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The Impact of Regional Industry-Education Integration Knowledge Flow System: A System Dynamics Approach

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Abstract

The purpose of this paper is to simulate the dynamic feedback effects of knowledge resources in the process of industry-education integration through system dynamics modeling, as well as to analyze the dynamic impacts of multiple factors on the knowledge flow system. The research employs a system dynamics model that considers the mechanisms driving knowledge flow. It simulates and analyzes the dynamic evolution characteristics of the knowledge flow system's development level in the Yangtze River Delta region over time under four driving scenarios, which include a baseline scenario, as well as scenarios driven by higher education innovation, enterprise innovation, and knowledge interaction environments. The findings indicate an overall positive trend in the comprehensive development level of the knowledge flow system under the current continuity development model in the Yangtze River Delta region. Although there are differences in the driving paths of the three factors influencing the knowledge flow system's development, they complement each other and effectively mitigate their respective shortcomings. Notably, the impact of knowledge interaction environment dynamics on the knowledge flow within the region is significantly stronger than that of higher education and enterprise innovation dynamics.

Keywords

Industry-education Integration; Knowledge Flow; System Dynamics; Simulation.

1. Introduction

The steady development of a country in today's complex global landscape and intense international competition increasingly depends on the presence of a highly skilled workforce. In particular, the significance of talent cultivation and development has never been more pronounced than in the current era of globalization and digitalization [1]. A workforce that possesses both innovative capabilities and advanced professional skills not only drives technological innovation and economic growth but also enables organizations to make strategic structural adjustments in response to rapid technological changes, thereby securing a competitive advantage and achieving sustainable development [2]. With the emergence of new technologies in fields such as artificial intelligence, big data, and biotechnology, the demand for talent to adapt to a digital society is growing. Consequently, higher education institutions must rethink their teaching methodologies and establish partnerships with industry to effectively meet the personal and professional development needs of their students [3-4].

The integration of industry and education, as a model designed to promote deep collaboration between educational institutions and industry, is increasingly recognized as a vital strategy to address the shortcomings of traditional talent development models in higher education. This approach holds significant importance for enhancing educational quality and driving innovation in knowledge and technology [5-6]. On one hand, this model fosters cooperation between schools and businesses, aligning the curriculum with the actual needs of the industry.

It provides students with a comprehensive learning and growth environment, ensuring that they acquire both theoretical knowledge and practical experience, thereby enhancing their employability upon graduation [4, 7]. On the other hand, this collaboration facilitates the integration of resources and the sharing of expertise among government, industry, and academia, thus creating a synergistic talent development mechanism. This not only bridges the gap between talent cultivation and employment but also promotes the intersection of knowledge creation and its commercialization [8-9].

Regional innovation systems have become a focal point of research in recent years, focusing on knowledge creation and transformation. Within these systems, higher education institutions, businesses, and other knowledge innovation entities collaborate to establish frameworks for regional knowledge flow and innovation, providing an environment that fosters cooperation and enhances innovation efficiency [10]. In the context of industry-education integration, businesses can leverage stakeholder resources through knowledge conversion, research and development, and technological innovation, thereby boosting their competitiveness [11]. Consequently, developing a framework that facilitates knowledge exchange between academia and industry, while analyzing the interactions and innovations in industry-education integration, can improve talent development, drive regional innovation, and strengthen competitiveness.

The Yangtze River Delta (the “Delta”) is at the forefront of China's economic and social development, leveraging its abundant resources and reform advantages to promote regional integration and high-quality growth [12]. With unique geographical strengths, the Delta actively dismantles regional knowledge barriers, consolidates innovation resources, and advances collaborative development through knowledge exchange and partnerships among universities, enterprises, and government entities [13]. However, issues like weak practical teaching, misalignment between curricula and industry needs, and insufficient knowledge flow channels persist, hindering the transformation of knowledge and the cultivation of talent. These challenges indicate a gap between the Delta’s current state and the demands of industry-education integration, necessitating in-depth exploration of underlying causes and potential solutions. Consequently, adopting a diversified, systematic, and dynamic research approach is vital for furthering industry-education integration [14].

To deepen the integration of industry and education while promoting regional collaboration and knowledge innovation between universities and enterprises, scholars have made significant research efforts across various dimensions. Chen and Peng (2021) examined the effective integration of educational resources with enterprise needs, focusing on the cultivation of innovative and application-oriented talent [15]. They proposed a robust, stable, and in-depth cooperative education mechanism between universities and enterprises to address the disconnect between talent development in higher education and industry requirements. Their research emphasized collaboration goals based on “talent cultivation, infrastructure development, resource sharing, personnel sharing, and quality assessment.” Gong (2024) assessed the performance levels of industry-education integration in higher education from the perspective of coordinated coupling between industry and education [16]. The study analyzed strategies to enhance the impact of this integration and promote sustainable economic and social development. Findings indicated that industry-education integration should be advanced collaboratively from multiple dimensions, including regional industry subsystems, higher education subsystems, integrated industry-education complexes, and external environments. Chen et al. (2021) developed an evaluation index system for urban industry-education integration based on the Context-Input-Process-Product (CIPP) evaluation model [17]. This system effectively analyzes the degree of integration between urban industries and education while identifying existing challenges. The research found that the policy environment provides a supportive framework for participants in the industry-education integration.

Du et al. (2022) proposed a conceptual model of Industry-Education Integration (IEI) based on collaborative development between teaching and industry within a school-enterprise partnership framework [18]. This model aims to enhance the quality of university education by aligning teaching with current market standards for talent, ultimately producing more competitive graduates. Zhang (2024) positioned the government as a co-creator of collaboration between universities and enterprises, forming an evolutionary game model involving government, enterprise, and university stakeholders [19]. This research analyzed the interactive behavior of each party in the decision-making process to explore ways to enhance synergistic collaboration among government, enterprises, and universities. Zou and Zhu (2021) focused on the transformation of scientific and technological achievements within universities, proposing a three-phase efficiency analysis framework for regional university technology transformation [20]. This framework encompasses the acquisition and conversion of foundational knowledge, the application of technological innovation, and the commercialization of technology. Their study analyzed strategies to improve the efficiency of technology transfer from universities and to promote application of regional technological innovations. Qi and Feng (2025) aimed to optimize the integration model between industry and education, investigating the application of artificial intelligence (AI) within the framework of industry-education integration [21]. Their research provided solid support for enhancing teaching quality and fostering the comprehensive capabilities of students in application-oriented universities.

Some scholars have examined industry-education integration through knowledge management and innovation. Tu et al. (2017) focused on knowledge and technology innovation, developing a collaborative evaluation model for academia-industry-research partnerships [22]. Dai et al. (2023) analyzed how cities create and innovate knowledge based on spatial knowledge spillover effects, highlighting the role of scientific centers like Shanghai in disseminating cutting-edge knowledge across industries, which boosts technological innovation in the Yangtze River Delta [23]. Wu et al. (2022) constructed a dynamic knowledge flow model to identify key factors affecting knowledge transfer in collaborations among universities, enterprises, and research institutions [24]. Zhang et al. (2022) classified the impact of these collaborations on regional economic development into three stages: knowledge interaction, creation, and application, emphasizing the importance of cooperation for economic growth [25]. These studies enrich our understanding of industry-education integration and provide insights for enhancing regional knowledge flow and collaborative innovation.

Despite extensive research on industry-education integration, existing studies primarily focus on foundational concepts and theoretical frameworks, often relying on qualitative analyses and single-disciplinary perspectives. There is a lack of in-depth examinations of the dynamic interactions within knowledge flow systems in this context. Specifically, systematic quantitative research on knowledge flow related to industry-education integration in the Yangtze River Delta—particularly that which applies system dynamics—remains limited.

This paper focuses on knowledge interaction and collaborative innovation within the framework of industry-education integration, innovatively introducing system dynamics simulation methods to develop and construct a comprehensive model of the knowledge flow system in industry-education integration, aimed at improving integration performance. First, we construct a stock-flow model encompassing four subsystems: knowledge supply, demand, policy support, and digital technologies. Second, we design various dynamic simulation scenarios to analyze the effects of key factors on the development of knowledge flow in industry-education integration within the Yangtze River Delta. Finally, based on simulation results and the actual conditions of industrial development, we propose suggestions for promoting regional knowledge flow in industry-education integration from different perspectives.

This study aims to address the following questions to provide deep insights into the integration of industry and education, as well as knowledge flow:

(1) How do various driving factors between universities and enterprises influence key parameters within the knowledge flow system, such as the rate of knowledge innovation in enterprises, research investment in universities, and the knowledge interaction environment?

(2) What effects do digital empowerment and policy support have on knowledge interaction and innovation between universities and enterprises, and how can these effects be integrated into the knowledge flow system of industry-education integration?

(3) What potential key strategies can promote knowledge cooperation and innovation between universities and enterprises, thereby enhancing the performance of the knowledge flow system in industry-education integration?

The value of this research is demonstrated in three main aspects. Theoretically, by constructing a spatially embedded dynamic feedback model, we aim to overcome the limitations of traditional static analyses in knowledge flow research, contributing a new paradigm from system sciences to the theory of regional innovation ecosystems. Methodologically, we develop a system dynamics (SD) model that incorporates novel parameters such as digital connectivity and policy support, thereby expanding the quantitative dimensions of knowledge flow research. Practically, through scenario simulations, we aim to provide local governments with decision support in formulating strategies for the digital transformation of industry-education integration and optimizing regional knowledge innovation networks. This research holds practical implications for addressing the imbalance in the allocation of regional innovation factors and promoting the deep integration of the education chain, talent chain, industry chain, and innovation chain.

The structure of the research is as follows: The first part introduces the research background, the significance of the research questions, and the study's objectives. The second part outlines the research design, data sources, and analysis methods. The third part presents and discusses the research findings, while the fourth part concludes the study.

2. Research Methodology

This chapter develops a System Dynamics (SD) model of the knowledge flow ecosystem for industry-education integration in the Yangtze River Delta region. The model clarifies the interactions among various elements and visually represents the system's structure. By defining the system boundaries, we analyze the components of university innovation, enterprise innovation, digital empowerment, and policy regulation, along with their interrelations. We construct causal loop diagrams for these subsystems, integrating them to create a comprehensive causal relationship diagram and stock-flow diagram for the knowledge flow ecosystem. Additionally, we complete the structural equation design for the system model.

2.1. Characteristics of the System Dynamics Method

System Dynamics (SD) is a methodology used to model and simulate the behavior of complex systems, facilitating the examination of decision-making effectiveness [26]. As a discipline that analyzes and studies nonlinear, complex systems [27], System Dynamics has been widely applied across various fields, including transportation planning [28], risk management [29-30], innovation management [31], and environmental governance [32]. In contrast to traditional linear analytical approaches, System Dynamics emphasizes dynamic, feedback-driven, and holistic systemic thinking, aligning well with the complex nature of regional industry-education integration knowledge management [33].

First, System Dynamics facilitates the modeling of nonlinear interactions among multiple actors, accurately capturing feedback loops influenced by government policy regulation, industrial demand drivers, and university knowledge supply. Second, by incorporating parameters related to industrial digitization and digital infrastructure, we can dynamically simulate the impact of digital technologies on the geographical reconfiguration of knowledge flow. Finally, by adopting a systematic approach that encompasses “knowledge flow, knowledge stock, and knowledge interaction,” we construct a System Dynamics model for the knowledge flow system of industry-education integration. This model reveals the knowledge interaction effects and innovation value-added patterns among different elements within regional industry-education integration.

The application of System Dynamics (SD) modeling is crucial for knowledge translation in policy formulation [34]. Knowledge translation explores how systems convert evidence into decision support [35]. In this context, data must align with the concepts of “stocks and flows” and “feedback.” Knowledge stock represents accumulated knowledge resources, while flow indicates their movement. This study uses knowledge interaction volume to represent knowledge sharing and transfer. SD modeling is particularly suited for the knowledge flow system of industry-education integration, as it considers critical factors and dynamic feedback that influence system behavior [36-37].

However, there are concerns regarding whether these efforts sufficiently critically assess whether knowledge “transfer” or “absorption” genuinely meets the specific needs and objectives of policymakers. Theoretically, if the system modeling process accurately reflects the concerns and values of decision-makers, it can aid in identifying the most suitable forms of evidence and their applications to achieve policy objectives. By formalizing the modeling process, a institutionalized system can be established that recognizes and applies evidence fitting for policy to address existing policy challenges [34].

The first step in the SD modeling process is to define the problem, which includes identifying the background of the issue, the research objectives, recognizing key variables, and delineating the system boundaries. This study determines the key variables and their interrelationships through literature reviews and consultations with experts. The validity of these connections is assessed through model verification testing. The system boundary encompasses factors crucial for generating the necessary behaviors.

