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The Gradient Division of Labor Pattern and Four-Stage Evolutionary Logic of Cross-Regional Innovation Collaboration among Advanced Manufacturing Clusters under NVC Reconstruction

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Abstract

Against the dual backdrop of accelerating global industrial chain restructuring and China's "independent and controllable" industrial chain strategy, building a National Value Chain (NVC) with domestic circulation as the main body has become a core issue for the high-quality development of China's manufacturing industry. Based on gradient transfer theory, this paper systematically analyzes the formation mechanism of the NVC gradient division of labor pattern among advanced manufacturing clusters in the eastern, central, and western regions under the "triple coupling" pattern of industrial transfer, and reveals the role positioning of the east as an "innovation cradle," the central region as a "transformation hub," and the west as a "manufacturing cornerstone," as well as the underlying collaborative motivations. On this basis, in response to the theoretical limitation that existing value chain analytical frameworks fail to incorporate forward-looking basic research into high value-added segments, this paper reconstructs a future-oriented NVC "smile curve" and proposes a four-stage evolutionary logic: "chain-supplementing innovation → chain-strengthening innovation → edge-forging innovation → technology-track leapfrogging innovation." The study shows that the gradient division of labor pattern and the four-stage evolutionary logic constitute a "foundation-elaboration" progressive relationship: the former answers "how the pattern is formed," while the latter answers "how the pattern evolves." The four-stage progressive approach follows the objective laws of technological evolution. Collaborative modes deepen progressively across stages and policy priorities exhibit stage-specific differences. This paper provides a systematic analytical framework for understanding how advanced manufacturing clusters move from "fragmented division of labor" to "systemic synergy."

Keywords

National Value Chain; Advanced Manufacturing Clusters; Cross-Regional Innovation Collaboration; Gradient Division of Labor Pattern; Four-Stage Evolutionary Logic; Independent and Controllable Industrial Chain.

1. Introduction

At present, the development of China's advanced manufacturing clusters stands at a historical intersection where multiple industrial transfers overlap. The "triple coupling" pattern of international industrial transfer, outward industrial transfer, and domestic industrial transfer is profoundly reshaping the spatial layout and division of labor among clusters in the eastern, central, and western regions. The "triple coupling" pattern has also provided unprecedented

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strategic opportunities and a realistic foundation. The strategic opportunities and realistic foundation are for building an independent and controllable industrial chain through cross-regional innovation collaboration.

General Secretary Xi Jinping has repeatedly emphasized that "key core technologies must be firmly held in our own hands, and manufacturing must also be firmly grasped in our own hands," and that "we should strengthen the principal position of enterprises in innovation, build advanced manufacturing clusters with international competitiveness, and forge industrial and supply chains that are independent, controllable, secure, and efficient, serving the whole country." These important statements have pointed the way for the high-quality development of China's manufacturing industry. However, problems that have long plagued China's manufacturing sector-such as the dependence on imports for key components and parts, and the constraint of core technologies by others-have not yet been fundamentally resolved. Advanced manufacturing clusters have failed to effectively achieve cross-regional innovation collaboration, making it difficult to better build independent and controllable industrial chains [1].

Li Minghui and Chen Gang pointed out that strengthening cross-regional innovation cooperation among industrial clusters in the eastern, central, and western regions in accordance with the principle of intra-product division of labor is the top priority for China to build and extend a National Value Chain (NVC) led by itself [2]. However, that study focuses on the review and outlook of existing literature and has not systematically revealed the formation mechanism of the gradient division-of-labor pattern or the stage-by-stage logic of its evolution toward an independent and controllable industrial chain. Against this background, this study focuses on the core question of "how the gradient division-of-labor pattern of cross-regional innovation collaboration among advanced manufacturing clusters forms and evolves under NVC reconstruction." It systematically analyzes the NVC positioning mechanism of the eastern, central, and western clusters under the "triple coupling" pattern of industrial transfer, reveals the formation logic of the gradient division-of-labor pattern, reconstructs the future-oriented NVC "smile curve," and proposes a four-stage progressive strategic approach.

