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The Intrinsic Logic and Implementation Paths of Computing Infrastructure Driving the Integration of Digital and Real Economies

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Abstract: As a new type of infrastructure, computing infrastructure—comprising data centers, intelligent computing centers, and supercomputing centers—plays a pivotal role in driving the deep integration of the digital and real economies. This paper systematically investigates the intrinsic logic and mechanisms through which computing infrastructure promotes digital-real economy integration. It constructs a three-dimensional analytical framework encompassing technological empowerment, organizational response, and ecological synergy. The findings indicate that: (1) The technological empowerment mechanism lowers the threshold for real economy enterprises to adopt digital technologies and unlocks the value of data elements, enabling inclusive and intelligent access to computing power. (2) The organizational response mechanism optimizes resource allocation and improves corporate governance by easing financing constraints, curbing the tendency of enterprises to shift from real to virtual activities, and enhancing information transparency. (3) The ecological synergy mechanism, built upon an open-source innovation commons, facilitates cross-regional and cross-industry knowledge spillovers and expands innovation networks. Based on these theoretical insights, the paper proposes a collaborative governance framework of “government guidance, market drive, and social participation,” which includes optimizing the spatial layout of computing infrastructure, strengthening institutional linkages between universal computing access and open-source sharing, and implementing differentiated industrial and regional policies. This study provides theoretical support and policy references for advancing digital-real economy integration and cultivating new quality productive forces.

Keywords: computing infrastructure; digital-real economy integration; technological empowerment; ecological synergy

1. Introduction

The real economy is the foundation of a nation's economy and serves as the "ballast stone" for stable economic operation. Concurrently, the rise of the digital economy is profoundly reshaping the global economic landscape, becoming a key force in reallocating production factors and restructuring industrial structures. Deepening the integration of the real and digital economies is not only a strategic choice for seizing new opportunities presented by the latest round of technological revolution and industrial transformation but also an intrinsic requirement for developing new quality productive forces and promoting high-quality development . However, advancing this integration faces a fundamental challenge: how to effectively unleash the value of data elements and embed digital technologies into every link of the real economy. Data elements possess economic attributes such as non-rivalry, increasing returns to scale, and positive externalities, but their value realization is highly dependent on robust computing, transmission, and storage capabilities. In this context, the importance of computing infrastructure becomes increasingly evident. As a new type of infrastructure centered around data centers, intelligent computing centers, and supercomputing centers, it integrates information computing power, network carrying capacity, and data storage capacity, gradually becoming the key foundation for overcoming the "last mile" bottleneck of digital-real economy integration.

In recent years, China has continuously strengthened its strategic deployment of computing infrastructure. In 2023, the Ministry of Industry and Information Technology, along with five other departments, jointly issued the "Action Plan for High-Quality Development of Computing Infrastructure," explicitly stating the goal to "promote the high-quality development of computing infrastructure and fully leverage its driving role in the digital economy." In 2026, the "15th Five-Year Plan" further emphasized "fully implementing the 'AI+' action," "strengthening computing facility support," and "promoting deep integration of the real and digital economies." Meanwhile, the "East Data, West Computing" project has been fully launched, with eight national computing hub nodes and ten data center clusters successively established, accelerating the formation of a national integrated computing network. Behind these policy deployments lies a core theoretical question that urgently needs answering: Through what mechanisms and under what conditions can computing infrastructure effectively promote the integration of the real and digital economies?

Theoretically, the core of digital-real economy integration lies in the technical synergy and complementarity between real industries and digital industries, ultimately leading to the formation of common technologies through boundary fusion . This process requires both the proactive introduction of digital technologies by real industries to transform traditional production functions and the validation and iterative upgrading of digital industry achievements in real-world scenarios. Computing infrastructure plays a dual empowerment role in this regard: on the one hand, it provides affordable, low-cost high-performance computing resources to real enterprises, lowering the technical barriers and financial pressures of digital transformation; on the other hand, by building an open and shared computing network and an open-source innovation ecosystem, it attracts digital technology developers, research institutions, and industry chain participants to collaborate, creating a virtuous cycle of knowledge spillover and technology diffusion. Therefore, computing infrastructure is not merely a physical carrier of computing power but also an innovative public good embedded with institutional design and governance rules.

Based on this, this paper focuses on the research question of how computing infrastructure promotes the integration of the real and digital economies. It attempts to construct a three-dimensional analytical framework encompassing technological empowerment, organizational response, and ecological synergy. It systematically explains the theoretical logic and empirical evidence through which computing infrastructure promotes deep integration by unleashing the information and knowledge value of data elements, driving data element marketization and distributed innovation, and optimizing corporate governance and industrial coordination. The conclusions will provide theoretical support and policy references for optimizing China's computing infrastructure layout, building a national integrated computing network, and accelerating the cultivation of new quality productive forces.

