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Article

The Interaction Mechanism and Dynamic Evolution of Digital Green Innovation in the Integrated Green Building Supply Chain

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Abstract: Although building enterprises are actively developing towards the direction of an integrated building supply chain (IBSC), they still face many difficulties in digital green innovation (DGI) activities. The purpose of this study is to reveal the interaction mechanism between the digital integration degree, green knowledge collaboration ability, and the DGI performance of IBSC enterprises in DGI activities under the influence of environmental characteristics of the integrated supply chain. In this study, firstly, a hierarchical regression method and a structural equation model are used to empirically study the static mechanism of DGI among enterprises in the IBSC. Secondly, this study adopts a complex system theory to construct a logistic dynamic analysis model to explore a dynamic evolution mechanism. The results of the study are as follows. (i) The digital integration degree and green knowledge synergy ability of the IBSC are conducive to improvements in digital green innovation performance among the enterprises involved in this chain. The digital integration degree of this chain is the dominant factor affecting the performance of digital green innovation among these enterprises. (ii) The digital network capability of this chain has a significant impact on its digital integration degree but has no significant effect on green knowledge synergy ability. The quality of digital relationships in the IBSC affects both the digital integration degree and green knowledge synergy ability. It has a higher impact on the digital integration degree than on the synergy ability of green knowledge. The resilience of the IBSC can effectively promote the improvement of digital integration and green knowledge synergy ability, but has no significant effect on digital green innovation performance. (iii) In the early stage of an IBSC, the effect of the digital integration degree on DGI performance is more obvious. Over the long term, under the effect of different digital relationship qualities of the IBSC, green knowledge collaboration ability plays a pivotal role. Improving this ability is conducive to the continuous improvement of DGI performance.

Keywords: building supply chain; integrated supply chain; digital innovation; green innovation; digital green innovation performance

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1. Introduction

In recent years, with the continuous and rapid development of the economy, the pressure on resources and environment has been increasing day by day. People pay more attention to the coordinated and sustainable development of the economy and the environment [1]. However, traditional building supply chain (BSC) management only considers the maximization of the interests of enterprises in the supply chain and does not consider how to treat, recycle, and reuse the waste and emissions of products [2]. Such a practice is not conducive to resource conservation and environmental protection. In this case, the BSC is gradually becoming green. At the same time, with the application of artificial intelligence, blockchain, the Internet of Things, and other new technologies, digitalization not only improves the efficiency of the supply chain and reduces the operating cost of enterprises, but also provides a more optimized decision-making basis for enterprises to formulate the overall industrial development strategy [3]. Entering the digital era, as an important pillar of the economic industry, the construction industry has also begun to actively promote the digital transformation, taking the digital supply chain as a breakthrough, to promote the transformation and upgrading of bilateral customers in the supply chain [4]. With the promotion of green transformation and digital transformation in the construction industry, on the one hand, due to the complexity of the cooperation environment, the instability of the development of digital green innovation (DGI) among building enterprises is enhanced, and the breadth and depth of the development of DGI are greatly affected [5]. On the other hand, under the environment of dynamic demand, it has become a difficult problem for BSC enterprises to develop personalized and diversified products [6]. Therefore, how to promote the development of DGI among building enterprises and meet the dynamic demand of consumers has become an important issue to be urgently solved. An integrated BSC is a relatively stable and durable cooperative relationship between building enterprises based on mutual trust [7]. With the deep integration of the BSC with the Internet and the Internet of Things, this relationship is constantly strengthened. Resource sharing among integrated BSC (IBSC) enterprises has gradually become the new normal [8]. The development of DGI among these enterprises has gradually become a suitable DGI mode. It can maximize the realization of resource sharing, complementary advantages, joint risk sharing, and achievement sharing. DGI among IBSC enterprises can help them integrate internal and external technical resources, reduce the cost and risk of DGI through upstream and downstream multi-party cooperation, achieve personalized and diversified products and solutions, and meet the dynamic needs of consumers [9].

Previous research has been biased towards a circular economy, social performance, and cooperation. A circular economy brings risks and opportunities to various stakeholders [10]. Improvement in social performance and innovation is rapidly developing an area of research [11]. Research on the factors affecting the improvement of social performance can effectively promote the development of enterprises [12]. The researchers found that managers can promote sustainable innovation through customer collaboration [13]. At the same time, green thinking and creative processes are important [14]. On this basis, more and more scholars are committed to the development of an IBSC. DGI among BSC enterprises has become a hot topic of research by experts and scholars. The research literature includes many concepts such as digital green research and development activities [15], as well as digital green alliance [16,17]. In terms of research fields, it mainly focuses on the evaluation and improvement of DGI capability among BSC enterprises [18], the knowledge spillover effect of DGI [19], the selection of DGI partners [20,21], and the perspective of knowledge management [22,23]. In terms of research scope, DGI is mainly focused on industry–university–research cooperation with industries, schools, and scientific research institutions [24]. There are few studies on DGI among IBSC enterprises, and even fewer studies on the mechanism and dynamic evolution of DGI among those enterprises. Research data on DGI among BSC enterprises mainly come from panel data and questionnaire data. Research on DGI among IBSC enterprises mainly relies on cases. Both of them use mathematical statistics to study the static mechanism of DGI among building enterprises, which lacks a certain timeliness and predictability. IBSC enterprises are also gradually carrying out DGI activities. Sichuan Huaxi Gathering E-commerce Co., Ltd. (Chengdu, China) is an industrial Internet platform company specializing in construction industry supply chain services and is also one of the earliest IBSC management companies in China. The company relies on the stable procurement demand and high-quality and reliable supplier resources of Huaxi Group to integrate supply chain resources. It has built an e-commerce platform focusing on the procurement of materials in the construction industry, integrating electronic bidding, online trading, logistics supervision, capital settlement, financing services, inventory management, and other multi-dimensional digital supply chain businesses. In this way, information flow, capital flow, business flow, and logistics are integrated. Build Cloud is a digital supply chain platform for construction enterprises. The platform constructs the technical architecture of "one network, three databases and many systems". Among them, "one net" refers to the construction digital supply chain website. "Three databases" refers to a supply and demand information database, a supplier management database, and a price index database. "Multi-system" refers to business support systems such as a source search system, a contract performance system, an inventory management system, a financial support system, an electronic invoice system, a mobile collaborative application system, a big data analysis system, and a supply chain financing service system. These run through the entire chain of the IBSC and, with the support of platform technology, jointly build the digital ecology of the industry and promote the development of the supply chain. Therefore, in this case, the research on the dynamic mechanism of DGI among IBSC enterprises can make up for the above research deficiencies. At the same time, this research can optimize BSC management, strengthen DGI among IBSC enterprises, and improve enterprise innovation efficiency. This research has high practical significance in promoting the innovation and development of the BSC.

In this study, a hierarchical regression method and a structural equation model are used to empirically study the static mechanism of DGI among IBSC enterprises. On this basis, by referring to the B–Z reaction model in the complex system theory, this study constructs a three-dimensional logistic dynamic analysis model to explore the dynamic evolution law of a DGI system among IBSC enterprises. This study will try to improve the methodology of such a DGI system and reveal the mechanism of the digital integration degree, green knowledge collaboration ability, and DGI performance in DGI activities among IBSC enterprises under the influence of its environmental characteristics. This provides direction and strategy for improving the performance of DGI among these enterprises.

The rest of this paper is as follows. Section 2 explores the formation mechanism of DGI among IBSC enterprises. The research hypotheses are clarified in Section 3. Section 4 describes the research design. Section 5 presents the static mechanism research of DGI. The research on the dynamic mechanism of DGI in IBSC is presented in Section 6. Conclusions and future prospects are presented in Section 7.

2. Interaction Mechanism of DGI

Building supply chain (BSC) management is a management mode that considers construction-related products as the core and connects suppliers, assemblers, distributors, and users of the entire BSC together through logistics, information flow, and capital flow [25]. An integrated BSC (IBSC) is the core and final development stage of BSC management [26]. An IBSC jointly manages the internal and external activities of enterprises and connects the supply and demand sources of the entire BSC together through efficient product flow, service flow, information flow, capital flow, and decision flow, so as to create maximum value for customers [27]. From this point of view, integration has broken through the limited and short-term cooperation relationship. On the basis of information resource sharing, enterprises jointly promote the efficient and orderly operation of the entire BSC through synchronized, shared, and integrated planning and control systems [28]. An IBSC is the continuous deepening and extension of the internal integration of enterprises. It is an optimization process from internal integration to external integration, from local integration to overall integration, and realizes the optimization of the integration of various resources and the management mode of the building industry chain. Therefore, the IBSC is a relatively stable and durable cooperation relationship between enterprises based on mutual trust. Through supplier collaboration, production collaboration, and demand collaboration, the IBSC links enterprises together, laying the organizational foundation for DGI among IBSC enterprises. At the same time, the IBSC uses product flow, service flow, information flow, capital flow, and decision flow to integrate and optimize, and uses the technology transfer flow to eliminate the non-value-added operations in the business process, laying the business foundation for DGI among IBSC enterprises. The IBSC structure model constructed in this paper is shown in Figure 1.

