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DIGITAL ECONOMY, CIRCULATION EFFICIENCY AND HIGH-QUALITY ECONOMIC DEVELOPMENT OF GUANGDONG, HONG KONG AND MACAO-ANALYSIS BASED ON SYSTEM DYNAMICS

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Abstract. Globalization and informatization have positioned the digital economy as a key driver of high-quality economic development. The Guangdong-Hong Kong-Macao Greater Bay Area, actively integrating into the global economy, exemplifies how digital economy advancements can bolster national economic growth. This study employs a system dynamics approach to examine critical elements of the digital economy, including digital infrastructure, data flow, technological innovation, policies, regulations, and talent cultivation. It explores how these factors optimize resource allocation, lower transaction costs, and enhance market responsiveness by improving circulation efficiency. Through system structure analysis, dynamic and resistance factors were identified, leading to the construction of causal diagrams and feedback loops to illustrate the relationship between system structure and behavior. Findings indicate that the digital economy significantly enhances high-quality economic development in the Greater Bay Area by streamlining circulation efficiency. The research offers valuable insights for policymakers and provides theoretical and practical guidance for advancing the digital economy in the Greater Bay Area and beyond.

1. Introduction

Amid globalization and the rapid evolution of information technology, the digital economy has emerged as a core driver of economic advancement. The Guangdong-Hong Kong-Macao Greater Bay Area is accelerating its integration into the global economic system.However, although existing studies have focused on the impact of digital economy on regional economic development, most of them tend to focus on a single factor or linear relationship, lacking a comprehensive analysis of the complex dynamics inside the digital economy system, especially in the multi-factor interaction analysis combined with the system dynamics method. This research gap limits our understanding of the deep mechanism and path of digital economy in regional economic transformation. Based on this, this study identifies and analyzes the key components of the digital economy and their interaction mechanisms through the system dynamics approach, and explores how the digital economy can promote the high-quality economic development of the Guangdong-Hong Kong-Macao Greater

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Bay Area by improving circulation efficiency.Specifically, the objectives of this study include identifying core components of the digital economy; Analyze how these components affect each other, and then affect the flow efficiency; Build a system dynamics model to simulate the dynamic effects of digital economy on circulation efficiency and regional economic quality; And evaluate the changes of system behavior under different policy scenarios to provide a basis for policy formulation.

This research focuses on the following key questions: First, what key components of the digital economy have a significant impact on improving circulation efficiency? Second, what interaction and feedback mechanisms exist between these components? Third, through what path and mechanism will the digital economy promote the high-quality economic development of the Greater Bay Area? Finally, what are the differences in the impact of digital economy on circulation efficiency and regional economic quality under different policy scenarios?

The system dynamics method is used to simulate the dynamic evolution process of various components of the digital economy and their interactions by constructing causal graphs and feedback loops. Through systematic literature review, key components are identified, system dynamics models are constructed to describe the relationship between various elements and the feedback mechanism, and dynamic behaviors of the system under different scenarios are simulated and analyzed to assess the impact of policies on the development of digital economy. Through the perspective of system dynamics, this study reveals the complex relationship between digital economy and circulation efficiency, and provides theoretical support and practical guidance for the development of digital economy in Greater Bay Area and other regions. The research results not only help policy makers to optimize policy design and improve the sustainability and high-quality development level of regional economy, but also provide a valuable reference for enterprises and scholars.

1.1. **Literature Review and Theoretical Basis.** The existing literature extensively explores the relationship between the digital economy and circulation efficiency from several perspectives:

1.2. **Impact of the Digital Economy on Circulation Efficiency.** Research consistently demonstrates that the digital economy enhances circulation efficiency by introducing innovative technologies and business models. For instance, e-commerce platforms streamline circulation by integrating supply chain information, optimizing inventory management, and improving logistics distribution [25]. In addition, the application of digital technology also promotes the intellectualization of the circulation industry and improves the data processing ability and decision-making efficiency in the circulation process [24]. Digital technologies such as big data and artificial intelligence further enhance data processing and decision-making capabilities, enabling logistics companies to optimize resource allocation, improve transportation and distribution efficiency, and reduce costs [14, 18]. Additionally, the integration of online and offline systems (e.g., O2O models) has improved consumer experiences while advancing circulation efficiency [6]. The digital economy also fosters technological and managerial innovation in the logistics sector, facilitating the transformation of business and operational models [9, 19].

