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Insight into the Balancing Effect of a Digital Green Innovation (DGI) Network to Improve the Performance of DGI for Industry 5.0: Roles of Digital Empowerment and Green Organization Flexibility

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Abstract: Under the background of double carbon target and digital intelligence era, the innovation resources and innovation environment that manufacturing enterprises rely on have shown exponential growth. Digital green innovation (DGI) has gradually become the mainstream paradigm of innovation. How to achieve a balance between a local DGI network (LDGIN) and a remote DGI network (RDGIN) and how to use the role of digital empowerment and green organization flexibility to improve the performance of DGI are very important issues facing manufacturing enterprises at present. However, this problem has not been fully addressed in the existing research. In this study, the influence mechanism of LDGIN and RDGIN on the DGI performance of manufacturing enterprises was revealed, considering the moderating role of digital empowerment and green organization flexibility. The linear regression method was used to analyze the 562 valid data obtained by questionnaire survey. The results of this study are as follows. The effect of the DGI network on manufacturing enterprises' DGI performance is heterogeneous because of LDGIN and RDGIN. The establishment of embedded links in a DGI network inevitably requires manufacturing enterprises to pay the corresponding costs. The over-embedding of manufacturing enterprises into RDGIN will have a negative impact on DGI performance. The balance between LDGIN and RDGIN has an important impact on manufacturing enterprises' operation. The comprehensive balance and relative balance indexes constructed in this paper show that an appropriate balance can promote the improvement of the DGI performance of manufacturing enterprises. Digital transformation and organizational structure innovation are changing the business model of manufacturing enterprises and can regulate the relationship between the LDGIN and RDGIN and the DGI performance of manufacturing enterprises. The balance of DGI network embedding in practice shows the important role and enlightening significance of local and remote search in developing countries.

Keywords: digital green innovation network; digital transformation; green organization flexibility; digital green innovation performance



Citation: Hu, C.; Yang, H.; Yin, S. Insight into the Balancing Effect of a Digital Green Innovation (DGI) Network to Improve the Performance of DGI for Industry 5.0: Roles of Digital Empowerment and Green Organization Flexibility. *Systems* **2022**, *10*, 97. <https://doi.org/10.3390/systems10040097>

Academic Editors: Yoshiki Shimomura and Shigeru Hosono

Received: 16 June 2022

Accepted: 4 July 2022

Published: 5 July 2022

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1. Introduction

China's manufacturing industry is in a new stage of development from a traditional production mode to digital, networked and intelligent, and the transformation and upgrading of the manufacturing industry is accelerating [1]. Under the background of a dual carbon target, low carbonization and energy saving becoming the inevitable trend of high-quality development of manufacturing industry. In recent years, measures to reduce carbon emissions have achieved certain results. However, in the development of China's manufacturing industry, there are still some problems, such as the rising trend of total

energy consumption, the consumption structure dominated by traditional energy and the level of green technology lower than the world's advanced level [2]. As countries around the world compete to develop digital low-carbon economy, the digital transformation and green manufacturing project implemented by China's manufacturing industry is crucial to accelerate the intelligent and green development of manufacturing industry.

How manufacturing enterprises achieve flexible, efficient production and sustainable development while reducing cost and increasing efficiency has become the focus of manufacturing enterprises' survival and competition [2,3]. A green manufacturing system based on green technology innovation is the key to solving the problems of a large carbon emission base from the manufacturing industry and the backward construction of green industry chain [4]. With the booming development of the digital economy, innovative breakthroughs in digital technologies such as artificial intelligence, big data, cloud computing and block chain have promoted the transformation of the manufacturing industry in all links through the penetration of the manufacturing industry [5]. Countries with strong industries have realized that using digital means to improve the green manufacturing level is an important way to achieve rapid economic growth and balance environmental benefits. Digital technology empowerment has become key to accelerating the greening and intellectualization of the manufacturing industry. As carbon dioxide emissions rise year by year, countries around the world have agreed to reduce greenhouse gases. The trend of green consumption is also forcing the digital transformation of manufacturing [6]. Green + intelligence is an important link to enhance the competitiveness of digital green manufacturing enterprises [5].

In the digital environment, the green innovation resources and forms that manufacturing enterprises rely on show exponential growth. Such an innovation environment is favorable for manufacturing enterprises to seek external green innovation resources and to try to carry out exchanges and cooperation with external entities in various ways [7]. Open cooperation can help manufacturing enterprises acquire key technologies, shorten the innovation cycle and reduce innovation costs and risks [4]. The change of the digital environment accelerates the breaking of the endogenous logic in the closed green innovation mode [8]. On the one hand, the use of digital green technology has expanded from within the same manufacturing enterprise to local and remote manufacturing enterprises [9]. On the other hand, the source and use of funds has also expanded from a single digital green R&D investment to the investment of external digital green innovation (DGI) risk assets [8]. This creates a more flexible logic of DGI. This phenomenon has attracted close attention from the academic circle, and the concept of open DGI has been proposed, which is the opposite of the traditional closed DGI [10]. This digital green leverages a wide range of external actors and resources to help them achieve and sustain DGI. This emphasizes that the source of DGI is no longer limited to the digital green knowledge and digital green resources within manufacturing enterprises but also includes the external entities that are widely connected with manufacturing enterprises [9].

However, the DGI of manufacturing enterprises often needs to face more complex and changeable challenges. On the one hand, the international operation and DGI integration of manufacturing enterprises have entered a new stage. The concept of market segmentation boundaries has gradually weakened [11]. The accessibility and extensibility of resources make the exact business position and status order of manufacturing enterprises in the market become more ambiguous [12]. It is also difficult for manufacturing enterprises to achieve success in DGI only by relying on their inherent advantages [9]. Manufacturing enterprises carry out DGI activities through rapid self-renewal and iteration by constantly learning from partners. More and more manufacturing enterprises are actively building multilateral cooperation networks from the strategic perspective of an innovation ecosystem [13]. This network can help manufacturing enterprises obtain DGI resources from members of the innovation ecological network by virtue of ecological advantages [14]. This helps network participants jointly cope with the rapid changes in the digital green market to improve innovation efficiency and achieve value co-creation [15]. However,

how to establish digital green knowledge and digital green resources in the specific digital environment is still very important. The development of digital technologies such as artificial intelligence and Internet of Things has shortened the time and space between manufacturing enterprises. At the same time, it also puts digital green competition face to face. Alternative competition, both within and outside the industry, is becoming very common [16]. The dynamic capability embodied by organizational flexibility in digital green is particularly important in the digital green context. Manufacturing enterprises need to redefine organizational boundaries to adapt to the competition rules of the digital green market and to seek a balance between the local DGI network (LDGIN) and the remote DGI network (RDGIN) [9,17].

On the other hand, digital technology has become the core driving force of green innovation in the innovation ecological strategy, but the tide of reverse innovation ecological strategy is getting worse and worse under the means of geo-cultural dominance and digital green competition [7,10]. Driven by digital technology, the interaction among digital enterprises, digital markets, digital users and digital governments has formed a digital ecosystem of interactive sharing of digital resource elements. A digital ecosystem breaks through organizational boundaries and technological distance limits and provides a lot of opportunities for manufacturing enterprises to search for digital green knowledge across the boundary [18]. DGI network can promote manufacturing enterprises to integrate ecological concept in DGI process. This concept helps to build a complementary collaboration network centered on manufacturing enterprises and radiating to suppliers, manufacturers, research institutions, intermediaries and customers [4,7,9,10]. The heterogeneous knowledge and resources of multiple innovation subjects can be effectively transferred and integrated to improve the DGI efficiency of manufacturing enterprises [19]. Due to cultural, geographic and institutional proximity, LDGIN can help manufacturing enterprises access familiar digital green knowledge and digital green resources at a very low cost [20]. This can not only strengthen the connection between new and old knowledge elements but also help reduce the difficulty of digital green knowledge integration and absorption in manufacturing enterprises [21]. The LDGIN can also promote the performance improvement of DGI by accelerating the iteration of new and old capabilities of manufacturing enterprises through the gradual inheritance and knowledge accumulation [22]. The RDGIN avoids the short-sighted and familiar trap of manufacturing enterprises focusing only on local digital green knowledge. This breaks through the path dependence of manufacturing enterprises and the constraints and fetters of existing experience. New technologies and new knowledge that cannot be obtained in the LDGIN can be acquired by manufacturing enterprises to promote the digital green technology track transition and digital green product innovation [23]. The RDGIN can also facilitate the adaptation and matching of manufacturing enterprises to the external dynamic environment, making it easier for manufacturing enterprises to find potential emerging markets.

Under the background of a digital economy, manufacturing enterprises realize the cross-border flow and sharing of digital green knowledge through a DGI network. On the one hand, some scholars believe that innovation networks can effectively promote communication and trust between cooperative subjects [24]. The cross-border flow of digital green knowledge is the key to improving the performance of DGI in manufacturing enterprises through a DGI network. On the other hand, some scholars believe that the higher the degree of network relationship between cooperative parties, the higher the degree of knowledge homogeneity [25]. This is not conducive to heterogeneous knowledge recombination and utilization. Scholars dispute the role of the DGI network in improving the performance of DGI in manufacturing enterprises. Moreover, due to the rapid transformation of the DGI network, the existing studies have not had time to fully discuss the above new problems. In the process of DGI, the digital green experience of manufacturing enterprises in developed countries is naturally regarded as the object to learn and imitate. However, the existing theories cannot provide a way out for the DGI of manufacturing enterprises in developing countries [26]. The factors that constrain and divide the digital

green market and the dynamic management practices of manufacturing enterprises should be discussed in a timely and adequate manner. The combination of digital context and green innovation network brings opportunities and challenges to traditional research. The digital environment is borderless, interconnected and uncertain, which makes the DGI network more valuable for research. However, the discussion based on digital context is still scarce, which highlights the urgent need for the current research on the integration of digital transformation and the green innovation network.

