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Research on the Mechanism and Countermeasures for the Digital Economy in Enhancing the Resilience of the Digital-Intelligent Health Industry Chain

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Abstract: *This study investigates how the digital economy enhances the resilience of the digital-intelligent health industry chain in coping with external shocks and internal vulnerabilities. The paper begins by defining the resilience of the digital-intelligent health industry chain, emphasizing that it represents a novel capability in the digital era—one that relies on data and intelligent decision-making, shifts from hard redundancy to soft resilience, and transitions from linear recovery to networked ecological adaptation. Regarding the core mechanism, the digital economy enhances the resistance of the industry chain by strengthening the data foundation and enabling intelligent early warning, improves its recovery capacity through optimized resource allocation and network collaboration, and strengthens its ability for transformation and upgrading by empowering intelligent decision-making and innovation in business models. The study also points out that current practical challenges, such as data flow barriers, technological dependency, fragmented ecosystems, lagging regulations, and security risks, constrain the enhancement of resilience. Finally, targeted countermeasures and recommendations are proposed, including establishing unified data standards, making breakthroughs in core technologies and promoting inclusive adoption, building an open and collaborative industrial ecosystem, and innovating regulatory and security frameworks. These suggestions aim to provide a reference for safeguarding national public health security and promoting the sustainable development of the industry.*

Keywords: *Industrial Chain Resilience, Digital Economy, Digital-Intelligent Health, Data as a Factor of Production, Collaborative Governance*

1. Instruction

National strategic development policies, such as the Outline of the Healthy China 2030 Plan and the 14th Five-Year Plan for the Development of the Medical Equipment Industry, have established digital and intelligent transformation as a key pathway for building a modern health system and identified enhancing industrial chain resilience as a critical objective. Strengthening the resilience of the digital-intelligent health industry can effectively promote high-quality development in the health sector and improve its capacity to cope with external shocks and internal pressures. As a product of the deep integration of new-generation information technologies and the healthcare sector, digital-intelligent health is typically defined as a new industrial form that uses data as a key driving factor, is supported by digital technologies such as artificial intelligence, the Internet of Things, and cloud computing, and systematically reshapes the entire health industry chain. However, during its development, China's digital-intelligent health industrial chain faces significant vulnerability challenges. At present, the overall level of resilience and security in China's pharmaceutical industrial chain remains relatively low, with weak international competitiveness and insufficient control over the value chain[1]. This issue is particularly evident during public health emergencies, such as the COVID-19 pandemic. The pandemic not only disrupted global logistics but also exposed the high external dependency of upstream critical raw materials and core components for high-end medical equipment, creating risks of supply chain disruption[2]. Furthermore, long-standing issues such as inconsistent data standards and lack of interoperability among systems across the industrial chain have resulted in severe "information silos," leading to inefficient resource allocation and coordination during emergencies. Therefore, effectively enhancing the resilience of the digital-intelligent health industrial chain has become an urgent task for safeguarding national public health security and promoting sustainable industrial development. The

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rapid development of the digital economy offers a new perspective for addressing this challenge. The digital economy can strengthen the data foundation of the digital-intelligent health industrial chain by facilitating the flow of data elements, optimizing resource allocation, and improving coordination efficiency. Moreover, through digital information systems and intelligent decision-making mechanisms, it can enhance the transparency, flexibility, and risk resistance of the industrial chain. In response to the vulnerabilities exposed by the digital-intelligent health industrial chain in complex environments, it is of great practical significance to deeply investigate the mechanisms through which the digital economy enhances its resilience and, based on this, construct an effective policy support system.

2. The Connotation and Characteristics of Resilience in the Digital-Intelligent Health Industrial Chain

2.1 Connotation of Digital-Intelligent Health Industrial Chain Resilience

The academic community generally views industrial chain resilience as the comprehensive ability of a system to resist, recover, and transform when subjected to shocks. Xu Yiliang et al. (2024) pointed out that the essence of industrial chain and supply chain resilience is a tripartite set of capabilities that a system exhibits when facing internal and external environmental disturbances: resistance (maintaining operation), recovery (rapid restoration), and transformation (optimization and upgrading). Its core objective is to achieve a dynamic balance of "stabilizing the chain," "supplementing the chain," and "strengthening the chain." In the context of the digital economy, this concept has been further deepened [3]. Li Yumei et al. (2024) emphasized that the digital economy, by consolidating the digital foundation and strengthening the allocation of data as a factor of production, significantly enhances the transparency and reconfiguration efficiency of the industrial chain, shifting resilience from passive physical redundancy reserves to proactive data-driven adaptation[4]. Focusing on the healthcare sector, the research of Wang Junyao et al. (2024) further defined that the resilience of the pharmaceutical and healthcare supply chain refers to the ability to maintain the stable supply and rapid adaptation of pharmaceutical products when facing risks such as raw material shortages and sudden demand changes, and that digital technology is a key enabling tool for achieving this goal[5].