The theoretical contributions of this paper are mainly reflected in two aspects. First, based on the gradient transfer theory, it reveals the formation mechanism of the NVC gradient division-of-labor pattern in cross-regional innovation collaboration among advanced manufacturing clusters under the "triple coupling" pattern of industrial transfer. Second, on the basis of reconstructing the NVC "smile curve," it proposes a four-stage evolutionary logic of "chain-supplementing innovation → chain-strengthening innovation → edge-forging innovation (forging competitive advantages) → technology-track leapfrogging innovation." The former answers the question of "how the pattern forms," while the latter answers the question of "how the pattern evolves"; together, they constitute a complete analytical framework for understanding cross-regional innovation collaboration among advanced manufacturing clusters. This study aims to provide a systematic analytical tool for understanding the internal logic of cross-regional innovation collaboration among advanced manufacturing clusters, and to offer a theoretical basis for formulating scientific and rational industrial development strategies.

2. The "Triple Coupling" Pattern of Industrial Transfer and the Gradient Division-of-Labor Pattern of Cross-Regional Innovation Collaboration among Advanced Manufacturing Clusters

2.1. The "Triple Coupling" Pattern of Industrial Transfer

At present, China is experiencing a "triple coupling" pattern in which international industrial transfer, outbound industrial transfer, and domestic industrial transfer are interwoven with

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one another. This pattern is profoundly reshaping the spatial layout and division-of-labor relations among the advanced manufacturing clusters in the eastern, central, and western regions, providing an important backdrop for understanding the practical foundation of cross-regional innovation collaboration.

With regard to international industrial transfer, China's undertaking of such transfer has mainly gone through four waves: the transfer of Britain's excess production capacity to the United States in the early 20th century; the transfer of labor-intensive industries from the United States to Japan and the Federal Republic of Germany in the 1960s–1970s; the transfer of textile, apparel, and other industries from the United States and Japan to the "Four Asian Tigers" in the 1980s; and, since the 1990s, the transfer from Europe, the United States, Japan, and the "Four Asian Tigers" to China and other developing countries. Currently, international industrial transfer exhibits five major new features: developed countries' technology blockade against China continues to intensify, narrowing the channels for acquiring core technologies; the "chokepoint" problem in high-end product markets remains prominent, and indigenous substitution has entered a critical phase; foreign investment in the central and western regions shows a new trend of "selective agglomeration"; the absorption of FDI in high-tech services continues to lead but faces geopolitical disturbances; and the developed countries' strategy of bringing high-end manufacturing back home has been upgraded into a "friend-shoring" system.

With regard to outbound industrial transfer, China's outbound industrial transfer began in the late 1970s and has gone through three stages: emergence, takeoff, and development. It currently exhibits six major new characteristics: the industry distribution has expanded from resources and energy toward high-end manufacturing and strategic assets; domestic transformation and upgrading and the cultivation of "new quality productive forces" jointly drive the adjustment of the outbound investment structure; cross-border M&A faces geopolitical resistance, with greenfield investment becoming the dominant mode; regional disparities in outbound direct investment remain significant, though the growth rate in the central and western regions is accelerating; the investment entities have shifted from SOE-dominated to a "dual-wheel drive" pattern of state-owned and private enterprises; and technology-seeking outbound investment faces a "high wall," which in turn compels the upgrading of independent innovation and collaborative models.

With regard to domestic industrial transfer, it has experienced a stage of unbalanced development (1978–1998) and a stage of coordinated development (1999 to the present). It currently presents three major characteristics: the industries transferred from the eastern region to the central and western regions have expanded from traditional low-end industries to high-end ones; the eastern, central, and western regions are concentrating on specific industry segments, forming a "fragmented" division of labor along the NVC [3]; and the central and western regions are accelerating industrial structural adjustment and forming distinctive competitive advantages. It is worth noting that, with the breakthroughs in core technologies and the enhancement of innovation capabilities in the eastern region, the traditional model of "R&D and design in the east, manufacturing and assembly in the central and western regions" is undergoing profound changes, and the national value chain has entered a process of reconstruction [4].

