DOI: 10.23977/ieim.2026.090104
ISSN 2522-6924 Vol. 9 Num. 1

Measurement of Localization Level and Optimization Paths of Integrated Circuit Equipment from the Perspective of Multi-Chain Integration

Qindi Zhang[1], Wenhan Fu[1,2,a,*], Yuxing Ma[1,3], Yunxiao Zhang[1]

[1]*Business School, University of Shanghai for Science and Technology, Shanghai, 200093, China*
[2]*School of Intelligent Emergency Management, University of Shanghai for Science and Technology, Shanghai, 200093, China*
[3]*Applied Materials (China) Co., Ltd., Shanghai, China*
[a]*whfu@usst.edu.cn*
**Corresponding author*

Keywords: Multi-Chain Integration; Chain Leader Enterprises; Collaborative Innovation; IC Equipment Localization

Abstract: Targeting the problems of inadequate independent controllability and suboptimal multi-chain synergy efficiency in China's IC equipment sector, from the perspective of multi-chain integration, this study constructs a multi-chain integration analytical framework dominated by the industrial chain and innovation chain, with the talent chain and value chain providing synergistic support, and introduces chain-leading enterprises as the core hub of multi-chain collaboration. By comprehensively adopting a combination of qualitative analysis and quantitative measurement, the research conducts comparative studies of representative domestic and international enterprises, establishes a multi-dimensional and quantifiable comprehensive evaluation model for the localization level of IC equipment, and proposes targeted multi-chain collaborative optimization pathways.

1. Introduction

The integrated circuit (IC) industry has emerged as a strategic focal point of global technological and economic competition[1]. According to statistics from the World Semiconductor Trade Statistics (WSTS), the global IC industry reached a record-high scale of $627.2 billion in 2024. China accounts for approximately 29.5% of the global IC market, making it the world's largest IC market[2]. Moreover, in the second quarter of 2025, sales of IC equipment in Chinese mainland reached $11.36 billion, representing a share of around 34.4% and securing its position as the world's largest IC equipment market.

As the largest market for IC equipment, the overall domestic substitution rate of IC equipment in China stands at only approximately 17.53%. Although the localization rate of domestic equipment has been steadily improving, a substantial gap remains relative to domestic market demand. Meanwhile, the overall market share of domestic equipment is roughly 30%, which is mainly concentrated in mid-to-low-end segments such as cleaning, etching, and inspection. In high-end critical equipment fields, including advanced lithography and ion implantation, core technologies and high-end complete machines still rely heavily on foreign manufacturers, resulting in generally low domestic substitution rates. In particular, the domestic market share of high-end lithography equipment remains in the single digits, with core components highly dependent on imports, revealing critical technological bottlenecks and potential supply chain security risks in key equipment sectors.

Owing to the high complexity and precision of integrated circuit equipment technologies, the R&D process is characterized by prolonged cycles, considerable trial-and-error costs, and rigorous demands for system-level collaboration[3]. Individual enterprises are rarely capable of independently sustaining long-term investment for technological breakthroughs. A persistent mismatch between R&D progress and industrial deployment exists along China's industrial chain, resulting in superior laboratory performance yet unsatisfactory scalability of domestic equipment in mass production. Moreover, long-term market dependence on imported products has substantially undermined the momentum of domestic substitution.

Against this backdrop, the integration of the industrial chain and innovation chain is urgently needed[4], while value enhancement enabled by the value chain and talent chain is equally critical[5]. Furthermore, as core entities coordinating the industrial chain and driving innovation, chain-leading enterprises play an indispensable role that must be emphasized. Therefore, in the process of domesticating IC manufacturing equipment, chain-leading enterprises serve both as end-users and technology drivers. A multi-chain integration mechanism led by chain-leading enterprises has become an important pathway to address bottlenecks in domestic substitution[6].