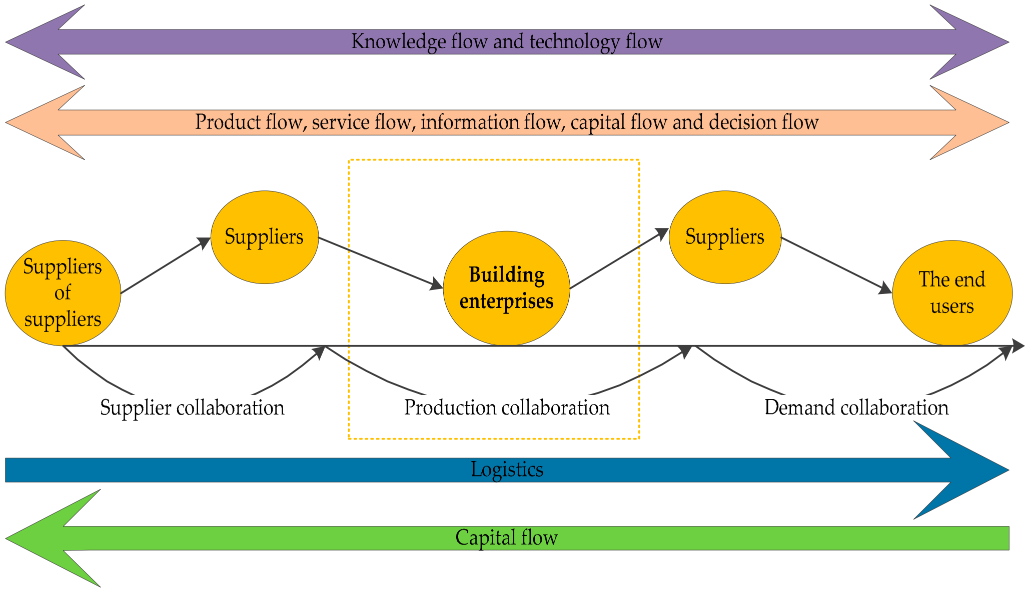

Figure 1. The IBSC structure model.

Under the relationship of the IBSC, enterprises form a strategic cooperative relationship through product flow, service flow, information flow, capital flow, decision flow, knowledge flow, and technology flow, which can realize information sharing and resource complementarity [29]. However, in the complex and changeable market environment, the gradual shortening of the life cycle of construction products and the increasing risk of scientific and technological innovation aggravate the situation in which most building enterprises cannot carry out digital green technology research and development activities alone. DGI among building enterprises has become an inevitable choice for digital green technology innovation. The integration of building enterprises and suppliers can help the former share the research and development capabilities of the latter, reduce the research and development investment of the enterprises, enhance the coordination degree of product design and process design of both sides, and accelerate the process of DGI [30]. An IBSC is conducive to knowledge transfer among building enterprises. Through knowledge transfer, such enterprises can more reasonably and effectively link resources, research, and development production with market demand. A knowledge chain is a cross-organizational consortium, including the suppliers, customers, and competitors of building enterprises [31]. BSC collaboration is an interconnected component of information sharing, goal alignment, knowledge sharing, and knowledge creation among building enterprises. All aspects are related to each other and co-vary. The DGI ability of building enterprises can be improved by reducing activity costs and improving resource efficiency [32]. It seems that, in the construction of an integrated supply chain, a building enterprise is no longer an independent DGI main body, but rather becomes a digital green technology transfer node in a network of BSCs. Digital green technologies will be transferred from a building in the supply chain, i.e., a node, to other nodes, and technology transfer inevitably causes the flow of knowledge. The flow of knowledge among IBSC enterprises has become the core of DGI. In this way, the cooperation of an IBSC is a collaboration among building enterprises on knowledge flow, and the core of DGI among building enterprises is green knowledge collaboration.

Based on the above analysis, this article describes the DGI mechanism of IBSC enterprises as the environmental characteristics of the IBSC, the digital integration degree of the IBSC, green knowledge collaboration, and DGI performance. The digital integration degree is an important part of this kind of collaboration among enterprises. The core enterprises in the BSC and the integration of suppliers based on procurement stability, business participation, production and sales, and the integration of customers based on market and customer demand, production, and sales together constitute the IBSC. The digital network capability, the digital relationship quality, and the environmental characteristics of toughness in the BSC are helpful to the main integration of the BSC, which is the power and support to promote the evolution of the main integration of the BSC. The knowledge flow among building enterprises forms a knowledge chain. The mechanism is formed through a synergy effect. The synergy of product flow, service flow, information flow, capital flow, decision flow, knowledge flow, and technology flow among BSC enterprises is mainly manifested as green knowledge collaboration in the knowledge chain. This collaboration is realized among IBSC enterprises through knowledge sharing, knowledge absorption, and knowledge innovation. Therefore, under the joint action of the environmental characteristics of the IBSC, the digital integration degree in the IBSC, and green knowledge collaboration, the IBSC realizes DGI among enterprises. The effect of DGI is mainly measured from the aspect of DGI performance. The formation mechanism of DGI among IBSC enterprises is a dynamic and complex process. DGI among IBSC enterprises highlights the knowledge among building enterprises from disorder to order, from difference to coordination, so as to realize the nonlinear effect of 1 + 1 > 2. At the same time, the formation of DGI among IBSC enterprises contributes to the knowledge flow and knowledge innovation among building enterprises. It is also affected by the diversity, flow, nonlinear interaction, and other characteristics of the BSC environment. The interaction and cooperation among IBSC enterprises has a special mechanism of action in the sharing, complementarity, and integration degree of information resources among building enterprises. In this paper, a conceptual model of the formation mechanism of DGI among IBSC enterprises is constructed, as shown in Figure 2.

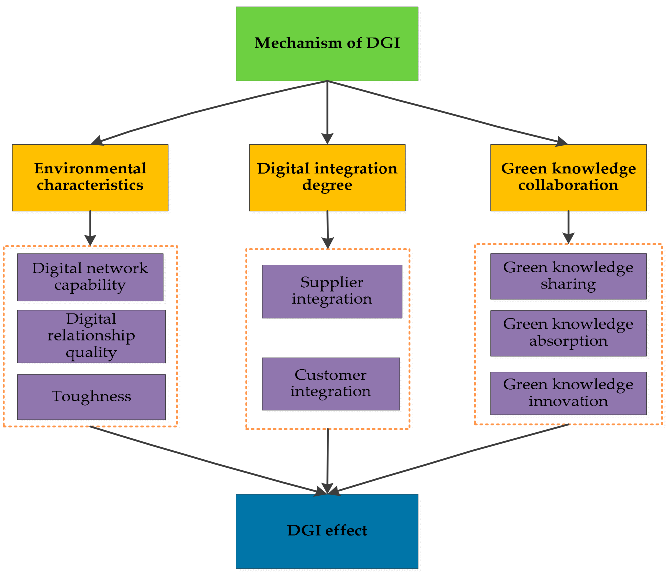

Figure 2. The theoretical model of the DGI mechanism among IBSC enterprises.

3. Hypotheses

The digital network capability among BSC enterprises is a complex organizational relationship [33]. The greater the digital network capability, the more network relations among building enterprises, the more resources embedded in the network relations, and the richer the knowledge resources among enterprises, which is conducive to the knowledge exchange among building enterprises. Digital network capabilities can help enterprises acquire key knowledge from external sources, thus improving DGI performance. This is because, with the acquisition, absorption, and application of external key knowledge, factors such as the cost of opening and absorption promote the improvement of DGI performance of building enterprises [34]. Openness and cooperation play a significant role in improving the performance of DGI, but we must pay attention to the search and application of digital green knowledge in the process of cooperation [35,36]. Building enterprises with more partners can help them obtain digital green resources from the outside and have a richer understanding of internal and external digital green resources. The more partners there are, the richer the understanding of digital green resources, and the more opportunities there are to evaluate partners. This, to some extent, increases the number of strategic alliance partner selection evaluations. At the same time, on the basis of a certain digital relationship quality, product flow, service flow, information flow, capital flow, and decision flow among building enterprises continue to penetrate. This improves the accuracy of obtaining key digital green knowledge resources between core building enterprises, suppliers, and customers and strengthens the digital integration degree between them [37].

Specifically, when the digital network capability of a BSC is low, the number of networks among building enterprises is small and the stability is good, which is helpful for knowledge sharing and knowledge absorption among building enterprises and the formation of various flows. When the capability of a digital network becomes stronger, the number of connected networks among building enterprises is larger. In order to maintain the stability among BSC enterprises, enterprises need to select strategic cooperative alliance partners from the BSC as well as form and promote the collaborative and dynamic development of green knowledge among building enterprises on the basis of knowledge sharing and knowledge absorption [38]. This has a positive impact on the improvement of technology and DGI performance. Various information flows create a good environment for the formation of the IBSC and contribute to the improvement of DGI performance [39].