This paper studies the balance mechanism of LDGIN and RDGIN in manufacturing enterprises from the dimensions of digital empowerment and green organization flexibility with the traditional structure–capacity empirical framework. This study covers not only the hard technology aspects of digital technology level and application range, but also the soft power aspects represented by green culture flexibility, green resource flexibility and green capability flexibility. Theoretically, the strategic orientation of DGI and the theoretical level of digital green economy are refined to the micro level of the DGI of manufacturing enterprises. The mechanism of digital empowerment and green organization flexibility on the green innovation performance of manufacturing enterprises is revealed. In practice, this study provides new practical support for manufacturing enterprises to embed strategy and incentive for DGI in the DGI network.

The rest of this paper is structured as follows. The second part is the theoretical basis and research hypothesis. The third part is the study design and the evaluation of questionnaire quality. The fourth part is the empirical test results and analysis of the research hypothesis. Finally, the conclusions of this paper are summarized, and corresponding practical suggestions and future research directions are put forward.

2. Theoretical Basis and Research Hypothesis

2.1. DGI Network and DGI Performance

The open innovation model is where external ideas and external market paths are defined at the same level of importance as internal ideas and internal market paths [27]. Manufacturing companies can leverage a wide range of players and resources to help them realize and sustain DGI. Open innovation mode emphasizes that manufacturing enterprises must cooperate with different types of subjects [28]. DGI value can be created by expanding the heterogeneity of digital green knowledge and the digital green capabilities of the combination of opportunities [29]. External resources and external partners are incorporated into the DGI network of manufacturing enterprises. The DGI network is the carrier for manufacturing enterprises to implement a digital innovation strategy and to carry out green innovation activities [23,24]. This innovation network can improve the speed of DGI and the ability to adapt to the market environment of manufacturing enterprises to obtain a competitive market advantage. Many scholars believe that the relationship between manufacturing enterprises and their partners in the DGI network is not only a cooperative relationship but also a competitive relationship that is the opposite of a cooperative relationship, rather than mutually exclusive, due to resource scarcity, interest divergence and cooperation risks [30]. The competition and cooperation relationship between the main bodies in the DGI network will influence the process and result of DGI [31]. The research of the innovation network mainly includes the competition and cooperation relationship of network members, the heterogeneity of partners and the direction of knowledge and resource flow. All of these discussions have promoted the development of theories related to the DGI network.

With the rapid development of digital technology, the geographical pattern of DGI in manufacturing enterprises has changed significantly. The spatial structure of the DGI network has become one of the key contents of economic geography. The spatial structure mainly forms the following three research perspectives. Firstly, the DGI of manufacturing enterprises should be rooted in the comparative advantages built on local digital green resources [32]. Secondly, the research horizon has gradually expanded to the range of remote DGI, advocating the construction of RDGIN to obtain heterogeneous DGI resources [33].

The expansion of DGI networks inevitably has inherent costs and obstacles. Thirdly, in recent years, scholars have proposed that DGI networks should be based on local and remote multi-space integration. This kind of view has gradually become the hot spot of current academic research [34]. However, how to construct the best DGI network to achieve the maximum effect is still an important and challenging problem facing manufacturing enterprises.

In the constrained environment of the rapid development of digital technology and a low-carbon economy, manufacturing enterprises are facing increasing pressure regarding DGI, and the demand for obtaining digital green competitive advantage has become prominent. This requires manufacturing enterprises to make the extensive use of internal and external digital green resources to improve their DGI performance. DGI performance has also gradually become a hot issue of academic attention and research. DGI performance is a real and effective way for manufacturing enterprises to form competitive advantages. It can fundamentally change organizational structure and use digital technology to fundamentally change the strategic direction of green innovation. The essence of the process of DGI is the acquisition and integration of resources, knowledge and technology in digital green by constructing DGI networks in different scopes. This helps manufacturing enterprises to continuously accumulate and enhance DGI capability to improve DGI output [35]. This paper divides a DGI network into LDGIN and RDGIN and discusses the influence mechanism of two kinds of DGI networks and their interaction on the DGI performance of manufacturing enterprises.

2.1.1. LDGIN and DGI of Manufacturing Enterprises

The LDGIN focuses on the integration of local digital green resources. Manufacturing enterprises carry out R&D, procurement and training activities within the LDGIN [36]. Manufacturing enterprises conduct DGI cooperation with suppliers, customers, peer enterprises, universities and institutes and other LDGIN entities. Such cooperation has prompted manufacturing companies to establish DGI systems [37]. The improvement effect of LDGIN on the DGI performance of manufacturing enterprises is mainly reflected in the following three aspects.

Firstly, from the perspective of relationship strength, the strength of the connections among manufacturing enterprises in a DGI network has an important impact on the DGI of manufacturing enterprises. This is also a hot topic in research into innovation performance. Compared with RDGIN, LDGIN has a smaller scope, more frequent communication and members who share the same value base and institutional environment [38]. In this way, strong relationships of small scope but high intensity are easy to form. This strong relationship is beneficial for manufacturing enterprises to obtain more digital green social capital, so as to promote the DGI of manufacturing enterprises. On this basis, the LDGIN further promotes the exchange and sharing of digital green knowledge among manufacturing enterprises to improve the performance of DGI [39]. Compared with a weak relationship, a strong relationship can promote deep cooperation and value creation among manufacturing enterprises, which is beneficial to the integration of digital green resources and the generation of DGI [40]. The strong relationship of LDGIN is conducive to the improvement of DGI performance of manufacturing enterprises.

Secondly, from the perspective of proximity, the geographical proximity of DGI network members often leads to the proximity of institutions, laws, human history, social cognition and other aspects. Such proximity contributes to the formation of similar cognition and consensus to promote the formation of social and cognitive proximity. This proximity can reduce trust and communication costs to build solid DGI partnerships [41]. At the same time, the closer manufacturing enterprises are to universities, research institutions and other partners in the LDGIN, the more conducive to digital green knowledge spillover. This can not only improve the reliability of digital green knowledge but also promote the performance of DGI in manufacturing enterprises [42]. The closer the geographical proximity, the greater the likelihood of face-to-face and in-depth communication between members. This is conducive to the spread of tacit knowledge and reduce the risk

of digital green caused by information asymmetry [43]. Moreover, DGI personnel have a similar educational background, which is conducive to the development of LDGIN.

Thirdly, from the perspective of similarity, LDGIN has the characteristics of local grounding. The government plays an incomparable and important role in policy formulation, infrastructure construction and DGI mechanism guidance [44]. This role can maintain the long-term stable operation of LDGIN. Compared with RDGIN, LDGIN members have more similar institutional and cultural backgrounds. The government and institutions will play a more significant role in promoting the LDGIN, which is more conducive to the DGI among network members [45]. Meanwhile, the network homogeneity of LDGIN is higher than that of RDGIN. The homogeneity of a DGI network can promote the absorption of digital green knowledge and the improvement of the DGI performance of manufacturing enterprises [46].

The LDGIN has a positive effect on the DGI performance of manufacturing enterprises from the perspective of the strength of DGI network membership, multiple proximity and multi-factor similarity. Therefore, this paper proposes the following hypothesis.

Hypothesis 1a. *There is a positive correlation between LDGIN and DGI of manufacturing enterprises.*

2.1.2. RDGIN and DGI of Manufacturing Enterprises

RDGIN concerns a large scale of activity, involving manufacturing enterprises in the remote range of DGI network activities. It is a DGI network established through remote cooperation with manufacturing enterprises. The influence of RDGIN on the DGI performance of manufacturing enterprises is mainly reflected in the following four aspects.

The first is a perspective based on relationship strength. Compared with the LDGIN, a RDGIN is more likely to form a weak relationship, with long-distance and infrequent contact. The scope of a DGI network under this weak relationship is very extensive [47]. Members have differentiated backgrounds, expertise and knowledge, which facilitates access to digital green knowledge and resources. Manufacturing enterprises can obtain heterogeneous, diversified and unique knowledge and resources. This can maintain the degree and breadth of digital green knowledge to improve the flexibility and performance of DGI [48]. However, this acquisition of digital green knowledge is usually not continuous and often random. Moreover, it is difficult for the members of a DGI network to form deep trust and to share important digital green knowledge and digital green resources in depth to create digital green value. When manufacturing enterprises over-embed and rely on RDGIN, such a weak relationship makes it difficult for manufacturing enterprises to share deep digital green resources and technologies [49]. Therefore, a RDGIN is not conducive to improving the performance level of DGI in manufacturing enterprises.