2. Related Work

The concept of industry-innovation dual-chain integration arises from the synergy of innovation-driven development and industrial upgrading, with its connotation evolving as research expands[7]. Based on value chain theory[8], the industrial chain involves linear value creation, transfer, and realization, while the innovation chain constitutes dynamic knowledge generation[9], R&D and achievement commercialization, both connected by value-added activities. Further research has extended dual-chain integration to multi-chain integration supported by the value chain and talent chain[10]. Studies suggest that multi-chain integration is an enterprise-led systematic collaboration integrating policy and talent, which aligns innovation entities, outputs, and talents with industrial needs to enhance technological innovation and value appreciation.

Multi-chain integration is supported by factor endowment, co-evolution, and innovation ecosystem theories[11]. Factor endowment theory explains cross-chain resource allocation, including talent allocation and value distribution. Applied to the integrated circuit industry, comparative advantages in market scale, policy support and talent reserve help tackle equipment technical bottlenecks; technology localization, supported by the talent chain and value chain[12], has realized domestic production of 28 nm etching equipment. Co-evolution theory highlights dynamic chain matching; relevant studies show that the four chains' coordination evolves gradually, improving equipment maturity. The double helix model promotes multi-chain interaction through factor flow, while the triple helix model supports an innovation ecosystem, with government-industry-university-research cooperation and chain-leading enterprise coordination alleviating innovation isolation via optimized talent and value distribution. Empirical evidence shows insufficient four-chain synergy is the core constraint in China's integrated circuit industry, especially in the equipment segment due to technological fragmentation, talent mismatch distorted value distribution and scattered policies.

3. Measurement and Evaluation of Localization in Integrated Circuit Manufacturing Equipment Driven by Multi-Chain Integration

To clarify the status and problems of multi-chain integration in China's IC manufacturing equipment industry, this paper uses qualitative and quantitative analyses for measurement and evaluation.

3.1. Qualitative Analysis

To optimize equipment localization and multi-chain integration pathways, this study analyzes global leaders and domestic gaps: ASML dominates lithography, AMAT leads multiple segments, and Tokyo Electron excels in niche fields. Domestic enterprises have made breakthroughs in etching, cleaning and CMP but are weak in high-end lithography; SMEE has commercialized DUV equipment, while AMEC mass-produces etching and deposition equipment. These gaps stem from insufficient technological accumulation, underdeveloped ecosystems and poor institutional coordination, unlike global leaders who build core technologies via long-term R&D, strengthen customer loyalty through full-process services, and integrate high-end components via quality supply chains.

China prioritizes breakthroughs in DUV and EUV lithography and radio frequency power supplies to boost high-end equipment proportion, but homogenized talent structure and lack of interdisciplinary professionals restrict enterprises to low-end OEM and imported components. The innovation chain drives patent growth but with low quality and external reliance on key technologies; the talent chain is supported by over 100,000 annual graduates and low core turnover.

China has established an industry-university-research-application mechanism, with policy support shifting to long-term innovation capacity. Leading enterprises guide SMEs, but excessive administrative intervention in niche fields, vicious competition and redundant construction hinder development. Optimizing market-oriented mechanisms and industrial ecosystems is critical for healthy multi-chain integration.

3.2. Quantitative Analysis

To quantitatively assess the level of multi-chain integration in China's integrated circuit equipment sector, this study employs a quantitative analysis approach for further verification. A comprehensive evaluation model is established across four dimensions: industrial chain, innovation chain, talent chain, and value chain, with five representative core indicators selected as listed in Table 1.

Given the inconsistent dimensions of the indicators, the Min - Max normalization method is adopted in this study to standardize the data to ensure comparability, with the formula expressed as follows:

$$N_i = \frac{X_i - L_i}{U_i - L_i} \tag{1}$$

where Ni denotes the normalized value of the i-th indicator, Xi is the original observed value, and Li and Ui represent the theoretical lower and upper bounds, respectively. Based on practical industrial conditions, the value ranges are set as follows: equipment localization rate [0, 0.5], patent commercialization rate [0, 1], R&D intensity [0, 5], talent ratio [0, 0.5], and market share [0, 0.5].Different weights are assigned to each indicator according to its impact on integration level: equipment 0.25, patents 0.20, R&D intensity 0.15, talent 0.15, and value chain position 0.25, as shown in Table 2.