Based on the above analysis, this study puts forward the following hypotheses:

H1. *There is a positive relationship between digital network capability and green knowledge collaboration among IBSC enterprises.*

H2. *There is a positive correlation between digital network capability and the digital integration degree among IBSC enterprises.*

H3. *There is a positive correlation between digital network capability and DGI performance among IBSC enterprises.*

The digital relationship quality of a BSC is formed in a digital trade behavior. It meets the requirements of BSC partners and the degree of dependence of these partners on future behavior choices [40]. It includes six aspects: service, communication, commitment, satisfaction, trust, and cooperation. Five aspects can be selected to measure digital relationship quality: communication, cooperation, atmosphere, trust, and adaptability. Digital relationship quality is not only included in the behavioral factors of relationships, but also involves environmental and contingency factors [41]. Therefore, the digital relationship quality of a BSC includes two aspects: a digital relationship occurrence process and a digital relationship interaction environment. The former includes the use of digital technology for communication, trust, cooperation, and conflict resolution, while the latter uses digital technology to adapt to the environment and regulate the relationship between building enterprises. These two aspects create a good environment for procurement stability, business participation, production, and sales in the BSC, and promote the digital integration of the BSC with suppliers and customers [42]. In terms of knowledge management and digital relationship quality, the digital relationship quality and relationship stability of building enterprises have a positive effect on the acquisition of digital green knowledge, the improvement of DGI ability, and the DGI performance of building enterprises. When the knowledge is very complex, a strong relationship has a positive impact on the absorptive capacity of digital green knowledge, and a weak relationship is more beneficial to the cultivation of an absorptive capacity of building enterprises. Relationship governance plays a significant role in the strategic level of green knowledge coordination in the BSC, and a high external contractual relationship is not conducive to the realization of green knowledge coordination. A stronger DGI network relationship and a higher absorptive capacity can help improve the DGI performance of building enterprises. A strong digital network relationship has a positive effect on the absorptive capacity and a significant effect on improving the DGI performance of building enterprises. Absorptive capacity plays an incomplete mediating role between the two. Building enterprise managers actively investing in digital relationship quality can effectively improve a product's DGI performance [43]. Improving the quality of digital relationships between BSC enterprises is the main factor for the improvement of DGI ability. The effective management of the digital relationship quality of building suppliers has a positive impact on the improvement of the DGI ability of building enterprises. The construction of network relations among building enterprises can help improve this ability. The interaction between the research and development of new digital green products and customer relationship management plays an important role in improving the advantages of DGI.

Based on the above analysis, this study puts forward the following hypotheses:

H4. *There is a positive correlation between digital relationship quality and green knowledge collaboration in the IBSC.*

H5. *There is a positive correlation between digital relationship quality and the digital integration degree in the IBSC.*

H6. *There is a positive correlation between digital relationship quality and DGI performance in the IBSC.*

Their partners in the BSC can make quick and accurate decisions on the potential demand and risk, so as to achieve the effect of quickly meeting the needs of customers [44]. Building enterprises use the toughness of the BSC to improve the knowledge performance of building enterprises through efficient knowledge flow, knowledge sharing, and knowledge creation. Digital green knowledge sharing in the BSC has a direct impact on the performance of building enterprises. Environmental dynamics can positively and significantly regulate the relationship between the toughness of the BSC and enterprise performance. This toughness can speed up decision-making and has a significant effect on the improvement of strategic flexibility and dynamic capabilities of building enterprises. It also has a positive impact on the performance of building enterprises [45]. The realization of such toughness is conducive to knowledge sharing among BSC enterprises. Building enterprises can timely grasp the market demand information and the development trend of digital green technology through product flow, service flow, information flow, capital flow, and decision flow in the BSC. A rapid response is conducive to the formation of an IBSC. The toughness of a BSC strengthens the cooperation among building enterprises through the control of information flow, logistics, and capital flow, which plays an important role in the BSC management practice [46].

Based on the above analysis, this study puts forward the following hypotheses:

H7. *There is a positive correlation between toughness and green knowledge collaboration in the BSC.*

H8. *There is a positive correlation between toughness and the digital integration degree in the IBSC.*

H9. *There is a positive correlation between toughness and DGI performance in the IBSC.*

Green knowledge collaboration in an IBSC is a process of transformation from externalization to internalization. The BSC only provides an external green knowledge sharing platform. Building enterprises need to have certain absorption and integration capabilities to effectively use the acquired green knowledge [47]. Green knowledge sharing among BSC enterprises promotes the decision-making of building enterprises to be more scientific, reasonable, and effective and then improves the performance of building enterprises [48]. Green knowledge sharing and green knowledge collaboration can improve the performance of all members in the BSC and significantly improve the performance of the entire BSC. In the case of green knowledge sharing, the selection, absorption, and integration of green knowledge, green information, and other resources acquired by building enterprises are the key factors that determine the degree of improvement of DGI performance. A higher capacity for green knowledge absorption in a building enterprise can improve its DGI performance and result in competitive advantages for building enterprises. Green knowledge integration and innovation can make up for the lack of absorptive capacity [49]. Green knowledge innovation is a process of exploring new rules or creating new green knowledge under the collaborative nonlinear influence of green knowledge sharing, transfer, acquisition, integration, and application among BSC enterprises, so as to realize green knowledge coordination and knowledge transformation coupling among BSC enterprises [50]. In the process of green knowledge absorption and integration, green knowledge resources are oriented by customer demand, refined, and created at a higher level, and improve the overall competitive advantage of the BSC. Green knowledge collaboration among BSC enterprises can reduce the cost of green technology innovation and enable building enterprises to achieve excellent performance [51]. The green knowledge collaboration of a local BSC and a hyperlocal BSC can both help to improve the DGI performance of building enterprises. Green knowledge innovation is the final stage and the highest realm of green knowledge collaboration in the BSC.

The digital integration of the BSC can be divided into supplier digital integration, customer digital integration, and internal digital integration. The digital integration of a BSC promotes the alignment of BSC partners in three aspects, including the integration and coordination of information and resources, strategic cooperation among building enterprises, and the management of intra-organizational and cross-organizational processes. Three digital integrations can improve business performance in terms of cost, quality, ordering, and resilience. The digital integration of suppliers can help building enterprises share the DGI ability of suppliers, reduce the input of DGI of building enterprises, enhance the coordination degree of the product and process design of both sides, and accelerate the process of DGI [52]. BSC cooperation promotes the sharing of digital green knowledge and technology, which is conducive to improving the input–output benefits of the digital green products of building enterprises and improving the performance of their DGI [53].

Based on the above analysis, this study puts forward the following hypotheses:

H10. *There is a positive correlation between green knowledge collaboration and DGI performance in the IBSC.*

H11. *There is a positive correlation between the digital integration degree and DGI performance in the IBSC.*

H12. *There is a positive correlation between green knowledge collaboration and the digital integration degree in the IBSC.*

According to the theory of dissipative structures in the theory of the complex system science, a complex system must have four characteristics—openness of the system, a far distance from equilibrium, nonlinear interaction, and fluctuation change—in order to form a dynamic dissipative structure [54].

Based on the above analysis, the DGI system of IBSC enterprises is a complex system with openness, nonlinear interaction, self-organization, and fluctuation. In the system, product flow, service flow, information flow, capital flow, decision flow, knowledge flow, and technology flow are the essence of realizing DGI among building enterprises. Green knowledge sharing, green knowledge absorption, and green knowledge innovation become the key links that affect the performance of DGI. The characteristics of an external network environment affect the DGI system of IBSC enterprises. The digital network capability of the IBSC provides a good platform for the digital integration of the BSC. The digital quality of the BSC creates opportunities for partner selection in the digital integration process. The toughness of the IBSC promotes the integration of the BSC from the aspects of information resource sharing and market response. The DGI system of IBSC enterprises has certain dynamic characteristics. In order to deeply analyze the influence of each network environment on the DGI process among IBSC enterprises, this paper constructs a theoretical research framework of the DGI mechanism, as shown in Figure 3.

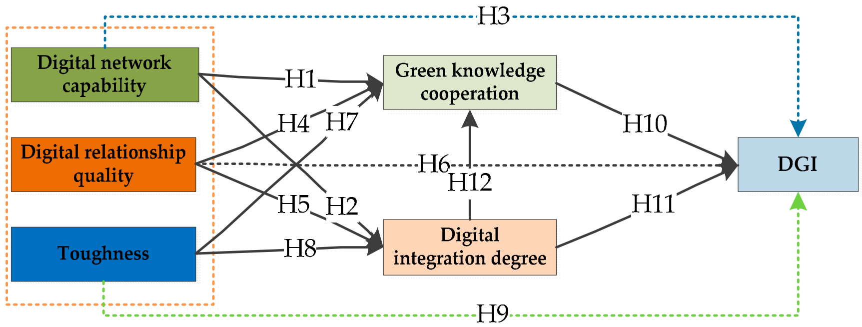

Figure 3. Framework of the DGI mechanism among IBSC enterprises.

