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Research article

Digital capability and green innovation: The perspective of green supply chain collaboration and top management's environmental awareness

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ABSTRACT

The emergence of the digital economy has accelerated digital transformation, and digitalization has shown new potential and solutions to increasingly severe environmental challenges. Based on the resource-based view, dynamic capability view, synergy effect and upper echelons theory, the connotation and measurement dimensions of digital capability and green supply chain collaboration are defined and improved. Then, a theoretical model of "digital capability-green supply chain collaboration-green innovation performance" is constructed. The influence mechanism and transmission process of digital capability on green innovation performance from the perspective of green supply chain collaboration is discussed. Meanwhile, the boundary condition of the influence of digital capability on green innovation performance in the view of top management's environmental awareness is explored. Finally, an empirical test is conducted based on the Chinese manufacturing corporates. The results indicate that green innovation performance is significantly and favorably impacted by digital capability, green supply chain collaboration plays a partial mediating role between digital capability and green innovation performance, and top management's environmental awareness can positively moderate the effect of digital capability on green innovation performance. This study offers valuable theoretical and practical enlightenments for manufacturing companies to foster the growth of green innovation through digital capability more effectively.

1. Introduction

Green development and environmental protection have progressively been part of business operations and development goals as a result of the growing prominence of global environmental issues [1,2]. Many corporations embrace green innovation as a form of innovation that may effectively address environmental issues. The strategy of green innovation entails taking the initiative to lessen the adverse effects of commercial operations on the environment and integrating environmental responsibility into the strategic planning of the firms [3]. As an effective technique to achieve economic transformation and green development, green innovation has emerged as a critical strategy for businesses seeking sustainable development and worldwide competitiveness in the market [4,5]. Green

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innovation performance (GIP) is an important metric to measure the implementation of green innovation activities. How to increase the GIP effectively has become a major concern for enterprises.

Artificial intelligence (AI), blockchain, and the Internet of Things are just a few examples of the new digital technologies that have emerged recently and significantly accelerated digitalization [6]. They have progressively evolved into the key players that businesses need in order to implement green innovation [7]. Utilizing digital technologies allows businesses to access additional data resources. It not only broadens the definition and meaning of innovation resources but also supports the best possible use of resources for green innovation. For manufacturing companies, data is now a crucial strategic resource [8] and an essential innovation resource [9]. Consequently, in order to generate commercial value and improve competitiveness, organizations now need to have the capacity to gather, process, evaluate, and synthesize data [10,11]. According to the dynamic capability theory [12], digital capability (DC) is a type of dynamic capability that can access data resources through digital technology and improve, integrate, update, and reorganize them to adapt to the changing market. DC plays a vital role in promoting green transformation [13] and sustainable development for corporates [14]. Scholars have attempted to investigate how DC impacts green innovation at the moment [15–17]. However, there was insufficient examination of the transmission mechanism linking DC and green innovation.

The current production and processing are no longer the responsibility of a single organization due to the rapid development of economic globalization, but the collaboration of upstream and downstream companies in the supply chain. The environmental issues brought about by production also need to be addressed by supply chain collaboration (SSC). When the idea of green development is integrated into each link of SSC, a new concept known as green supply chain collaboration (GSCC) is created, which can achieve the coordination and unification of economic and environmental benefits. According to the synergistic effect theory [18], GSCC can enhance the competitiveness and green performance of the entire supply chain and provide a favorable environment for cooperative operation, mutual benefit, coexistence and win-win for all of the companies in the system. However, the GSCC still has problems with information exchange, resource coordination and member integration in practice. Innovative digital technologies such as big data, blockchain, and the Internet of Things offer fresh avenues for resource integration and information exchange. For example, digital platforms facilitate the exchange and utilization of mutual knowledge both within and across firms by corporates [19]. Furthermore, DC gives businesses new behavioral tools to work together to advance GSCC. It can generate creative corporate behaviours and strategic alliances for sustainable development in the supply chain by using digital technology and collaborative management concepts [20]. In this regard, a comprehensive investigation is conducted into the transmission mechanism of GSCC on the effect of DC on the green innovation performance (GIP) of firms.

