open source communities, and facilitate the open sharing and collaborative innovation of technology resources.

6.2 Institutional Level: Deepen Reform and Innovation and Improve the Guarantee System

Build a flexible and inclusive regulatory system: Innovate future industry regulatory models, shifting from "industry-specific regulation" to "functional regulation" and "comprehensive regulation". Establish a cross-departmental regulatory coordination mechanism, clarify regulatory subjects and regulatory responsibilities, and avoid regulatory vacuums and overlaps; Implement the "sandbox regulation" system, designate regulatory pilot areas for emerging industrial forms formed by technology integration, allow market testing of innovative achievements within a controllable range, and dynamically adjust regulatory rules based on the test results; Establish a "regulatory tolerance" mechanism, providing a certain margin of tolerance for innovation exploration in the process of technology integration, provided that it does not violate laws, regulations and public interests, and encouraging enterprises to boldly innovate.

Optimize the design of the intellectual property system: Improve the intellectual property system that adapts to technology integration and strengthen the protection of cross-domain innovation achievements. First, improve the classification system of intellectual property rights, add patent classification for cross-domain technologies, and clarify the scope of protection of intellectual property rights; Second, establish rules for cross-subject intellectual property rights ownership and benefit distribution, clarify the rights and obligations of various subjects in the innovation consortium, and implement a "contribution-oriented" benefit distribution mechanism; Third, build cross-domain intellectual property trading and transformation platforms, introduce professional intellectual property assessment agencies and transformation service agencies, and promote the market transfer and industrial application of intellectual property; Fourth, strengthen international cooperation on intellectual property rights and establish a cross-border intellectual property protection mechanism to address cross-border intellectual property disputes arising from technology integration.

Build a systematic policy support system: Integrate existing policy resources and formulate special policies for future industrial technology integration and cross-border symbiosis. In terms of policy coordination, establish a multi-sectoral policy coordination mechanism involving science and technology, industry, finance, education, etc., to form a policy synergy; In terms of policy content, focus on key links such as the formulation of technical standards, the construction of cross-disciplinary collaborative innovation platforms, and the cultivation of compound talents, and reduce the cost of enterprise innovation through means such as fiscal subsidies, tax incentives, and financial support; In terms of policy orientation, strengthen the policy guidance of "technology for good", encourage enterprises to pay attention to social responsibility in the process of technology integration, take into account efficiency and fairness, and promote the coordinated development of future industries and society.

6.3 At the Social Level: Build Consensus and Synergy to Optimize the Development Environment

Strengthen popular science publicity and cognitive guidance: Conduct popular science publicity activities on the integration of future industrial technologies through various forms such as media publicity, popular science lectures, and experience activities to disseminate knowledge of cutting-edge technologies and the development trends of cross-border integration to the public, and eliminate cognitive biases and fears. Encourage industry associations, enterprises and universities to participate in science popularization work and create a number of high-quality science popularization platforms and contents; Strengthen the training of business operators to enhance their understanding and mastery of technology integration and cross-border symbiosis, and guide enterprises to establish the concept of "ecological development" and actively participate in cross-border collaborative innovation.

Improve the training system for compound talents: Reform the existing education system and strengthen the training of cross-disciplinary talents. At the university level, optimize the discipline Settings, add interdisciplinary majors such as "Digital Biology" and "New Energy and Space Technology", and establish cross-college and cross-disciplinary teaching teams and curriculum systems; Promote the "project-based learning" and "industry-university-research collaboration" model, allowing students to participate in real cross-disciplinary technology integration projects to enhance practical and collaborative innovation capabilities; At the talent evaluation system level, establish diversified talent evaluation standards, incorporate cross-disciplinary innovation achievements and collaborative contributions into evaluation indicators, and encourage talents to participate in cross-border integration and innovation; At the talent mobility level, break down industry barriers and geographical restrictions, establish a cross-domain talent mobility market, and promote the optimal allocation of talent resources.

Promote social equity and inclusive development: Establish a mechanism for preventing and controlling social risks brought about by technology integration, taking into account efficiency and equity. First, strengthen employment security and skills training. For the labor force whose traditional positions have been replaced, carry out vocational skills training to help them transition to employment and alleviate the polarization in the job market; Second, promote equalization of digital infrastructure, increase investment in digital infrastructure in less developed regions, and narrow the "technology gap" between regions; Third, establish a benefit-sharing mechanism for future industrial development, and encourage enterprises to share the development dividends brought by technology integration with low-income groups and underdeveloped regions through public welfare donations, industrial assistance, etc. Fourth, strengthen the construction of technology ethics, formulate ethical standards and behavioral norms for technology integration, prevent social risks brought about by technology abuse, and ensure that the development of future industries is in the common good of mankind.

7. Conclusions and Prospects

7.1 Research Conclusions

Based on the cross-disciplinary perspective of technology philosophy, industrial economics and systems science, this paper systematically analyzes the internal logic, evolutionary path, core effects, real challenges and realization path of future industrial technology integration, and draws the following core conclusions:

First, the essence of future industries is the reconfiguration of industrial forms and the innovation of value systems triggered by the cross-border integration of technologies. Technology integration promotes the development of future industries towards cross-border symbiosis through four logics: knowledge spillover, element recombination, functional complementarity, and demand traction.

Second, future industry technology integration follows a progressive evolutionary path of "single-point breakthrough - chain integration - ecological symbiosis", presenting different characteristics and core tasks at each stage, ultimately forming a symbiotic system of "technology - industry - society" embedded in each other.

Thirdly, the cross-border symbiosis driven by technological integration has had a disruptive impact on future industries: industrial boundaries have shifted from rigid demarcation to fuzzy reconstruction, production factors have changed from tangible dominance to intangible core, organizational forms have shifted from hierarchical to networked collaboration, and the innovation ecosystem has changed from closed to open symbiosis.

Fourth, future industry technology integration and cross-border symbiosis face realistic challenges such as technology integration barriers, lagging institutional rules, and social cognitive biases. It is necessary to construct a coordinated implementation path from three levels: technology collaborative innovation, institutional reform and improvement, and social environment optimization.

7.2 Research Outlook

The cross-border symbiosis of future industrial technology integration is a dynamic evolutionary process. With the deepening of technological revolution and industrial transformation, new features and new problems will continue to emerge, requiring continuous in-depth research.

In terms of the research perspective, theories such as complexity science and evolutionary economics can be further introduced to construct a more dynamic and systematic analytical framework to reveal the evolutionary laws of cross-border symbiosis of future industrial technology integration; In terms of research content, focus on specific areas of technology integration, conduct case studies, and deeply analyze the unique logic and implementation paths of technology integration in different fields; In terms of research methods, quantitative research methods such as big data analysis and simulation can be combined to conduct quantitative analysis of the effects and evolution paths of technology integration, enhancing the scientific and precise nature of the research.

Future industries, as the core carriers of the new round of technological revolution and industrial transformation, will directly determine a country's technological competitiveness and industrial discourse power in terms of the depth and breadth of their technological integration and cross-border symbiosis. In the context of increasingly fierce global technological competition, China should proactively adapt to the development trend of technological integration, break down integration barriers, improve institutional guarantees, optimize the social environment, promote the high-quality development of future industries, and make greater contributions to the transformation and upgrading of the economy and society and the progress of human civilization.

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