The second is from the perspective of organizational learning. Digital green technology achievements from remote partners flow within the RDGIN. Manufacturing enterprises can acquire digital green knowledge in the same professional field through imitation and learning, including learning advanced digital green R&D concept, design thought and R&D process [50]. At the same time, manufacturing enterprises learn advanced digital green management knowledge and digital green marketing means. This enables manufacturing enterprises to produce new digital green products embedded in LDGIN and RDGIN [51]. In addition, digital green innovators within manufacturing enterprises are influenced by RDGINs. This can not only improve the professional quality and level of digital green technical personnel but also contribute to the improvement of DGI performance of manufacturing enterprises [52]. RDGIN can improve the breadth of digital green knowledge search. Manufacturing enterprises improve the novelty and efficiency of DGI by acquiring knowledge from a wide range of sources. However, due to the large geographical range of RDGIN, geographical proximity is low. Different RDGINs have economic, political, cultural and social heterogeneity. Therefore, manufacturing enterprises need to develop different DGI strategies according to the LDGIN to improve their absorption capacity and transfer efficiency of heterogeneous digital green knowledge and technology [53]. At the

same time, manufacturing enterprises will face too much external digital green knowledge and skills in the RDGIN. The excessive search of external digital green knowledge will have a negative impact on the DGI of manufacturing enterprises.

The third is based on the perspective of resource utilization. In the context of the rapid development of digital low-carbon economy, the competitiveness of manufacturing enterprises not only depends on the richness of their internal digital green resources but also reflects on their ability to integrate and utilize remote digital green resources [54]. The establishment of RDGIN can help manufacturing enterprises to promote their own digital green technology upgrading by using remote high-quality digital green resources. LDGIN and RDGIN can be used to acquire, transfer, integrate and create digital green knowledge and technology. However, if too many digital green R&D resources and R&D talents of manufacturing enterprises are used to build RDGIN, the R&D resources of LDGIN will be occupied. This will lead to the scarcity and loss of R&D talent within the LDGIN [55]. In the long run, this will adversely affect the LDGIN that manufacturing companies have.

The fourth is based on the perspective of innovation benefits and risks. The construction of RDGIN can make use of the digital green technology advantages of network members within a large range. This can help manufacturing companies gain revenue from the vast remote market. The expansion of DGI network space is conducive to the upgrading of old technology structure and the generation of new digital green products [56]. Manufacturing enterprises in a LDGIN establish a RDGIN connection. This can promote the development of LDGINs and improve the performance of DGI in manufacturing enterprises. However, if manufacturing enterprises excessively embed in a RDGIN, they will strengthen their dependence on external digital green technology. This is not conducive to the continuous improvement in the DGI performance of manufacturing enterprises. Moreover, manufacturing enterprises will share the digital green knowledge and technology of a LDGIN with partners in a RDGIN during cooperation [57]. There is a risk of leakage of digital green intellectual property.

Therefore, under the background of the dual carbon goal and digital economy, the RDGIN constructed by the expansion of DGI networks by manufacturing enterprises plays a positive role in DGI. Therefore, this paper proposes the following hypothesis.

Hypothesis 1b. *There is an inverted U-shaped relationship between the RDGIN and the DGI of manufacturing enterprises.*

2.1.3. Balance of LRDGIN and DGI of Manufacturing Enterprises

Many scholars emphasize the importance of the interrelation and interaction between local innovation networks and remote innovation networks. Under the background of the rapid development of a digital low-carbon economy, the generation of DGI is not only the process of local DGI expanding to remote DGI but also the process of a RDGIN deepening to LDGINs [51]. DGI in manufacturing enterprises is the result of the two-way development of LDGINs and RDGINs. Therefore, the development of DGI needs to establish a local RDGIN. It is particularly important to establish the connection between LDGINs and a RDGIN.

Many scholars often use the concept of balance in their research on the correlation and interaction between two factors. For example, He and Wong (2004) established a balance between exploratory innovation and exploitative innovation to discuss the impact of the balance between the two innovation strategies on sales growth [58]. Cao et al. (2009) believed that the balance formed by product term emphasizes a comprehensive effect, while the balance formed by absolute difference emphasizes a relative effect [59]. At the same time, the results show that the comprehensive balance is more favorable to enterprises with more internal or external resources. Relative balance is better for firms with limited resources. With limited resources, managers may strike a balance between exploratory and exploitative innovation. Jin et al. (2015) constructed the product term of knowledge depth and knowledge breadth to represent the balance effect [60]. In this study, the relationship

between LDGINs and RDGINs is established to study the effect mechanism of the balance between the two networks on the DGI performance of manufacturing enterprises. The balance of a DGI network is divided into two types of balance. Firstly, the comprehensive balance is constructed to measure the impact of their interaction on DGI performance through the product term of the two. Secondly, relative balance is constructed by taking the absolute value of the difference between the two networks to measure the impact of the difference and fit degree on DGI performance.

The interaction and comprehensive balance between LDGINs and RDGINs will affect the DGI of manufacturing enterprises. The two DGI networks have their own advantages and can play complementary roles. First, the advantages of digital green knowledge and resources brought by the two kinds of DGI networks for manufacturing enterprises are different [61]. Manufacturing enterprise with local partners to establish within the DGI network connection that is not only beneficial to the manufacturing enterprise to obtain the local digital green resources and policy information to make up a the lack of local digital green knowledge but also in the system of legitimacy, local resource acquisition, homogeneity and knowledge acquisition for their own advantage. The connection established between manufacturing enterprises and the partners of a RDGIN is not only conducive to the timely acquisition of diversified digital green knowledge but also can bring advantages to manufacturing enterprises in the acquisition of advanced digital green technology and heterogeneous knowledge [62]. Second, based on the perspective of binary learning, the two kinds of DGI networks have different mechanisms of effect on DGI. Compared with a RDGIN, a LDGIN has more effects on DGI through exploitative learning. This is not only conducive to manufacturing enterprises to further explore and extend existing technologies and capabilities to improve performance by quickly obtaining short-term benefits [63]. The RDGIN plays an important role in DGI through exploratory learning. Although this is conducive to the search and acquisition of new digital green knowledge for manufacturing enterprises, it will also bring a certain degree of external risks.

The fit degree and relative balance between LDGINs and RDGINs will affect the DGI of manufacturing enterprises. Both types of DGI networks are indispensable. The absence of either party will bring harm to the DGI of manufacturing enterprises. On the one hand, if manufacturing enterprises pay too much attention to LDGINs and neglect RDGINs, organizational inertia and capacity rigidity are very easy to cause. Manufacturing enterprises rely too much on the existing small range of digital green knowledge and resources. Due to the insufficient learning of heterogeneous knowledge and diversified technologies in manufacturing enterprises, it is not conducive for manufacturing enterprises to carry out DGI activities to obtain long-term innovation benefits. On the contrary, if manufacturing enterprises pay too much attention to RDGINs and ignore LDGINs, it will not only cause the problem of new knowledge that is difficult to absorb and integrate, but also easily causing manufacturing enterprises to become path-dependent and putting them in the passive position of digital green technology catch-up.

Therefore, manufacturing enterprises that can not only integrate into a LDGIN but also take a place in a RDGIN tend to have high DGI capability and performance level. The following hypotheses are proposed in this paper.

Hypothesis 1c. *There is a positive correlation between the comprehensive balance (product) between LDGINs and RDGINs and the DGI of manufacturing enterprises.*

Hypothesis 1d. *There is a positive correlation between the relative balance (absolute difference) between LDGINs and RDGINs and the DGI of manufacturing enterprises.*

2.2. The Moderating Role of Digital Transformation

The wide and in-depth application of digital technologies such as big data, cloud computing and artificial intelligence marks the arrival of the era of digital economy [64]. The central feature of the digital age is that data has become a key element of innovation. This will expand the original green innovation factor system and change the traditional green in-

novation development economic system. The rapid digitization of green innovation process and results has greatly expanded existing green innovation management theory. Digital technology includes hardware technology, software technology, blockchain technology, big data technology, cloud computing technology, artificial intelligence technology, Internet of Things technology and virtual reality technology, etc., which are general-purpose technologies. In the era of the digital economy, digital technology is changing the original mode of production, organizational form, business model and innovation theory and is expanding the connotations of product and service innovation [65]. Digital technology is not only the key to maintain the continuous competitiveness of manufacturing enterprises in the digital economy era but is also an important factor to enhance the core competitiveness of manufacturing enterprises [66]. Digitization endows manufacturing enterprises with higher productivity and more intellectual capital, which helps to improve the performance level of green innovation by using data.

In the process of digital transformation, manufacturing enterprises apply a variety of digital technologies to green products, green operation, green management, strategic thinking, business model and other aspects to improve the performance of DGI. Digital transformation emphasizes the application of a variety of digital technologies and the application of digital technologies in the operation and management of manufacturing enterprises [67]. In this study, DGI performance is taken as a dependent variable, and the improvement of DGI performance level is one of the results of digital transformation of manufacturing enterprises, which reflects the effect of digital transformation. Therefore, digital transformation is divided into two dimensions [68]. The first dimension is the level of digital technology, focusing on the types of digital technology. The second dimension is the scope of digital application, which emphasizes the application of digital technology in different green innovation processes. The influence of digital technology on green innovation is a process of enabling. The development of various digital technologies improves the green innovation efficiency of manufacturing enterprises [69]. Manufacturing enterprises have applied digital technology to many aspects and fields of management. This is a process that promotes business model innovation and value creation and enables innovation. Therefore, this paper discusses the moderating effect of the two dimensions acting alone on the process of green innovation, and the moderating effect of the interaction between the two dimensions.