1.3. **Circulation Efficiency and Regional Economic Development.** The integration of the digital economy with the circulation industry not only improves circulation efficiency but also drives industrial upgrading. Digital technology enables the circulation industry to better support manufacturing, extending the industrial chain and enhancing the value chain [1]. Additionally, innovation in the digital economy propels the circulation industry toward high-end and intelligent development [20].Improved circulation efficiency positively influences regional economic growth. As a critical link between production and consumption, higher circulation efficiency optimizes resource allocation, lowers transaction costs, and stimulates market vitality, thereby fostering high-quality regional economic development [10]. Furthermore, it narrows urban-rural development gaps and promotes regional economic integration [11].

1.4. **Digital Economy and Agricultural Product Circulation.** In the agricultural sector, the digital economy plays a pivotal role in improving circulation efficiency by enhancing information transparency, reducing transaction costs, and optimizing logistics [12]. Digital technologies address information asymmetries, promoting the healthy development of agricultural markets [13]. However, regional disparities exist; eastern regions benefit significantly from digital economy advancements, while central and western regions require enhanced digital infrastructure [15,22]. In order to make better use of the digital economy to promote the development of the logistics industry, it is suggested to strengthen the construction of digital infrastructure, enhance the digitalization level of the logistics industry [17]. Strengthening digital infrastructure and adopting region-specific strategies are essential to balance development and promote green logistics practices [21].

The existing literature primarily explores how digital technology enhances circulation efficiency by optimizing supply chains, improving logistics performance, and fostering the integration of online and offline systems. It highlights the positive role of the digital economy in driving circulation model innovation, enhancing consumer experiences, and promoting regional economic growth. Additionally, studies emphasize the impact of improved circulation efficiency on industrial structure upgrading, particularly in agricultural product distribution.Electronic word of mouth (EWOM), as an important means of information dissemination in the digital age, has a profound impact on consumer behavior and market dynamics. EWOM not only influences consumer behavior as a channel for information dissemination, but also influences corporate decision-making and policy making through feedback mechanisms, thus indirectly affecting circulation efficiency [3–5].

However, most studies concentrate on the positive impacts of the digital economy on circulation efficiency, with limited attention to potential challenges, such as the digital divide, data security, and privacy concerns. Furthermore,Existing research predominantly overlooks the specific applications and implementation challenges across different industries and enterprise scales.Questions regarding the effective integration of digital technology into traditional circulation systems and the development of policies and regulations to support this integration require further investigation. This study bridges these gaps by examining the practical applications of the digital economy in the circulation field. It explores how to balance technological

innovation with social responsibility and outlines strategies for achieving sustainable economic development through policy guidance and institutional innovation, fostering deeper integration of the digital economy with circulation industries.

2. Theoretical basis and framework construction

The digital economy encompasses economic activities underpinned by digital information and communication technologies, spanning all sectors where value is created, exchanged, and distributed through digital means. It involves the adoption of digital applications, technological advancements, and the growth of digital industries. Key indicators commonly used to evaluate the digital economy include:

Digital Infrastructure: Internet penetration rates, broadband access, and the adoption of digital technologies, such as e-commerce transaction volumes and mobile payment usage.

Workforce Metrics: Ratios of digital-skilled workers and the integration of digital tools in workforce operations.

Innovation and Research: Investments in R&D, patent applications related to digital technologies, and the development of policies supporting digital advancements.

Circulation efficiency, a critical concept in this context, refers to the speed and cost-effectiveness with which goods, services, and information flow through supply chains. It is commonly measured by input metrics (e.g., fixed assets, logistics workforce size, transportation infrastructure) and output metrics (e.g., goods movement and delivery performance).

To explore these dynamics, this study adopts two foundational theoretical perspectives:

Innovation-Driven Development Theory: This framework emphasizes innovation–spanning technological, business model, and management innovations–as the primary driver of economic growth. Innovations not only enhance the quality of products and services but also improve production efficiency and overall competitiveness.

Supply Chain Management and Logistics Theory: This perspective examines the comprehensive process through which products are delivered from raw material sources to end consumers. Effective supply chain management reduces costs, increases operational efficiency, and enhances responsiveness to shifting market demands.

By integrating these theories, the study constructs a comprehensive analytical framework to evaluate how the digital economy influences circulation efficiency and economic development. The theoretical framework is illustrated in Figure 1.