(1) Physical boundaries

External Variables: These are not directly controlled by the system and are derived from statistical methods or historical data, such as R&D personnel in enterprises, technology market transaction volumes, enterprise profits, and university research funding. Digital connectivity is indicated by a composite measure of e-commerce participation and internet penetration rates.

Inflow Boundaries: These include variables like knowledge innovation volume, knowledge transfer from universities, feedback on enterprise knowledge, and innovation volumes in enterprises.

Outflow Boundaries: These refer to variables exiting the system, including the depreciation of university knowledge and the obsolescence of enterprise knowledge.

(2) Temporal boundaries

The study spans from 2015 to 2035, with 2015 as the baseline year and one-year simulation steps. The period from 2015 to 2023 serves as the validation interval for model simulations using historical data to calibrate parameters and validate the model’s accuracy. The interval from 2023 to 2035 focuses on scenario forecasting, simulating potential future trends to support subsequent policy analysis.

(3) Spatial boundaries

The spatial scope of this study is the Yangtze River Delta region, including Shanghai, Jiangsu, Zhejiang, and Anhui, which is pivotal for China's economic development due to its advanced economy and strong industrial base. This area exhibits high complementarity and synergy in local economic, technological, and educational resources. By concentrating on this region, the study aims to analyze interactions and knowledge flow characteristics during industry-education integration, providing a robust geographical basis for modeling efforts.

In the second step, subsystems were delineated to analyze the functions of different variables, leading to the establishment of causal relationships in the third step. While causal loop diagrams helped clarify interdependencies and feedback processes, they were insufficient for defining stocks and flows. Therefore, in the fourth step, we utilized Vensim software to convert these diagrams into stock-and-flow diagrams by formulating equations and assigning parameter values, thus constructing the model.

To assess the model's credibility, we employed Vensim's built-in verification tools and compared results to historical data. The fifth step involved rigorous testing for validity, essential for ensuring the model accurately reflects real-world conditions before evaluating various factors. In the subsequent steps, we integrated dynamic factors from literature and expert opinions into the model, evaluated its performance under different scenarios, conducted sensitivity analyses to test robustness, and formulated policy recommendations aimed at enhancing system performance. The final step focused on developing these policies.

2.2. Description of Causal Relationships in the Knowledge Flow System

2.2.1. Subsystem Delineation and Functions

In the analysis of the regional industry-education integration knowledge flow system, a well-defined subsystem delineation can substantially enhance the clarity of the model and the specificity of the analysis. The system is thoroughly divided into four subsystems based on the dimensions of university innovation, enterprise innovation, digital empowerment, and policy regulation, exploring the functions and interactions of each.

(1) University innovation subsystem

The university innovation subsystem focuses on the roles of higher education institutions and research organizations in knowledge creation and dissemination. It analyzes the effects of university innovation investments, knowledge innovation rates, and knowledge transfer on the knowledge flow system in industry-education integration. Collaborative efforts and external partnerships influence university research investments, which, along with knowledge innovation rates, increase knowledge stocks and transfer volumes. This analysis has led to the development of a causal relationship diagram that illustrates the dynamic changes in university knowledge stocks, as shown in Fig. 1.

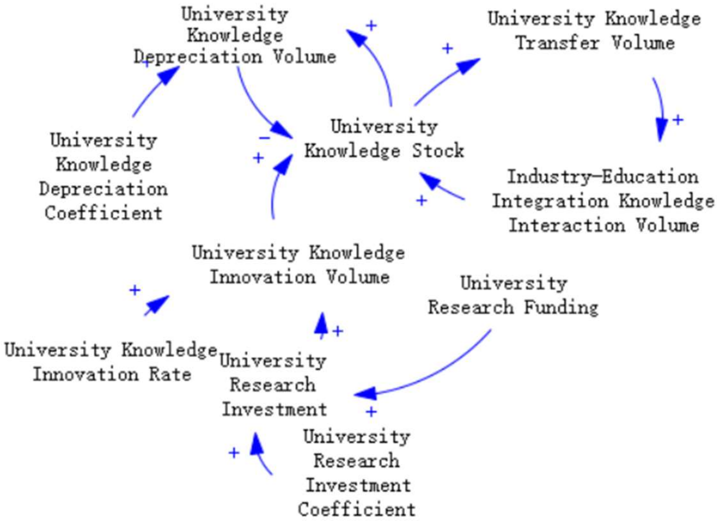

Fig. 1 Causal relationship diagram of the university innovation subsystem.

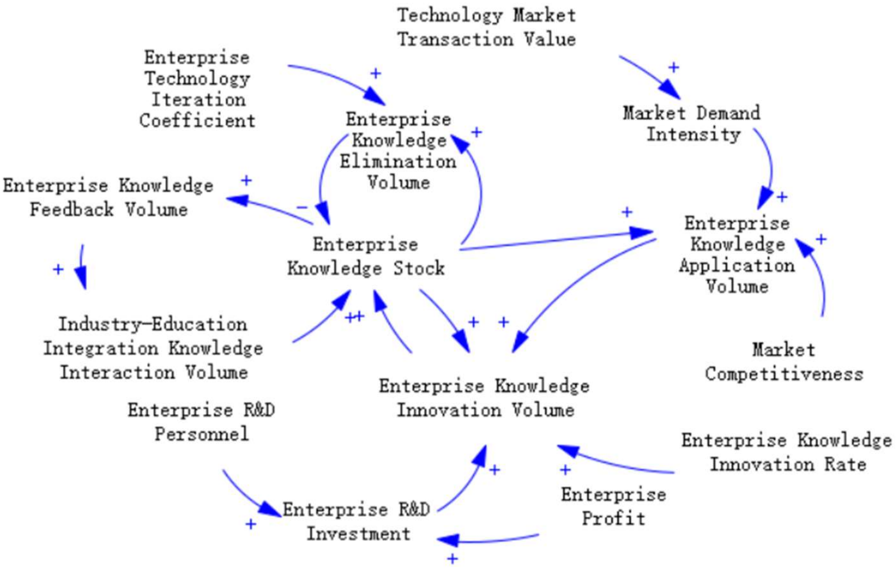

Fig. 2 Causal relationship diagram of the enterprise innovation subsystem.

(2) Enterprise innovation subsystem

The enterprise innovation subsystem examines technology demands and innovations within companies, emphasizing the importance of technological innovation and market application of knowledge. By addressing industry technology needs, companies can boost innovation investments and commercialize technological knowledge, leading to increased knowledge innovation and stocks. Key factors influencing enterprise R&D investment include human capital and financial resources, with R&D personnel providing essential support. A strong enterprise innovation subsystem is crucial for enhancing university-business interactions and fostering the knowledge flow ecosystem in industry-education integration. This analysis has also resulted in a causal relationship diagram for the enterprise innovation subsystem, as illustrated in Fig. 2.

(3) Digital empowerment subsystem

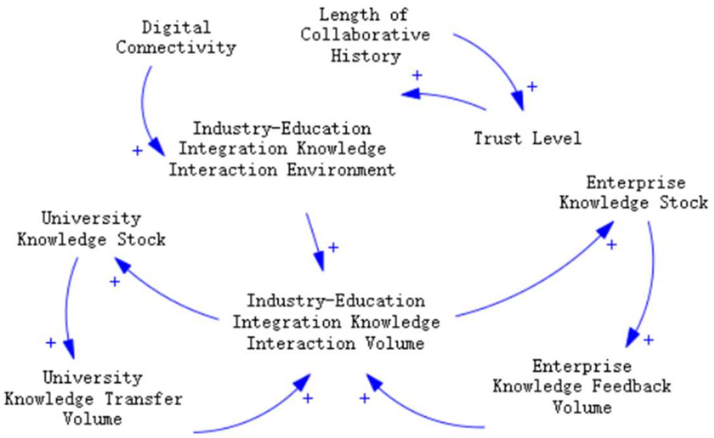

Fig. 3 Causal relationship diagram of the digital empowerment subsystem.

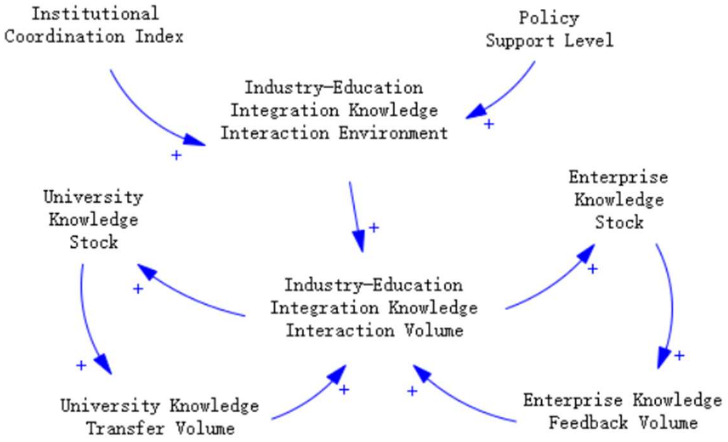

Fig. 4 Causal relationship diagram of the policy regulation subsystem.

The digital empowerment subsystem has emerged as a vital component of contemporary knowledge flow, driven by advancements in digital technologies. Regional digital media facilitate information sharing and interaction among stakeholders involved in industry-education integration, enabling improved articulation and dissemination of tacit knowledge. This enhancement in digital connectivity creates an optimal environment for knowledge exchange, increasing knowledge stocks and transfer volumes while fostering feedback mechanisms within the integration framework. Collaborative history and trust levels between universities and enterprises also influence the effectiveness of the knowledge exchange environment. A causal relationship diagram for the digital empowerment subsystem has been developed to illustrate these dynamics, as demonstrated in Fig. 3.

(4) Policy regulation subsystem

The policy regulation subsystem focuses on the guidance and support provided by government bodies through policy instruments that promote industry-education integration. Government interventions facilitate collaboration between universities and enterprises via macro regulation, including policy guidance and financial support. These effective policy mechanisms create an institutional environment conducive to innovation and knowledge flow, reducing structural barriers and enhancing knowledge exchange among stakeholders. Additionally, policy incentives stimulate participation and enthusiasm in the integration process, fostering a vibrant knowledge environment that increases interaction and accumulation. A causal relationship diagram for the policy regulation subsystem has also been formulated, as illustrated in Fig. 4.

Through a comprehensive analysis of the various subsystems, this study elucidates the interaction mechanisms among different stakeholders within the region. This understanding provides both a theoretical foundation and practical guidance for optimizing knowledge flow pathways and enhancing the effectiveness of industry-education integration.

2.2.2. Development of the Causal Relationship Diagram

Drawing from relevant literature and research paradigms [33, 38-40], this study identifies crucial variables impacting knowledge enhancement during the knowledge flow process (as shown in Table 1) and analyzes the causal relationships among these variables. Using Vensim PLE 10.2.2, a causal relationship diagram for the knowledge flow system in the Yangtze River Delta region's industry-education integration was created, presented in Fig. 5. This diagram includes nine primary feedback loops that manage changes in knowledge stock and knowledge interaction volume within the knowledge flow system:

(1) University Knowledge Stock → University Knowledge Innovation Volume → University Knowledge Stock

(2) University Knowledge Stock → University Knowledge Transfer Volume (the amount of knowledge transferred from universities to enterprises) → Industry-Education Integration Knowledge Interaction Volume → University Knowledge Stock

(3) University Knowledge Stock → University Knowledge Depreciation Volume → University Knowledge Stock

(4) Enterprise Knowledge Stock → Enterprise Knowledge Innovation Volume → Enterprise Knowledge Stock

Table 1. Variables in the causal relationship analysis diagram.