2.2.1. The Moderating Effect of Digital Transformation on the Relationship between a LDGIN and DGI

In a LDGIN, manufacturing enterprises use digital technology to carry out green innovation activities, which will produce positive green innovation effects. Firstly, LDGIN is a regional concept, in which there is a certain physical distance between different members [9]. Digital technology can overcome the limitation of space and resources to the greatest extent to expand the process and scope of green innovation. This will not only greatly enhance the connectivity between participants in green innovation but will also contribute to the efficient use of digital green resources. Secondly, artificial intelligence, block chain, cloud computing, big data and other digital technologies are used in a LDGIN to reduce the cost of digital green knowledge transfer among network members and to improve the efficiency of communication and information exchange [70]. This is conducive to promoting DGI among different members. Thirdly, the application of digital technology can increase the heterogeneity of digital green resources and knowledge and the possibility of launching new digital green products and services [71]. To some extent, the recombination of existing digital green products and services can make up for the very low heterogeneity of information, knowledge and technology caused by the heterogeneity of LDGINs and RDGINs. Therefore, digital technology and its application can strengthen the role of LDGINs in improving the DGI performance of manufacturing enterprises to a greater extent, and the following hypothesis is proposed.

Hypothesis 2a. *Digital technology level positively moderates the positive correlation between LDGIN and DGI performance.*

Hypothesis 2b. *Digital application range positively moderates the positive correlation between LDGIN and DGI performance.*

Hypothesis 2c. *When a high level of digital technology is combined with a high digital application range, there is a strong positive correlation between LDGIN and DGI performance.*

2.2.2. The Moderating Effect of Digital Transformation on the Relationship between RDGIN and DGI

Digital technology plays a positive role in reducing spatial and resource constraints, expanding the scope of communication and communication between different subjects and increasing the heterogeneity of knowledge and resources. Digital transformation has a complex moderating effect on the inverted U-shaped relationship between the RDGIN and DGI performance of manufacturing enterprises.

When the embedment degree of manufacturing enterprises in a RDGIN is at a low level, digital transformation will strengthen the positive effect of the RDGIN on DGI performance of manufacturing enterprises [72]. Firstly, manufacturing enterprises have a very high demand for the breadth of digital green knowledge and resources. The application of digital technology can help manufacturing enterprises break through the limitation of time and space and reduce the cost of digital green knowledge transmission to enhance the connectivity between manufacturing enterprises and other members of the network [73]. This can not only improve the heterogeneity of manufacturing enterprises' access to digital green knowledge and resources but also help promote the cooperation among heterogeneous DGI participants to enhance performance improvement. Secondly, at the initial stage of embedding RDGIN, manufacturing enterprises have strong demand for digital green knowledge transfer among network members. Distance, cultural barriers and other reasons will lead to less communication between members and high communication costs [74]. With the development of digitization, the rules and patterns followed by manufacturing enterprises with different backgrounds can be measured with objective data. Data homogeneity reduces the barrier of digital green knowledge transfer between different manufacturing enterprises. Thirdly, digitization promotes the resolution and blurring of the boundary of a RDGIN. The skilled application of a series of information communication tools, such as email, online video and network broadcast overcame the asynchronism of communication between different members [75].

When manufacturing enterprises over-embed in a RDGIN, digital transformation will strengthen the negative effect of a RDGIN on the DGI performance of manufacturing enterprises. First, if manufacturing enterprises are over-embedded in RDGINs, the loose and weak links formed between them and other members will deepen the crisis of trust. This could lead to the risk of intellectual property leakage and the possibility of weakening local control over digital green technology. Digital technology speeds up the rapid flow of various digital green resources among different subjects. This further increases the risk that the specific digital green assets of manufacturing enterprises can be utilized across borders [76]. Second, as the embedment of manufacturing enterprises in a RDGIN deepens, manufacturing enterprises become more dependent on partners in the RDGIN. At the same time, the demand of manufacturing enterprises for heterogeneous digital green resources gradually turns to the demand for in-depth communication and cooperation [77]. However, due to the limitations of geographical boundaries, it is difficult to form deep trust and to carry out deep cooperation between manufacturing enterprises. In this context, the possibility of sharing important digital green information and resources is reduced. This will further negatively impact DGI and value creation. Third, compared with a LDGIN, a RDGIN has a larger scope. In the application process of digital technology, manufacturing enterprises frequently move between different customers and subjects, and the probability of forming lasting emotional connection with specific organizations will be reduced. This

will lead to greater fragmentation among members of RDGINs and make deep collaboration more difficult.

This paper argues that the level and application of digital technology strengthen the inverted U-shaped relationship between a RDGIN and DGI in manufacturing enterprises. The following three hypotheses are proposed.

Hypothesis 3a. *Digital technology level negatively moderates the inverted U-shaped relationship between RDGIN and DGI performance.*

Hypothesis 3b. *Digital application range negatively moderates the inverted U-shaped relationship between RDGIN and DGI performance.*

Hypothesis 3c. *The combination of high digital technology level and high digital application range will negatively adjust the inverted U-shaped relationship between RDGIN and DGI performance.*

2.3. The Moderating Effect of Green Organization Flexibility

As a dynamic capability, green organization flexibility can help manufacturing enterprises to issue a green response in time under the dual carbon scenario. This can not only stabilize the green market position of manufacturing enterprises and maintain green competitive advantage but also help improve the success rate of green innovation and the performance of green organizations [78]. Green organization flexibility is a multidimensional concept. It can be divided into resource flexibility, ability flexibility and culture flexibility. In this study, green organization flexibility is divided into three dimensions: green culture flexibility, green resource flexibility and green capability flexibility.

2.3.1. The Moderating Effect of Green Culture Flexibility

Green cultural flexibility means that manufacturing enterprises use innovative, coordinated, green, open and shared culture and ideas to continuously learn green knowledge and skills and improve their green response ability. The more flexible the green culture of manufacturing enterprises is, the more beneficial it is for employees to participate in the informal green information exchange and the process of enterprise green development [79]. This is conducive to the absorption of tacit knowledge, technology and know-how to improve the ability to integrate green resources. At the same time, green information exchange can improve the sensitivity and initiative of manufacturing enterprises to the dual carbon scenario and can actively adjust the factors unfavorable to the development of manufacturing enterprises. This is conducive to manufacturing enterprises to respond to external threats and improve the ability for organizational green change. This innovative and relaxed green cultural atmosphere can encourage employees to actively learn green knowledge to enhance their ability to adapt to the environment, dare to challenge and take risks [80]. The positive green cultural atmosphere of manufacturing enterprises is conducive to improving green innovation ability, production efficiency and the profit level of manufacturing enterprises, as well as enhancing sustainable development ability. In the case of strong green culture flexibility of manufacturing enterprises, manufacturing enterprises will have stronger green learning ability and green absorption capacity [81]. Therefore, green cultural flexibility can enhance the positive effect of a LDGIN on the digital innovation of manufacturing enterprises. At the same time, manufacturing enterprises with strong green culture flexibility have more acute observation ability and greater ability to resist risks. This can make manufacturing enterprises better deal with the innovation risks caused by the RDGIN and reduce the over-dependence of members on the RDGIN [82]. This can reduce the negative effect of over-embedding in the RDGIN on the DGI performance of manufacturing enterprises. Based on this, this paper puts forward the following hypotheses.

Hypothesis 4a. *Green cultural flexibility positively moderates the positive correlation between LDGIN and DGI performance.*

Hypothesis 5a. *Green culture flexibility positively moderates the inverted U-shaped relationship between RDGIN and DGI performance.*

2.3.2. The Moderating Effect of Green Resource Flexibility

Green resource flexibility is the ability of manufacturing enterprises to quickly, cheaply and easily convert existing green resources into another green resource to improve the utilization range and conversion efficiency of green resources in the process of dealing with the dual carbon target scenario [83]. Green resource flexibility emphasizes the accumulation of its own green resources through a variety of ways, while the scope of the application of green resources is expanded to match the existing green opportunities. When manufacturing enterprises deal with the dual carbon target scenario, they often need new green resources and new green ways to carry out green innovation [84]. In this process, it is very important to find new green resources and to change the use of existing green resources. There are two ways for green resource flexibility to promote green innovation. The first is to alleviate the demand for green resources generated by the change of the dual-carbon target scenario for manufacturing enterprises to reduce the risk of environmental pollution in green innovation activities [85]. Second, green resources are transferred to reduce cost consumption in the process of green innovation [86]. The green innovation performance of manufacturing enterprises can be improved from the qualitative and quantitative aspects based on these two paths. Manufacturing enterprises can launch green new products at a faster speed to improve the performance of green product innovation. This is not only conducive to green progressive innovation and green breakthrough innovation of manufacturing enterprises but is also conducive to the formation of green competitive advantage [87]. Green resource flexibility can help manufacturing enterprises make full use of green resources in LDGINs and RDGINs. This can undoubtedly strengthen the positive correlation between the LDGIN and DGI performance of manufacturing enterprises, as well as the positive correlation between the RDGIN and DGI performance of manufacturing enterprises [88]. However, in the process of embedding manufacturing enterprises into a RDGIN, with the deepening of the degree of embedding, the green resource base of manufacturing enterprises becomes stronger and stronger. The weak relationship among the members of a RDGIN makes it difficult to share deep green resources with each other. Other members can offer less and less help with green resources. If manufacturing firms continue to absorb shallow and highly overlapping green resources provided by other members, the negative impact of the excessive search on DGI will be exacerbated. Based on this, this paper puts forward the following hypotheses.