3. System dynamics analysis

3.1. **Subsystem Analysis.** The digital economy comprises several core components, including essential digital infrastructure such as Internet access, data centers, and cloud services. These elements support a variety of digital services and platforms, including e-commerce, online payment systems, and digital media. Additionally, advanced technologies like big data analysis, artificial intelligence (AI),

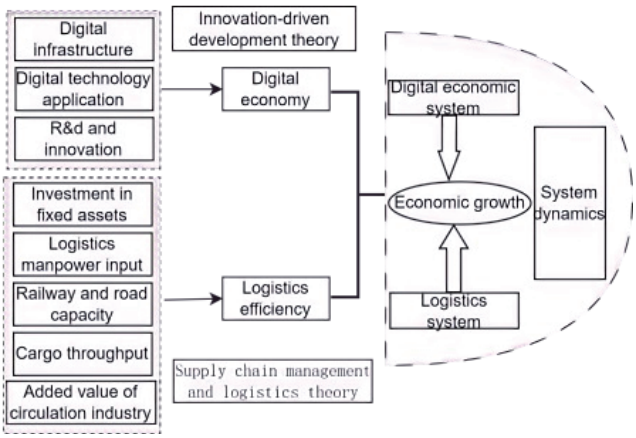

FIGURE 1. Theoretical framework (This figure was analyzed and organized by the author)

and the Internet of Things (IoT) underpin these services, driving technological innovation and enabling the creation of new business models and services [23]. By leveraging data collection, analysis, and application, these technologies enhance decision-making efficiency and market insight. Moreover, digital technologies are progressively transforming traditional industries, facilitating their digital evolution. However, the pace and direction of this transformation are influenced by factors such as technological advancements, policy and regulatory frameworks (e.g., data protection and cybersecurity), and the digital literacy and acceptance levels of users [16].

Logistics and supply chain systems form another critical pillar of economic activity. They consist of extensive supply chain networks involving suppliers, manufacturers, distributors, and other stakeholders, supported by logistics infrastructure such as warehousing, transportation, and distribution systems [8]. Information management tools, including supply chain management software and enterprise resource planning (ERP) systems, are vital to this network.

Continuous enhancements in logistics efficiency not only reduce costs and improve service quality but also enhance the supply chain's responsiveness to market changes. Simultaneously, the proliferation of automation and intelligent technologies is revolutionizing logistics and supply chain management. The interplay between these two systems–the digital economy and the logistics network–is both interdependent and mutually reinforcing in regions like Guangdong, Hong Kong, and Macao.

The digital economy accelerates the digitization and intelligence of logistics and supply chain management by employing advanced analysis for inventory optimization and logistics planning. In turn, the efficiency of logistics and supply chain systems directly influences the digital economy, particularly in improving service quality and user experiences in e-commerce.

3.2. **Dynamic and Resistance Analysis of the System.**

3.2.1. *Dynamic Factors in Large Systems.* In large systems, dynamic factors play a crucial role in driving growth and evolution. These factors, ranging from technological progress to policy support, influence the development and optimization of systems, such as the digital economy and logistics. As industries adapt to changing global landscapes, understanding these key dynamics becomes essential for harnessing their full potential. This section will explore the main drivers contributing to the transformation of large systems, with a focus on technological advancements, market demand, policy support, and globalization.

(1) Technological Progress:

In the digital economy, technological advancements, such as artificial intelligence, big data, and cloud computing, drive the emergence of innovative business models. These technologies enhance process intelligence and operational efficiency, enabling the creation of novel products and services. Similarly, in logistics and supply chain systems, technologies such as automation and IoT have significantly optimized supply chain management, reduced human errors, and improved overall logistics efficiency.

(2) Growing Market Demand:

With the growing demand for digital services and products, the digital economy system is experiencing unprecedented opportunities for expansion. The increasing demand from users for convenient, efficient and innovative digital solutions is driving the continued development of this sector . Concurrently, the growth of e-commerce and international trade has driven the expansion of logistics systems, reinforcing their role as a foundation of modern economies.

(3) Policy Support:

Government incentives, such as funding for R&D and tax relief, bolster innovation in the digital economy. Policies supporting logistics systems, including subsidies and cost-reduction measures, further promote the healthy growth of supply chains [7].

(4) Globalization:

The digital economy's global reach allows businesses to transcend geographic boundaries, broadening customer bases and market access. For logistics and supply chains, globalization enhances efficiency through integrated global operations, offering enterprises flexibility and scalability in their logistics solutions.

3.2.2. *Resistance Factors in Large Systems.* In large systems, resistance factors often create obstacles to growth and transformation.These factors can stem from various sources, including regulatory challenges, technical limitations, economic volatility,social constraints, and resource shortages.While dynamic factors drive change, understanding and addressing resistance factors is equally important to ensure sustainable development and long-term success.