Primary Variable	Secondary Variable	Tertiary Variable
Knowledge Stock	University Knowledge Stock	University's Knowledge Depreciation Rate (University Knowledge Depreciation Coefficient)
	Enterprise Knowledge Stock	Enterprise Knowledge Elimination Rate (Enterprise Technology Iteration Coefficient)
Knowledge Innovation	University Knowledge Innovation Volume	University Knowledge Innovation Rate, University Research Investment (University Research Investment Coefficient, University Research Funding)
	Enterprise Knowledge Innovation Volume	Enterprise Research and Development Investment (Number of R&D Personnel, Enterprise Profit), Enterprise Knowledge Innovation Rate, Enterprise Knowledge Application Volume (Market Competitiveness, Market Demand Intensity, Technology Market Transaction Value)
Knowledge Interaction	Enterprise Knowledge Feedback Volume	
	University Knowledge Transfer Volume	Enterprise Absorptive Capacity (Enterprise Technology Absorption Funding)
	Industry-Education Integration Knowledge Interaction Environment	Digital Connectivity, Trust Level (Length of Collaborative History), Policy Support Level, Institutional Coordination Index

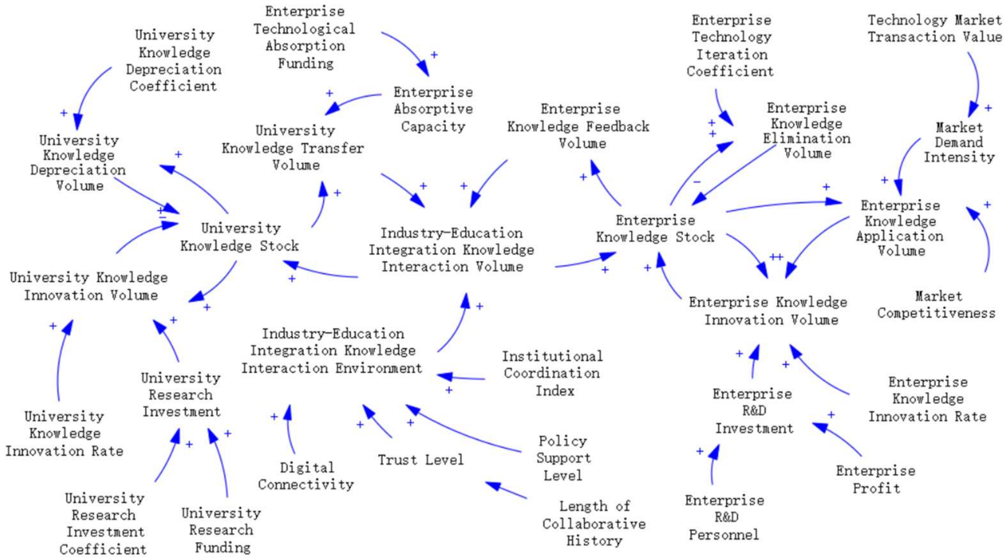

Fig. 5 Causal relationship analysis diagram of the industry-education integration knowledge flow system.

(5) Enterprise Knowledge Stock → Enterprise Knowledge Application Volume → Enterprise Knowledge Innovation Volume → Enterprise Knowledge Stock

(6) Enterprise Knowledge Stock → Enterprise Knowledge Feedback Volume (the amount of knowledge transferred from enterprises back to universities) → Industry-Education Integration Knowledge Interaction Volume → Enterprise Knowledge Stock

(7) Enterprise Knowledge Stock → Enterprise Knowledge Elimination Volume → Enterprise Knowledge Stock

(8) Industry-Education Integration Knowledge Interaction Volume → University Knowledge Stock → University Knowledge Transfer Volume → Industry-Education Integration Knowledge Interaction Volume

(9) Industry-Education Integration Knowledge Interaction Volume → Enterprise Knowledge Stock → Enterprise Knowledge Feedback Volume → Industry-Education Integration Knowledge Interaction Volume

The industry-education integration knowledge interaction volume is influenced by the university knowledge transfer volume, enterprise knowledge feedback volume, and knowledge environment. Key factors of the knowledge interaction environment include digital connectivity, levels of trust, and policy support. Generally, higher digital connectivity between universities and enterprises leads to greater efficiency in knowledge transfer. Enterprises with stronger absorptive capacity are better positioned to comprehend and internalize knowledge effectively, resulting in a greater volume of transferred knowledge and knowledge interactions. The knowledge transfer and feedback between universities and enterprises constitute significant aspects of knowledge interaction volume. The interaction volume is positively correlated with university knowledge transfer, enterprise knowledge feedback, and the knowledge interaction environment.

The fundamental model demonstrates stability, primarily driven by multiple positive feedback relationships. The actual level of knowledge stock is estimated based on knowledge innovation volume, knowledge interaction volume, and knowledge loss volume to meet demand over a specified time frame. Arrows indicating the direction of influence point from one factor to another, representing the impact of one element on another. The “+” and “-” symbols are utilized to define the nature of these influences, which can be either positive or negative. If the trends of the two factors align, a positive pattern is observed; conversely, differing trends indicate a negative pattern.

2.2.3. Development of the SD Model

To further clarify the logical relationships and interactions among various elements within the system, as well as to identify the feedback loops and control mechanisms, we built upon the causal relationship diagram by distinguishing the nature of the variables involved. In this phase, we converted the causal relationship diagram into a stock-and-flow diagram, considering both the computability and practicality of the data. Using Vensim software, we developed this stock-and-flow diagram by incorporating stock variables, flow variables, auxiliary variables, and constants to illustrate the causal relationships and provide quantifiable information, as detailed in Table 2.

Table 2. Variables in the dynamics model of the knowledge flow system.

No.	Type	Variable	No.	Type	Variable
1	Stock Variable	University Knowledge Stock	17	Auxiliary Variable	Institutional Coordination Index
2	Stock Variable	Enterprise Knowledge Stock	18	Auxiliary Variable	Policy Support Level
3	Stock Variable	Industry-Education Integration Knowledge Interaction Volume	19	Auxiliary Variable	Enterprise R&D Personnel
4	Flow Variable	University Knowledge Depreciation Volume	20	Auxiliary Variable	Enterprise R&D Investment
5	Flow Variable	University Knowledge Transfer Volume	21	Auxiliary Variable	Enterprise Profit
6	Flow Variable	Enterprise Knowledge Innovation Volume	22	Auxiliary Variable	Enterprise Knowledge Innovation Rate
7	Flow Variable	Enterprise Knowledge Elimination Volume	23	Auxiliary Variable	Enterprise Technological Absorption Funding
8	Flow Variable	University Knowledge Innovation Volume	24	Auxiliary Variable	Enterprise Absorptive Capacity
9	Flow Variable	Enterprise Knowledge Feedback Volume	25	Auxiliary Variable	Market Competitiveness
10	Auxiliary Variable	University Knowledge Innovation Rate	26	Auxiliary Variable	Enterprise Knowledge Application Volume
11	Auxiliary Variable	University Research Investment	27	Auxiliary Variable	Market Demand Intensity
12	Auxiliary Variable	University Research Funding	28	Auxiliary Variable	Technology Market Transaction Value
13	Auxiliary Variable	Digital Connectivity	29	Constant	University Research Investment Coefficient
14	Auxiliary Variable	Length of Collaborative History	30	Constant	University Knowledge Depreciation Coefficient
15	Auxiliary Variable	Trust Level	31	Constant	Enterprise Technology Iteration Coefficient
16	Auxiliary Variable	Industry-Education Integration Knowledge Interaction Environment			

The industry-education integration knowledge flow system interlinks different subsystems, facilitating collaborative development across four key aspects: university innovation, enterprise innovation, digital empowerment, and policy support. This system model aligns with the triple helix model, which emphasizes the knowledge interaction and collaborative efforts among academia, industry, and government [41-42]. The dynamics of the industry-education integration knowledge system are illustrated in Fig. 6 through a stock-and-flow diagram. This variable configuration includes three stock variables, six flow variables, nineteen auxiliary variables, and three constants. Rectangular blocks represent the stock variables, which are structural components of the model. In this framework, university knowledge stock, enterprise knowledge stock, and industry-education integration knowledge interaction volume are considered stocks to demonstrate the accumulation of both knowledge reserves and transferred knowledge quantities. Flow variables, in contrast, are employed to convey available resources that influence changes in stock levels.

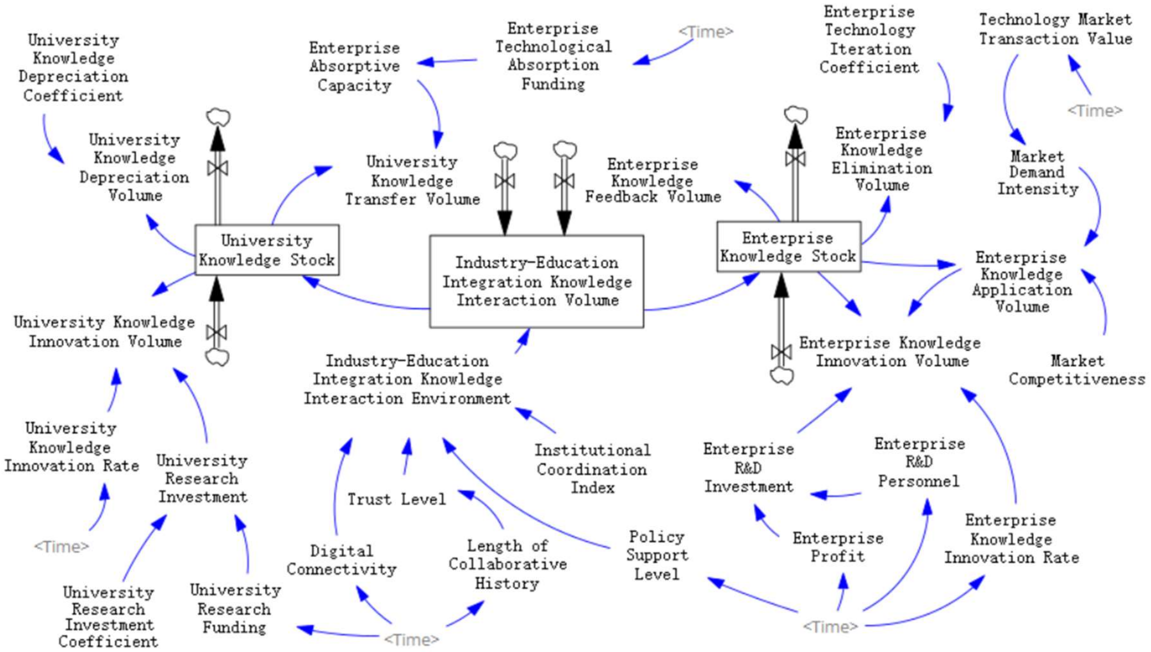

Fig. 6 Stock-flow model of the industry-education integration knowledge flow system.

2.2.4. Equations Setup

The developed knowledge flow model for industry-education integration serves as a framework to identify the roles and impacts of various factors within the knowledge flow system. These dynamic elements influence knowledge innovation and interaction, ultimately affecting the overall performance of the system. By simulating different dynamic scenarios, we can explore how various driving forces impact system performance. Structurally, we have prepared a System Dynamics (SD) model. To simulate this model using Vensim software, a set of equations is required to define the relationships between the variables. These equations consist of algebraic expressions that describe the causal connections between one variable and others. Based on the previous analysis of causal relationships among various types of variables in the system, as well as the structure of the stock-flow diagram, we list below the variable equations for the dynamics model of the knowledge flow system, specifically categorized into equations related to knowledge stock, knowledge innovation, knowledge interaction, and knowledge depreciation.

(1) Knowledge stock-related equations

Knowledge stock refers to the total amount of knowledge resources held by an organization (such as a university or enterprise) over a specific period. Knowledge innovation is the primary source of knowledge resources, while knowledge transfer and feedback significantly supplement both enterprise and university knowledge resources, contributing to the increase in knowledge stock. Knowledge depreciation and elimination refer to the process by which outdated knowledge, resulting from the passage of time or technological advancements, is phased out, leading to a decrease in knowledge stock. The equations for knowledge stock from all parties are as follows.

- University Knowledge Stock = INTEG (Industry-Education Integration Knowledge Interaction + University Knowledge Innovation - University Knowledge Depreciation, Initial Value)

This equation reflects the net addition to university knowledge stock derived from university knowledge innovation and industry-education integration knowledge interaction, minus the natural depreciation of knowledge, illustrating the dynamic evolution of university knowledge stock.

- Enterprise Knowledge Stock = INTEG (Enterprise Knowledge Innovation - Enterprise Knowledge Elimination + Industry-Education Integration Knowledge Interaction)

This equation calculates the net increase in enterprise knowledge stock from the sum of enterprise knowledge innovation and industry-education integration knowledge interaction, minus the natural elimination of knowledge, thus demonstrating the dynamic evolution of enterprise knowledge stock.