4. Methodology

4.1. Samples and Data Sources

In order to obtain effective research data, all the respondents were enterprises in the BSC. The research was conducted among BSC enterprises and their reliable, stable, and durable strategic alliance partners, vendors, and customers of the BSC. During the implementation of the survey, the BSC enterprises had the following requirements. First, the BSC enterprises had digital green technology innovation and development, and had begun implementing new digital green product development projects with strategic alliance partners of the BSC in the past four years. Second, the BSC enterprises organized at least three communication activities related to new digital green product development between the building enterprises, vendors, and customers in the past four years. In order to carry out effective matching, a questionnaire survey was conducted on the strategic alliance partners, vendors, and customers of the above IBSC. In the questionnaire survey, the respondents were limited to middle and senior managers of enterprises, including the enterprises' new digital green product innovation and development managers, new digital green product development department managers, and digital green product designers. In this paper, Beijing, Shanghai, Tianjin, Heilongjiang, Guangdong, Hebei, Henan, Shandong, Jiangsu, Zhejiang, Anhui, and other provinces were selected as the main research sites. These provinces and cities were representative because their IBSCs had high levels of digitalization and greenization. When the purpose of the study was explained, questionnaires were distributed in both electronic and online forms and were collected every other week. After more than five months of investigation, the team had distributed a total of 600 questionnaires and recovered 386, with a recovery rate of 64.33%. After eliminating the questionnaires with incomplete data and obvious errors, 275 valid questionnaires were obtained, and the effective rate of the questionnaire was 71.24%.

4.2. Variables and Measurement

Based on the review of the cooperation mechanism between BSC enterprises and the related research literature, the index systems of relevant independent variables, intermediate variables, and dependent variables of the research on DGI among IBSC enterprises were sorted, as shown in Table 1. In order to ensure data quality from the source, a pre-survey questionnaire was formulated by adopting empirical research indicators of the relevant research literature and the measurement indicators of major scholars in the field before the formal survey. A total of 100 questionnaires were distributed to the MBA students at Zhejiang University of Technology and Soochow University, and 78 of them were returned. In terms of the source of the questionnaires, there were 38 questionnaires from Zhejiang University of Technology and 40 questionnaires from Soochow University. In terms of relevant working years, the proportion of less than 5 years was 6.41%, the proportion of 6–10 years was 41.03%, and the proportion of more than 10 years was 52.56%. In terms of gender, males accounted for 63.72% and females accounted for 36.28%. There were no questions about the ability hypothesis and DGI performance on the questionnaires. This practice prevents the respondents from obtaining causal implications of the research and reduces the degree of the subjectivity of the respondents. At the same time, experts in fields related to IBSC research and senior managers of building enterprises were invited to modify the questionnaire according to the test results, and a formal questionnaire was finally formed. All variables were measured using a seven-level Likert scale. The numbers 1–7 in the evaluation scale, respectively, represented the following judgments of the facts stated in the questionnaire: not at all consistent, relatively inconsistent, slightly inconsistent, generally, somewhat consistent, relatively consistent, and completely consistent.

Table 1. Variable description and source.

Variable Types	Latent Variable Names	Variable Measurement Elements	Literature Sources
Independent Variables	Environmental characteristics of the IBSC	Digital network capability	[55]
		Digital relationship quality	[56]
		Toughness	[57]
Intermediate Variables	Digital integration degree of the IBSC	Supplier digital integration	[58]
		Customer digital integration	[59]
	Green knowledge cooperation	Green knowledge sharing	[60]
		Green knowledge absorption	[61]
		Green knowledge innovation	[62]
Dependent Variables	DGI performance	New digital green product development and description; new digital green product-related database and knowledge base; new digital green market development.	[63–66]

4.3. Deviation Test

In order to avoid the homology bias of the study samples, the data of the study were tested by homology method bias and non-responder bias. On the deviation of the homology method, the Harman univariate analysis method was used to test, and the exploratory factor analysis (EFA) program provided by SPSS software was used. The results showed that the loading amount of the unrotated first principal component was only 18.35%, and there was no single factor that could explain most of the variation, indicating that homology method bias did not have a significant effect. In terms of non-responder bias, the first third and last third of the samples were sorted according to the return time of the questionnaire for the t-test. The results showed that there was no significant difference in more than 89.37% of the observed variables, indicating that the non-responder bias did not have a significant impact.

4.4. Reliability and Validity Test

The reliability and validity of this paper were tested in the following ways: First, the Cronbach alpha coefficient test was conducted for each variable to evaluate the internal consistency of the sample data. Second, the combined reliability of the sample data was tested by calculating the CR value. Third, the KMO value and the Bartlett sphere method were used to test the conception validity of the sample data. Fourth, the research questionnaire was summarized and revised after the results of the relevant literature research. The content effectively reflects the variable information, and the scale has high content validity. The test results using SPSS 20.0 are shown in Table 2.

As can be seen in Table 2, the Cronbach alpha coefficient of all variables range from 0.719 to 0.817, which is higher than the general recommendation of 0.7, indicating that the intrinsic consistency reliability of the sample data is high. A composition reliability of 0.7 is an acceptable threshold, and CR values of all variables in the table range from 0.801 to 0.892, which are all higher than the general recommendation of 0.8, indicating that the sample data combination reliability is high. The results of factor analysis showed that the KMO values of all factors (0.726–0.812) are all greater than 0.7, and the Bartlett sphere test results are all significant, which is suitable for factor analysis, indicating that the sample data has appropriate conceptual validity. In addition, the skewness coefficient and kurtosis coefficient analysis are used to test the normal distribution of the sample data. When the absolute value of the skewness coefficient is less than 3 and the absolute value of the kurtosis coefficient is less than 10, it means that the sample data obey the normal distribution. In this study, the absolute values of skewness and kurtosis coefficients of all variable measurement items were less than 2.5. This indicates that the samples in this paper obey the normal distribution, so the correlation analysis can be carried out in the next research.

Table 2. Reliability and validity test results.

Inspection Items	Variables	Cronbach Alpha	CR	KMO Value	Bartlett's Test of Sphericity
Environmental Characteristics of BSC	Digital network capability Digital relationship quality Toughness	0.817 0.719 0.728	0.892 0.801 0.809	0.726 0.803 0.812	Notable Notable Notable
Digital Integration Degree of BSC	Customer digital integration Supplier digital integration	0.789	0.835	0.784	Notable
Green Knowledge Cooperation	Green knowledge sharing Green knowledge absorption Green knowledge innovation	0.737	0.806	0.759	Notable
DGI Performance	New digital green product development New digital green product description New digital green product-related database New digital green market development	0.754	0.829	0.811	Notable

5. Static Interaction Mechanism of DGI

5.1. Correlation Analysis and Multicollinearity Diagnosis

In this study, SPSS 20.0 was used to analyze the mean, standard deviation, and Spearman correlation coefficient of each variable, and the results are shown in Table 3. It can be seen from the correlation coefficients in the table that there is a certain correlation between the variables, ranging from 0.273 to 0.532. The diagonal line in the table shows that the variance inflation factor (VIF) (1.122–1.394) is always less than 10, indicating that the multicollinearity problem is not serious and meets the requirements of hypothesis testing.

Table 3. Descriptive statistics, correlation coefficient matrix, and variance inflation factor of the main variables.

Variables	Mean	Standard Deviation	Digital Network Capability	Digital Relationship Quality	Toughness	Digital Integration Degree	Green Knowledge Collaboration	DGI Performance
Digital Network Capability	4.314	1.023	1.263					
Digital Relationship Quality	4.298	0.967	0.356 **	1.394				
Toughness	4.395	1.033	0.273 **	0.406 **	1.125			
Digital Integration Degree	4.452	0.981	0.321 **	0.387 **	0.532 **	1.267		
Green Knowledge Collaboration	4.395	0.915	0.275 *	0.391 **	0.487 **	0.407 **	1.122	
DGI Performance	4.406	1.105	0.292 **	0.425 **	0.395 **	0.358 **	0.364 **	—

Note: ** and * are significant at 0.01 and 0.05 levels, respectively. The values on the diagonal are the variance expansion factor.

5.2. Regression Analysis

Hierarchical regression analysis and structural equation modeling are common research methods in marketing, organizational behavior, management information systems and other fields. Their respective effectiveness has been widely verified in previous studies. Compared with structural equation model analysis, regression analysis will be more suitable to study the specific mechanism of action in the model. Structural equation modeling has unique advantages in systematically understanding research models. The research purpose of this paper mainly includes the following two aspects. On the one hand, it endogenously reveals the interaction mechanism of DGI in the integrated green building supply chain. On the other hand, it systematically dissects the dynamic evolution of DGI in the integrated green building supply chain. Therefore, hierarchical regression analysis and structural equation modeling are used in this study to reveal mechanisms and dissect system dynamics.