The resilience of the digital-intelligent health industrial chain is not a simple transplantation of traditional concepts, but rather a new form of capability in the digital era. Integrating existing literature and industrial practice, this paper defines it as: within the digital-intelligent health industrial ecosystem, supported by data as a key factor of production and new-generation information technologies such as artificial intelligence and the Internet of Things, the comprehensive ability of each node and the overall network of the industrial chain to maintain the continuity, stability, and security of the supply of core medical products and services, and to achieve system recovery or even functional optimization and upgrading, when facing shocks such as public health crises, geopolitical fluctuations, or technological supply disruptions, through data-driven intelligent perception, dynamic assessment, and collaborative reconfiguration. The core of this definition lies in emphasizing the fundamental reshaping of the resilience logic by "digitization and intellectualization" — shifting from reliance on physical inventory (hard redundancy) to reliance on data flows and algorithmic decision-making (soft resilience), and from linear chain recovery to networked ecological self-adaptation.

2.2 Main Characteristics of Digital-Intelligent Health Industrial Chain Resilience

The resilience of the digital-intelligent health industrial chain has manifested a form fundamentally distinct from the past, with its core shift being from static response to dynamic adaptation. This resilience is built upon the real-time flow and intelligent analysis of data. Through technologies such as the Internet of Things and artificial intelligence, the industrial chain can anticipate and manage risks in unprecedented ways. The system continuously aggregates diverse data from drug R&D, manufacturing, and clinical application, employing algorithmic models to identify potential demand fluctuations or supply bottlenecks weeks in advance. This enables managers to proactively adjust production plans and optimize logistics and inventory strategies, establishing effective buffers before disruptions occur, thereby significantly enhancing proactive adaptive capacity in the face of uncertainty.

The resilience of the digital-intelligent health industry is deeply rooted in a networked, collaborative, and elastic structure. It no longer relies solely on the strength of a single leading enterprise but has evolved into an ecosystem where multiple stakeholders—hospitals, pharmaceutical companies, logistics providers, and regulators—are tightly interconnected and flexibly responsive.

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Through shared data platforms and standardized interfaces, these parties, while ensuring security and compliance, can achieve interoperability of critical information and efficient operational synergy. When confronting major challenges like public health emergencies, this network structure enables cross-institutional and cross-regional sharing of production capacity, emergency logistics coordination, and mutual recognition of standards, thereby allowing for the rapid pooling of resources to address the crisis. Simultaneously, establishing a diversified, distributed, and qualified source system for critical raw materials and core components forms a strategic, resilient backup, effectively preventing systemic disruptions triggered by the failure of a single node and strengthening the industry's ability to survive and recover amidst volatility.

Ultimately, this resilience is embodied in the pursuit of end-to-end transparency, controllability, and the balancing of multiple objectives. Leveraging technologies like IoT sensing and blockchain for trust, the industrial chain achieves full traceability from source to end-user and real-time visibility of status, significantly improving the precision of quality and safety control and the efficiency of emergency response. Crucially, given its high dependence on data and network interconnectivity, resilience building must be deeply integrated and advanced in parallel with cybersecurity, data privacy protection, and operational efficiency improvements. This necessitates that the system embeds robust security defenses and rapid fault recovery capabilities, while continuously optimizing processes and reducing costs through intelligent tools. Therefore, the resilience demonstrated by the digital-intelligent health industrial chain is a more robust, more sustainable, and continuously evolving comprehensive competitiveness. It is forged upon a solid foundation of ensuring business continuity, reliability, and data security/compliance, leveraging digital and intelligent means to perpetually enhance overall operational effectiveness.