2.2. The NVC Positioning Mechanism of Advanced Manufacturing Clusters in the Eastern, Central, and Western Regions under Cross-Regional Innovation Collaboration

The "gradient division-of-labor pattern" referred to in this paper is an analytical generalization, based on gradient transfer theory, of the spatial distribution of the eastern, central, and western clusters within the NVC. It aims to reveal the formation mechanism and evolutionary logic of this pattern, rather than to make value judgments about the development levels of different

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regions. The formation of this division-of-labor pattern is not accidental; rather, it is the objective result of the inherent mechanisms of industrial transfer and gradient transfer. Significant disparities exist in the economic and technological development levels among China's three major regions-the eastern, central, and western regions-presenting an overall gradient pattern of "high in the east, intermediate in the center, and low in the west." According to gradient transfer theory, innovation activities such as emerging industries, new products, and new technologies usually originate in high-gradient regions; with the passage of time and changes in the life-cycle stage, differences in the economic and technological gradient will drive the transfer of traditional industries, mature products, and conventional technologies from high-gradient regions to low-gradient regions.

Under the pattern of intra-product division of labor, the interregional disparities in economic and technological gradients within China will drive the transfer of lower value-added segments of the value chain from high-gradient regions to low-gradient regions. In this process, the industrial clusters of the three major regions extend the NVC in a "fragmented" form, presenting a spatial distribution pattern of high-, medium-, and low-value-added segments [5]: eastern clusters mainly undertake high-value-added segments such as product design, R&D and manufacturing of core components, and brand marketing; central clusters mainly undertake medium-value-added segments such as R&D and manufacturing of key components and high-tech services; and western clusters mainly undertake low-value-added segments such as assembly and processing and general component manufacturing. This gradient division-of-labor pattern is typically manifested in a number of advanced manufacturing sectors. Take the electronic information industry as an example: chip design and brand operations are concentrated in eastern cities such as Shanghai and Shenzhen; the manufacturing of key components such as display panels and optical modules is agglomerated in central cities such as Hefei and Wuhan; and complete-unit assembly is completed in western cities such as Chongqing and Chengdu. Take the new energy vehicle industry as another example: complete-vehicle design and R&D of electronic control systems are mainly located in the eastern region; battery materials and cell manufacturing are concentrated in central provinces such as Jiangxi and Hunan; and complete-vehicle assembly is deployed in western cities such as Xi'an and Chongqing. In the high-end equipment manufacturing industry, R&D, design, and core component manufacturing are concentrated in the eastern region; key component processing and process optimization are deployed in central cities such as Wuhan and Changsha; and final assembly and testing are completed in western cities such as Chengdu and Xi'an. It should be noted that the above examples illustrate the overall trend of the gradient division of labor. Owing to historical layouts, resource endowments, and policy factors, the regional distribution of certain specific segments may overlap, but this does not alter the basic characteristics of the gradient division-of-labor pattern.

Constrained by the comparative advantages of developed countries and their protection of core technologies, multinational corporations usually transfer only the lower and middle value-added segments of the global value chain to developing countries [6,7]. Since the eastern, central, and western clusters each possess comparative advantages in the high-, medium-, and low-value-added segments of the NVC respectively, they will attract the international industrial transfer of the corresponding segments of the global value chain, and this transfer in turn reinforces the comparative advantages of the eastern, central, and western clusters in their respective segments. Under the interaction of domestic industrial transfer, international industrial transfer, and outbound industrial transfer, the positioning of the advanced manufacturing clusters of the eastern, central, and western regions in the high-, medium-, and low-value-added segments of the NVC is continuously strengthened and locked in.