After obtaining the normalized results, the comprehensive score is calculated using the following formula:

$$F = \sum_{i=1}^{n} w_i N_i \tag{2}$$

Table 1: Chain Integration Measurement Indicator System and Data Sources

No.	Dimension	Indicator Name	Indicator Meaning
1	Industrial Chain	Equipment Localization Rate	Measures the self-sufficiency capability of upstream manufacturing equipment
2	Innovation Chain	Patent Grant Rate	Measures the effective transformation capability of innovation achievements
3	Innovation Chain	Industrial R&D Intensity	Reflects the R&D investment level of enterprises
4	Talent Chain	Share of R&D Employees	Measures the density of the talent chain and the agglomeration of R&D personnel
5	Value Chain	Market Share	Reflects the position of the industry in the global value chain

Table 2: Normalization Results of Each Indicator

Indicator	Original Value	Interval (L, U)	Normalized Value N_i	Weight w_i	Weighted Contribution $w_i N_i$
Equipment Localization Rate	0.22	[0 , 0.5]	0.44	0.25	0.11
Patent Grant Rate	0.53	[0 , 1]	0.53	0.20	0.106
Industrial R&D Intensity	0.18	[0 , 0.5]	0.36	0.15	0.054
Share of R&D Employees	0.3	[0 , 0.5]	0.6	0.15	0.09
Market Share	0.34	[0 , 0.5]	0.68	0.25	0.17

Substituting the results in Table 2 yields a total score of 0.53, indicating that China’s integrated circuit industry remains at a moderate synergy level, with an efficient integration mechanism yet to be fully formed. While the industrial chain has expanded and the innovation chain has driven growth, the lagging talent chain, value chain, and regional collaborative chains have become critical bottlenecks hindering overall industrial upgrading.

These quantitative findings align with qualitative observations. Although China’s industry boasts scale and innovation potential, structural issues limit integration depth: weaknesses in upstream equipment sectors, low R&D commercialization efficiency, uneven talent distribution, and insufficient regional coordination. Positioned in the mid-to-downstream manufacturing and packaging and testing segments of the global value chain, China relies heavily on imported upstream high-value-added equipment and materials. This dependence undermines industrial autonomy and impedes the closed-loop transformation of innovation chain achievements.

Overall, multi-chain integration has shifted from initial coordination to systematic collaboration. The synergy between industrial and innovation chains is significant, while the coupling of talent and value chains needs strengthening. With chain-leading enterprises as the core, cross-regional industry-university-research platforms should be built to accelerate R&D, verification and industrialization. Policy and investment support will promote breakthroughs in key equipment, and optimized talent systems will facilitate higher-level closed-loop synergy. The four-chain integration will help China's IC industry transform from scale-driven to structural and innovative advantages.

4. Path Optimization and Institutional Guarantee Design for Chain Integration

4.1. Main Chain Interconnection: Removing Breakpoints in Industrial - Innovation Chain Integration

The industrial chain refers to a complete and interdependent industrial organizational form formed around the value creation and delivery of chips and integrated circuit devices. It connects enterprises, research institutions, and other entities with upstream and downstream techno-economic linkages through multiple links such as material supply and equipment manufacturing.

The innovation chain is a functional chain formed around innovation activities. It not only reveals the laws of knowledge and technology flow and transformation, but also reflects the collaboration and value transmission relationships among various innovation actors. The basic structure of the innovation chain is illustrated in Figure 1.