In this paper, four regression equations are established as follows: the relationship between digital network capability, digital relationship quality, toughness, and DGI performance in the environmental characteristics of the IBSC, the relationship between the digital integration degree, green knowledge collaboration, and DGI performance of the IBSC, the relationship between the environmental characteristics of the IBSC and its digital integration degree, and the relationship between the environmental characteristics of the IBSC, its digital integration degree, and green knowledge collaboration. The regression results are shown in Table 4. It can be seen that the F-test of each regression model is significant, and the variance inflation factor is always less than 10, indicating that the overall effect of each regression model is good, and there is no multicollinearity problem.

Table 4. Regression results.

Independent Variables	Dependent Variables	Beta Value	T Value	Sig Value	F Value	VIF Value
Constant	DGI performance		3.896	0.000	18.624	
Digital network capability		0.135	1.682	0.097		1.138
Digital relationship quality		0.426	4.263	0.000		1.125
Toughness		0.224	1.625	0.102		1.117
Constant	DGI performance		2.989	0.001	32.791	
Digital integration degree		0.492	4.856	0.000		1.116
Green knowledge cooperation		0.263	2.902	0.008		1.128
Constant	Digital integration degree of IBSC		5.986	0.000	24.672	
Digital network capability		0.156	2.106	0.034		1.134
Digital relationship quality		0.374	3.869	0.000		1.158
Toughness		0.306	4.724	0.000		1.129
Constant	Green knowledge collaboration		4.983	0.000	16.985	
Digital network capability		0.186	1.038	0.297		1.173
Digital relationship quality		0.201	2.627	0.010		1.251
Toughness		0.298	4.258	0.000		1.212
Digital integration degree		0.177	2.186	0.022		1.357

5.3. Structural Equation Model Analysis

Multiple regression and path analysis of the structural equation model have the advantages of data analysis. In this study, AMOS statistical analysis software was used to empirically study the DGI mechanism of enterprises in the integrated supply chain, and structural equation analysis was conducted on the sample data. First, the model is preliminarily fitted, and the model is modified by the modification method. The fitting degree index of the full model after modification is shown in Table 5.

Table 5. Index of the fitting degree of the structural equation model.

Fitting Index	χ^2/df	GFI	AGFI	RMSEA	NFI	IFI	TLI	CFI
Parameter Values	2.132	0.989	0.942	0.069	0.964	0.982	0.924	0.961

As can be seen in Table 5, the ratio of the chi-square value to the degrees of freedom (χ^2/df) is 2.132, which is less than the generally recommended value of 3, indicating a good degree of fit. The goodness-of-fit index (GFI) is 0.989, which is higher than the general recommended value of 0.9, indicating that the model fits well. The adjusted goodness-of-fit index (AGFI) is 0.942, greater than 0.9, indicating a good degree of model fitting. The root mean square of the approximation error (RMSEA) is 0.069, which is less than the general recommended value of 0.08 and fits the reasonable interval. The relative fitting index (NFI) is 0.964, greater than 0.9. The increasing fitting index (IFI) is 0.982, and the closer it is to 1, the better the model fit. The Tucker–Lewis index (TLI) is 0.935, greater than 0.9, indicating a good degree of fit. If the CFI is greater than 0.9, the model fits well. The above analysis thus shows that the model fits well.

According to the sample data, AMOS statistical software was used to verify the conceptual model and the relevant assumptions of DGI among enterprises in the IBSC proposed above, so as to determine the final structural equation model, including the various hypotheses proposed in this paper, as shown in Figure 4. The standardized estimates of all parameters are moderate, the C.R. test values are basically greater than 1.98, the standard deviations of parameter estimates are all greater than zero, and the model fit is basically good.

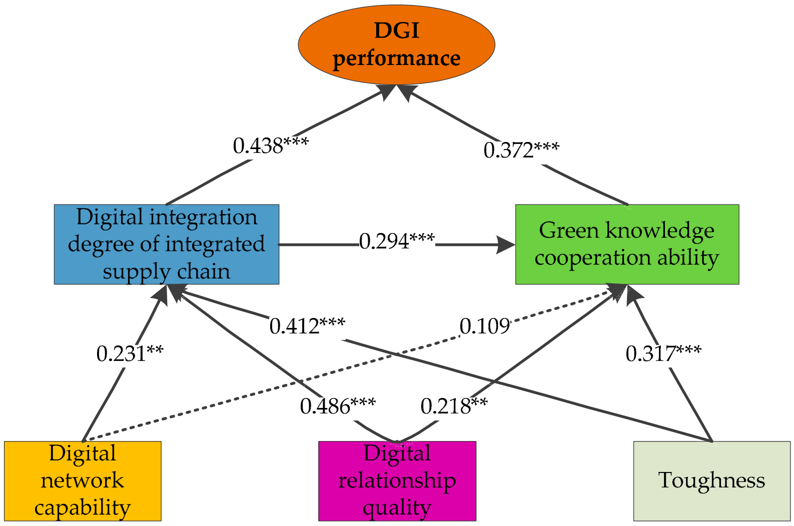

Figure 4. Fitting results of the internal mechanism research model of DGI. Note: ** and *** are significant at $p < 0.05$ and $p < 0.01$, respectively. A dashed line indicates that the path is not significant.

6. Dynamic Interaction Mechanism of DGI

6.1. Variables and Parameters

The B–Z reaction system is a typical system with self-organizing characteristics, and DGI among IBSC enterprises is similar to this, which is also a typical informal organization with self-organizing characteristics. Therefore, this paper constructs a dynamic evolution system of DGI among enterprises in the IBSC, which is dominated by the digital integration degree of the IBSC, green knowledge collaboration, and DGI performance. It is necessary to determine the interaction coefficient between the state variables of the three factors, that is, to adjust the parameters. According to the research results of the static mechanism of DGI among enterprises in the IBSC, the corresponding state variables and parameters are determined, as shown in Table 6. The logistic equation is expressed as follows: x_1, x_2 and x_3 represent three state variables, namely, the green knowledge collaboration status, the digital integration degree status of the IBSC, and the DGI performance level, in the process of DGI among enterprises in the IBSC. The formula $\frac{dx_i}{dt}(i = 1, 2, 3)$ represents the rate of change of the state variable over time. Variables α, β, and γ are, respectively, the adjustment parameters of the green knowledge collaboration state x_1, the digital integration degree state x_2 of the IBSC, and the DGI performance level x_3. Because the digital relationship quality of the IBSC directly affects the integration process of the BSC, and the system operation process is affected by the service, communication, commitment, satisfaction, trust, and cooperation of the IBSC, the digital relationship quality of the IBSC was selected as an external control variable. Variable δ is the control variable, that is, the comprehensive effect of the digital relationship quality environment of the IBSC on the collaborative support ability of the system, so δ is the common control variable of the three state variables x_1, x_2, and x_3.

Table 6. Variables and parameters.

Variables	Variable Names	Interpretation of Variables
State Variable 1	Green knowledge collaboration status	This variable describes the green knowledge collaboration ability of IBSC enterprises and reflects the impact of green knowledge collaboration ability on DGI performance.
State Variable 2	Digital integration degree status of the IBSC	This variable describes the integration degree of the IBSC and reflects the impact of the integration degree of the IBSC on DGI performance.
State Variable 3	DGI performance level	This variable describes the status of DGI among IBSC enterprises and reflects the effect of DGI among building enterprises.
Control Variables	Digital relationship quality of the IBSC	This variable describes the comprehensive effect of the digital relationship quality environment of the IBSC on the system's collaborative support ability.
Adjusting Parameter 1	Green knowledge collaboration ability level index	This variable measures the level of green knowledge collaboration capability of IBSC enterprises, which is obtained through the measurement of green knowledge sharing, green knowledge absorption, and green knowledge innovation.
Adjusting Parameter 2	Digital integration degree level index of the IBSC	This variable measures the digital integration degree level of the IBSC, which is obtained by measuring the digital integration with suppliers and customers.
Adjusting Parameter 3	DGI performance level index	This variable measures the level of DGI performance, obtained through the relevant situation of new digital green products.

6.2. Model Construction

Three-dimensional equations of green knowledge collaboration, the digital integration degree of the IBSC, and DGI performance are constructed in this section [67].