(1) Regulatory and Policy Challenges:

Stringent data protection laws, privacy regulations, and cybersecurity requirements increase the complexity and costs of operating digital businesses. Similarly, logistics systems face uncertainties stemming from trade policies and geopolitical tensions, which can disrupt cross-border supply chains.

(2) Technical Challenges:

Ensuring technical stability and security is paramount, as failures or breaches can disrupt operations and erode trust. High implementation costs and technological integration difficulties in logistics systems further complicate advancements in automation and intelligence [2].

(3) Market and Economic Volatility:

Competitive pressures and market fluctuations pose risks to the digital economy, necessitating agility and adaptability. For logistics systems, demand volatility and supply disruptions–particularly in a globalized context–remain key concerns.

(4) Social and Cultural Constraints:

Uneven digital adoption and the persistence of the digital divide hinder widespread access to and acceptance of digital technologies. Similarly, logistics systems face growing expectations for environmental sustainability, requiring enterprises to balance operational efficiency with ecological responsibility.

(5) Resource Limitations:

The digital economy often struggles with resource shortages, such as insufficient funding or a lack of skilled talent. Logistics systems, too, face challenges related to infrastructure inadequacies and workforce constraints, both of which hinder their ability to scale effectively.

The digital economy faces several critical challenges, including issues of data security and privacy protection, the adaptability demands posed by rapid technological advancements, and the persistent problem of the digital divide. Addressing these challenges is essential to ensure sustainable growth and equitable access to the benefits of digital transformation.

3.3. **System Causal Path Analysis.** In large systems, causal paths represent the interconnected relationships between various factors that drive growth and evolution. Understanding these causal relationships is crucial for identifying how different elements influence each other and contribute to system-wide change. This section will analyze the causal feedback loops within both the digital economy and logistics systems, as well as the interactive feedback between the two, highlighting how each system reinforces and drives the other forward.

(1) Causal Feedback Path in the Digital Economy System:

Digitalization - Technological innovation - Market expansion

Investments in digital infrastructure drive the adoption of advanced technologies such as cloud computing, big data, and AI. These advancements improve product quality and operational efficiency, fostering economic growth [26]. As businesses achieve higher efficiency and lower costs, they are incentivized to reinvest in digital infrastructure, creating a self-reinforcing cycle of innovation and economic expansion.

(2) Causal Feedback Path in Logistics and Supply Chain Systems:

Logistics Efficiency - Field response - Supply chain collaboration and cost control

Enhancements in logistics efficiency, such as optimized inventory management and faster distribution, improve customer satisfaction and market responsiveness. Close collaboration between supply chain stakeholders, facilitated by information

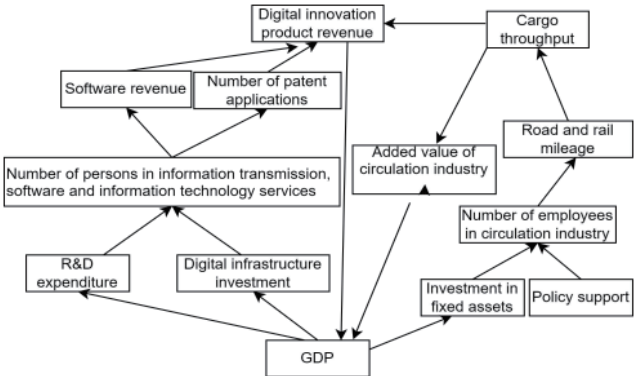

FIGURE 2. Causal Feedback Path (This figure was analyzed and organized by the author).

sharing and cooperative strategies, further reduces operational costs. These improvements attract more partners and customers, perpetuating the system's growth and adaptability.

(3) Interactive Feedback Between the Two Systems:

The digital economy drives innovations in logistics by increasing demand for efficient and flexible supply chains, prompting the logistics industry to adopt advanced technologies. Simultaneously, logistics efficiency positively impacts the digital economy by improving user experiences and cost management in sectors like e-commerce. This interplay creates a virtuous cycle, where each system reinforces the growth and efficiency of the other.

Building a system dynamics model allows for the quantification of these interactions, enabling policymakers and stakeholders to predict how various policy changes or market conditions might influence the systems. The model also highlights key drivers and potential risks, offering strategic insights for sustainable economic growth in the Guangdong-Hong Kong-Macao Greater Bay Area. The causal feedback path of the construction system is shown in Figure 2.