3. Mechanism of Digital Economy in Enhancing the Resilience of the Digital-Intelligent Health Industrial Chain

3.1 Mechanisms of the Digital Economy in Enhancing the Resilience of the Digital-Intelligent Health Industry Chain

The development of the digital economy effectively enhances the resistance of the digital-intelligent health industry chain to shocks by strengthening the data foundation and building an intelligent early warning system. Its core lies in the shift from passive response to active prevention. Based on technologies such as the Internet of Things and medical information systems, the digital economy enables real-time dynamic collection of data from the entire process of the industry chain—"R&D, production, supply, sales, application, and management"—breaking the traditional "information silo" phenomenon. Utilizing these integrated multi-source data, combined with artificial intelligence and big data analytics models, a high-precision risk identification and prediction system for the industry chain can be established. For instance, by analyzing regional disease surveillance data and drug inventory consumption data, potential shortages of specific drugs can be predicted in advance. This enables industry chain managers to gain early insights into potential risks and, before the impact escalates, establish effective defense measures by adjusting production plans, mobilizing strategic inventories, and activating alternative suppliers. Research shows that digital transformation, by improving risk prediction capabilities, can significantly enhance the robustness of the industry chain, thereby strengthening its "immunity" and maintaining the stability of its essential functions [6].

3.2 Mechanisms of the Digital Economy in Enhancing the Recovery Capacity of the Digital-Intelligent Health Industry Chain

The digital economy significantly enhances the recovery capacity of the industrial chain after a shock occurs and accelerates the process of functional restoration by optimizing resource allocation and promoting networked collaboration. In the face of shocks such as public health emergencies or supply chain disruptions, the interconnected industrial internet platforms, supply chain collaboration platforms, and medical data exchange platforms built by the digital economy can effectively break down the "information silos" among medical institutions, pharmaceutical companies, logistics providers, and regulatory authorities, achieving global resource visibility. When local supply is disrupted, real-time platform data can be used to quickly identify resource gaps and bottleneck links. Intelligent algorithms can then be employed to dynamically allocate redundant production capacity, inventory, and transportation resources across the entire network, or activate alternative logistics channels. This transforms the originally scattered, isolated recovery efforts into a systematic, networked, and

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collaborative response. For example, in emergency situations, a platform can efficiently coordinate multiple enterprises for the collaborative production of scarce drugs or organize multi-party logistics for relay transportation, significantly shortening the recovery cycle. Relevant research indicates that the digital economy reduces communication, coordination, and logistics costs, serving as a key pathway to improving supply chain recovery efficiency [7].

3.3 Mechanisms of the Digital Economy in Strengthening the Transformation and Upgrading Capacity of the Digital-Intelligent Health Industry Chain

The digital economy not only helps the industrial chain withstand shocks and recover quickly but also fundamentally strengthens its capacity for transformation and upgrading—its "evolutionary capability"—by empowering intelligent decision-making and driving model innovation. This pushes the industrial chain to achieve structural optimization and value leaps after experiencing disruptions. Deep-seated problems exposed during shocks are clearly quantified and revealed at the data level, providing a basis for precise improvement. Based on this, industrial chain participants can leverage clinical real-world data and other sources to drive more targeted R&D or promote iterative upgrades of key technologies and products through performance analysis. At the same time, the digital economy itself fosters entirely new industrial forms and value growth points, such as big data-driven precision medicine, AI-assisted diagnosis and treatment, internet hospitals, and intelligent chronic disease management platforms. These new models not only improve the accessibility and efficiency of services but also build a more resilient industrial ecosystem. Ultimately, with the support of technologies like blockchain and smart contracts, more trustworthy data sharing and value distribution mechanisms can be established, driving the industrial chain toward transformation and upgrading in the directions of standardization, integration, intelligence, and personalization. This helps build a stronger core competitiveness oriented toward the future.

4. Practical Challenges in Building Resilience for the Digital-Intelligent Health Industry Chain

4.1 Data Element Circulation Barriers Constrain Coordinated Recovery Capacity

From the perspective of industrial chain resilience, the efficient circulation of data serves as the neural network for building coordinated recovery capacity across the entire "R&D–Production–Supply–Application" chain. However, the current digital-intelligent health industry faces a severe "data silo" predicament, which directly weakens the system's response speed and resource reallocation capabilities in the face of shocks. On the one hand, inconsistent data standards and fragmented systems hinder the establishment of a real-time, chain-wide data view. This makes it difficult to quickly aggregate and gain a holistic awareness of critical information—such as drug inventories and equipment distribution—during public health emergencies, resulting in delayed early warning capabilities. This, in essence, reflects a deficiency in the digital foundation necessary for the industry chain's resistance. On the other hand, under strict regulatory frameworks, mechanisms for data rights confirmation, benefit sharing, and security compliance remain underdeveloped, leading stakeholders to hesitate or refuse to share data. Such circulation barriers directly translate into impediments to coordinated recovery during emergencies, delaying optimal response times and severely impairing the industry chain's ability to swiftly contain losses and recover from disruptions [8].