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2.3. The NVC Role Positioning of Advanced Manufacturing Clusters in the Eastern, Central, and Western Regions under Cross-Regional Innovation Collaboration

Under this pattern, the advanced manufacturing clusters of the eastern, central, and western regions have formed clear and relatively solidified NVC role positions:

The eastern clusters, as the "innovation cradle" and "strategic hub" of the NVC, rely on their dense scientific research resources, active capital markets, abundant high-end talent, and mature industrial ecosystems to lead basic research, applied development, product definition, breakthroughs in core components, and brand operations, remaining at the frontier of the global knowledge network. Their core mission is to conquer key core technologies through independent innovation and seize the initiative in the development of future industries.

The central clusters, as the "transformation hub" and "key support" of the NVC, leverage their solid industrial foundation, well-developed supporting capabilities, and geographical advantages linking the east and the west to focus on the manufacturing of key components, the optimization of core processes, and engineering realization, providing a platform for the industrialization of the eastern region's innovation achievements [8]. Their core task, through collaborative innovation, is to transform the cutting-edge technologies developed in the east into product modules with stable performance, controllable costs, and scalable production, serving as a critical link in safeguarding the resilience of the industrial chain.

The western clusters, as the "manufacturing cornerstone" and "capacity guarantee" of the NVC, rely on their factor cost advantages and resource endowments to undertake large-scale, standardized production and manufacturing tasks, providing guarantees for the supply of basic production capacity and economies of scale, while also offering stable primary product support for the segments in the central and eastern regions.

This gradient positioning pattern is not only the objective result of the combined effects of market mechanisms and comparative advantages, but also the most fundamental practical basis and intrinsic motivation for cross-regional innovation collaboration: the eastern region needs the central and western regions to provide rapid feedback, iterative trial and error, and capacity support on the manufacturing side in order to accelerate the innovation cycle; the central and western regions urgently need the technology spillover, order-driven demand, and management empowerment from the east in order to achieve value chain upgrading. Together, the three regions constitute a capability-complementarity-based "innovation–manufacturing" symbiotic relationship.

It should be pointed out that the gradient division-of-labor pattern is a stage-specific result of the combined effects of market mechanisms and comparative advantages. With the dynamic changes in the innovation capabilities of the eastern, central, and western regions, this pattern may also evolve toward forms such as "networked collaboration" and "polycentric symbiosis."

3. The Reconstruction of the NVC "Smile Curve" and the Four-Stage Evolutionary Logic of Cross-Regional Innovation Collaboration among Advanced Manufacturing Clusters

3.1. The Future-Oriented Reconstruction of the NVC "Smile Curve"

On the basis of an in-depth analysis of the gradient division-of-labor pattern, it is crucial to establish a future-oriented strategic direction. Under the traditional development pattern, the preliminary basic theory, technology development, and applied research required for the formation of forward-looking or strategic industries were usually undertaken by research institutions in developed countries or multinational corporations, with developing countries rarely involved. The main reasons are that such research involves long cycles, large capital

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requirements, high sunk costs, and high risks of failure. However, under the new development pattern, the reshaping of industrial chains places greater emphasis on the importance of preliminary basic theory, technology development, and applied research for forward-looking and strategic emerging industries.

Numerous scholars in academia have studied the "smile curve" of the value chain. Tu Niansong and Yi Zehua systematically reviewed the theoretical framework and evolutionary mechanism of value chain reconstruction [9], while Yuan Zhonghua and Zhan Haoyong analyzed the logic of constructing the national value chain from the perspective of producer services agglomeration and the division of knowledge [10]. In the traditional NVC "smile curve," the division-of-labor segments of the value chain can be classified into three categories according to their value-added levels: high-value-added segments, medium-value-added segments, and low-value-added segments. Specifically, the high-value-added segments include product design, R&D and manufacturing of core components, branding, and marketing; the medium-value-added segments refer to the R&D and manufacturing of key components; and the low-value-added segments include general component manufacturing and assembly processing. However, existing studies generally fail to incorporate the preliminary basic theory, technology development, and applied research that promote the formation of forward-looking or strategic industries into the value chain analytical framework. The report of the 20th National Congress of the Communist Party of China explicitly proposed accelerating the implementation of the innovation-driven development strategy, with particular emphasis on strengthening basic research and highlighting original science and technology, fully demonstrating the fundamental supporting role of original basic research in scientific and technological innovation.