Hypothesis 4b. *Green resource flexibility positively moderates the positive correlation between LDGIN and DGI performance.*

Hypothesis 5b. *Green resource flexibility negatively moderates the inverted U-shaped relationship between RDGIN and DGI performance.*

2.3.3. The Moderating Effect of Green Capability Flexibility

Green capability flexibility is the ability of manufacturing enterprises to identify new green resources and their applicable scope and to rationally allocate green resources to maximize the effectiveness of green resources. Compared with green resource flexibility, green capability flexibility not only discovers and allocates green resources but also emphasizes adaptation and response to the changes of the dual carbon target scenario [89]. With the increase of environmental uncertainty, it is difficult for manufacturing enterprises to maintain a green competitive advantage only by obtaining green resources. Green capability flexibility can make up for the weakness of green resource flexibility. Various green resources are integrated to make them play a greater value in response to external uncertainties [85,88]. The most important characteristic of DGI is its risk and uncertainty. Manufacturing enterprises with high green capability and flexibility have a better ability

to deal with risks. Manufacturing enterprises can respond quickly to external changes, which is conducive to improving the success rate of DGI [90]. The LDGIN forms a strong relationship through its local embeddedness and the proximity of network members. This strong relationship enables members to exchange and share green knowledge, green technology and green resources more fully. This is conducive to the improvement of the DGI performance of manufacturing enterprises [91]. Green capability flexibility is a characteristic that manufacturing enterprises can effectively use all kinds of green resources and green capabilities. It can make the LDGIN promote the performance of DGI more smoothly. However, the deep embedment of manufacturing enterprises in the RDGIN may hinder the improvement of DGI performance. At the same time, green capability flexibility can help manufacturing enterprises better cope with and solve the risks arising from the deep embedding into a RDGIN [92]. To some extent, the negative effects caused by the deep embedment of manufacturing enterprises into the RDGIN are alleviated. The following hypotheses are proposed in this paper.

Hypothesis 4c. *Green capability flexibility positively moderates the positive correlation between LDGIN and DGI performance.*

Hypothesis 5c. *Green capability flexibility positively moderates the inverted U-shaped relationship between RDGIN and DGI performance.*

The overall framework of this study is shown in Figure 1.

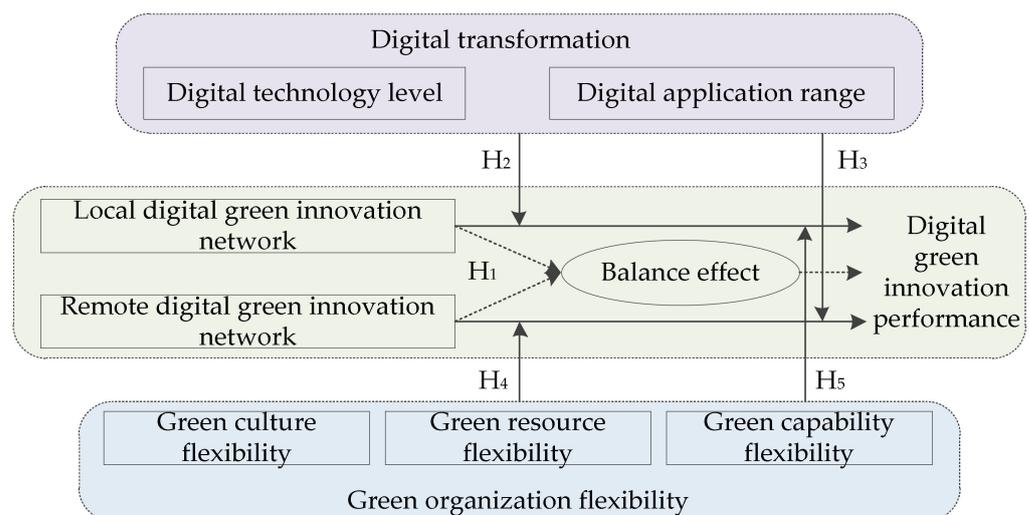


Figure 1. Theoretical framework.

Figure 1 shows the five main hypotheses of this study. Hypothesis 1 includes the following four sub-hypotheses. ① There is a positive correlation between LDGIN and DGI of manufacturing enterprises. ② There is an inverted U-shaped relationship between RDGIN and DGI of manufacturing enterprises. ③ There is a positive correlation between the comprehensive balance (product) between LDGIN and RDGIN and DGI of manufacturing enterprises. ④ There is a positive correlation between the relative balance (absolute difference) between LDGIN and RDGIN and DGI of manufacturing enterprises. Hypothesis 2 includes the following three sub-hypotheses. ① Digital technology level positively moderates the positive correlation between LDGIN and DGI performance. ② Digital application range positively moderates the positive correlation between LDGIN and DGI performance. ③ When a high level of digital technology is combined with a high digital application range, there is a strong positive correlation between LDGIN and DGI performance. Hypothesis 3 includes the following three sub-hypotheses. ① Digital technology level negatively moderates the inverted U-shaped relationship between RDGIN and DGI performance. ② Digital application range negatively moderates the inverted U-shaped

relationship between RDGIN and DGI performance. ③ The combination of high digital technology level and high digital application range will negatively adjust the inverted U-shaped relationship between RDGIN and DGI performance. Hypothesis 4 includes the following three sub-hypotheses. ① Green cultural flexibility positively moderates the positive correlation between LDGIN and DGI performance. ② Green resource flexibility positively moderates the positive correlation between LDGIN and DGI performance. ③ Green capability flexibility positively moderates the positive correlation between LDGIN and DGI performance. Hypothesis 5 includes the following three sub-hypotheses. ① Green culture flexibility positively moderates the inverted U-shaped relationship between RDGIN and DGI performance. ② Green resource flexibility negatively moderates the inverted U-shaped relationship between RDGIN and DGI performance. ③ Green capability flexibility positively moderates the inverted U-shaped relationship between RDGIN and DGI performance.

3. Material and Methods

3.1. Data Sources and Samples

In this study, the data were collected from the database of surveys on the operating conditions, digital transformation status and green innovation activities of manufacturing enterprises in most areas of China from June 2021 to March 2022. The respondents were middle and senior managers of manufacturing enterprises. The questionnaire covers four dimensions: local policies, operating conditions, operating measures and digital transformation. Due to the COVID-19 pandemic, online questionnaires were used to obtain data. One thousand questionnaires were sent out, and 773 were returned. The 612 questionnaires were valid. Samples that did not fit the research situation and invalid samples with more missing values were removed. Finally, 562 valid sample data were used in this study. The descriptive statistical characteristics of the samples are shown in Table 1.

Table 1. Descriptive statistical characteristics of the sample.

Attribute	Classification	Sample Size	Percentage (%)
Age	1–10 years	289	51.42
	10 to 30 years	223	39.68
	More than 30 years	49	8.72
Size	Under 50 people	110	19.57
	50–100 people	102	18.15
	101–500 people	108	19.22
	501–1000 people	92	16.37
	More than 1000 people	150	26.69
Average revenue over the past three years	Less than 1 million yuan	67	11.92
	1 million to 10 million yuan	116	20.64
	10 million to 50 million yuan	179	31.85
	50 million to 100 million yuan	113	20.11
	More than 100 million yuan	86	15.30
Ownership type	State-owned enterprise	148	26.33
	Collective enterprise	17	3.02
	Private enterprise	295	52.49
	Foreign investor enterprise	102	18.15
Main business models	Mainly online mode	194	34.52
	Mainly offline mode	368	65.48

3.2. Standardized Model

The data in this paper were collected through questionnaires, and the measurement of variables was based on existing mature studies. A 5-point Likert scale was used to measure variables. 1 means completely disagree or very low, and 5 means completely agree or very high. Variables are defined in Table 2, and specific measurement items are shown in Table 3.

Table 2. Variable definitions.

Variable	Symbol	Variable Declaration
Dependent variable	DGIP	DGI performance
Independent variables	LDGIN RDGIN	LDGIN RDGIN
Moderating variable	DTL DAR GCF GRF GCF	Digital technology level Digital application range Green culture flexibility Green resource flexibility Green capability flexibility
Control variables	Age Size Revenue Ownership Industry Province	The natural log of the firm’s age Number of employees Operating income level Ownership type Niche business Province

Table 3. Factor analysis results of each variable.