(2) Knowledge innovation volume-related equations

In the context of industry-education integration, knowledge innovation by universities and enterprises stems from their respective resource reserves. The volume of knowledge innovation is influenced by factors such as each party's knowledge stock and investment in innovation. The relevant equations are as follows:

- University Knowledge Innovation Volume = University Research Investment × University Knowledge Innovation Rate × University Knowledge Stock
- Enterprise Knowledge Innovation Volume = Enterprise R&D Investment × Enterprise Knowledge Innovation Rate × (Enterprise Knowledge Application Volume + Enterprise Knowledge Stock)

The university and enterprise knowledge innovation rates are measured by the growth rate of the number of invention patents for universities and large-scale industrial enterprises, respectively. University research investment is affected by the university research investment coefficient and university research funding, while enterprise R&D investment is influenced by the number of R&D personnel and enterprise profits. The university research investment coefficient is a constant (0.03). Enterprise knowledge application volume is affected by factors such as market competitiveness, market demand intensity, and the enterprise's own knowledge stock. To account for the time delay in the knowledge application process, a first-order delay function is employed, reflecting that knowledge application begins one time unit after the initial input, with the assumption that enterprise knowledge application volume starts at zero. To simplify the model, market competitiveness is represented by a random function: RANDOM NORMAL (mean, max, mean, stdev, seed), and market demand intensity is indicated by the technology market transaction value.

- University Research Investment = University Research Funding × University Research Investment Coefficient
- Enterprise R&D Investment = Enterprise Profit × Number of R&D Personnel
- Enterprise Knowledge Application Volume = DELAY1I(Enterprise Knowledge Stock × Market Demand Intensity × Market Competitiveness, 1, 0)
- Market Demand Intensity = Technology Market Transaction Value
- Market Competitiveness = RANDOM NORMAL (0, 0.1, 0.05, 0.01, 2023)

(3) Knowledge interaction volume-related equations

Knowledge interaction volume is a crucial indicator for measuring the knowledge exchange between universities and enterprises. It primarily encompasses the volume of knowledge feedback from enterprises to universities and the volume of knowledge transfer from universities to enterprises. Additionally, this process is influenced by the environmental factors associated with industry-education integration. The knowledge interaction environment is affected by factors such as institutional synergy index, digital connectivity, trust level, and policy support. Digital connectivity represents how the level of digitalization promotes knowledge flow and value addition, while the institutional synergy index indicates the degree to which institutional safeguards facilitate knowledge transfer between universities and enterprises. The relevant equations are as follows:

- Knowledge Interaction Volume in Industry-Education Integration = INTEG(Knowledge Interaction Environment × (Enterprise Knowledge Feedback Volume + University Knowledge Transfer Volume))
- Knowledge Interaction Environment = Trust Level × Institutional Synergy Index × Digital Connectivity × Policy Support Level

Knowledge transfer and feedback within the industry-education integration context are complex processes. Universities are required to share the knowledge transferred, while enterprises must absorb and integrate this knowledge. The enterprise's technological absorption capability is represented by the funding allocated for technical absorption. Importantly, knowledge transfer and feedback do not commence immediately upon collaboration; they exhibit a certain degree of latency. Thus, the equations for university knowledge transfer and enterprise knowledge feedback are modeled using a first-order delay function, indicating that these processes begin half a time unit after the initial interaction, with the initial volume of transferred and feedback knowledge set to zero.

- University Knowledge Transfer Volume = DELAY1I(Enterprise Technological Absorption Capability × University Knowledge Stock, 0.5, 0)
- Enterprise Knowledge Feedback Volume = DELAY1I(Enterprise Knowledge Stock, 0.5, 0)
- Enterprise Technological Absorption Capability = Enterprise Technical Absorption Funds

The variable for trust level, which is subjective, is set to an initial value of zero. If the general trust level is low, the initial value remains at 0; conversely, if the trust level is high and concentrated, the initial value is set to 0.5. Trust level is influenced by the history of collaboration and is modeled using a first-order delay function, with a delay of one time unit.

- Trust Level = DELAY1I (Collaboration History Length, 1, 0)
- Institutional Synergy Index = RANDOM NORMAL (0, 0.1, 0.05, 0.01, 2023)

(4) Knowledge Depreciation Equations

Knowledge depreciation encompasses the volume of knowledge eliminated by enterprises and the depreciation of knowledge at universities, representing the knowledge that is rendered obsolete or lost due to aging. The enterprise technological iteration coefficient is set at (i = 0.01) and the university knowledge depreciation coefficient at (j = 0.03) (Su et al., 2012). Furthermore, acknowledging that knowledge depreciation also experiences a certain delay, we represent university knowledge depreciation and enterprise knowledge elimination using the step functions (STEP (University Knowledge Stock \times i, h)) and (STEP (Enterprise Knowledge Stock \times j, h)) respectively. Here, (h) indicates the time at which knowledge loss begins, with (i) and (j) representing the corresponding knowledge loss coefficients. The equations imply that, starting from the simulation time (h) (beginning in 2015), knowledge loss occurs, where the amount of knowledge lost is the product of the knowledge stock of each party and the respective loss coefficients ((i) and (j)).

- University Knowledge Depreciation Volume = (STEP (University Knowledge Stock \times University Knowledge Depreciation Coefficient, 2015))
- Enterprise Knowledge Elimination Volume = (STEP (Enterprise Knowledge Stock \times Enterprise Technological Iteration Coefficient, 2015))

2.3. Initial Operating Conditions

2.3.1. Research Assumptions

Given the complexity of the actual system, we have formulated several assumptions in our model. First, the industry-education integration knowledge flow system is a progressive dynamic system, where subsystems influence one another and collectively impact the overall performance of the knowledge flow system. Second, all system entities are assumed to operate under normal behavioral conditions, with knowledge innovation being the primary source of knowledge stock within the system. Finally, we do not account for significant fluctuations in market conditions, natural disasters, or abrupt failures of policies and regulations.

2.3.2. Data Sources

The data for this study primarily comes from authoritative databases such as the "China Statistical Yearbook," "Anhui Statistical Yearbook," "Zhejiang Statistical Yearbook," "Jiangsu Statistical Yearbook," "Shanghai Statistical Yearbook," the National Bureau of Statistics, and the Ministry of Science and Technology of China, covering the years 2015 to 2023. For the short and random data gaps, the linear interpolation method is used to fill in the gaps.

2.3.3. Parameter Setting

Based on the aforementioned fundamental assumptions and historical data for certain variables, we initially determined the parameters for the model using trend extrapolation and table function methods [43-44]. Throughout the model development process, we continually adjusted the parameters and equations of the variables in conjunction with real-world empirical data. This iterative approach seeks to ensure that the values and trends of the variables in the model closely align with the reality of the knowledge flow in the context of industry-education integration in the Yangtze River Delta region.

The dynamic model of the knowledge flow system presented in this study operates within the time frame of 2015 to 2035, using one year as the unit of simulation time, for a total of 26 years. The model's reasonableness is primarily assessed through the fitting of historical data from the years 2015 to 2023 in the Yangtze River Delta region. The period from 2015 to 2023 serves as a validation interval for assessing model accuracy. Due to the patent application process, which typically requires a 3 to 5-year granting period, patent data for the most recent three years is somewhat incomplete; thus, we reference patent data up to the year 2023. This data is utilized to determine relevant parameters and to calibrate the model, providing a pragmatic reference for evaluating the simulation's accuracy and effectiveness. The subsequent period from 2023 to 2035 is designated for model simulation and scenario forecasting, enabling us to model and predict potential future trends and evolutionary pathways within the system for subsequent policy analysis. In this study, the initial values for knowledge stock are based on the number of invention patent applications filed by universities and enterprises in 2015 (measured in ten thousands). Consequently, the initial knowledge stock values are set at 8.9693 for universities and 3.6913 for enterprises.

In the regional industry-education integration knowledge flow system dynamics model, several variables require assignment of values based on case data. Prior to this, it is essential to characterize these variables using real data from the Yangtze River Delta region. The knowledge innovation rates for universities and enterprises are represented by the growth rates of invention patents filed by universities and large-scale industrial enterprises in Shanghai, Jiangsu, Zhejiang, and Anhui from 2015 to 2023. The digital connectivity is measured as the product of the proportion of enterprises engaged in e-commerce transactions and the internet penetration rate in the Yangtze River Delta region. E-commerce activity reflects industry digitization, while the internet penetration rate indicates the state of digital infrastructure, which significantly enhances information transmission efficiency in the region and provides innovative channels for knowledge flow.

The research funding for universities is represented by the R&D project expenditures of universities in the Yangtze River Delta region, with a baseline future growth rate set at the average growth rate of 14.7% from 2021 to 2023. For enterprise technology absorption funding, we consider the sum of technology introduction expenditures and expenses related to the assimilation of technologies for large-scale industrial enterprises in the region. The average value from the past five years (2019-2023) is used as a baseline for future projections. Enterprise profits and R&D personnel are represented by the total profits of large industrial enterprises in the Yangtze River Delta and the number of personnel in enterprise R&D institutions, respectively. For the years following 2024, enterprise profits are projected using the compound annual growth rate (CAGR) from 2015 to 2023, with an annual growth trend set at 2.05%. The number of R&D personnel in enterprises after 2024 will be based on the five-year average.

Market demand intensity is indicated by the transaction volume of the technology market in the Yangtze River Delta, with the five-year average serving as a future baseline. Policy support levels are reflected in the total value of significant technology transfer projects facilitated by national technology transfer demonstration institutions in Shanghai, Jiangsu, Zhejiang, and Anhui, thereby showcasing the government's incentive effects. The future growth baseline for this variable will be the difference from the last two periods (2022-2023). The institutional collaboration index reflects the effective coordination of policies within the region, positively impacting resource allocation and knowledge sharing. The length of cooperative history is mapped by the ratio of the actual number of years of cooperation in simulations to the maximum number of simulation years.

To enhance the comparability of the data, we performed normalization on the original datasets. The processed data were then incorporated into the equations of the knowledge flow system dynamics model. The time-varying variables from 2015 to 2035 can be represented using table functions as follows:

University Knowledge Innovation Rate = WITH LOOKUP(Time,([(2015,0)-(2035,1)],(2015,0.141),(2016,0.191),(2017,0.136),(2018,0.036),(2019,0),(2020,0.085),(2021,0.102),(2022,0.125),(2023,1.000),(2024,0.262),(2025,0.262),(2026,0.262),(2027,0.262),(2028,0.262),(2029,0.262),(2030,0.262),(2031,0.262),(2032,0.262),(2033,0.262),(2034,0.262),(2035,0.262)))

Enterprise Knowledge Innovation Rate = WITH LOOKUP(Time,([(2015,0)-(2035,1)],(2015,0.392),(2016,1),(2017,0.492),(2018,0.542),(2019,0),(2020,0.621),(2021,0.235),(2022,0.557),(2023,0.246),(2024,0.332),(2025,0.332),(2026,0.332),(2027,0.332),(2028,0.332),(2029,0.332),(2030,0.332),(2031,0.332),(2032,0.332),(2033,0.332),(2034,0.332),(2035,0.332)))

Digital Connectivity = WITH LOOKUP(Time,([(2015,0)-(2035,1)],(2015,0),(2016,0.097),(2017,0.091),(2018,0.176),(2019,0.333),(2020,0.408),(2021,0.473),(2022,0.519),(2023,1),(2024,0.547),(2025,0.547),(2026,0.547),(2027,0.547),(2028,0.547),(2029,0.547),(2030,0.547),(2031,0.547),(2032,0.547),(2033,0.547),(2034,0.547),(2035,0.547)))

University Research Funding = WITH LOOKUP(Time,([(2015,0)-(2035,1)],(2015,0.005),(2016,0),(2017,0.008),(2018,0.017),(2019,0.045),(2020,0.052),(2021,0.066),(2022,0.080),(2023,0.122),(2024,0.153),(2025,0.188),(2026,0.229),(2027,0.275),(2028,0.329),(2029,0.390),(2030,0.460),(2031,0.541),(2032,0.633),(2033,0.739),(2034,0.861),(2035,1)))

Enterprise Technology Absorption Funding = WITH LOOKUP(Time,([(2015,0)-(2035,1)],(2015,0),(2016,0.691),(2017,0.381),(2018,0.861),(2019,0.880),(2020,0.437),(2021,1),(2022,0.828),(2023,0.924),(2024,0.814),(2025,0.814),(2026,0.814),(2027,0.814),(2028,0.8

14),(2029,0.814),(2030,0.814),(2031,0.814),(2032,0.814),(2033,0.814),(2034,0.814),(2035,0.814)))

Enterprise Profit = WITH LOOKUP(Time,([(2015,0)-(2035,1)],(2015,0.118),(2016,0.319),(2017,0.324),(2018,0.171),(2019,0),(2020,0.173),(2021,0.565),(2022,0.341),(2023,0.412),(2024,0.456),(2025,0.501),(2026,0.546),(2027,0.593),(2028,0.640),(2029,0.688),(2030,0.738),(2031,0.788),(2032,0.839),(2033,0.892),(2034,0.945),(2035,1)))