This study argues that, under the new development pattern, the basic theory, technology development, and applied research of forward-looking strategic emerging industries should be defined as high-value-added segments. Although such research may not generate direct economic returns for a considerably long period (ten or even twenty years), for enterprises committed to long-term development, it is the fundamental prerequisite for obtaining excess monopoly profits in the future. Without early-stage R&D investment, it would be impossible to give rise to emerging industries with disruptive impact. Therefore, future excess monopoly profits, through appropriate discounting methods, can be converted into expected high returns on current investment, and should thus be regarded as high-value-added creation activities at the current stage.

Based on the above understanding, this study reconstructs the NVC "smile curve." In the new curve, the value chain segments can be classified into three categories according to their value-added levels: high-value-added segments, including product design, R&D and manufacturing of core components, branding, and marketing in existing industries, as well as basic theoretical research, technology development, and application in forward-looking strategic emerging industries; medium-value-added segments, including the R&D and manufacturing of key components and high-tech services in existing industries; and low-value-added segments, including general component manufacturing and assembly processing in existing industries. The reconstructed smile curve provides a new strategic coordinate system for the gradient division of labor among the eastern, central, and western clusters: the eastern clusters focus on high-value-added segments (including forward-looking basic research), the central clusters focus on medium-value-added segments, and the western clusters focus on low-value-added segments, with the three forming a collaborative pattern of "innovation–transformation–manufacturing" in the new value coordinate system.

The theoretical reconstruction of the NVC "smile curve" is not only an innovation in analytical tools but also carries profound strategic implications. The future-oriented NVC "smile curve" imposes entirely new systematic requirements on cross-regional innovation collaboration among advanced manufacturing clusters: the duality of collaboration objectives—innovation

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collaboration must simultaneously serve the two strategic goals of "strengthening and supplementing the chain" in existing industry tracks and "overtaking on a new track" in future industry tracks; the whole-process extension of the collaboration chain-collaborative activities must be shifted substantially forward from industrialization breakthroughs at the back end to basic research and applied research at the front end; the long-term orientation of collaboration incentives-collaborative activities oriented toward innovation source regions are characterized by long return cycles and high failure risks, requiring the design of special institutional arrangements that can effectively incentivize long-termist behavior; and the forward-looking nature of value distribution-the design of the collaborative benefit distribution mechanism must take into account how to provide reasonable "future value discounting" or "risk compensation" for the regions and entities participating in high-risk front-end innovation activities.

3.2. The Four-Stage Progressive Strategic Approach to Cross-Regional Innovation Collaboration

According to industrial chain theory, technological innovation evolution theory, and technology track theory [11], building an independent and controllable industrial chain is not something that can be accomplished overnight. It is a long-term, dynamic, and step-by-step evolutionary process. The theory of cross-regional innovation systems further points out that actors of cross-regional innovation can leverage digital technologies to build integrated innovation scenarios in virtual space to form a system in which regional subsystems are mutually coupled [12]. This provides a systems-theory perspective. The systems-theory perspective is for understanding the collaboration mechanisms of the eastern, central, and western clusters in the four-stage evolution. The long-term scientific and technological innovation development of cross-regional innovation collaboration among advanced manufacturing clusters should follow the core logic. The core logic is "from filling shortcomings to forging strengths, from catch-up learning to track creation." Based on this, this study proposes a "four-stage progressive" strategic approach. The "four-stage progressive" strategic approach is chain-supplementing innovation → chain-strengthening innovation → edge-forging innovation → technology-track leapfrogging innovation. These four stages are sequentially connected and progressively advanced. These four stages jointly constitute a complete path toward the independent controllability and global leadership of the industrial chain.