First, the dynamic evolution equation of the green knowledge collaboration capability of building enterprises is constructed. In the early stage of BSC integration, there are certain DGI demands among BSC enterprises, namely, mainly product flow, service flow, information flow, capital flow, and decision flow. The digital integration degree of the IBSC positively affects the green knowledge collaboration ability of enterprises. With the enhancement of the digital integration degree, the green knowledge collaboration ability of building enterprises is constantly improved, and the digital integration degree of the IBSC is affected by the digital relationship quality of the IBSC. Therefore, under the influence of the digital relationship quality δ of the IBSC, the logistic evolution equation of state variable x_1 is:

$$\frac{1}{\alpha}\frac{dx_1}{dt} = \delta x_1 + \delta\frac{\beta}{\alpha}x_2 + \gamma x_1 x_3 \tag{1}$$

Here, δx_1 represents the self-influencing factor of x_1 under the influence of the control variable digital relationship quality δ of the IBSC. Formula $\delta\frac{\beta}{\alpha}x_2$ represents the influence factor of x_2 with respect to x_1 under the effect of digital relationship quality δ; that is, the digital integration degree promotes the improvement of green knowledge collaboration ability. Variable δ reflects the influence of digital relationship quality of the IBSC on x_1. Variable $\gamma x_1 x_3$ is the effect of x_1 on x_3. The DGI performance of building enterprises will increase with the improvement of green knowledge collaboration ability, which is weakly affected by digital relationship quality.

Second, the dynamic evolution equation of digital integration degree of the IBSC is constructed. In the early stage of BSC integration, BSC integration has a significant effect on the improvement of green knowledge collaboration and DGI performance. With the BSC reaching a certain digital integration degree, the cooperation between building enterprises reaches a certain depth and breadth, which restricts the development of digital green knowledge heterogeneity and digital green knowledge innovation, and the marginal revenue brought by the digital integration degree decreases. Therefore, under the influence of digital relationship quality δ of the IBSC, the logistic evolution equation of state variable x_2 is:

$$\frac{1}{\beta}\frac{dx_2}{dt} = -\delta x_2 - \alpha\delta x_1 x_2 + \frac{\gamma}{\beta}x_3 \tag{2}$$

Here, $-\delta x_2$ represents the self-influencing factor of x_2 under the influence of δ. $-\alpha\delta x_1 x_2$ is the influence factor of x_1 on x_2. Building enterprises need to improve their green knowledge collaboration ability and digital integration degree. The improvement of this ability depends on the digital integration degree of the IBSC, and it then has a certain crowding-out effect on digital integration. Formula $\frac{\gamma}{\beta}x_3$ is the effect of x_3 on x_2. The improvement of DGI performance of building enterprises can increase the frequency at which suppliers and customers are contacted and improve the digital integration degree of the IBSC.

Thirdly, the dynamic evolution equation of DGI performance is constructed. On the one hand, the improvement of DGI performance of IBSC enterprises is affected by their own absorptive capacity. On the other hand, it is also affected by the digital relationship quality of the IBSC and the cooperation between building enterprises. The high digital integration degree of the IBSC is conducive to DGI among BSC enterprises. Therefore, under the influence of digital relationship quality δ of the IBSC, the logistic evolution equation of state variable x_3 is:

$$\frac{1}{\gamma}\frac{dx_3}{dt} = \varphi_1 x_3 + \varphi_2\delta\frac{\alpha}{\gamma}x_1 + \varphi_3\delta\frac{\beta}{\gamma}x_2 \tag{3}$$

Here, $\varphi_1 x_3$ represents the influencing factor of DGI performance, and φ_1 is a constant. The endogenous impetus of cooperation among enterprises in the IBSC promotes the improvement of DGI performance. $\varphi_2\delta\frac{\alpha}{\gamma}x_1$ and $\varphi_3\delta\frac{\alpha}{\gamma}x_2$, respectively, show that, under the effect of the digital relationship quality of the IBSC, green knowledge collaboration capability and the digital integration degree of the IBSC have a positive impact on DGI performance. φ_2 and φ_3 are constants, usually greater than 1. The hypothesis $\varphi_1 = 1$ in this paper indicates that DGI performance can maintain a steady improvement without the action of external factors. $\varphi_2 = \varphi_3 = 2$ indicates that the synergy of green knowledge collaboration ability and the digital integration degree of the IBSC can multiply DGI performance.

In summary, the system dynamic evolution model based on the B-Z response, composed of green knowledge collaboration capability, the digital integration degree of the IBSC, and DGI performance, is as follows:

$$\begin{cases} \frac{dx_1}{dt} = \alpha\delta x_1 + \beta\delta x_2 + \alpha\gamma x_1 x_3 \\ \frac{dx_2}{dt} = -\beta\delta x_2 - \alpha\beta\delta x_1 x_2 + \gamma x_3 \\ \frac{dx_3}{dt} = \gamma x_3 + 2\alpha\delta x_1 + 2\beta\delta x_2 \end{cases} \tag{4}$$

6.3. Model Stability Analysis

In the evolution process from chaos to order, the system needs to undergo certain fluctuations, and the system finally breaks through the stability condition and realizes self-organization under order parameters. Here, the linear stability principle is used to analyze the stability of the system dynamic evolution model. The quasi-disturbance term is

$$\begin{cases} p_1 = p_1^0 + \mu_1 \\ p_2 = p_2^0 + \mu_2 \\ p_3 = p_3^0 + \mu_3 \end{cases} \tag{5}$$

Here, μ_1, μ_1, and μ_3 are small perturbations of the stationary solution. In the assumption $p_1^0 = p_2^0 = p_3^0 = 0$, a new dynamic evolution equation can be obtained after linearization:

$$\begin{cases} \frac{dx_1}{dt} = \alpha\delta x_1 + \beta\delta x_2 \\ \frac{dx_2}{dt} = -\beta\delta x_2 + \gamma x_3 \\ \frac{dx_3}{dt} = \gamma x_3 + 2\alpha\delta x_1 + 2\beta\delta x_2 \end{cases} \tag{6}$$

According to vector form $\frac{dX}{dt} = VX$, we can obtain:

$$V = \begin{bmatrix} \alpha\delta & \beta\delta & 0 \\ 0 & -\beta\delta & \gamma \\ 2\alpha\delta & 2\beta\delta & \gamma \end{bmatrix} \tag{7}$$

Thus, the condition $V - \lambda I = 0$ satisfying the non-zero solution is:

$$\begin{vmatrix} \alpha\delta - \lambda & \beta\delta & 0 \\ 0 & -\beta\delta - \lambda & \gamma \\ 2\alpha\delta & 2\beta\delta & \gamma - \lambda \end{vmatrix} = 0 \tag{8}$$

Solving this equation leads to:

$$\lambda^3 + (\beta\delta - \alpha\delta - \gamma)\lambda^2 + (\alpha\gamma\delta - 3\beta\gamma\delta - \alpha\beta\delta^2)\lambda + \alpha\beta\gamma\delta^2 = 0 \tag{9}$$

According to the Hurwitz criterion, the necessary and sufficient conditions for the stability of a linear system are as follows. First, all coefficients of the characteristic equation are positive. Second, the values of the Hurwitz determinant and its principal determinant are all positive. Since all characteristic roots in the equation are negative real parts, the DGI system built between enterprises in the IBSC cannot meet the steady state condition, and there is no system threshold. In the following, a MATLAB simulation is used to analyze and adjust the system evolution trend of the control variable δ.

6.4. Simulation Analysis

In this paper, the DGI co-evolution equation of the IBSC enterprises constructed above is simulated and analyzed, and the initial state is set as $X_0 = [x_1, x_2, x_3]$. x_1, x_2 and x_3, respectively, represent the initial situation of the synergy degree, the digital integration degree, and the DGI performance of the IBSC. In this paper, the digitized relationship quality of the IBSC is distinguished among the environmental characteristics of the IBSC. Let $\delta = 0.1$ reflect that the digital relationship quality of the IBSC is weak in supporting DGI among IBSC enterprises, and the DGI among enterprises is in an uncertain state. Let $\delta = 1$ reflect that the digital relationship quality creates a good environment for purchasing stability, business participation, production, and sales in the IBSC and plays a certain role in promoting the integration of the IBSC. By enhancing communication, trust, cooperation, conflict resolution, environmental adaptability, and relationship atmosphere between building enterprises, DGI among IBSC enterprises is promoted. Based on the dynamic mechanism research and analysis, in order to investigate the long-term action mechanism of the synergy degree of the IBSC on DGI performance, this paper studies three different situations in the DGI process among IBSC enterprises, which are as follows. First, the synergy degree of the IBSC is set as a weak state, and the digital integration degree is set as a strong state. Considering the time delay of DGI performance, this performance is set as a weak state. Second, the synergy degree and digital integration degree of the IBSC are set as strong states. Considering the time delay of DGI performance, this performance is set as a weak state again. Third, based on the results of the static mechanism research, the effect of DGI and digital relationship quality among the sample IBSC enterprises is investigated.

In the first state, the initial simulation state is $X_0 = [0, 1, 0]$, and the simulation result of $\delta = 0.1$ in the environment of the low digital relationship quality of the IBSC is shown in Figure 5. Figure 6 shows the simulation results of $\delta = 1$ in the environment of the low digital relationship quality of the IBSC.