R&D Personnel in Enterprises = WITH LOOKUP(Time,([(2015,0)-(2035,1)],(2015,0),(2016,0.070),(2017,0.164),(2018,0.169),(2019,0.256),(2020,0.421),(2021,0.564),(2022,0.855),(2023,1),(2024,0.619),(2025,0.619),(2026,0.619),(2027,0.619),(2028,0.619),(2029,0.619),(2030,0.619),(2031,0.619),(2032,0.619),(2033,0.619),(2034,0.619),(2035,0.619)))

Technology Market Transaction Volume = WITH LOOKUP(Time,([(2015,0)-(2035,1)],(2015,0),(2016,0.021),(2017,0.044),(2018,0.112),(2019,0.188),(2020,0.293),(2021,0.506),(2022,0.741),(2023,1),(2024,0.546),(2025,0.546),(2026,0.546),(2027,0.546),(2028,0.546),(2029,0.546),(2030,0.546),(2031,0.546),(2032,0.546),(2033,0.546),(2034,0.546),(2035,0.546)))

Policy Support Level = WITH LOOKUP(Time,([(2015,0)-(2035,1)],(2015,0.405),(2016,0.152),(2017,0),(2018,0.363),(2019,0.186),(2020,0.532),(2021,0.823),(2022,0.389),(2023,0.436),(2024,0.483),(2025,0.530),(2026,0.577),(2027,0.624),(2028,0.671),(2029,0.718),(2030,0.765),(2031,0.812),(2032,0.859),(2033,0.906),(2034,0.953),(2035,1)))

Length of Cooperative History = WITH LOOKUP(Time,([(2015,0)-(2035,1)],(2015,0.001),(2016,0.05),(2017,0.10),(2018,0.15),(2019,0.20),(2020,0.25),(2021,0.30),(2022,0.35),(2023, .40),(2024,0.45),(2025,0.50),(2026,0.55),(2027,0.60),(2028,0.65),(2029,0.70),(2030,0.75),(2031,0.80),(2032,0.85),(2033,0.90),(2034,0.95),(2035,1)))

2.4. Model Validation

In order to ensure that the system dynamics model accurately and reliably simulates the real system, it is essential to conduct validation before performing model simulations and scenario analyses. Typically, various validation methods can be employed, including intuitive checks, operational tests, and historical validations, to assess the model's rationality and validity [45]. The model developed in this study operates within the time frame of 2015 to 2035, and its validity is primarily tested through operational checks and historical validations.

2.4.1. Operational Verification

Operational verification encompasses two main aspects: model structure and units. The purpose of structural verification is to ensure that the system's dynamic equations correctly represent the relationships between the variables without any omissions. Unit verification aims to confirm that the units on both sides of the dynamic equations are consistent. The model structure was examined using the "Check Model" function in Vensim software, and the results indicated that the model is "Model is OK."

2.4.2. Historical Validation

Historical validation involves comparing the model's simulation results with historical data for select variables, assessing the fit of the simulation results to the real system. Mean Absolute Percentage Error (MAPE) can be employed as an indicator for measuring the relative error of the model, with the calculation formula as follows [46].

$$\text{MAPE}=\frac{1}{n}\sum_{i=1}^{n}\left|\frac{\hat{Y}_i-Y_i}{Y_i}\right| \tag{1}$$

In this formula, "n" represents the number of historical data points used for forecasting (specifically, the number of years of historical data, excluding the starting year, totaling five years). Y_i denotes the actual value of the indicator for the (i)-th year, while $\hat{Y}_i$ represents the simulated forecast value for the same year. The criteria for assessing the model's forecasting accuracy are as follows: if MAPE ≤ 10%, the model's predictive accuracy is considered high; if 10% < MAPE ≤ 20%, the accuracy is deemed good; if 20% < MAPE ≤ 50%, the predictions are considered feasible to some extent; and if MAPE > 50%, the model's predictions exhibit significant deviation [47].

Based on the characteristics of the system model, this study selects knowledge stock from universities and enterprises within the innovation subsystems of higher education and enterprise innovation for historical validation. The results of the historical validation are presented in Tables 3 and 4. Table 3 compares the historical values and simulation values of the variables from 2015 to 2023 on a year-by-year basis, revealing that the maximum absolute error is 14.91%, while the minimum is 0.05%. Most absolute errors fall within 10%, indicating a good fit between the model's outcomes and actual conditions, effectively simulating the resource flows within the integrated knowledge ecosystem of industry and education.

Table 4 uses MAPE as an evaluation metric for the historical validation of the model. The data in this table are used to determine whether the simulation results align with the characteristics of the integrated knowledge ecosystem of industry and education, thereby verifying the model's validity. As seen in Table 4, the model demonstrates commendable simulation forecasting performance and accurately reflects the fundamental knowledge flow in the Yangtze River Delta region's integration of industry and education. Therefore, it is appropriate to proceed to the next stage of simulation and scenario analysis.

Table 3. Historical validation results of the knowledge flow ecosystem model (yearly comparison).

Year	University Knowledge Stock (Number of University Patent Applications)			Enterprise Knowledge Stock (Number of Patent Applications for Enterprises)		
	Actual Value	Fitted Value	Error Rate	Actual Value	Fitted Value	Error Rate
2015	3.6913	3.6913	0	8.9693	8.9693	0
2016	4.5432	4.25064	-0.0644	10.3124	9.54961	-0.0740
2017	4.8748	4.79312	-0.0168	10.4259	10.3374	-0.0085
2018	6.1055	5.31949	-0.1287	12.2658	11.1745	-0.0890
2019	6.8519	5.83002	-0.1491	12.6557	11.9082	-0.0591
2020	6.4396	6.33018	-0.0170	14.2838	12.4642	-0.1274
2021	7.0538	6.8224	-0.0328	15.4114	13.5889	-0.1183
2022	7.3273	7.33113	0.0005	17.0059	15.2009	-0.1061
2023	7.7449	7.87576	0.0169	18.5907	18.346	-0.0132

Table 4. Historical validation results of the knowledge flow ecosystem model (MAPE values).

Variable	MAPE (%)	Prediction Accuracy
University Knowledge Stock	4.74	High Accuracy Prediction
Enterprise Knowledge Stock	6.62	High Accuracy Prediction

3. Simulation and Results

This study designs various scenarios for sensitivity analysis across dimensions such as universities, enterprises, and knowledge environments. The approach involves altering a specific parameter in the model and subsequently observing the changes in system state or model output, thereby determining the influence of that parameter on the model. The research primarily focuses on simulating and analyzing the sensitivity of key parameters, including knowledge innovation rate, innovation investment, and knowledge environment, to explore the driving mechanisms behind knowledge flow between universities and enterprises in the context of regional integration of industry and education. The core issue investigated is the dynamic driving effects of different key motivating factors on the development of the knowledge flow system in the Yangtze River Delta region. The simulation uses knowledge stock, knowledge innovation, and the volume of knowledge interactions as output variables.

3.1. Simulation Scenario Design

The simulation scenarios are categorized into four types, including a baseline scenario representing the model's initial state without any other changes, as well as three additional scenarios designed around the dimensions of university innovation motivation, enterprise innovation motivation, and the dynamics of the knowledge interaction environment. Specifically, the scenarios are defined as follows.

(1) Baseline Scenario: This scenario maintains the model's initial parameters without any alterations to the system.

(2) University Innovation Motivation Scenario: This scenario assesses changes in university innovation factors (by altering the university knowledge innovation rate and research investment) while keeping other parameters constant.

(3) Enterprise Innovation Motivation Scenario: Similar to the previous one, this scenario adjusts enterprise innovation factors (by changing the enterprise knowledge innovation rate and R&D investment) without modifying other parameters.

(4) Knowledge Interaction Environment Dynamics Scenario: This scenario investigates the impact of modifications in knowledge interaction factors (by adjusting digital connectivity and policy support levels) while keeping other parameters unchanged.

Each of the scenarios in categories 2, 3, and 4 includes two sub-scenarios. One sub-scenario compares the state of the system after a change in a specific driving factor to the model's initial condition, while the other sub-scenario reflects the extent to which improvements in a driving factor affect the simulation results of the corresponding output variables. For instance, the University Innovation Motivation Scenario consists of two sub-scenarios: University Innovation Motivation Scenario 1 and University Innovation Motivation Scenario 2. Likewise, the Enterprise Innovation Motivation Scenario includes Enterprise Innovation Motivation Scenario 1 and Scenario 2, while the Knowledge Interaction Environment Dynamics Scenario includes Knowledge Interaction Environment Dynamics Scenario 1 and Scenario 2.

Additionally, the fourth category of scenarios analyzes the overall changes in the knowledge interaction environment's impact on the system. Within this analysis, both the digital connectivity from the digital technology subsystem and the policy support from the policy support subsystem are treated as regulatory variables. To ensure a clear distinction in the effect of these variables, two additional sub-scenarios are created: Digital Environment Dynamics Scenario 3, which changes only the digital connectivity factor within the knowledge interaction environment, and Policy Environment Dynamics Scenario 4, which alters only the policy support factor within the same environment while keeping other parameters constant.

3.2. Baseline Scenario Analysis

In this section, we maintain the initial state of the system dynamics model to conduct simulations, resulting in the baseline scenario (status quo development model) for the innovation development of the knowledge flow system in the Yangtze River Delta region. This encompasses the development trends of knowledge stock, knowledge innovation, and knowledge interaction, as illustrated in Fig. 7.

The simulation results for the baseline scenario indicate a generally positive trend in the development of the knowledge flow system for the integration of industry and education within the region throughout the simulation period. This positive outcome is primarily attributed to the proactive and continuous knowledge interactions and collaborative innovations among universities, enterprises, and government bodies in the Yangtze River Delta. Moreover, the system demonstrates a self-reinforcing positive feedback effect.

Observations reveal that prior to 2020, the growth rates of university knowledge stock, enterprise knowledge stock, university knowledge innovation, enterprise knowledge innovation, and the volume of knowledge interactions related to the integration of industry and education were relatively slow, particularly for university and enterprise knowledge innovations. However, there was a notable acceleration in growth rates following this period, exhibiting an exponential growth trend. This suggests that there is substantial potential for growth in knowledge innovation related to the integration of industry and education in the Yangtze River Delta region in the forthcoming years.

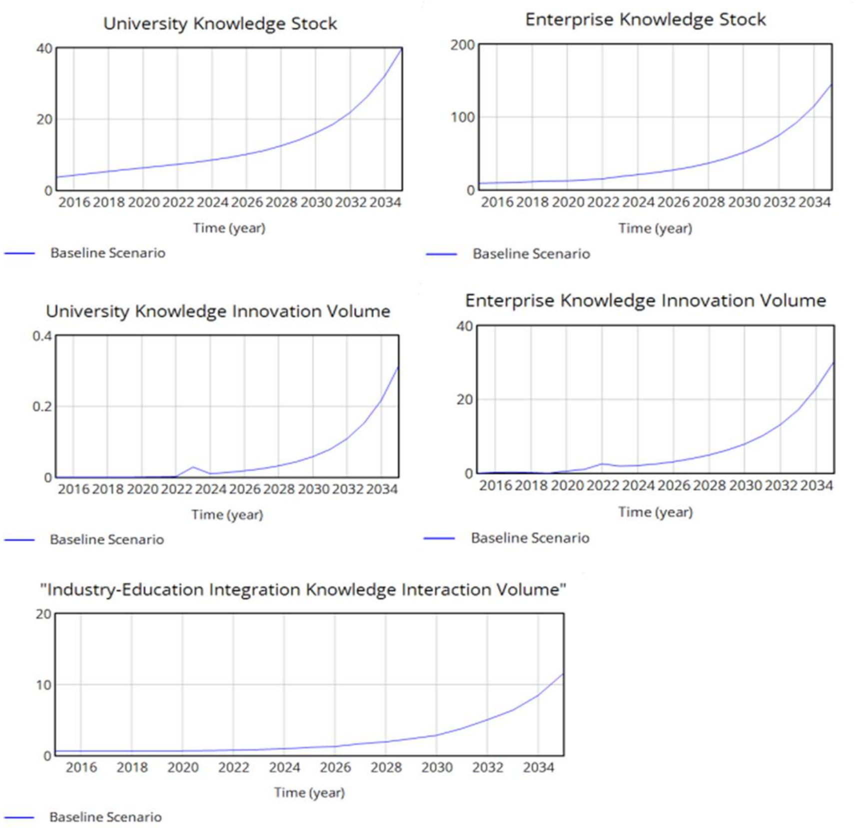

Fig. 7 Simulation results of knowledge flow system of industry-education integration under the base scenario.