Stage One: Chain-supplementing innovation. The core objective of this stage is to break through the "chokepoint" bottlenecks. This stage can ensure the security and basic connectivity of the industrial chain. The innovation focus is on key substitution. The key substitution is achieving indigenous substitution "from nothing to something" for core components, key materials, and basic software that are subject to external control. This will effectively defuse the risk of "chain breakage." The key to collaboration lies in demand-driven reverse breakthrough efforts. The reverse breakthrough efforts are system integrators (chain-leader enterprises) located downstream in the east identify technological pain points and, by forming innovation consortiums and releasing "unveiling-the-list and taking-command" tasks. The chain-leader enterprises join forces with midstream and upstream enterprises and research institutes distributed across the eastern, central, and western regions to conduct targeted joint research. The strategic significance of this stage in NVC reconstruction lies in filling the key "breakpoints" of the NVC, realizing the basic autonomous circulation of the industrial chain, and shaking off fatal dependence on a single external supply chain. Taking the electronic information industry as an example, a typical manifestation of chain-supplementing innovation is the indigenous substitution in the integrated circuit packaging and testing segment. For a long time, high-end packaging and testing equipment and materials depended on imports. In recent years, enterprises such as JCET and Tongfu Microelectronics have achieved breakthroughs in

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advanced packaging. The enterprises gradually shift the packaging and testing segment from "external dependence" to "domestic supporting supply." Taking the new energy vehicle industry as another example, chain-supplementing innovation focuses on the indigenization of automotive-grade chips and high-end separator materials. Through targeted research, enterprises such as BYD Semiconductor and Enjie have gradually filled the domestic gaps in key components. From the perspective of the gradient division of labor, the research tasks of chain-supplementing innovation are mainly concentrated in the core component manufacturing of high-value-added segments and the key materials and basic software of medium-value-added segments. The research tasks of chain-supplementing innovation require coordinated action in which eastern chain leaders take the lead, central key enterprises provide supporting capabilities, and western manufacturing segments provide support.

Stage Two: Chain-strengthening innovation. The core objective of this stage is to enhance the performance, reliability, and market competitiveness of indigenous products, achieving the leap from "usable" to "good to use" and "durable." The innovation focus is on performance catch-up and quality improvement—by benchmarking against advanced international standards, improving the stability, yield, and cost advantages of indigenous products. The key to collaboration lies in process and quality coordination: after achieving core technology breakthroughs, eastern leading enterprises export technical standards and process specifications to the central and western clusters, and the eastern, central, and western clusters carry out coordinated optimization of manufacturing processes, joint quality management of the supply chain, and joint reliability testing around unified technical standards. Meanwhile, relying on the public R&D platforms of domestic innovation highlands (such as national laboratories and technology innovation centers), support services such as testing and verification and process optimization are provided for enterprises in the central and western regions. The strategic significance of this stage in NVC reconstruction lies in consolidating and strengthening the NVC, improving overall operational efficiency and resilience, endowing the autonomous segments with market competitiveness, and laying a solid foundation for value chain upgrading. Taking the electronic information industry as an example, a typical manifestation of chain-strengthening innovation is the performance catch-up in display panels and memory chips—BOE has moved from "following" to "keeping pace" in the LCD panel field, and YMTC has achieved breakthroughs in the number of layers in 3D NAND flash memory, enabling indigenous products to move from "usable" to "good to use." Taking the new energy vehicle industry as another example, chain-strengthening innovation focuses on improving the energy density of power batteries and the reliability of electronic control systems. By benchmarking against advanced international standards, enterprises such as CATL and Inovance (United Power) have made indigenous battery and electronic control products globally competitive in performance, yield, and cost; among them, Inovance ranks first in China among third-party electronic control suppliers.