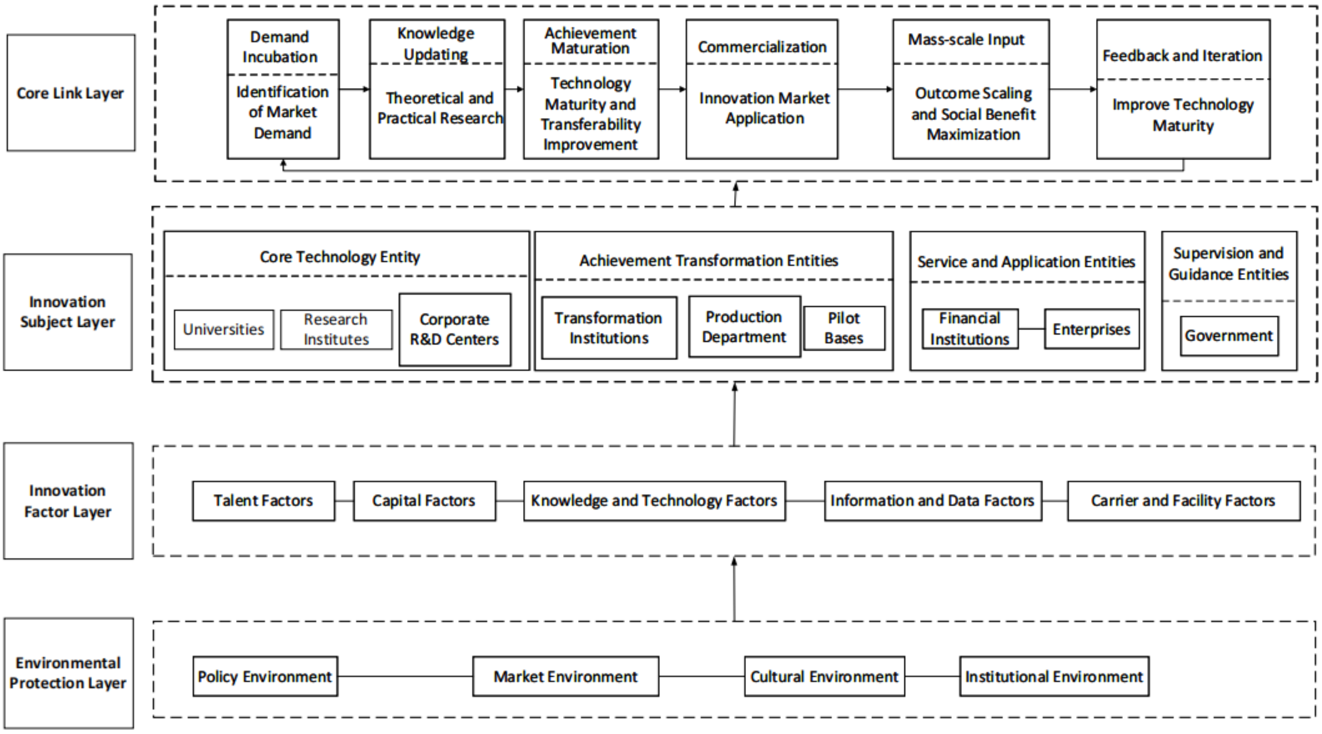

Figure 1: Basic Composition of the Innovation Chain in the IC Industry

In the localization of IC manufacturing equipment, the industrial chain and innovation chain are not isolated systems. Supported by the talent chain and value chain, they constitute a deeply coupled organic system through functional complementarity and efficient factor flow. The industrial chain converts technological outputs from the innovation chain into practical productivity through scenario adaptation, factor integration and market feedback. The innovation chain promotes the industrial chain to overcome technical bottlenecks and improve value addition via basic research, applied development and technological iteration. Their synergistic coupling is critical to addressing core constraints in IC equipment development, and provides a theoretical basis for promoting domestic substitution from technological independence to industrial self-reliance.

Without the support of the industrial chain, innovations in IC equipment can hardly be applied and may only stay at the theoretical level. As a key bridge connecting innovation and market, the industrial chain offers scenario-based verification conditions for the transformation and industrialization of innovative achievements. Given the high complexity and customization characteristics of IC equipment, core technologies must be tested and validated in real wafer manufacturing environments. The innovation chain breaks resource limitations of the industrial chain and boosts industrial upgrading through continuous technological breakthroughs. The R&D of IC equipment relies on interdisciplinary integration, and the innovation chain facilitates efficient collaboration by integrating industrial resources.