2. Literature Review

Research on computing infrastructure construction mainly unfolds across three dimensions: micro-level enterprise effects, industrial technology integration and innovation network evolution, and green transformation and competitive advantage reshaping.

2.1.Micro-level Enterprise Effects of Computing Infrastructure: Productivity, Digital Transformation, and Technological Innovation

A substantial body of empirical research confirms that computing infrastructure construction can generate significant productivity-enhancing and technology-empowering effects at the micro-enterprise level. Studies have found that the commissioning of national supercomputing centers significantly boosts corporate total factor productivity, an effect closely related to the level of enterprise intelligence. The underlying mechanisms primarily involve promoting cooperative innovation and adjusting the skill structure of the corporate workforce (Min etal. , 2026). Regarding digital transformation, improvements in regional computing infrastructure significantly drive corporate digital transformation. This effect manifests both as substantive transformation that enhances long-term corporate value through technological upgrades and as strategic transformation that improves information disclosure quality. The former is achieved through deepening R&D and citing digital patents, while the latter is driven by signaling and legitimacy pressures (Wu etal. , 2023). Furthermore, computing infrastructure construction significantly promotes corporate AI technology development by reducing management costs, easing financing constraints, and enhancing digital technology capabilities. This effect is particularly pronounced among small and medium-sized enterprises (SMEs), manufacturing firms, and technology-intensive industries (Zhao & Dong, 2025). Additionally, computing infrastructure can curb the "shifting from real to virtual" tendency of corporate funds by lowering the threshold for intelligent transformation and guiding firms towards digital asset investment. Simultaneously, by empowering fintech development and alleviating financial resource misallocation, it curbs corporate financialization motives. This governance effect is more pronounced in non-state-owned enterprises, firms in core digital industries, and regions with better data ecological environments (Jiang, 2025).

2.2.Computing Infrastructure Driving Technology Integration between Real and Digital Industries and the Evolution of Innovation Networks

The core of digital-real economy integration lies in the deep penetration and synergistic complementarity between real industries and digital industries at the technological level. Research indicates that computing infrastructure significantly promotes technology integration between real and digital industries. The intrinsic mechanisms can be explained from two dimensions: "unleashing information value" and "extracting knowledge value." On one hand, computing infrastructure, through the marketization of data elements, expands the scope of information search, improves the quality of information matching, and accelerates the release of the information value of data elements. On the other hand, through distributed innovation, it breaks traditional linear innovation models, forming decentralized, highly interactive collaborative innovation networks that facilitate the transfer and integration of tacit and explicit knowledge among different actors (Shi etal. , 2020). These effects are more pronounced in key supported industries, regions with strong intellectual property protection, and areas with a strong willingness to invest in digitalization. At the level of industrial innovation networks, research using the construction of supercomputing centers as a quasi-natural experiment finds that computing infrastructure significantly enhances the linkage strength of a city's future industrial innovation network. The transmission mechanisms include knowledge innovation linkages, innovation factor absorption, and innovation boundary expansion (Li & Xu, 2025). Notably, computing infrastructure mainly strengthens a city's external innovation network connections, while its effect on collaboration among internal innovation actors is limited. This suggests that its innovation network restructuring function is more prominent in breaking through administrative boundaries to establish external connections. Furthermore, some studies propose the concept of an "open-source innovation commons," arguing that only when computing power is supplied as a public good and innovation results are openly shared and fed back into the community platform through open-source rules can computing infrastructure transform from a general public facility into a key hub supporting continuous innovation. The formation of this commons relies on the coupling of three elements: an "intelligent full-stack technology base," "hybrid governance rules," and the "public value of open-source innovation" (Huo etal., 2025).

2.3.Computing Infrastructure Reshaping Corporate Strategic Directions: Green Transformation and Digital Competitive Advantage

In the realm of green and low-carbon transformation, research focusing on listed high-energy-consuming companies finds that computing infrastructure significantly promotes corporate low-carbon transformation. The mechanisms include technological innovation and supervisory governance. Climate policy uncertainty positively moderates this relationship; that is, in environments with high climate policy uncertainty, firms face heightened environmental legitimacy pressures, making the empowering effect of computing infrastructure even more prominent (Liu etal., 2026). This finding suggests that computing infrastructure is not only an efficiency tool but also a strategic resource helping firms cope with external institutional pressures. Regarding digital competitive advantage, research shows that computing infrastructure construction significantly enhances firms' digital competitive advantage by improving operational efficiency and information transmission efficiency. This effect is more pronounced among firms with higher levels of internet adoption, those in non-core digital industries, and those in cities with higher levels of digital infrastructure (Hu etal., 2025). Moreover, in the context of strategic competition between major powers, computing infrastructure construction can promote breakthroughs in key core technologies by curbing corporate financialization tendencies, easing financing constraints, and improving R&D efficiency. This positive effect is stronger in industries affected by tariff shocks, cities designated as computing hub nodes, pilot cities for a new generation of AI development, and firms with strong technological grasp (Yong, 2013).