Stage Three: Edge-forging innovation. The core objective of this stage is to achieve partial leadership and ecosystem dominance in advantageous fields, realizing a competitive pattern of "chain versus chain." The innovation focus is on deepening advantageous fields and ecosystem building-in fields where advantages have already been established, such as complete units, systems, or emerging areas, world-class products and brands are to be created, with extension upward into upstream core segments to build an industrial ecosystem led by China itself. The key to collaboration lies in joint ecosystem building and standard leadership: chain-leader enterprises take the lead in uniting upstream and downstream partners, universities, and research institutes to jointly define products, formulate and export standards, and cultivate the industrial ecosystem. In this stage, the advanced manufacturing clusters in the eastern region play the core roles of "innovation cradle" and "ecosystem leader," forming irreplaceable competitive advantages in key fields through the synergy of original independent innovation

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and the national strategic scientific and technological forces. The strategic significance of this stage in NVC reconstruction lies in forming a "control bulge" in specific sections of the NVC, acquiring the capability of "driving the whole chain from a single point," and beginning to compete for governance power and dominance in value distribution within the global value chain. Taking the electronic information industry as an example, Huawei promoted the adoption of the polar code scheme as an international standard in the formulation of 5G standards, and BOE has led multiple international standards in the field of flexible display, marking the eastern clusters' leap from "product competition" to "standard competition." Taking the new energy vehicle industry as another example, CATL, as a major drafting unit, participated in the formulation of national standards for power battery safety, and BYD has developed its own technological route in electric vehicle platform architecture, beginning to acquire the ecosystem-leading capability of "driving the whole chain from a single point."

Stage Four: Technology-track leapfrogging innovation. The core objective of this stage is to open up new tracks, define new rules, and achieve the historic leap from global following to partial and even comprehensive leadership. The innovation focus is on frontier exploration and paradigm transformation-making forward-looking arrangements in disruptive technologies and future industries, promoting original innovation in basic research, and creating new technology tracks, industrial standards, and value chain forms. The key to collaboration lies in frontier exploration consortiums-relying on the national strategic scientific and technological forces and eastern innovation highlands, cross-regional, interdisciplinary, and deeply industry-academia-research integrated future industry innovation consortiums are to be formed to pursue asymmetric catch-up and source innovation. Research has shown that cross-regional innovation cooperation has a significant promoting effect on the development of future industries [13], providing empirical support for advancing frontier exploration and forming future industry innovation consortiums through cross-regional collaboration. In this process, the eastern clusters not only assume the leading role in technological breakthroughs but also, through reverse outsourcing (establishing R&D centers overseas to absorb global intellectual resources) and open-source community collaboration, integrate global innovation resources to serve indigenous technological leaps. The strategic significance of this stage in NVC reconstruction lies in leading or even defining a new global value chain, achieving the fundamental transformation from "climbing" within established tracks to "creating new tracks and leading the direction," and ultimately seizing the ultimate initiative in industrial development. In frontier directions such as quantum information, artificial intelligence, and biomanufacturing, the eastern clusters are relying on the national strategic scientific and technological forces to form future industry innovation consortiums and explore paths of asymmetric catch-up.

3.3. The Internal Logic and Evolutionary Relationship of the Four Stages of Cross-Regional Innovation Collaboration

This four-stage progressive approach is not subjective conjecture. It builds upon profound internal logic.

First, a strong orientation toward real-world problems. This approach directly responds to problems such as "chain-type vulnerability," "insufficient collaboration," and "impeded factor mobility." "Chain-supplementing innovation" and "chain-strengthening innovation" aim to systematically address the shortcomings of "chokepoint" constraints and weak foundations. "Edge-forging innovation" and "technology-track leapfrogging innovation" aim to break through the long-standing bottlenecks of insufficient innovation momentum and the absence of high-end leadership. The four stages advance progressively and target the problems with precise remedies.

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Second, adherence to the objective laws of technological evolution. The four stages comprehensively depict the classic transition process of industrial technological capability. The classic transition process is from "filling gaps and consolidating foundations" (chain-supplementing and chain-strengthening), to "forging advantages and leading the frontier" (edge-forging), and ultimately toward "original innovation and disruptive breakthroughs" (track leapfrogging). It profoundly embodies the core ideas of technology track theory. This path is consistent with the common experience of technologically latecomer countries and has a solid theoretical basis.