4. Conclusion and discussion

4.1. **Conclusion.** This study highlights the crucial role of system dynamics in analyzing the relationship between the digital economy and logistics systems, offering a multidimensional perspective to understand the intricate interactions and dependencies within large-scale economic systems. Key findings reveal that technological innovation and growing market demand are the primary drivers behind the development of both sectors, while resistance factors such as regulatory constraints, technical challenges, market volatility, socio-cultural barriers, and resource limitations hinder their growth. The causal feedback analysis further illustrates how these systems interact dynamically, showcasing their mutual reinforcement and the mechanisms that shape economic outcomes. In the context of the Guangdong-Hong Kong-Macao Greater Bay Area, the deep integration of digital technologies has significantly enhanced logistics and supply chain management, fostering intelligence,

networking, and sustainability. These advancements improve logistics efficiency, reduce operational costs, and enable businesses to rapidly respond to market changes and meet consumer demands. Technologies like big data analytics, cloud computing, and IoT allow for precise inventory management, real-time logistics tracking, and data-driven decision-making, offering enterprises a competitive edge. The synergy between a robust digital economy and an efficient logistics system provides a solid foundation for high-quality economic development in the region.

4.2. **Discussion.** To promote digital innovation while ensuring data security and privacy protection, it is essential to formulate flexible policy frameworks. Strengthening public-private partnerships can advance infrastructure development in both digitalization and logistics, while providing targeted incentives, such as tax benefits and subsidies, will encourage technological adoption and optimize logistics systems. Additionally, supporting green logistics initiatives by encouraging sustainable practices, reducing energy consumption, and minimizing carbon emissions is crucial. Future research should focus on conducting empirical studies using real-world data to validate the theoretical findings of this study, with system dynamics software simulating quantitative models to provide deeper insights into policy impacts and market trends. Further exploration is needed into the long-term effects of specific interventions on the interaction between the digital economy and logistics systems, assessing their scalability and sustainability. Research should also investigate the unique challenges faced by industries of varying sizes and sectors, particularly in integrating digital technologies into their circulation systems, while addressing social and environmental dimensions, such as bridging the digital divide and promoting environmentally conscious logistics practices. Expanding research in these areas will enable policymakers and enterprises to better navigate the complexities of a rapidly evolving economic landscape, ensuring that technological advancements lead to equitable and sustainable growth.

5. Research limitations and future research prospects

5.1. **Research Limitations.** Although this study has achieved certain results in the construction and analysis of the system dynamics model, the following limitations still exist:

(1) Simplified assumptions for model construction: Due to the limitations of space and data acquisition, certain complex factors were simplified in the construction of the system dynamics model in this study. For instance, although electronic word-of-mouth (eWOM) and its related factors were discussed in the literature review, their dynamic effects were not fully integrated into the model. This may lead to certain deviations in the model's reflection of the actual situation, restricting a deeper understanding of the impact on information dissemination and user behavior.

(2) Lack of empirical data support: This study mainly focuses on the theoretical construction and simulation analysis of the system dynamics model, without yet integrating actual data for empirical verification. This makes the accuracy and reliability of the model's prediction results in practical applications still require further testing, limiting the practicality and generalizability of the research conclusions.

5.2. **Future Research Directions.** In light of the above limitations, future research can be expanded in the following aspects:

(1) Application and reference to the theories and methods of new resources: Future research should respond to considering electronic word-of-mouth (eWOM) as an important way of information dissemination in the digital age, and apply the research results on its role and influencing factors to the system dynamics model to more comprehensively reflect the impact of information dissemination and user behavior on the circulation efficiency of the digital economy.

(2) Collect empirical data for model validation and simulation: Future research should collect relevant empirical data through field research or online surveys, etc., to validate and optimize the existing system dynamics model. By introducing actual data, the accuracy and credibility of the model can be enhanced, ensuring that the simulation results are closer to reality. Moreover, the introduction of empirical data can also help identify potential problems and improvement spaces in the model, further deepening and broadening the research.

In conclusion, this study provides a systematic analytical framework for understanding the mechanism by which the digital economy enhances circulation efficiency and promotes high-quality regional economic development. However, future research needs to further improve the model structure on the basis of combining theory with empirical evidence, and enhance the practicality and generalizability of research conclusions, in order to better support the development of the digital economy in the Guangdong-Hong Kong-Macao Greater Bay Area and other regions.

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