4.2. Efficiency-Enhancing Path of Auxiliary Chains: Empowering Main Chain Integration through Value Chain and Talent Chain

In the field of integrated circuit equipment, the value chain constitutes a complete system for value creation, delivery, and appreciation throughout the entire life cycle of IC equipment. It involves the division of labor and collaboration among upstream and downstream entities in core component supply, equipment manufacturing, and other related links. Centered on technological scarcity and industrial adaptability as value anchors, it exhibits the typical characteristics of the smile curve, as illustrated in Figure 2. Ultimately, the value distribution pattern across different segments is reflected in profit levels, market dominance, and industrial influence.

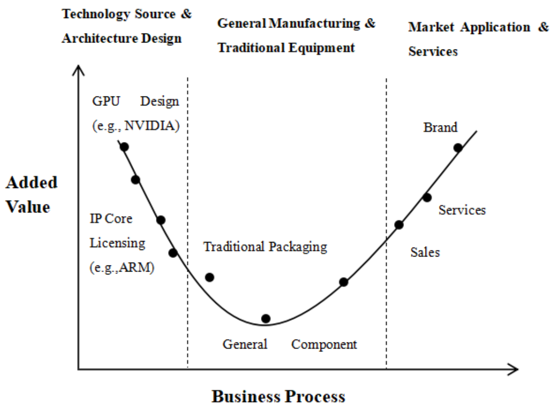

Figure 2: Value Smile Curve

The talent chain is a hierarchical, synergistic ecosystem of technical, interdisciplinary, and leading talents, whose core is hierarchical allocation and capability complementarity to support IC equipment full-chain development from basic research to industrial upgrading.

In the multi-chain integration dominated by industrial and innovation chains, the talent chain acts as a key auxiliary, supporting main chain coordination. Optimized talent chains enhance technological innovation and engineering transformation, improving main chain integration accuracy and sustainability, and consolidating domestic substitution systems.

The talent chain supports the innovation chain in addressing industrial bottlenecks for technological breakthroughs-core technology monopoly essentially reflects high-end talent monopoly. China must accelerate innovation via talent cultivation and high-end talents tackling key research. Data shows a 1% increase in high-end talent density boosts basic research speed by 0.9% and localization rate by 0.8%. For efficiency improvement, it shortens industrial iteration cycles and accelerates value realization by promoting coordinated R&D and transformation.

4.3. Multi-Chain Synergistic Coupling and Institutional Guarantee for IC Equipment Localization

Multi-chain integration is a systematic framework featuring deep interaction between the industrial chain and innovation chain, supported by the value chain and talent chain. The synergistic coupling of the four chains enables efficient factor allocation, strategic coordination and functional complementarity. The innovation chain provides core technologies for industrial upgrading, while the industrial chain feeds market demand to optimize R&D. Driven by high value-added distribution and talent support, this two-way linkage breaks resource bottlenecks, reduces mismatches between research and application, and promotes the industrial chain toward the high-end of the smile curve, supporting the high-quality development of domestic IC equipment.

China's multi-chain integration still faces prominent constraints. High-end equipment relies heavily on imported core components; domestic equipment suffers from low market recognition and insufficient application verification. Poor coordination among R&D, industry and policies also limits the synergy of the four chains, hindering the independent control and large-scale localization of integrated circuit manufacturing equipment.

A sound institutional system underpins the deepening of multi-chain integration. Targeted policies coordinate technological innovation, supply chain security, talent cultivation and market application to strengthen key technological breakthroughs. Optimized evaluation mechanisms guide chain-leading enterprises to shift to ecological construction and full-stack independent innovation. Rational institutional arrangements balance openness and industrial security, transforming phased progress into long-term independent capabilities for high-level localization of IC equipment.