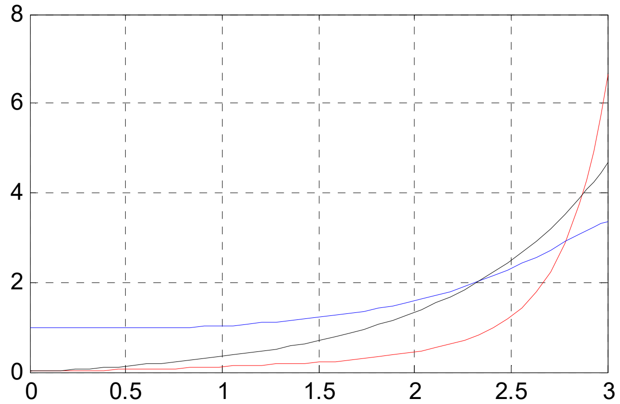

Figure 5. Evolution trend in the absence of green knowledge collaboration capability in the case. of $\delta = 0.1$. Note: The black line is the synergy degree of the IBSC, the blue line is the digital integration degree of the IBSC, and the red line is the DGI performance.

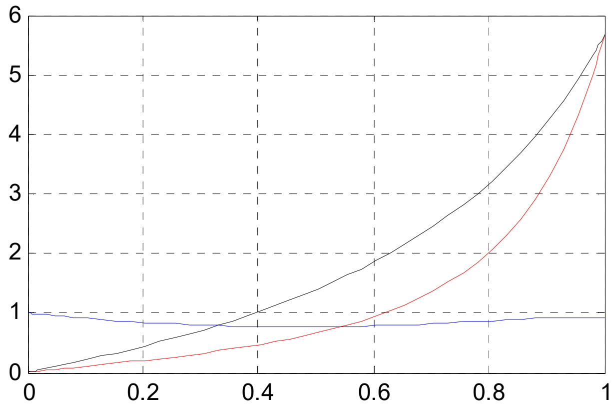

Figure 6. Evolution trend in the absence of green knowledge collaboration capability in the case of $\delta = 1$.

As can be seen in Figure 5, when the synergy degree of the IBSC is low, the effect of simply relying in its digital integration degree to promote the improvement of DGI performance is not obvious, and the growth of DGI performance is slow and generally poor. When $t = 1$, the DGI performance is less than 0.5. When $t = 2.5$, the three are in an adhesive state. With the improvement of the digital integration degree, the coordination degree of the IBSC is greatly improved. The results show that enterprises require a high amount of time to adjust the practice of promoting DGI to other IBSC enterprises when the IBSC has a low digital relationship quality.

As can be seen in Figure 6, when the synergy degree of green knowledge in the IBSC is low, a higher digital relationship quality in the IBSC can promote the performance of DGI to a certain extent, but this performance among the IBSC enterprises is general. When $t = 1$, DGI performance exceeds 5, which is larger than the value of 0.5 when $\delta = 0.1$, without the synergy degree of green knowledge in the IBSC, but the effect is not optimistic. The results show that the synergy degree and DGI performance of IBSC increase rapidly in the environment when the IBSC has a high digital relationship quality. As the situation develops, the digital integration degree of the IBSC decreases first and then increases, which also indicates that the current digital integration degree of the IBSC is general.

In the second state, the initial simulation state is $X_0 = [1, 1, 0]$, and the simulation results of $\delta = 0.1$ in an environment where the IBSC has a low digital relationship quality are shown in Figure 7. Figure 8 shows the simulation results of $\delta = 1$ in this environment.

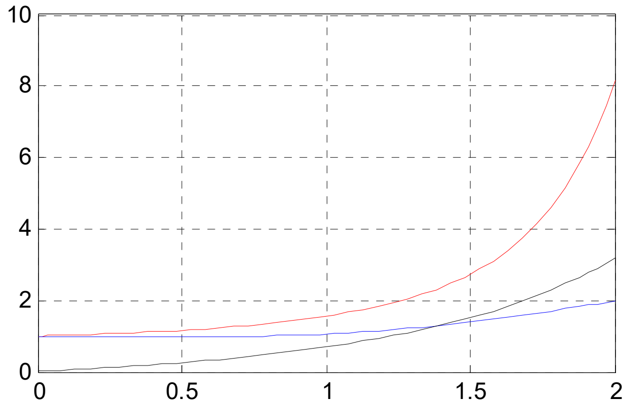

Figure 7. Evolution trend of the three elements in the case of $\delta = 0.1$.

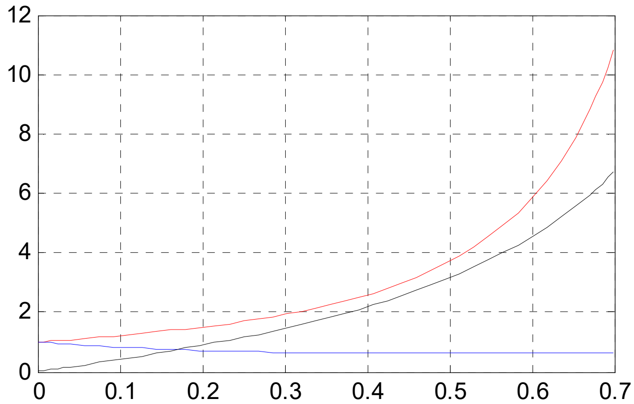

Figure 8. Evolution trend of the three elements in the case of $\delta = 1$.

As can be seen in Figure 7, when the digital relationship quality of IBSC is low and $t = 2$, the DGI performance is greater than 3, which is higher than the DGI performance under the condition of $t = 2$ in Figure 5. The collaboration degree of the IBSC and the collaboration degree of digital integration promote the rapid improvement of DGI performance, and the digital integration degree is also gradually improved. When the digital relationship quality is low, the DGI performance improves with the increase in information flow and technology flow in the integration of the IBSC. The realization of information collaboration, incentive collaboration, and green knowledge collaboration can promote DGI performance. Over the long term, the improvement of the IBSC synergy degree and DGI performance promotes the slow improvement of the digital integration degree. The rapid improvement in DGI performance helps enterprises increase innovation input, which is conducive to improving the synergy degree of the IBSC and realizing the co-evolution trend of the three elements.

As can be seen in Figure 8, when the digital relationship quality of the IBSC is high, the synergy degree and DGI performance show the same change trend as that of an IBSC with a low digital relationship quality, and the DGI performance shows rapid improvement. When $t = 0.7$, the DGI performance is greater than 6, which is more than 6 times that when the IBSC has a low digital relationship quality. In the long term, the digital integration degree of the IBSC shows a slow decline trend. The reason for this is that, with the improvement of the digital relationship quality of the IBSC, DGI among IBSC enterprises increases, and the degree of collaboration of the IBSC further improves DGI performance. This substantially restricts the generation of knowledge heterogeneity in the collaboration degree of the IBSC and restricts the incentive of DGI cooperation among building enterprises, leading to a slow decline in the digital integration degree of the IBSC.

In the third state, according to the research results of the static mechanism, under the condition of DGI of sample building enterprises, the influence of the synergy degree of the unit IBSC on DGI performance is 0.372, and the influence of the digital integration degree of the unit IBSC on DGI performance is 0.438. The influence of the digital relationship quality on the collaboration degree and the digital integration degree of the IBSC is 0.218 and 0.486, respectively, and the average value of the two is 0.352. The initial simulation state is then $X_0 = [0.372, 0.438, 0]$. When $\delta = 0.352$, the simulation result of the digital relationship quality of the IBSC is shown in Figure 9.

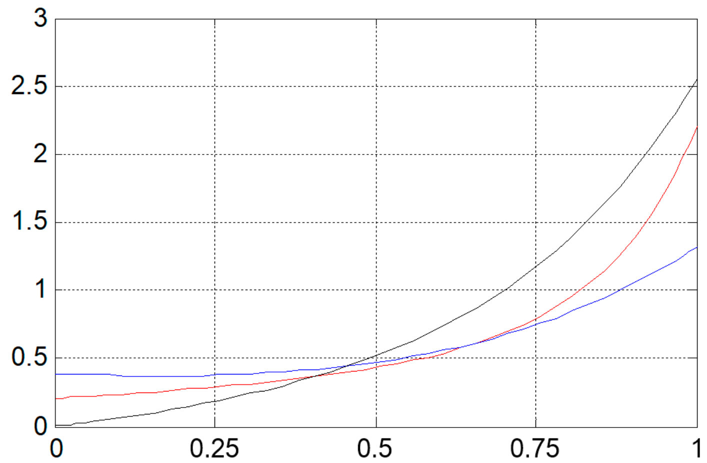

Figure 9. Evolution trend of the three factors based on empirical results and $\delta = 0.352$.

As can be seen in Figure 9, the DGI performance among the sample IBSC enterprises is at a relatively low level. When $t = 0.5$, the DGI performance is greater than 0.5, and the DGI performance begins to grow rapidly. When $t = 0.75$, the DGI performance exceeds 1. When $t = 1$, the DGI performance exceeds 2.5. The synergy degree of the IBSC, the digital integration degree of the IBSC, and DGI performance are highly correlated with the evolution of time. DGI among enterprises in the sample IBSC is in the initial stage of BSC integration, the digital integration degree is gradually increasing, and the evolution trend is stable.