3.3. Analysis of University Innovation Motivation Scenario

The analysis of the University Innovation Motivation Scenario builds upon the baseline scenario by improving the driving factors for university knowledge innovation. It aims to observe changes in the output variables (knowledge stock, knowledge innovation, and knowledge interaction) of the knowledge flow system for the integration of industry and education in the Yangtze River Delta before and after the adjustments. This analysis explores the extent of the impact of university knowledge innovation motivation on the development of the integration system. In this study, the knowledge innovation rate and research funding of universities are selected as the regulatory variables for university knowledge innovation. By adjusting the parameters of these scenario variables, we examine the trends in the output variables under the influence of university innovation motivation.

Table 5 presents a comparison of the university knowledge innovation rate and research funding values under the University Innovation Motivation Scenario with those in the baseline scenario. Specifically, Sub-scenario 1 enhances both the university knowledge innovation rate and research funding by 20%, while Sub-scenario 2 increases these relevant variable values by 40%. Additionally, the university research funding coefficient is raised from 0.03 in the baseline scenario to 0.05 in the University Innovation Motivation Scenario. The simulation results for this scenario are illustrated in Fig. 8.

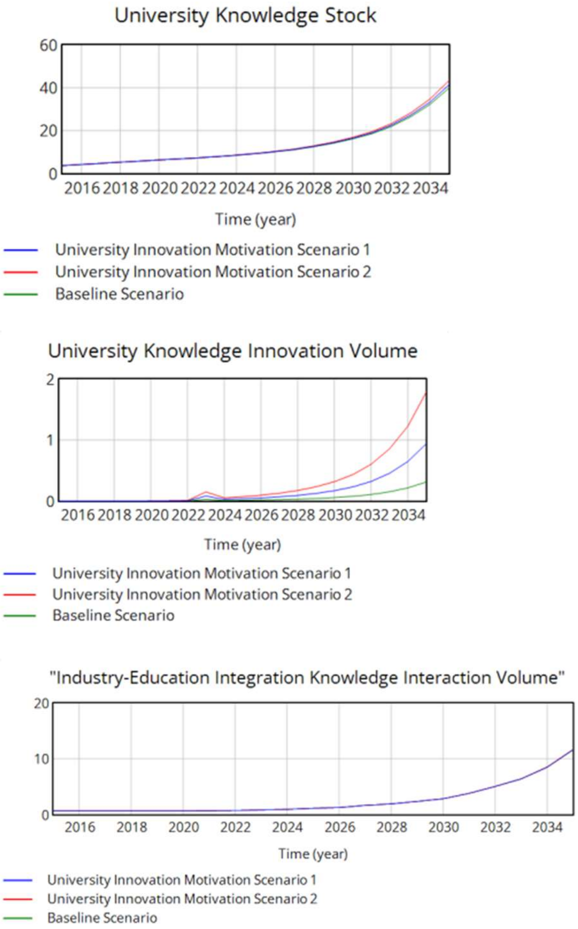

Fig. 8 Simulation results of knowledge flow system of industry-education integration under the scenario of innovation motivation of universities.

From Fig. 8, it is evident that with the gradual improvement of the driving factors for university knowledge innovation, there is a significant increase in the amount of knowledge innovation generated by universities. However, in the early stages of the simulation, the increase in university knowledge innovation was relatively modest, though its growth rate became markedly larger over time. In contrast, the knowledge stock within universities showed only a slight improvement, with a negligible degree of enhancement. Additionally, the trend of knowledge interaction for the integration of industry and education did not exhibit any significant changes.

Table 5. Data comparison between the baseline scenario and the university innovation motivation scenario.

Year	University Knowledge Innovation Rate			University Research Funding		
	Baseline Scenario	Scenario 1	Scenario 2	Baseline Scenario	Scenario 1	Scenario 2
2015	0.141	0.169	0.198	0.005	0.006	0.007
2016	0.191	0.229	0.267	0.000	0.000	0.000
2017	0.136	0.163	0.190	0.008	0.010	0.011
2018	0.036	0.043	0.050	0.017	0.020	0.023
2019	0.000	0.000	0.000	0.045	0.055	0.064
2020	0.085	0.102	0.120	0.052	0.062	0.073
2021	0.102	0.122	0.142	0.066	0.079	0.092
2022	0.125	0.149	0.174	0.080	0.096	0.112
2023	1.000	1.200	1.400	0.122	0.146	0.171
2024	0.262	0.315	0.367	0.153	0.183	0.214
2025	0.262	0.315	0.367	0.188	0.226	0.263
2026	0.262	0.315	0.367	0.229	0.274	0.320
2027	0.262	0.315	0.367	0.275	0.330	0.385
2028	0.262	0.315	0.367	0.329	0.394	0.460
2029	0.262	0.315	0.367	0.390	0.468	0.546
2030	0.262	0.315	0.367	0.460	0.552	0.644
2031	0.262	0.315	0.367	0.541	0.649	0.757
2032	0.262	0.315	0.367	0.633	0.760	0.886
2033	0.262	0.315	0.367	0.739	0.887	1.035
2034	0.262	0.315	0.367	0.861	1.033	1.205
2035	0.262	0.315	0.367	1.000	1.200	1.400

The reasoning behind these simulation results is that modifying the driving variables of university knowledge innovation primarily influences the dynamics of positive feedback relationships within the overall system. Consequently, variables in the subsystems closely related to this driving variable experience corresponding increases. However, as the simulation time extends, the positive feedback relationships among certain subsystems tend to weaken, leading to a noticeable decrease in the sensitivity of these subsystem variables to changes in scenario variables. Furthermore, the integration of industry and education knowledge flow system in the Yangtze River Delta is subject to significant uncertainties influenced by external factors, making it challenging to pinpoint specific variables that have a determinative directional effect. This results in a simplification in the simulation of university innovation motivation scenarios. As a consequence, the trend of knowledge interaction for the integration of industry and education remains unchanged. Nonetheless, this simplification does not undermine the overall efficacy of the model's simulation. The system dynamics model developed for this study focuses on the interaction of knowledge among the stakeholders within the integration of industry and education, as evidenced by the unchanged regulatory variables for knowledge interaction in the university innovation motivation scenario (which will be addressed in the knowledge interaction environment scenario). Furthermore, the model considers both changes in knowledge innovation and the total volume of knowledge.

Thus, it is clear that in this model, the university knowledge innovation rate and research funding primarily drive the flow of knowledge within the system by enhancing the amount of knowledge innovation produced by universities and, to some extent, by improving the knowledge stock. However, the simulation results related to the knowledge interaction for the integration of industry and education reveal that this variable is not particularly sensitive to changes in the innovation motivation scenario variables. This outcome reflects the limited effectiveness of unilateral innovation enhancements by universities in improving the knowledge flow system for the integration of industry and education in the Yangtze River Delta, especially in the absence of knowledge interactions with enterprises. This observation aligns with the actual processes of knowledge flow in the region and underscores the feasibility of employing a system dynamics approach to study knowledge flow within the context of industry and education integration. The simulation results of the university innovation motivation scenario highlight the significance of university innovation motivation in the knowledge flow system, while also indirectly emphasizing the indispensable nature of knowledge interaction between universities and enterprises within this framework.

3.4. Analysis of Enterprise Innovation Motivation Scenarios

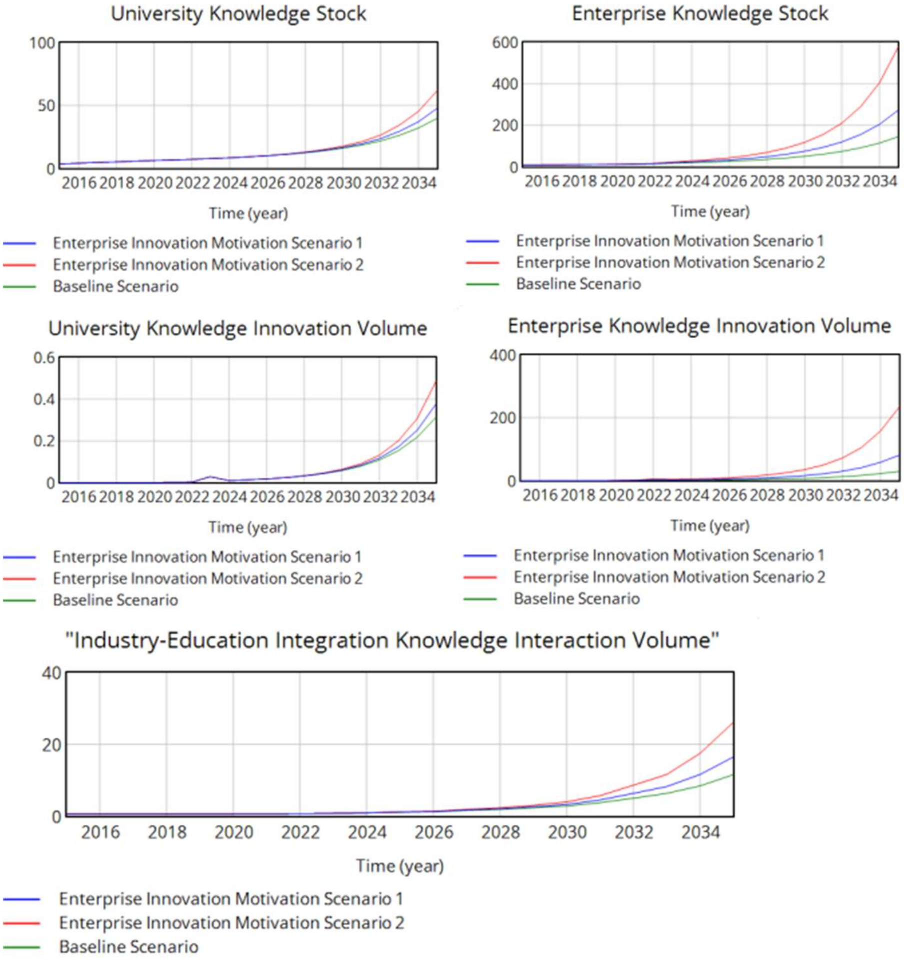

Fig. 9 Simulation results of knowledge flow system of industry-education integration under the scenario of enterprise innovation motivation.

The analysis of enterprise innovation motivation scenarios builds on the baseline scenario. By improving the driving factors for enterprise knowledge innovation, this analysis observes the changes in the output variables of the knowledge flow system for the integration of industry and education in the Yangtze River Delta before and after adjustments. The aim is to explore the extent to which enterprise knowledge innovation motivation impacts the development of the knowledge flow system within this integration framework. In this study, the enterprise knowledge innovation rate and research and development (R&D) investment-such as enterprise profits and the number of R&D personnel-are selected as the regulatory variables for enterprise knowledge innovation motivation. By altering the parameters of these regulatory variables, we examine the trends in changes in the relevant output variables under the influence of enterprise innovation motivation. In the enterprise innovation motivation scenarios, the parameter values for the enterprise knowledge innovation rate and R&D investment are presented below. Specifically, in Scenario 1, both the enterprise knowledge innovation rate and R&D investment are increased by 20%, while in Scenario 2, these values are increased by 40%. The simulation results for the enterprise innovation motivation scenario are illustrated in Fig. 9.

As shown in Fig. 9, enhancing the enterprise knowledge innovation rate and R&D investment leads to increases in the knowledge stock and knowledge innovation amounts of both enterprises and universities, along with a rise in the knowledge interaction facilitated by the integration of industry and education. With the gradual improvement of enterprise innovation levels and investments, there is a significant enhancement in enterprise knowledge stock and knowledge innovation. Additionally, there is a corresponding increase in university knowledge stock, university knowledge innovation, and the knowledge interaction between industry and education to some extent. This indicates that enterprise innovation motivation factors drive the flow of knowledge within the system not only by enhancing enterprise knowledge innovation, knowledge stock, and the integration of industry and education knowledge interaction but also by improving university knowledge innovation and knowledge stock to some degree. The increase in university knowledge innovation correlates positively with enterprise innovation levels and investments. This result underscores the importance of improving enterprise innovation levels and research funding as instrumental to fostering knowledge interactions between universities and enterprises, thereby effectively promoting the development of the knowledge flow system underlying the integration of industry and education in the Yangtze River Delta.

Furthermore, it is evident from the trends depicted in Fig. 9 that the growth rates of the curves in Scenario 2 surpass those in Scenario 1, with the differences being most pronounced in the trends of enterprise knowledge innovation and knowledge stock. This indicates that enterprise knowledge innovation and knowledge stock are particularly sensitive to changes in enterprise innovation motivation factors. In the context of industry and education integration, it is crucial not only to enhance knowledge innovation rates but also to increase investments in research and development, thereby augmenting the knowledge stock of innovative entities. This approach fosters greater knowledge value creation and more effectively facilitates the knowledge flow process.