5. Conclusions

The interconnection of main chains, auxiliary chains' empowerment, and chain-leading enterprises' synergy are key drivers for China's domestic integrated circuit manufacturing equipment. The proposed multi-chain integration framework resolves traditional R&D obstacles: fragmented research, transformation gaps and supply-demand misalignment. Guided by chain-leading enterprises in technology roadmap, resource allocation and ecological organization, a coupled system covering R&D, engineering verification and industrial implementation is built. This collaborative network accelerates innovation verification, promotes component iteration, and matches capital, policies, and market demand, significantly improving domestic equipment's R&D and industrialization efficiency and driving key fields from usable to reliable and stable.

Overall, China's multi-chain integration for such equipment is still growing. High-end equipment still relies on imports for core components and technologies, with weak industrial chain risk resistance. Domestic equipment lacks market recognition; some enterprises need to improve capabilities in batch verification, process adaptation and maintenance. Policy support also needs optimization in sustainability and cross-regional coordination, putting higher demands on chain-led development.

In the future, we need to refine the multi-chain integration evaluation system, deepen differentiated research, and strengthen international experience learning. This will promote chain-leading enterprises to shift from project-based joint research to ecological construction, advancing from single-link domestic substitution to full-stack independent innovation.

Acknowledgements

This research is supported by Shanghai High level Institution Construction and Operation Plan Soft Science Research Project (No. 25692116600)

References

[1] Ma Y. Fu, W. (2025). Demand analysis and effectiveness evaluation of digital twin system for semiconductor equipment operation and maintenance. Industrial Engineering and Innovation Management, 2025, 8(2), 112-119.
[2] Yu A ,Yu S. (2025). Effective Availability in Global Semiconductor Trade: Assessing U.S. Supply Chain Risks and Policy Response. Modern Economy, 16(11), 1763-1784.
[3] Fu, W., Chien, C.F., & Chen, C.H. (2023). Advanced quality control for probe precision forming to empower virtual vertical integration for semiconductor manufacturing. Computers & Industrial Engineering, 183, 109461.
[4] Li, Y., & Zhou, B. (2024). The spatial-temporal evolution characteristics and influencing factors of the coupling between the industrial chain and innovation chain in China. Sustainable Futures, 8, 100366.
[5] Liu, Q., Xue, D., & Li, W. (2024). A sustainable production segment of global value chain view on semiconductors in China: Temporal and spatial evolution and investment network. Sustainability, 16(19), 8617.
[6] Hu, J., Xie, X. L., Wang, L., & Yao, D. F. (2026). Leading the Chain, Lifting the Output: The Chain Leader System Policy and Supply Chain Participants' Productivity. International Journal of Finance & Economics, 1-21.
[7] Xu, Y., Hunjra, A. I., Mishra, T., & Zhao, S. (2025). Carbon neutrality and synergy between industrial and innovation chains: Green finance perspective. International Journal of Production Research, 63(22), 8295-8319.
[8] Macher, J. T., Mowery, D. C., & Simcoe, T. S. (2002). E-Business and disintegration of the semiconductor industry value chain. Industry and Innovation, 9(3), 155-181.
[9] Hu, X., & Zhang, L. (2023). Research on the integration level measurement and optimization path of industrial chain, innovation chain and service chain. Journal of Innovation & Knowledge, 8(3), 100368.
[10] Zhang, Y., Chen, Y., Yang, L., & Ji, Y. (2026). Evaluation of technological innovation efficiency in the integration of innovation, capital, talent, and industry chains in patent-intensive industries. Managerial and Decision Economics, 1-18.
[11] Wang, H. J., & Zhao, H. Y. (2026). Exploring configurations of industrial internet platforms' empowerment for the integration of industrial and innovation chains: An fsQCA approach. Journal of Innovation & Knowledge, 14, 100962.
[12] Song, H. S., Ding, D. E., & Zhou, J. J. (2025). Escaping the GVC trap: How does global value chain (GVC) participation impact the integration of the industrial and innovation chains? Finance Research Letters, 78, 107146.