4.2 High Reliance on Foreign Technology Weakens Independent Resistance Capabilities

The foundational support for industrial chain resilience lies in technological self-reliance, controllability, and effective transformation. However, current challenges, such as the evident risks of "being choked" and application gaps, constrain the fundamental risk resistance capacity. In terms of core technologies, the dependence on imported core components for high-end medical equipment and key industrial software constitutes inherent vulnerabilities in the supply chain. In the event of geopolitical volatility or global crises, this dependency can easily escalate into supply chain disruption risks, rendering the process optimization enabled by digital technologies ineffective in the face of underlying supply interruptions. This directly reflects a deficiency in the resistance capacity of the industrial chain. Moreover, the weakness in grassroots digital infrastructure and the shortage of talent result in a lack of accessibility to advanced early warning and response services. This imbalanced level of digitalization creates vulnerable areas within the resilience network of the industrial chain. When facing localized shocks, the failure of these weak links may trigger systemic risks, thereby weakening

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the overall robustness of the industrial chain.

4.3 Fragmented Ecosystem and Profitability Challenges Hinder Networked Restructuring Capacity

The high-level manifestation of resilience is the restructuring capacity of an industrial chain to evolve toward a superior structure after suffering a shock, which relies on a closely collaborative industrial ecosystem. However, the current fragmented state of the ecosystem severely constrains this capacity. First, there is a lack of cross-entity coordination mechanisms. Hospitals, pharmaceutical companies, platforms, and other nodes lack efficient data interfaces and operational linkage rules. During a crisis, decentralized resources such as production capacity and inventories cannot be rapidly reorganized into an efficient service network. This results in the failure to form a combined force in responding to shocks, exposing a shortfall in rapid self-organization and resource reallocation capabilities. Second, the underlying cause lies in the absence of a sustainable business model. New services that enhance resilience, such as internet-based healthcare and health management, have yet to fully establish a clear value creation and return mechanism, and their coverage under medical insurance payment systems remains limited. This lack of a mature model deprives market entities of the internal economic incentive to continuously invest in resilience capacity building, thereby stifling the motivation for the entire industrial chain to evolve toward a more elastic form in the long term.

4.4 Regulatory Lag and Security Risks Amplify Systemic Vulnerabilities

A resilient industrial chain requires a stable and predictable institutional environment as a protective bulwark. However, the current lack of regulatory adaptability, coupled with security risks, not only fails to provide protection but may instead amplify systemic vulnerabilities. On the one hand, lagging regulatory rules create compliance uncertainty. Gaps or conflicting regulations under multi-agency governance concerning AI diagnosis liability and data flow pathways result in ambiguous compliance boundaries. This uncertainty causes enterprises to act hesitantly in building collaborative platforms, potentially missing critical response windows during emergencies due to complex approval processes, reflecting how an institutionally fragile environment drags down resilience. On the other hand, escalating cybersecurity and data security risks pose a direct threat. Medical systems are high-value targets, yet primary-level institutions generally have weak security defenses. A single successful cyberattack could paralyze core business systems or cause large-scale data breaches. Such digital shocks can instantly cripple the operational continuity of the industrial chain and undermine its social trust foundation, highlighting the urgency of building digital security resilience[9].

5. Policy Suggestions for Enhancing the Resilience of the Digital-Health Industrial Chain through the Digital Economy

5.1 Unified Data Standards and Sharing Mechanisms

To break through the constraints that data barriers impose on the coordinated recovery capacity of the industrial chain, establishing a standardized and interoperable data governance system is an urgent priority. This system requires the development of medical and health data standards that cover the entire chain, including R&D, production, supply, clinical application, and regulation, unifying the definitions of core data elements, interface protocols, and exchange formats. Building on this foundation, and drawing on the concept of a trusted data space, national or regional-level medical data infrastructure platforms can be constructed. Utilizing technologies such as privacy-preserving computation, federated learning, and blockchain, these platforms can enable the secure flow of key business data under the principles of "usable but invisible, controllable, and measurable" while ensuring data security. Supporting institutional development is equally critical, requiring clear rules for defining data property rights and the exploration of establishing a market-oriented mechanism for the distribution of benefits from data as a factor of production.