3.5. Analysis of Knowledge Interaction Environment Dynamics

3.5.1. Knowledge Interaction Environment Dynamics Scenario 1 and 2

The analysis of knowledge interaction environment dynamics is based on the baseline scenario, wherein we examine the impact of alterations to the parameters of the regulatory variables associated with the knowledge interaction environment on the development of the knowledge flow system for the integration of industry and education. In this study, digital connectivity and policy support are selected as regulatory variables for the knowledge interaction environment dynamics. By increasing these regulatory variables by 20% (Knowledge Interaction Environment Dynamics Scenario 1) and 40% (Knowledge Interaction Environment Dynamics Scenario 2) respectively, we investigate the trends of the relevant output variables in these scenarios. Specifically, in Scenario 1, both digital connectivity and policy support are increased by 20% for simulation purposes, while in Scenario 2, these values are elevated by 40%. Additionally, in Digital Environment Dynamics Scenario 3, only the digital connectivity variable is increased by 40%, and in Policy Environment Dynamics Scenario 4, only the policy support variable is raised by 40%.

The comparisons of the values of digital connectivity and policy support between Knowledge Interaction Environment Dynamics Scenarios 1 and 2 and the baseline scenario are presented in Table 6. The simulation results for these scenarios are illustrated in Fig. 10.

Table 6. Comparison of data between the baseline scenario and knowledge interaction environment dynamics scenarios.

Year	Digital Connectivity			Policy Support Level		
	Baseline Scenario	Scenario 1	Scenario 2	Baseline Scenario	Scenario 1	Scenario 2
2015	0.000	0.000	0.000	0.405	0.486	0.567
2016	0.097	0.117	0.136	0.152	0.183	0.213
2017	0.091	0.109	0.127	0.000	0.000	0.000
2018	0.176	0.211	0.246	0.363	0.436	0.508
2019	0.333	0.400	0.467	0.186	0.224	0.261
2020	0.408	0.490	0.571	0.532	0.638	0.744
2021	0.473	0.567	0.662	0.823	0.988	1.153
2022	0.519	0.623	0.727	0.389	0.467	0.545
2023	1.000	1.200	1.400	0.436	0.523	0.610
2024	0.547	0.656	0.765	0.483	0.580	0.676
2025	0.547	0.656	0.765	0.530	0.636	0.742
2026	0.547	0.656	0.765	0.577	0.692	0.808
2027	0.547	0.656	0.765	0.624	0.749	0.874
2028	0.547	0.656	0.765	0.671	0.805	0.939
2029	0.547	0.656	0.765	0.718	0.862	1.005
2030	0.547	0.656	0.765	0.765	0.918	1.071
2031	0.547	0.656	0.765	0.812	0.974	1.137
2032	0.547	0.656	0.765	0.859	1.031	1.203
2033	0.547	0.656	0.765	0.906	1.087	1.268
2034	0.547	0.656	0.765	0.953	1.144	1.334
2035	0.547	0.656	0.765	1.000	1.200	1.400

As shown in Fig. 10, with the gradual improvement of the regulatory variables related to the knowledge interaction environment dynamics in the Yangtze River Delta, there is a noticeable increase in the stock of knowledge held by universities, the stock of knowledge held by enterprises, as well as the knowledge innovation output from both universities and enterprises. Additionally, the volume of knowledge interaction within the integration of industry and education also exhibits a marked increase. This indicates that the dynamics of the knowledge interaction environment in the Yangtze River Delta primarily drive the development of the knowledge flow system for the integration of industry and education by enhancing the aforementioned factors. Comparing the simulation time points at which there is a significant increase in knowledge stock, knowledge innovation, and knowledge interaction, we observe that the volume of knowledge interaction in the integration of industry and education shows a notable increase relatively early in the timeline. This suggests that digital technologies and policy support exert a direct influence on knowledge interaction activities within the integration of industry and education, thereby elevating the level of knowledge flow in this context.

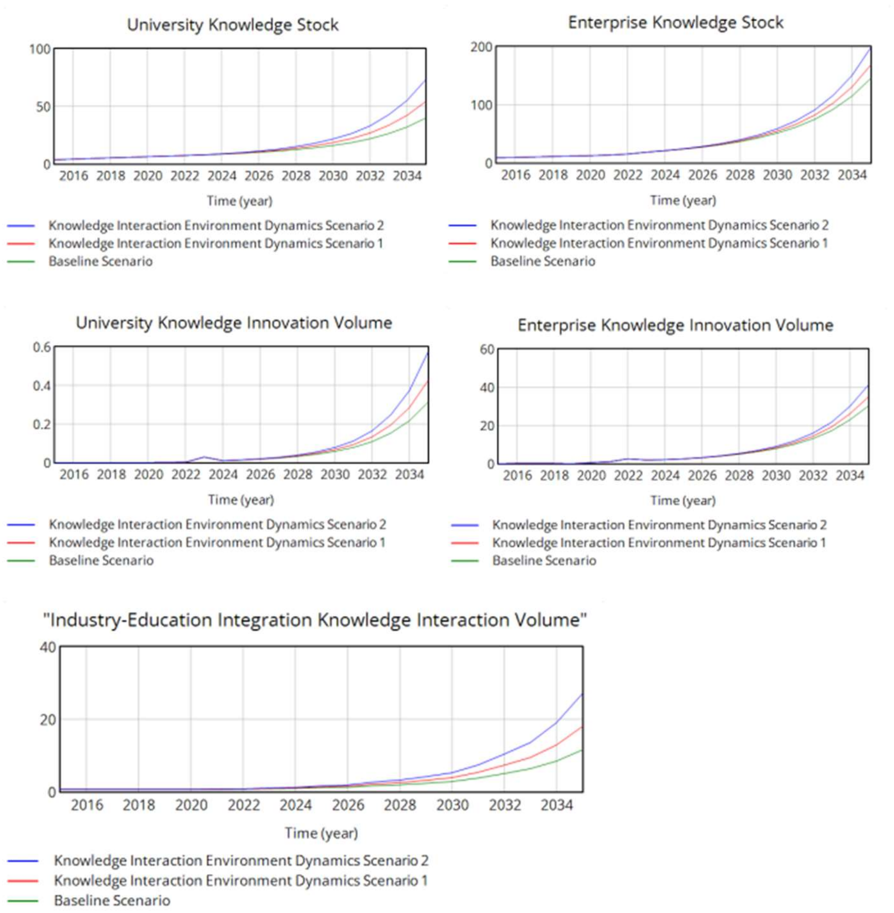

Fig. 10 Simulation results of knowledge flow system of industry-education integration under dynamic scenario of knowledge interaction environment.

In analyzing the curves depicted in Fig. 10, it is evident that the growth trends in Scenario 2 surpass those in Scenario 1 across all metrics, with the trends for knowledge innovation output from universities, knowledge stock held by universities, and knowledge interaction in the integration of industry and education being particularly pronounced. This underscores that improvements in the knowledge interaction environment can facilitate growth in both the knowledge stock and knowledge innovation output at universities, as well as an increase in knowledge interaction within the integration of industry and education. Furthermore, the sensitivity of these factors-knowledge innovation output from universities, knowledge stock held by universities, and the volume of knowledge interaction-is highest in response to changes in the knowledge interaction environment dynamics. In the context of the integration of industry and education, universities and enterprises should not only enhance their own levels of knowledge innovation but also significantly increase their interactions with external knowledge environments. This will promote collaboration and exchanges between universities and enterprises, thereby enhancing knowledge interaction and further deepening the regional integration of industry and education.

3.5.2. Digital Environment Dynamic Scenario 3

The analysis of the digital environment dynamics scenario focuses on the impact of digital connectivity on the input variables of the system from a digital perspective. The digital connectivity indicator is assessed from two dimensions: industrial digitalization and regional digital infrastructure. In this scenario, digital connectivity serves as the regulatory factor. By increasing the regulatory factor by 40% while keeping other parameters constant, we aim to observe the trends in the output variables. The configuration of scenario parameter variations is represented by the following equation, and the trends in the output variables are illustrated in Fig. 11.

Digital Connectivity (Digital Environment Dynamic Scenario 3) = WITH LOOKUP(Time,([(2015,0)-(2035,2)],(2015,0),(2016,0.136),(2017,0.127),(2018,0.246),(2019,0.467),(2020,0.571),(2021,0.662),(2022,0.727),(2023,1.400),(2024,0.765),(2025,0.765),(2026,0.765),(2027,0.765),(2028,0.765),(2029,0.765),(2030,0.765),(2031,0.765),(2032,0.765),(2033,0.765),(2034,0.765),(2035,0.765)))

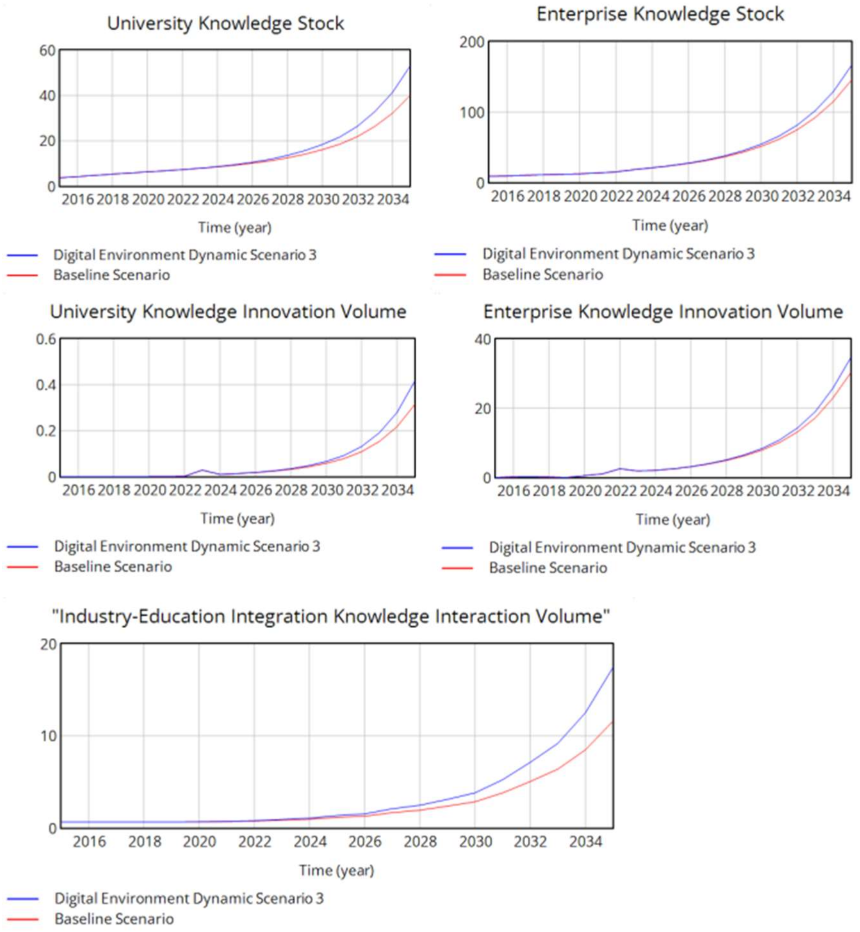

Fig. 11 Simulation Results of the Industry-Education Integration Knowledge Flow System under Digital Environment Dynamic Scenario 3.

As shown in Fig. 11, an increase in the digital environment dynamic factor corresponds to a rise in the values of the system's output variables. The advancement of digital technologies often brings developmental opportunities, and the level of industrial digitalization and digital infrastructure construction in a region to some extent reflects its potential for development in the digital era. The scenario simulation results indicate that improvements in digital connectivity lead to enhancements in the volume of knowledge interaction in the industry-education integration context, as well as increases in the knowledge stock and innovation output of higher education institutions. Although there is a relative improvement in enterprise knowledge innovation volume and stock, the degree of enhancement is comparatively smaller. Moreover, it is evident that as digital connectivity increases, the positive effects on the relevant output variables of the system also strengthen, particularly regarding the influence of digital environment factors on the volume of knowledge interaction in industry-education integration.

This finding suggests that enhancing the digital environment factors will significantly increase the frequency of knowledge interactions between higher education institutions and enterprises, while also reinforcing the overall development of the industry-education integration knowledge flow system. It underscores the necessity and importance of industrial digitalization and the establishment of digital technology infrastructures for regional industry-education integration. Therefore, establishing and improving digital interaction platforms, promoting collaborative projects between universities and enterprises, as well as facilitating the exchange of internship opportunities and employment information are essential steps to enhance digital connectivity. These initiatives will not only boost students' employability but also enable enterprises to stay informed about talent market conditions and demand fluctuations in a timely manner.