Third, the progression and deepening of collaboration modes. Collaboration modes upgrade continuously with the evolution of the stages: from the early-stage "task-oriented joint research collaboration" (Stage One), to "process and standard collaboration" (Stage Two), then to "ecosystem and governance collaboration" (Stage Three), and finally to "vision and exploration collaboration" (Stage Four). Collaboration evolves from short-term project-based cooperation into long-term strategic symbiosis, moving from solving specific problems toward jointly creating the future.

Fourth, stage-specific differences in policy priorities. At different stages, the roles and policy needs of the government, clusters, and enterprises vary. The chain-supplementing stage requires a powerful "new type of whole-nation system" and precise industrial policies to concentrate efforts on breaking through "chokepoint" segments; the chain-strengthening stage requires support from quality infrastructure, standard systems, and generic technology platforms; the edge-forging stage calls more for competition policy, standard strategies, and ecosystem cultivation policies; and the track-leapfrogging stage requires long-term strategic arrangements such as investment in basic research, forward-looking exploration and layout, and the cultivation of disruptive technologies.

4. Conclusion

Based on the NVC division-of-labor pattern, this paper systematically analyzes the formation mechanism of the gradient division-of-labor pattern of the eastern, central, and western advanced manufacturing clusters under the "triple coupling" pattern of industrial transfer. This paper reconstructs the future-oriented NVC "smile curve" and proposes a four-stage progressive strategic approach. The main conclusions are as follows:

First, the NVC gradient division-of-labor pattern of the eastern, central, and western advanced manufacturing clusters constitutes the practical foundation for cross-regional innovation collaboration to build an independent and controllable industrial chain. The three segments are the east as the "innovation cradle," the center as the "transformation hub," and the west as the "manufacturing cornerstone". The three-segment division of labor creates a complete spatial layout of all segments of the industrial chain across the eastern, central, and western regions. It provides "spatial guarantees" for independent controllability. This pattern is not only the objective result of the combined effects of market mechanisms and comparative advantages, but also the most fundamental practical basis and intrinsic motivation for cross-regional innovation collaboration. It should be emphasized that this gradient division-of-labor pattern is characterized by stage-specific and dynamic features. With the relative changes in the innovation capabilities of the eastern, central, and western regions, its specific form may evolve toward "networked collaboration," "polycentric symbiosis," and other directions. The four-stage evolutionary logic revealed in this paper is precisely a systematic depiction of this dynamic process.

Second, the reconstruction of the NVC "smile curve" carries profound strategic implications. The basic theory, technology development, and applied research of forward-looking strategic emerging industries are incorporated into high-value-added segments. it establishes the

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duality of collaboration objectives. The duality of collaboration objectives is "strengthening and supplementing the chain" in existing industry tracks and "overtaking on new tracks" in future industry tracks. This reconstruction imposes systematic requirements on innovation collaboration, including the whole-process extension of the collaboration chain, the long-term orientation of collaboration incentives, and the forward-looking nature of value distribution.

Third, the four-stage progressive strategic approach to cross-regional innovation collaboration provides a clear evolutionary framework for building an independent and controllable industrial chain. The four stages are "chain-supplementing innovation → chain-strengthening innovation → edge-forging innovation → technology-track leapfrogging innovation". The four stages are sequentially connected and progressively advanced, comprehensively depicting the classic transition of industrial technological capability. The four stages are from "filling gaps and consolidating foundations" to "forging advantages and leading the frontier" and ultimately toward "original innovation and disruptive breakthroughs." The four-stage progressive approach follows the objective laws of technological evolution, with collaboration modes deepening progressively as the stages advance and policy priorities exhibiting stage-specific differences.

Fourth, the gradient division-of-labor pattern and the four-stage evolutionary logic constitute a progressive "foundation–elaboration" relationship. The gradient division-of-labor pattern answers the question of "how the pattern forms." The four-stage evolutionary logic answers the question of "how the pattern evolves". They constitute a complete analytical framework for understanding cross-regional innovation collaboration among advanced manufacturing clusters. This framework not only reveals the formation mechanism of the current NVC spatial layout, but also points out the dynamic evolutionary path from "fragmented division of labor" to "systematic collaboration."

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