Existing literature has verified the positive value of computing infrastructure from multiple dimensions, including improvements in corporate productivity, promotion of digital transformation, empowerment of industrial technological innovation, and support for green development. However, regarding the core issue of "how computing infrastructure actually drives digital-real economy integration," current research still has a theoretical gap concerning the exploration of underlying mechanisms, which constitutes the starting point for this paper.

3.Theoretical Mechanisms and Paths for Computing Infrastructure to Promote Digital-Real Economy Integration3.1 Participants

3.1.Technological Empowerment Mechanism: Lowering Transformation Barriers and Unleashing Data Value

The first mechanism by which computing infrastructure promotes digital-real economy integration is technological empowerment, i.e., directly lowering the thresholds and costs for real enterprises to apply digital technologies by providing affordable, efficient, and scalable computing resources. Specifically, computing infrastructure plays a technological empowerment role in the following three aspects. First, the infrastructuralization of computing supply breaks the constraints of enterprise resource endowments. Traditionally, high-performance computing resources are expensive and complex to maintain, affordable only to a few large enterprises or tech companies. Through centralized deployment, large-scale operation, and elastic scheduling, computing infrastructure achieves the "pooling" and "servicification" of computing resources, enabling SMEs to access previously unattainable computing power on a pay-as-you-go basis (Kulshreshtha, 2018). This "universal access to computing" directly alleviates the high upfront investment risk faced by real enterprises in the early stages of digital transformation, encouraging them to experiment with cutting-edge technologies like AI, big data analytics, and digital twins.

Second, computing infrastructure accelerates the value realization process of data elements. Data itself is valueless raw records; only after cleaning, integration, analysis, and mining can it be transformed into valuable information and knowledge. Leveraging its powerful storage capacity and computing speed, computing infrastructure can efficiently process massive volumes of heterogeneous data, converting fragmented data into structured, standardized information products (Sarker etal., 2025). This process not only improves the utilization efficiency of internal corporate data assets but also facilitates the flow and sharing of data across the industrial chain, providing high-quality data fuel for technology integration between real and digital industries.

Third, the synergistic development of computing infrastructure, algorithms, and models fosters an intelligent application ecosystem. Computing power is not just "processing ability"; it is the "engine" for algorithm training and model iteration. With the proliferation of intelligent computing centers and supercomputing centers, the training time for large-scale deep learning models has shrunk from months to days or even hours. This enables real enterprises to obtain customized AI solutions at lower costs (Sharir etal., 2025). For example, manufacturing firms can use public computing platforms to train product quality inspection models, and agricultural firms can develop crop pest recognition algorithms. This synergistic empowerment of "computing + algorithms + data" allows digital technologies to truly embed into the core business operations of the real economy, rather than remaining on the periphery of management informatization.

3.2.Organizational Response Mechanism: Optimizing Resource Allocation and Improving Governance Structures

The promoting effect of computing infrastructure on digital-real economy integration is not only reflected at the technological level but also profoundly impacts the organizational behavior and governance structures of real enterprises. Computing infrastructure reshapes corporate resource allocation logic and strategic decision-making preferences by easing financing constraints, curbing financialization tendencies, and improving information transparency.

First, computing infrastructure significantly eases financing constraints for real enterprises. Information asymmetry is the fundamental reason for the difficulty and high cost of financing for SMEs. Computing infrastructure supports financial institutions in building more accurate corporate credit evaluation models, reducing information friction between banks and firms. Simultaneously, innovative models like supply chain finance and data asset pledge, supported by computing power, expand the boundaries of eligible collateral, making a company's data and technology flows new bases for financing. Easing financing constraints directly increases the long-term capital available for corporate digital transformation and R&D innovation, thereby accelerating the process of digital-real economy integration.

Second, computing infrastructure effectively curbs the "shifting from real to virtual" tendency of real enterprises. For a long time, real enterprises, facing declining profit margins in their main businesses, have allocated substantial funds to financial assets, crowding out real investment. Research finds that computing infrastructure construction, by improving the total factor productivity of main businesses, fundamentally changes the relative returns of financial assets versus industrial investment, thereby inhibiting corporate financialization motives. Specifically, computing-empowered smart manufacturing, flexible production, and precision marketing significantly enhance the profitability and market competitiveness of real enterprises, causing them to refocus on core technology R&D and production process optimization rather than chasing short-term financial gains. This "main business revitalization" effect is the micro-foundation for the sustained deepening of digital-real economy integration.