Variable Extraction	Factor	Measurement Items	Factor Loading	Cronbach’s Alpha	CIV (%)	CR	AVE	KMO
Open DGI network	LDGIN	The enterprise tends to internal digital green research and development	0.736	0.882	76.431	0.903	0.526	0.894
		Purchase digital green products from other local enterprises or organizations	0.683					
		Cooperate with local suppliers for digital green R&D	0.714					
		Cooperate with local customers in digital green research and development	0.730					
		Cooperate with local enterprises in digital green research and development	0.781					
		Cooperate with local universities and institutes in digital green research and development	0.687					
		RDGIN	The enterprise tends to remote digital green research and development					
	Purchase digital green results from other businesses or institutions remotely		0.691					
	Collaborate with remote suppliers on digital green R&D		0.683					
	Cooperate with remote customers in digital green development		0.767					
	Cooperate with remote industry enterprises in digital green research and development		0.729					
	Cooperate with remote universities and institutes in digital green research and development		0.801					
	Digital technology level		The degree of adoption of intelligent technology	0.737	0.897	72.783	0.883	
		Adoption of cloud computing technology	0.794					
Adoption of iot technology		0.667						
Adoption of social interaction technologies		0.811						
Adoption of platform eco-technologies		0.748						
Digital application range	The digital infrastructure of the enterprise is very complete	0.782	0.885	78.947	0.912	0.563		
	The company will develop or build digital products (services), platforms and infrastructure by itself	0.675						
	The company will externally purchase and apply digital products (services), platforms and infrastructure	0.682						
	The enterprise has a high degree of digital business model	0.768						
	The enterprise has a high degree of digital internal management and operation mode	0.821						

Table 3. Cont.

Variable Extraction	Factor	Measurement Items	Factor Loading	Cronbach's Alpha	CIV (%)	CR	AVE	KMO	
Green organization flexibility	Green culture flexibility	Employees can solve environmental problems in the enterprise	0.793	0.947	79.016	0.876	0.524		
		Management can lead employees in times of environmental crisis	0.821						
		Management can ensure the implementation of digital green strategy and the achievement of strategic goals through continuous and correct decisions	0.698						
		Management can steer digital green strategic direction and implementation process	0.789						
	Green resource flexibility	Green resource flexibility	The same green resources are highly shared among various departments within the enterprise	0.689	0.855	76.105	0.857	0.576	0.901
			The same green resources are used to develop, manufacture and sell different products or services to a high degree	0.765					
			The cost and difficulty of changing the same green resource from one use to another is minimal	0.741					
			The same green resource can change from one use to another in a very short time	0.790					
	Green capability flexibility	Green capability flexibility	Companies allow departments to break formal working procedures to keep green work flexible and dynamic	0.806	0.842	73.805	0.896	0.601	
			The green working mode of enterprise internal operation varies from person to person, according to the situation	0.749					
			Enterprises have very smooth internal communication channels and mechanisms to deal with environmental crisis	0.658					
			Enterprises can actively and actively respond to green competition	0.694					
DGI performance	DGI performance	The enterprise can achieve high DGI ability	0.869	0.818	79.326	0.872	0.597	0.875	
		The enterprise has enough digital green research and development funds	0.718						
		The enterprise has enough digital green research and development talents	0.758						
		The enterprise has a complete digital green research and development system	0.735						

In terms of dependent variable and independent variable, DGI performance is the dependent variable. The scale designed by the existing research is used for reference from the input–output perspective. Four questions were designed to measure the level of DGI performance. An open DGI network is an independent variable. It is divided into two dimensions: a LDGIN and a RDGIN. The LDGIN mainly includes the local DGI activities and partners of manufacturing enterprises. The RDGIN mainly includes the remote DGI activities of manufacturing enterprises.

In terms of moderating variables, digital transformation is the first one. Digital transformation can be divided into two dimensions: digital technology level and digital application range. The level of digital technology is divided into five kinds of digital technology, such as intelligent technology and cloud computing technology. A digital application range measured by manufacturing enterprises for digital technology to master methods and application range. Green organization flexibility is the second moderating variable. Green organization flexibility can be divided into three dimensions: green culture flexibility, green resource flexibility and green capability flexibility.

In terms of control variables, the age, scale, operating income level, ownership type, subdivided industry and province of manufacturing enterprises are control variables. The age of a manufacturing firm is measured by the time the firm was established. Manufacturing firm size is measured by the number of employees currently employed. The scale of manufacturing companies is divided into five grades: 50 employees or less, 50–100 employees, 101–500 employees, 501–1000 employees and more than 1000 em-

ployees. The operating income level is divided into 5 levels, including below 1 million yuan, 1 million to 10 million yuan, 10.1–50 million yuan, 50.1 million to 100 million yuan and more than 100 million yuan, which are assigned 1–5 in order. Ownership types are divided into four categories, including state-owned enterprises, collective enterprises, private enterprises, foreign investors and enterprises invested in Hong Kong, Macao and Taiwan. The province in which the enterprise is located is confirmed according to its registration place. The enterprises investigated in this paper are from 24 different provincial administrative regions.

3.3. Deviation Test and Reliability and Validity Test

3.3.1. Deviation Test

To avoid homologous bias in the study sample, homologous method bias and non-responder bias were used for bias testing. Since the questionnaire used in this paper was filled in by the same person at the same point in time, there may be the problem of common methodological bias of data from the same source. Therefore, Harman's single-factor test was used to test whether the problem was seriously affected. The results show that the variance explained by the first principal component after rotation is 21.604%, which is lower than the requirement of 40%. There is no serious problem of common method bias. In terms of the non-responder bias, the top 1/3 and bottom 1/3 samples were selected for a *t*-test, in order of questionnaire return. The results showed that there was no significant difference in more than 91.207% of the observed variables, indicating that the non-responder bias would not have a significant effect.

3.3.2. Reliability and Validity Test

In this study, the scales were used to perform exploratory factor analysis and confirmatory factor analysis respectively. The factor analysis results are shown in Table 3. The results show that the Cronbach's alpha coefficient of each factor is greater than 0.7 and that the combined reliability coefficient is greater than 0.8, which is much higher than the critical value of 0.6. This indicates that the scale has good reliability. Factor loading values of all scale items were greater than 0.5, indicating that the scale had good aggregation validity. The Bartlett sphericity test value reached significance level. The cumulative explanatory variances of each variable were all greater than 60%, and the KMO values were all greater than 0.7. This shows that the content of the item explains most of the information about this variable. The square root of the average extraction variance of each variable is greater than 0.5, which indicates that the metric has high discriminant validity. In conclusion, the data used in this paper have a good level of structural validity.

3.4. Methods

In the study, Pearson correlation was used to analyze the descriptive statistics and correlation. In the process of regression analysis, independent variables and moderating variables are centralized, and the product term of two-factor interaction effect is constructed. In addition, according to the model setting, control variables, independent variables, moderating variables and interaction terms were successively added into the model for regression analysis. In this study, the regression model reduces the impact of heteroscedasticity by robust standard error.

4. Empirical Results

4.1. Descriptive Statistics and Correlation Analysis

The variable data were analyzed for descriptive statistics and correlation, and the results are shown in Table 4. Pearson correlation coefficients between the variables were all less than 0.8. Meanwhile, the independent variables were tested by a variance inflation factor. The results show that the variance inflation factors of the respective variables are all less than 10, so there is no serious multicollinearity problem. As shown in Table 4, independent variables (LDGIN and RDGIN) and moderating variables (digital technology

level, digital application range, green cultural flexibility, green resource flexibility, green capability flexibility) all have a significant positive correlation with DGI performance. This preliminary support for the theoretical hypothesis of this paper also indicates that it is suitable for further regression analysis by the model.

Table 4. Results of descriptive statistics and correlation.

Variable	Mean Value	Standard Deviation	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1 Age	2.356	0.892	1													
2 Size	3.378	1.369	0.518***	1												
3 Revenue	3.627	1.281	0.483***	0.588***	1											
4 Ownership	2.934	1.103	0.056***	−0.351***	−0.134**	1										
5 Industry	7.156	4.164	−0.118**	−0.124**	−0.154***	0.103	1									
6 Province	5.230	7.265	0.103	−0.147**	−0.201**	−0.116*	−0.143**	1								
7 LDGIN	3.024	1.235	0.237**	0.442***	0.365***	−0.153*	−0.155*	0.103	1							
8 RDGIN	2.986	1.107	0.198***	0.432***	0.326***	0.103	−0.206***	−0.004	0.163*	1						
9 DTL	2.868	1.312	−0.124	0.356***	0.105	0.125	0.107	−0.113	0.328**	0.196**	1					
10 DAR	3.164	1.019	0.204***	0.431***	0.226***	−0.124	−0.131	−0.033	0.359***	0.546***	−0.114	1				
11 GCF	3.112	1.114	0.120	0.115***	0.163***	0.102	0.086	−0.108	0.369***	0.224***	0.401***	0.318***	1			
12 GRF	2.907	1.257	−0.205***	−0.163*	0.175*	−0.110	0.137	0.096	0.213	0.103	0.226***	0.134*	−0.015	1		
13 GCF	3.027	1.208	−0.289***	−0.286***	−0.224***	0.210***	−0.013	0.009	0.198***	−0.010	0.189***	0.056	−0.004	−0.032	1	
14 DGIP	3.698	1.304	0.055	0.099**	0.089**	−0.035	−0.021	0.032	0.234***	0.201***	0.269***	0.337***	0.304***	0.301**	0.171***	1

Note: *, ** and *** represent $p < 0.1$, $p < 0.05$ and $p < 0.01$, respectively.