3.5.3. Policy Environment Dynamic Scenario 4

The analysis of the policy environment dynamics scenario examines the impact of policy support from government and other organizations on the system's knowledge flow and innovation development. In this scenario, the level of policy support is designated as the regulatory factor. We have established a range of values for this regulatory variable, as indicated in the following equation. The trends in the output variables are illustrated in Fig. 12.

Policy Support Level (Policy Environment Dynamic Scenario 4) = WITH LOOKUP(Time,([(2015,0)-(2035,2)],(2015,0.567),(2016,0.213),(2017,0),(2018,0.508),(2019,0.261),(2020,0.744),(2021,1.153),(2022,0.545),(2023,0.610),(2024,0.676),(2025,0.742),(2026,0.808),(2027,0.874),(2028,0.939),(2029,1.005),(2030,1.071),(2031,1.137),(2032,1.203),(2033,1.268),(2034,1.334),(2035,1.400)))

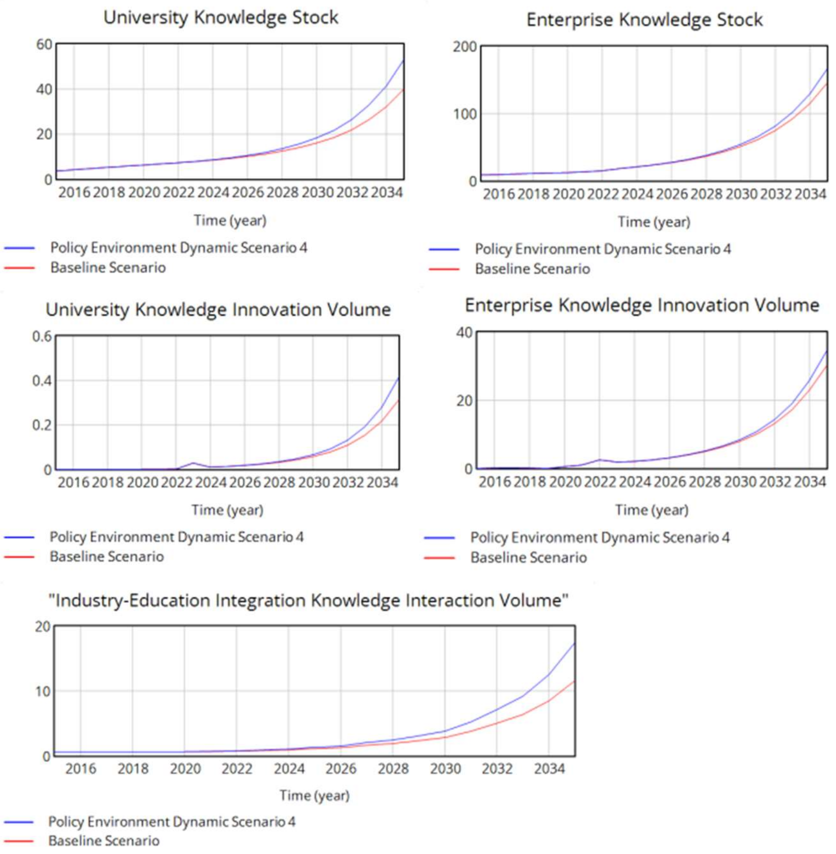

Fig. 12 Simulation Results of the Industry-Education Integration Knowledge Flow System under Policy Environment Dynamic Scenario 4.

As shown in Fig. 12, when the level of policy support increases, the output variables of the system significantly rise, with the most substantial effects observed on the volume of knowledge interaction in industry-education integration and the knowledge stock of higher education institutions. On one hand, policy support can provide essential financial assistance to both parties through funding, scholarships, and project grants. This financial support facilitates collaborative projects between enterprises and educational institutions, enhances interaction frequency, and promotes knowledge sharing and exchange. On the other hand, policy support encourages innovative collaborations between universities and enterprises, facilitating the transformation of research outcomes. Policies can guide joint participation in technology research and development as well as research projects, thereby promoting knowledge innovation and resource accumulation within higher education institutions.

From the perspective of the impact pathways of the knowledge interaction environment dynamic regulatory variables on the development of the industry-education integration knowledge flow system, digital connectivity is a variable within the digital empowerment subsystem, while policy support is a variable within the policy regulation subsystem. Consequently, both have a marked influence on the relevant variables in these subsystems. The simultaneous increase in the levels of digital connectivity and policy support promotes improvements in the knowledge interaction environment of the industry-education integration system, subsequently enhancing the volume of knowledge interaction, innovation output, and knowledge stock. Furthermore, compared to traditional knowledge interaction mediums, digital technologies facilitate smoother communication between universities and enterprises, resulting in a more transparent industry-education integration process. This accelerates the flow of knowledge among stakeholders and rejuvenates the knowledge flow ecosystem, thereby adding value to the knowledge resources during this process. The level of policy support further enhances the engagement and initiative of participants in the industry-education integration process through policy incentives, fostering an increase in knowledge interaction, innovation output, and knowledge stock, thus positively contributing to the industry-education integration knowledge flow system.

In assessing the degree of impact from the knowledge interaction environment dynamic regulatory variables on the development of the industry-education integration knowledge flow system, we observe that the improvements from Knowledge Interaction Environment Scenario 1 and Scenario 2 are equivalent (with Scenario 1 improving by 20% from the baseline scenario and Scenario 2 also improving by 20% from Scenario 1, each resulting in a 20% enhancement), yielding similar levels of improvement in knowledge stock and innovation output for both universities and enterprises, as well as in the volume of knowledge interaction. When comparing these simulation results with those of the Higher Education Innovation Dynamics Scenario and the Business Innovation Dynamics Scenario, it becomes evident that the improvement in the volume of knowledge interaction within this scenario significantly exceeds that of the Higher Education Innovation Dynamics Scenario and is slightly higher than that of the Business Innovation Dynamics Scenario.

These results indicates that the impact of the knowledge interaction environment dynamics on the development of industry-education integration in the Yangtze River Delta region is stronger than that of the higher education and business innovation dynamics. Overall, the industry-education integration knowledge flow system exhibits high sensitivity to the knowledge interaction environment factors and enterprise innovation dynamics, while the importance of higher education and business innovation dynamics primarily lies in offsetting the inadequacies in knowledge innovation and value-added drivers stemming from the knowledge interaction environment.

4. Conclusion and Discussion

4.1. Conclusion

The integration of industry and education in regional knowledge flow represents a complex and organic system that continuously evolves and functions in an orderly manner. The driving factors behind this system are worthy of in-depth analysis and research. This paper employs a system dynamics approach to construct a model for knowledge flow integration between industry and education in the Yangtze River Delta region. We conducted simulations and analyses of four driving scenarios-baseline scenario, university innovation-driven scenario, enterprise innovation-driven scenario, and knowledge interaction environment-driven scenario-revealing the dynamic evolution characteristics of the development level of the knowledge flow integration system over time. Additionally, we compared the effects of different critical driving factors on the development of this system, while also analyzing the reasons for the variations in simulation results across different scenarios. The findings not only enhance the theoretical framework related to the system dynamics of knowledge flow but also provide insights for the practical development of industry-education integration in the Yangtze River Delta.

The main conclusions are as follows:

- Under the status quo continuity development model, the overall trend of the comprehensive development level of knowledge flow integration in the Yangtze River Delta is positive, as evidenced by the increasing interactions of industry-education knowledge, university knowledge stock, and enterprise knowledge stock, with the growth rate accelerating over time.
- The endogenous innovation drivers (factors related to university and enterprise innovation) primarily promote the development of knowledge flow integration in the region by improving the total knowledge resources of the innovation entities (university knowledge stock and enterprise knowledge stock).
- The exogenous innovation drivers (digital environment and policy environment factors) propel the development of knowledge flow integration mainly by enhancing the total knowledge resources of the innovation entities (university knowledge innovation, university knowledge stock, enterprise knowledge innovation, and enterprise knowledge stock) and facilitating regional knowledge synergies (industry-education knowledge interactions). Notably, university knowledge innovation, university knowledge stock, and industry-education knowledge interactions exhibit the highest sensitivity to changes in the knowledge interaction environment driver.
- The impact of exogenous innovation drivers (digital environment and policy environment factors) on enhancing university-enterprise knowledge interactions is significantly stronger than that of endogenous drivers (university innovation factor).
- The university innovation factor (university knowledge innovation rate and research funding) primarily drives the development of knowledge flow integration in the region by enhancing the total volume of university knowledge resources (university knowledge innovation and university knowledge stock), rather than by improving regional knowledge interactions.
- The enterprise innovation driver (enterprise knowledge innovation rate and R&D

investment) not only advances the development of knowledge flow integration by increasing the total volume of enterprise knowledge resources (enterprise knowledge innovation and enterprise knowledge stock) and facilitating regional knowledge interactions (industry-education knowledge interactions) but also contributes to enhancing the total volume of university knowledge resources (university knowledge innovation and university knowledge stock).

- The effects of the digital environment factor (digital connectivity) and the policy environment factor (policy support) on enhancing university-enterprise knowledge interactions are comparable, indicating that regional policy support and digital technology support play equally important roles in driving the development of the knowledge flow integration system in the region.

4.2. Management Implications

The analysis suggests that that the development of industry-education integration can only be realized through the establishment of a clearly defined policy support framework, the strengthening of academic cooperation, and the implementation of digital intelligence technologies. Relying solely on "knowledge innovation" and innovation investment from either higher education institutions or enterprises is insufficient to promote deep integration within the regional industry-education landscape. Therefore, in the knowledge management process of industry-education relationships, while higher education institutions and enterprises focus on their own innovative development and collaborative exchanges, the government must also play a crucial role in macro regulation to guide the deep integration and collaborative innovation of regional industries and education. On one hand, the government should establish a more comprehensive and flexible policy support system to facilitate the efficient flow and sharing of knowledge. This can be achieved by setting up special funds, encouraging projects that combine research with practical applications, and creating collaborative platforms with multi-party participation, thereby providing essential resources and support for higher education institutions and enterprises within the region, enhancing their engagement and creativity in industry-education integration.

On the other hand, reinforcing the application of digital technologies is equally vital. The government should actively promote the digital transformation of education, encouraging higher education institutions and enterprises to leverage the latest technological means to create and share knowledge. This includes the development of online learning platforms, smart campuses, and enterprise training systems to establish a more open and flexible learning environment. Such a digitized collaborative model can effectively reduce temporal and spatial constraints, facilitating the rapid movement of knowledge among various stakeholders and ultimately improving the quality and efficiency of industry-education integration. In summary, achieving effective industry-education integration requires not only the concerted efforts of higher education institutions and enterprises but also a key role for the government in policy guidance, resource allocation, and the application of digital technologies. Only through multi-party collaboration in constructing an ecosystem that embodies innovative thinking and practice can we genuinely realize the efficient development of regional knowledge flow, drive progress in both the economy and education, and nurture more high-quality talents for society.

4.3. Discussion

This study lays a theoretical foundation for knowledge management between higher education institutions and enterprises. By analyzing the knowledge interactions among stakeholders in industry-education integration, this research unveils the dynamic mechanisms and evolutionary pathways of cross-organizational knowledge flow, deepening our understanding of knowledge movement within the context of industry-education collaboration, thus fostering an innovative cooperative environment conducive to integration. The comparative analysis of different driving factors in the development of regional knowledge flow systems is often overlooked in previous studies. The findings of this research not only corroborate the viewpoint that "an effective policy framework is crucial for facilitating knowledge flow in the integration of industry and education" [48-49], but also stimulate thinking on "how digital technologies can transform educational frameworks to promote richer knowledge exchange between academia and industry." In addition, the proposed model serves as an advanced tool for investigating complex knowledge flow systems. This model can also act as a template, demonstrating the concepts and potential applications of System Dynamics (SD) in other research domains.

It is important to note that the system dynamics model developed in this study provides a high-level abstraction of the driving mechanisms behind the development of knowledge flow integration between industry and education. Given the inherent complexity of real-world systems, some simplifications were inevitably necessary. However, numerous complexities and uncertainties present in actual systems have not been fully accounted for, indicating that there is significant room for further expansion and improvement of the model. Future research should focus on optimizing and validating the model’s applicability. For instance, this model simplifies the role of digital technology and policy support factors in the integration of industry and education, and it inadequately considers the endogenous variables related to university and enterprise innovation. Future studies should aim to identify the core factors that affect knowledge flow integration in this region and clarify the intricate relationships among these factors. This will facilitate the construction of a simulation model that more closely aligns with real-world conditions. In addition, considering more specific case data related to industry-education integration and knowledge management is also an area that requires further exploration in the future.

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