Third, computing infrastructure improves internal control quality and information transparency for enterprises. According to legitimacy theory, the negative externalities of corporate carbon emissions and digital transformation subject them to strict supervision by the government, investors, and the public. Computing infrastructure provides technical means such as real-time data collection, intelligent monitoring, and blockchain-based notarization, enhancing the traceability and auditability of corporate production and operation activities (Mahendran et al., 2025). This not only helps alleviate principal-agent problems like managerial myopia but also enables firms to more effectively communicate the genuine progress of their digital transformation in capital markets, thereby attracting more long-term investors and strategic partners.

3.3.Ecological Synergy Mechanism: Building an Open-Source Innovation Commons and Expanding Industrial Networks

The highest state of digital-real economy integration is not the digitalization of individual enterprises but the systemic restructuring of the entire industrial ecosystem. Computing infrastructure plays an irreplaceable hub role in promoting ecological synergy, with its core function being to facilitate the formation and evolution of an "open-source innovation commons." Computing infrastructure accelerates cross-regional, cross-industry technology diffusion through knowledge innovation linkages. Empirical research based on supercomputing centers shows that computing infrastructure significantly increases the level of inter-city research collaboration and the number of joint patent applications. Its mechanism lies in reducing the marginal cost of knowledge search and integration, enhancing the effectiveness of long-distance knowledge collaboration (Yang et al., 2024). These knowledge innovation linkages break the traditional constraint of geographical proximity for industrial innovation, enabling western regions or cities lacking innovation resources to access the collaborative innovation network led by computing hub nodes, thus narrowing regional gaps in digital-real economy integration.

Computing infrastructure fosters the agglomeration of talent and capital through the absorption of innovation factors. The construction and operation of computing infrastructure themselves create numerous high-skilled jobs, attracting new types of talent such as data scientists, algorithm engineers, and AI trainers to flow towards computing hub cities (Yang et al., 2024). Concurrently, the public platform nature of computing infrastructure lowers the entrepreneurial barriers for startups and individual developers, fostering a small-scale innovation ecosystem around computing platforms. This coordinated agglomeration of "talent-capital-technology" provides a continuous source of innovative energy for digital-real economy integration.

Furthermore, computing infrastructure achieves a value cycle of "use → contribute back → reuse" through open-source rules. Unlike traditional public infrastructure, computing infrastructure is not merely a one-way supplier of resources. Using open-source large models, open-source algorithm libraries, and open-source datasets as carriers, users of computing infrastructure are also contributors to innovation outcomes. When a firm uses public computing power to train an industry-specific model and open-sources it, other firms can conduct secondary development based on it, creating a multiplier effect for technological iteration. This institutional design of "universal access to computing + open-source sharing" transforms computing infrastructure from a "consumable public resource" into a "self-reinforcing innovation hub," which is a fundamental feature distinguishing it from traditional infrastructure like electricity or transportation.

4.Policy Implications: Building a Collaborative Governance System of "Government Guidance - Market Drive - Social Participation"

Based on the theoretical analysis above, this paper proposes the following policy recommendations for promoting digital-real economy integration driven by computing infrastructure.

First, optimize the spatial layout and supply model of computing infrastructure. Continue advancing the "East Data, West Computing" project, deploying large and ultra-large data center clusters in western regions to leverage their climatic and energy advantages for lower computing costs, while deploying edge computing nodes in eastern regions to meet low-latency application needs like industrial internet and autonomous driving. Simultaneously, establish a unified national computing scheduling platform and trading mechanism to enable efficient cross-regional, cross-entity allocation of computing resources.

Second, strengthen the institutional linkage between "universal access to computing" and "open-source sharing." The government can issue "computing vouchers" or establish open-source contribution reward funds to incentivize firms and developers to contribute their innovation outcomes back to the community in open-source form after using public computing power. Concurrently, establish a sound open-source licensing system, data security and privacy protection rules, and dispute resolution mechanisms for intellectual property to provide legal guarantees for the healthy development of the open-source innovation commons.

Third, implement differentiated industry and regional policies. For manufacturing, technology-intensive industries, and SMEs, priority should be given to providing computing subsidies and technical consulting services to help them overcome the "first hurdle" of digital transformation. For central and western regions and areas with high information costs, investment in computing infrastructure should be increased, and paired east-west cooperation mechanisms should be used to transfer computing application experiences and mature models from the eastern region to the west.

Competing Interests Statement

The authors declare that they have no financial or personal relationships that may have inappropriately influenced them in writing this article.

Data Availability Statement

The authors confirm that the data supporting the findings of this study are available within the article.

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