7. Discussion

The empirical results are as follows. First, the digital integration degree of the IBSC and the green knowledge collaboration ability among the IBSC enterprises are conducive to the improvement of their DGI performance. The digital integration degree of the IBSC and the green knowledge collaboration ability are the intermediate variables that promote DGI performance. The effect of the digital integration degree of the IBSC on DGI performance is more obvious (0.438 > 0.372). It is the leading factor affecting the performance of DGI among enterprises in the IBSC. The reason for this may be that, in the early stage of the IBSC, the sharing of various digital green resources helps to improve the performance of DGI rapidly in the short term. In the long term, building enterprises are more in need of DGI in terms of knowledge. This will be tested in the dynamic mechanism. Second, the digital network capability of the IBSC has a significant impact on the digital integration degree of the IBSC, while it has no significant effect on the green knowledge collaboration ability. Hypothesis H1 has not been verified. The main reason for this may be that the digital network capability of the IBSC is high, which is conducive to selecting excellent partners and promoting the integration of the IBSC. In this process, building enterprises spend a large amount of time and rely on partners to a certain extent, which restricts their own green knowledge sharing, green knowledge absorption, and green knowledge innovation, and this is not conducive to an improvement in green knowledge collaboration ability. Another reason may also be the lack of green knowledge sharing, absorption, and DGI ability of building enterprises, which restricts the breadth, depth, and interactivity of open digital green learning among building enterprises. Third, the digital relationship quality of the IBSC has an impact on its digital integration degree and the green knowledge collaboration ability among the integrated supply chain enterprises, and the impact on this digital integration degree is higher than the collaboration ability. This indicates that the digital relationship quality among sample BSC enterprises has not reached the point of promoting the large-scale flow of green knowledge among building enterprises. A higher digital relationship quality promotes the integration of the BSC, which is conducive to the formation of the IBSC. Fourth, the toughness of the IBSC can effectively promote its digital integration degree and the improvement of green knowledge collaboration ability among IBSC enterprises, but it has no significant effect on DGI performance. Hypothesis H9 has not been verified. The main reason for this may be that the cooperation between IBSC enterprises increases the dependence of building enterprises on the digital green resources of partners to a certain extent, while the contribution to partners is reduced, and in-depth cooperation is restricted. Another reason may be that building enterprises, by taking advantage of the toughness of the IBSC, need to learn from efficient building enterprises to influence DGI performance.

On the basis of the static mechanism research, the research conclusions of the dynamic mechanism of DGI among IBSC enterprises are as follows. First, under the condition that the green knowledge collaboration ability of IBSC enterprises is low, the effect of simply relying on the digital integration of the IBSC to promote the performance improvement of DGI is not obvious, and the overall effect is poor. Enterprises require a high amount of time to adjust to the practice of promoting DGI to other IBSC enterprises. A higher digital relationship quality in the IBSC plays a certain role in promoting DGI performance. Second, when the digital relationship quality of the IBSC is low, improvement in green knowledge collaboration ability and collaboration with digital integration promote rapid improvements in DGI performance. A higher digital relationship quality in the IBSC, compared to a low digital relationship quality, has a more than six times greater effect on DGI performance. Third, in the case of a high digital relationship quality in the IBSC, the digital integration degree of the IBSC shows a slow downward trend over the long term. The reason for this is that, with an improvement in the digital relationship quality of IBSC, DGI among IBSC enterprises increases, and green knowledge collaboration further improves DGI performance. This substantially restricts the generation of knowledge heterogeneity and the cooperation between enterprises, which leads to a slow decline in the digital integration degree of the IBSC, which also unstably supports the DGI system among IBSC enterprises. Fourth, the samples selected in the study show that the DGI performance of enterprises in the BSC is low. The digital integration degree, green knowledge collaboration ability, and DGI performance of the IBSC are highly correlated with the evolution of time. DGI among sample IBSC enterprises is in the initial stage of IBSC integration, the digital integration degree is gradually increasing, and the evolution trend is stable.

Compared with previous studies, the contributions of this study are as follows. Compared with Reference [17], this paper reveals the interaction mechanism between digital integration degree, green knowledge collaboration capability, and DGI performance of IBSC enterprises under the influence of environmental characteristics of an integrated supply chain. Based on the effective survey sample data of construction integrated supply chain enterprises, this paper studies the static mechanism of DGI among enterprises of IBSC. Compared with References [68,69], this paper introduces the "B-Z" three-dimensional analysis model in the complex system theory and studies the dynamic evolution mechanism of DGI among enterprises in the IBSC. Therefore, this study has important theoretical and practical implications, as follows. Firstly, this paper reveals the interaction mechanism between the digital integration degree, green knowledge collaboration capability, and DGI performance in the IBSC enterprises, and the research conclusions are more systematic. Secondly, this paper conducts dynamic research based on the static mechanism of DGI among enterprises in the IBSC, and the research conclusions are more specific and profound. Thirdly, this study attempts to improve the methodology of the DGI system among IBSC and provide direction strategies for improving the performance of DGI among IBSC enterprises.

8. Conclusions and Future Prospects

8.1. Conclusions

Based on the effective survey sample data of IBSC enterprises, SPSS and AOMS software were used to study the static mechanism of DGI among IBSC enterprises. On this basis, the B–Z three-dimensional analysis model of the complex system theory is introduced. The dynamic evolution mechanism of DGI among IBSC enterprises is simulated by software. The results of this study are as follows.

First, the digital integration degree of IBSC and green knowledge collaboration ability among enterprises are beneficial to improve the DGI performance of enterprises. The digital integration degree of IBSC is the dominant factor affecting the DGI performance of these enterprises. Second, the digital network capability of IBSC has a significant impact on the digital integration degree, but not on the green knowledge collaboration ability. The digital relationship quality in IBSC has an impact on digital integration and green knowledge collaboration ability. Moreover, its influence on the digital integration degree is greater than that on green knowledge collaboration ability. The resilience of IBSC can effectively promote the improvement of the digital integration degree and green knowledge collaboration ability, but has no significant effect on DGI performance. Third, at the beginning of IBSC, the impact of digital integration degree on DGI performance is more obvious. In the long term, the green knowledge collaboration ability plays a key role under the influence of IBSC with different digital relationship qualities. Enhancing this capability is beneficial to the continuous improvement of DGI performance.

8.2. Implications on Theory and Practice

Under the influence of environmental characteristics of an integrated supply chain, this study reveals the mechanism of the interaction between the digital integration degree, green knowledge collaboration ability, and DGI performance in DGI among enterprises in the IBSC, which has certain theoretical and practical implications.

This study has important theoretical significance. Compared with the previous single research method, this study innovatively combines a static mechanism and a dynamic analysis model for analysis. In this study, a hierarchical regression method and a structural equation model were used to empirically study the static mechanism of DGI among enterprises in the IBSC. On the basis of the static mechanism, this study draws on the B–Z reaction model in a complex system theory to construct a three-dimensional logistic dynamic analysis model, and explores the dynamic evolution law of a DGI system among IBSC enterprises through this model.

This research also has important practical significance. This study attempts to improve the methodology of the DGI system among BSC enterprises and provide direction strategies for improving DGI performance among IBSC enterprises.

In addition, this study has brought forth some lessons, specifically as follows. Enterprises with a high digital network capability in the IBSC need to prevent dependence on partners and continuously improve their knowledge sharing ability, absorption ability, and knowledge innovation ability, so as to enhance green knowledge collaboration ability and enhance the breadth, depth, and interactivity of open learning among building enterprises. On the one hand, enterprise managers should prevent dependence on their partners' information resources, increase their contribution to partners, and promote in-depth cooperation. On the other hand, enterprises need to improve their efficient learning ability by making rapid and accurate decisions and creating efficient knowledge flow, knowledge sharing, and knowledge creation in the BSC. DGI performance improves with the increase in information flow and technology flow in the integration of the BSC, and developing the synergistic ability of these information resources and green knowledge can promote DGI performance. Over the long term, the improvement of green knowledge collaboration capability and DGI performance will promote the slow improvement of digital integration. In the mature stage of an integrated supply chain, enterprises should prevent the consolidation of enterprise knowledge among that chain and actively explore cooperation with enterprises with knowledge heterogeneity outside the chain to promote the knowledge innovation of enterprises.

8.3. Limitations

This study has some limitations, which need to be improved in future research. First, the study sample size is small, and the samples from different regions are not balanced. There are limitations in sample size, regional selection, and other aspects. Future studies could include a larger number of samples and include samples from a higher number of locations. Second, the research on the relationship between green knowledge collaboration capability, the digital integration degree of the IBSC, and DGI performance in this paper does not deeply explore the internal operation mechanism of the system according to the index dimension. The action mechanism of supplier integration and customer integration on the three dimensions of green knowledge collaboration capability can be further discussed in future research. Third, how the digital relationship quality of an IBSC can be optimized has not been thoroughly analyzed, which requires further research.

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