5.2 Breakthroughs in Core Technologies and Promoting Inclusive Access

To enhance the autonomous resilience of the industrial chain, it is essential to implement a dual-track technology strategy that combines "upward breakthroughs" with "downward penetration." At the high-end technology breakthrough level, efforts should focus on tackling the "bottleneck" challenges in areas such as high-end medical imaging equipment and life support systems, particularly

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in core components like high-performance sensors, specialized chips, and core algorithms. Through mechanisms such as national major science and technology projects, the integration of industry-academia-research resources should be mobilized for concentrated efforts, aiming to achieve self-reliance and controllability in key technological domains. Simultaneously, it is imperative to address the application gap of digital health technologies at the grassroots level. This can be achieved through policy instruments such as special financial subsidies and government procurement of services, to support the informatization upgrade of primary healthcare institutions. The development of lightweight, smart health solutions tailored to grassroots needs should be encouraged, and digital skills training for primary healthcare personnel should be strengthened. This will ensure the practical implementation and application of digital service tools, such as intelligent early warning systems and remote consultations, at the grassroots level.

5.3 Fostering an Open and Collaborative Industrial Ecosystem

To address the fragmentation of the industrial ecosystem, the key lies in fostering an open and collaborative environment for industrial innovation. It is essential to support the establishment and operation of open industrial internet platforms led by industry-leading enterprises, authoritative industry associations, or third-party specialized institutions. Such platforms should be positioned as digital connectors of the industrial chain, reducing the system connection costs and business collaboration barriers among diverse stakeholders by providing standardized interfaces, collaborative tools, and common technical services. To address the challenges of the business model, it is necessary to deepen the reform of healthcare payment methods, exploring the inclusion of digital services such as internet follow-up consultations, telemedicine, and health management within the scope of medical insurance coverage. Concurrently, commercial health insurance companies should be encouraged to develop innovative products and explore new payment models, such as value-based payment and outcomes-based reimbursement. This combination of platform empowerment and market value-sharing mechanisms helps create a virtuous cycle of resource sharing and risk sharing within the ecosystem.

5.4 Innovating Regulatory Mechanisms and Security Systems

The adaptability of the regulatory framework and the robustness of the security system together constitute the institutional guarantee for industrial development. To address the regulatory challenges posed by rapid technological iteration, the regulatory paradigm must shift toward agile governance. For emerging fields such as AI-assisted diagnosis and digital therapeutics, a "regulatory sandbox" mechanism can be introduced, allowing innovators to test products within a defined safety space. Regulatory authorities can then dynamically optimize rules based on test data. While fostering innovation, the safety bottom line must be upheld: all institutions involved in medical and health data processing activities must fully implement the cybersecurity multi-level protection system. Given the unique nature of the healthcare sector, security protection guidelines covering the entire data lifecycle should be formulated, and regular cybersecurity incident emergency response drills should be organized. By establishing a governance framework that combines agile regulation with rigid security, a stable institutional environment for industrial chain development can be provided. The World Health Organization also emphasizes that building a governance structure that balances both security and interoperability is fundamental to the sustainable development of digital health.

6. Conclusion

This study explores how the digital economy enhances the resilience of the digital-intelligent health industry chain. The article points out that the resilience of the digital-intelligent health industry chain is a comprehensive capability that enables proactive early warning, rapid recovery, and optimization and upgrading, all driven by data. This resilience is primarily achieved through three dimensions: enhancing the identification of and resistance to risks through data collection and intelligent analysis, accelerating the recovery process by achieving efficient resource scheduling via digital platforms, and leveraging digital tools to drive business model innovation, thereby enabling the industrial chain to achieve structural optimization and value enhancement after experiencing shocks. The article also notes that the current process of enhancing resilience faces multiple challenges, including difficulties in data sharing, dependence on foreign core technologies, insufficient industrial collaboration, inadequate regulatory adaptability, and digital security risks. To systematically address these issues, the article suggests promoting the standardization of data and strengthening the innovation and widespread

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application of core technologies at the technical level; building a collaborative and open industrial platform and exploring sustainable business models at the ecosystem level; and establishing a more agile and secure regulatory and safeguard system at the governance level. Through coordinated advancement in technology, ecosystem, and governance, the foundation of industrial chain resilience can be effectively consolidated, thereby safeguarding public health security and promoting the high-quality and sustainable development of the digital-intelligent health industry.

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