4.2. Analysis of Hierarchical Regression Results

4.2.1. Analysis of Main Effect Test Results

Table 5 shows the hierarchical regression results of the main effects. According to Model 2, the coefficient of LDGIN is positive ($\beta = 0.264$) and significant at the 1% level ($p < 0.01$). This indicates that there is a positive correlation between LDGIN and DGI performance, and Hypothesis 1a is verified. According to Model 3, the coefficient of the primary term of the RDGIN is positive ($\beta = 0.231$) and significant at the 1% level ($p < 0.01$). The coefficient of quadratic term of the RDGIN is negative ($\beta = -0.177$) and significant at the 1% level ($p < 0.01$). This indicates that there is an inverted U-shaped relationship between RDGIN and DGI performance, and Hypothesis 1b is verified. It can be seen from Model 4 that the coefficient of the product term of the LDGIN and the RDGIN is positive ($\beta = 0.188$) and significant at 10% ($p < 0.1$). This indicates that there is a positive correlation between the comprehensive balance between the LDGIN and the RDGIN and DGI performance, and Hypothesis 1c is verified. According to Model 5, the coefficient of absolute value difference between the LDGIN and the RDGIN is negative ($\beta = -0.270$) and significant at 5% ($p < 0.05$). This indicates that the smaller the difference between the LDGIN and the RDGIN, the better the performance of DGI (the smaller the absolute difference is, the higher the relative balance degree is). There is a positive correlation between the relative balance between the LDGIN and the RDGIN and DGI performance. Hypothesis 1d is verified.

Table 5. Regression results of the main effect level.

Variable	DGIP				
	Model 1	Model 2	Model 3	Model 4	Model 5
Age	−0.016	−0.012	−0.126	−0.114	−0.096
Size	0.034	−0.058	−0.091	−0.124	−0.143
Revenue	0.134	0.095	0.073	0.081	0.108
DTL	0.121 **	0.062 *	0.137 **	0.112 *	0.067 *
DAR	0.172 ***	0.079 **	0.234 ***	0.158 *	0.109 *
GCF	0.198 ***	0.131 ***	0.189 ***	0.122 **	0.101 **
GRF	0.086 *	0.093 *	0.088 *	0.094 *	0.091 *
GCF	0.121 **	0.116 **	0.203 ***	0.132 *	0.134 **
LDGIN		0.264 ***		0.312 ***	0.268 ***
RDGIN			0.231 ***	0.108 **	0.127 **
RDGIN ²			−0.177 ***		
LDGIN × RDGIN				0.188 *	
LDGIN-RDGIN					−0.270 **
Constant	0.134 *	0.157 *	0.298	0.183 *	0.304
Ownership	Yes	Yes	Yes	Yes	Yes
Industry	Yes	Yes	Yes	Yes	Yes
Province	Yes	Yes	Yes	Yes	Yes
R ²	0.162	0.177	0.203	0.231	0.268
Adj-R ²	0.155	0.162	0.194	0.219	0.256
F-Value	6.381 ***	7.206 ***	7.335 ***	8.091 ***	8.634 ***

Note: *, ** and *** represent significance at levels of 10%, 5% and 1%, respectively.

4.2.2. Analysis of the Test Results of the Regulating Effect

(1) The moderating effect of digital transformation. In Table 6, it can be seen from Model 6 that the interaction coefficient between the LDGIN and digital technology level is negative ($\beta = -0.024$). The interaction coefficient between the LDGIN and digital application range is positive ($\beta = 0.064$) but does not meet the significance requirement. This indicates that the level of digital technology and the scope of digital application have no significant moderating effect on the positive correlation between LDGIN and DGI performance. Hypothesis 2a and 2b are not tested. Three interaction items were constructed to test the synergistic moderating effect of digital technology level and digital application range on the main effect. According to Model 7, the coefficient of the product of the LDGIN, digital technology level and digital application range is positive ($\beta = 0.109$) and significant at 1% level ($p < 0.01$). This indicates that, when a higher digital technology level is combined with a higher digital application range, the positive impact of the LDGIN on DGI performance is greater. Hypothesis 2c is verified. It can be seen from Model 8 that the interaction coefficient between the secondary term of the RDGIN and digital technology level is negative ($\beta = -0.189$) and significant at the 1% level ($p < 0.01$). This indicates that the digital technology level can strengthen the inverted U-shaped relationship between RDGIN and DGI performance. Hypothesis 3a is verified. The interaction coefficient between the quadratic term and the digital application range of RDGIN is negative ($\beta = -0.026$) but not significant. These results indicate that the digital application range has no significant moderating effect on the inverted U-shaped relationship between RDGIN and DGI performance. Hypothesis 3b is not verified. It can be seen from Model 9 that the coefficient of the product term of the RDGIN, digital technology level and digital application range is negative ($\beta = -0.019$) but does not meet the significance requirement, and Hypothesis 3c has not been verified.

Table 6. Regression results of the moderating effect of digital transformation.

Variable	DGIP			
	Model 6	Model 7	Model 8	Model 9
Age	−0.018	−0.014	−0.067	−0.081
Size	−0.037	−0.058	−0.073	−0.105
Revenue	0.061	0.054	0.047	0.026
DTL	0.123 **	0.106 *	0.266 ***	0.183 ***
DAR	0.180 ***	0.142 ***	0.257 ***	0.197 ***
LDGIN	0.289 ***	0.304 ***		
RDGIN			0.134 **	0.168 ***
RDGIN ²			−0.142 ***	−0.191 ***
LDGIN × DTL	−0.024			
LDGIN × DAR	0.064			
LDGIN × DTL × DAR		0.109 ***		
RDGIN × DTL			0.177 **	
RDGIN × DAR			0.102	
RDGIN ² × DTL			−0.189 ***	
RDGIN ² × DAR			−0.026	
RDGIN × DTL × DAR				0.083 **
RDGIN ² × DTL × DAR				−0.019
Constant	0.156 *	0.034	0.251 *	0.293 *
Ownership	Yes	Yes	Yes	Yes
Industry	Yes	Yes	Yes	Yes
Province	Yes	Yes	Yes	Yes
R ²	0.132	0.148	0.121	0.115
Adj-R ²	0.127	0.138	0.116	0.108
F-Value	9.632 ***	10.957 ***	8.604 ***	9.260 ***

Note: *, ** and *** represent significance at levels of 10%, 5% and 1%, respectively.

(2) The moderating effect of green tissue flexibility. In Table 7, it can be seen from Model 11 that the interaction term coefficient between LDGIN and green culture flexibility is positive ($\beta = 0.134$) and significant at 5% ($p < 0.05$). The interaction coefficient between LDGIN and green resource flexibility is positive ($\beta = 0.142$), and significant at the 1% level ($p < 0.01$). The interaction coefficient between the LDGIN and green capability flexibility was positive ($\beta = 0.170$) and significant at 5% ($p < 0.05$). These results indicate that green cultural flexibility, green resource flexibility and green capability flexibility can positively regulate the positive correlation between LDGIN and DGI performance. Hypothesis 4a, 4b and 4c are verified. It can be seen from Model 13 that the interaction coefficient between the quadratic term of the RDGIN and green cultural flexibility is negative ($\beta = -0.167$) and significant at 5% ($p < 0.05$). But the sign is the opposite of the hypothesis. The interaction coefficient between the quadratic term and green resource flexibility of RDGIN is negative ($\beta = -0.204$) and significant at the 1% level ($p < 0.01$). The interaction coefficient between the quadratic term and green capability flexibility of the RDGIN is negative ($\beta = -0.102$) but not significant. This indicates that green resource flexibility can strengthen the inverted U-shaped relationship between RDGIN and DGI performance, and Hypothesis 5b is verified. Meanwhile, the moderating effect of green cultural flexibility on the inverted U-shaped relationship between RDGIN and DGI performance is the opposite of the hypothesis. Green capability flexibility has no significant moderating effect on the inverted U-shaped relationship between RDGIN and DGI performance, and Hypothesis 5a and 5c have not been verified.

Table 7. Regression results of the tissue flexibility regulation effect.

Variable	DGIP			
	Model 10	Model 11	Model 12	Model 13
Age	−0.014	−0.018	−0.028	−0.034
Size	−0.012	−0.010	0.037	0.024
Revenue	0.012	0.015	0.021	0.027
GCF	0.198 ***	0.186 ***	0.268 ***	0.294 ***
GRF	0.164 *	0.150 *	0.224 ***	0.253 ***
GCF	0.176 **	0.143 **	0.182 ***	0.231 ***
LDGIN	0.237 ***	0.295 ***		
RDGIN			0.176 ***	0.134 ***
RDGIN ²			−0.183 ***	−0.128 **
LDGIN × GCF		0.134 **		
LDGIN × GRF		0.142 ***		
LDGIN × GCF		0.170 **		
RDGIN × GCF				0.108
RDGIN × GRF				0.137 ***
RDGIN × GCF				−0.173
RDGIN ² × GCF				−0.167 **
RDGIN ² × GRF				−0.204 ***
RDGIN ² × GCF				−0.102
Constant	0.053	0.062 *	0.181 *	0.182 *
Ownership	Yes	Yes	Yes	Yes
Industry	Yes	Yes	Yes	Yes
Province	Yes	Yes	Yes	Yes
R ²	0.153	0.167	0.124	0.126
Adj-R ²	0.145	0.162	0.118	0.122
F-Value	9.863 ***	9.247 ***	7.206 ***	6.984 ***

Note: *, ** and *** represent significance at levels of 10%, 5% and 1%, respectively.

4.2.3. Analysis of Robustness Test Results

The existing research on DGI performance mainly includes the following two aspects. First, the path of DGI input, DGI process and DGI output are used to measure innovation performance based on input and output perspectives. Second, manufacturing enterprises' digital green research and development, production, marketing, business model, resource integration and business expansion are investigated to comprehensively measure the performance of DGI based on the operation and management process of manufacturing enterprises. The first perspective is used to measure the performance of DGI and conduct regression analysis. In order to further verify the reliability of the empirical analysis results, another measurement perspective of DGI performance is adopted to establish alternative dependent variables for robustness test. The DGI performance of the alternative dependent variable is composed of four questions, which are, respectively, "the enterprises to continuously optimize the green innovative business models to meet customer demand", "DGI the company actively explore the market marketing channel", "the company has the ability to enter the DGI new areas of business" and "the enterprise to strengthen integration of DGI supply chain and green innovation resources". The factor loading values of these four items are all greater than 0.7. The Bartlett sphericity test values reached the significance level ($p < 0.000$). KMO value is greater than 0.7. This indicates that the measurement has good reliability and validity. For reasons of space, the robustness testing process is not shown here.

The results of the robustness test are as follows. The robustness test results of the main effect were consistent with those of the previous test. The robustness test results of the moderating effect of digital transformation are basically consistent with the previous test results, except for Hypothesis 3a. The results of the robustness test of the moderating effect of green tissue flexibility were consistent with the above results. Through the above tests, it can be seen that the robustness test results of the main effect are completely consistent with

the above. In the robustness test results of the moderating effect of digital transformation, it is assumed that the direction of the test results of Hypothesis 3a is consistent with the above but not significant. This indicates that, after the measurement method of dependent variable DGI is replaced, the strengthening effect of digital technology level on the inverted U-shaped relationship between RDGIN and DGI performance becomes insignificant. In summary, except for Hypothesis 3a, other hypothesis verification results are consistent with the above. This shows that this study has a good robustness.

5. Conclusions and Discussion

At present, the spatial structure perspective of open DGI network is an extremely important topic in the field of DGI management. In this study, the dual carbon goal and the background of the digital intelligence era are fully considered in the study of open DGI network. Open DGI network is divided into LDGINs and RDGINs. The questionnaire sample data from middle and senior managers of manufacturing enterprises are used to test the influence mechanism of the balance between LDGINs, RDGINs and two DGI networks on the DGI performance of manufacturing enterprises. At the same time, different dimensions of digital transformation and green organization flexibility are examined to reveal their moderating effects.

The results of this study are as follows. (i) The effect of an open DGI network on the DGI performance of manufacturing enterprises is heterogeneous due to LDGINs and RDGINs. (ii) The establishment of embedded links in DGI networks inevitably requires the corresponding costs of manufacturing enterprises. (iii) The balance between LDGINs and RDGINs has an important impact on the DGI performance of manufacturing enterprises. (iv) Digitization and organizational innovations are changing the way manufacturing companies operate. (v) The balance of DGI network embedding in practice shows the important role and enlightening significance of local and remote search in developing countries.

The discussion on the above five results is as follows.

(i) The LDGIN positively promotes the DGI performance of manufacturing enterprises. However, the embedment of the RDGIN has a marginal diminishing mechanism. On the one hand, LDGIN focus on the local scale. This not only emphasizes that manufacturing enterprises conduct DGI activities with different DGI subjects in the local scope but also establishes comprehensive DGI connections. The main bodies in the LDGIN have more similar institutions, laws, human history and social cognition [38–40]. Therefore, frequent and close digital green information interaction is conducive to the formation of strong relational links. This will not only make it easier to establish DGI partnerships and maintain the long-term stable operation and development of DGI networks but also promote the practice of DGI in manufacturing enterprises and improve the performance of DGI. On the other hand, a RDGIN emphasizes the DGI network links within the reach of manufacturing enterprises [48–50,52]. When manufacturing enterprises are embedded in a RDGIN to a low degree, manufacturing enterprises can acquire a large amount of heterogeneous, diverse and unique digital green knowledge and digital green resources through communication with subjects with different backgrounds in the network. This can not only improve the breadth of digital green knowledge and the flexibility of DGI but also help manufacturing enterprises to acquire, transfer, integrate and create digital green knowledge and digital green technology by taking advantage of local and remote resources and markets [51,52,54].

(ii) Manufacturing enterprises are over-embedded in the RDGIN and rely more heavily on network members. This will not only cause excessive redundancy of digital green resources and reflect as excessive reliance on DGI but also increase the risk of digital green intellectual property leakage [50–53]. At the same time, such weak links are difficult to effectively share important digital green knowledge and digital green resources, and it is difficult to quickly reach a solution to the problem with the same interests in the changing environment. Moreover, due to the large differences in economy, politics and culture among network members, the DGI strategies formed and the DGI process experienced are often quite different. This will reduce the absorption capacity and transfer efficiency of

manufacturing enterprises for digital green knowledge and digital green technology [55,56]. Manufacturing enterprises' excessive embedding in a RDGIN has a negative impact on the improvement of the DGI performance of manufacturing enterprises.

(iii) The comprehensive balance and relative balance indicators constructed in this paper show that the moderate balance between LDGINs and RDGINs can promote the improvement of the DGI performance of manufacturing enterprises. The generation of a DGI is not only the process of a LDGIN expanding into a RDGIN but also the process of a RDGIN deepening to LDGINs [51,59,60]. Its essence is the result of the two-way development of a LDGIN and a RDGIN. Variables of digital transformation and green organization flexibility are used to verify the appropriateness of the embedding degree of DGI [63]. On the one hand, isolated digital green technology elements are difficult to bring a digital green effect into play. The relationship between LDGIN and DGI performance of manufacturing enterprises can be enhanced only when the realization of higher digital technology level is combined with a greater digital application range. On the other hand, the realization and application of digital green core technology will not appear in a wide range of diffusion phenomenon.

(iv) The realization of the management efficiency of manufacturing enterprises comes from the arrangement of hierarchical and functional organizational structure [72,73]. However, the problems of information asymmetry and layer redundancy in traditional operation mode make the improvement of organizational performance always face a bottleneck. Digital transformation enables application entities to coordinate and use resources in new ways [63–65]. Digital is not only the carrier of effective information transmission but also has become a factor of production in collaborative circulation. In the process of reshaping organizational methods and processes, AI, 5G and edge computing are, respectively, used to solve intelligence problems, connectivity problems and efficiency problems to improve organizational performance. The establishment of digital economy innovation platform should strengthen the data-driven ability and form the open innovation pattern of enabling industry with platform digitization [76,77].

(v) Developing countries have great dependence on external digital green resources in terms of digital green core technologies. This inevitably requires national policies to tilt toward the digital green core technology field. The digital green technology and digital green resources of the LDGIN should be fully utilized to consolidate the performance of DGI [82–86,90]. The positive role of the two DGI networks should be brought into full play to improve the level of digital green core technology and digital green competitiveness.

The theoretical and practical implications of this study are as follows. This study covers not only the hard technology aspects of digital technology level and application range but also the soft power aspects represented by green culture flexibility, green resource flexibility and green capability flexibility. Theoretically, the strategic orientation of DGI and the theoretical level of digital green economy are refined to the micro level of the DGI of manufacturing enterprises. The mechanism of digital empowerment and green organization flexibility on the green innovation performance of manufacturing enterprises is revealed. In practice, this study provides new practical support for manufacturing enterprises to embed strategy of and incentives for DGI in a DGI network. The flexibility and dynamic capability brought by the flexibility of green organizations should be effectively improved to enhance the degree of embeddedness and integration among digital green technologies. The digital green upgrading of the old technology structure should be promoted to improve the DGI performance of manufacturing enterprises.

Although the research objective has been achieved, there are still some shortcomings in this paper, which provides a direction for follow-up research. First, DGI in the context of dual carbon goals and digital intelligence is a leading topic in innovation management and business practice. There is a lack of large-sample empirical studies and standardized measures for many of these constructs. This is not only the novelty of this paper but also, objectively, the inevitable challenge of this research. It is expected that more scholars will participate in the discussion of DGI in the future. Second, this paper focuses on DGI

performance as a variable factor. In this paper, the overall process of DGI performance improvement is not fully reflected. In future studies, the theoretical framework of the spiraling path of network construction, capacity improvement and performance promotion can be established to reveal the mechanism of the DGI performance improvement process.

Author Contributions: Conceptualization, C.H. and S.Y.; methodology, C.H.; software, C.H.; validation, H.Y. and C.H.; writing—original draft preparation, C.H.; writing—review and editing, H.Y., C.H. and S.Y. All authors have read and agreed to the published version of the manuscript.

Funding: Philosophy and Social Science Project of Guangdong Province (GD21YGL08); Key Platforms and Scientific Research Projects of Colleges and Universities in Guangdong (2021WQNCX013).

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: The data presented in this study are available on request from the corresponding author.

Conflicts of Interest: The authors declare no conflict of interest.

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