Green innovation is a crucial tactic to achieve sustainable development [21]. It is influenced not only by external elements including institutional pressure [22] and external environmental regulation [23] but also by internal stakeholders such as managers' environmental awareness [24]. Top management's environmental awareness (TMEA) describes the mental state of environmental preservation that senior managers have developed through thought processes. The degree of environmental consciousness among managers in various organizations varies in China, owing to variations in executive cognition and development levels. According to the upper echelons theory, top managers with various upbringings and traits will have distinct morals and ways of thinking. Executives typically hold more power when it comes to making business decisions. They feel pressure from other institutions based on their personal beliefs, which affects how enterprise innovation is implemented [25,26]. Given this, investigating the impact of DC on corporates' GIP from a TMEA perspective is imperative within the framework of the ongoing digital transformation.

On the grounds of the resource-based view and dynamic capability view, a theoretical model of "digital capability-green supply chain collaboration-green innovation performance" is constructed in the study (see Fig. 3) by following the logical evolution process of "capability-behavior-performance" and examining the transmission mechanism of GSCC on the impact of DC on enterprises' GIP. Simultaneously, the higher echelons theory is applied to explore the boundary conditions of the impact of DC on corporates' GIP from the standpoint of TMEA. Finally, the aforementioned two inquiries are empirically explored through the investigation of Chinese manufacturing companies. The following three aspects are primarily addressed in the study.

(1) Does DC have a direct and positive impact on enterprises' GIP?
(2) Does GSCC play a mediating role between DC and enterprises' GIP?
(3) Can TMEA positively moderate the impact of DC on enterprises' GIP?

Compared with the existing literature, the contributions of this study are as follows: (1) Relying on the dynamic capability theory, big data and digitalization are brought to the capability level, improving the meaning of DC. Moreover, according to the logical process of "collection-analysis-integration" of digital resources, DC is divided into three dimensions of digital technology application capability (DTAC), data information analysis capability (DIAC) and digital resource collaboration capability (DRCC), which expands and sublimates the meaning of digital capability. (2) On the basis of synergistic effect, the transmission mechanism of GSCC between DC and GIP of enterprises is explored, which partially unlocks the "black box" between DC and green innovation and broadens the body of knowledge regarding the mechanisms that drive green innovation. (3) In accordance with the upper echelons theory, the function of TMEA in green innovation is repositioned as an internal factor to depict the value effect of DC on corporate green innovation more clearly. Additionally, the boundary condition of DC supporting enterprises' GIP is further investigated.

This article is organized as follows. The research hypotheses, theoretical model construction, and theoretical basis introduction are covered in the second section. The research methodology is presented in the third section, which mostly covers sample measurement and data collection procedures. The analysis and result-derived part is the fourth step. The research findings, theoretical contributions, and management implications are covered in detail in the fifth section. The pertinent results are summed up in the sixth section, which also anticipates future study areas.

2. Theoretical foundation and hypotheses

2.1. Theoretical foundation

2.1.1. Digital capability

According to the resource-based view, resources obtained via digital technology are heterogeneous and have the attributes of valuable, scarce, imperfectly imitable, and non-substitutable (VRIN) [27], so data resources are critical strategic resources for firms to gain competitiveness. The dynamic capability view is a theory that goes beyond the traditional resource-based view to describe how companies establish and sustain a competitive edge in unpredictable and chaotic settings [12]. The dynamic capability view takes resources and capabilities as sources of competitive superiority and argues that resources can only adapt to changing contexts and maintain long-term competitiveness if they possess capabilities in addition to resources [28].

As the trend of enterprises' digital transformation continues to grow, academics are becoming more and more interested in corporates' DC. The existing literature has mainly studied the connotation of DC from the perspectives of resource-based view and dynamic capability view. The former holds that data resources are a type of resource obtained through digital technology. Some scholars believe that it is composed of technical, management and human skills [29,30]. It is also an information asset that needs to have cutting-edge technology infrastructure deployed in order to swiftly, precisely, and scalable assess a variety of big data [31]. From the latter standpoint, DC is a dynamic capability which can use digital technology to reconstruct or regenerate existing resources, structure, value and other factors. It can also cultivate and strengthen the capacity to turn digital economy production factors into innovative business models, so as to support corporates to achieve strategic and operational goals as well as create value and strengthen their competitive edge [16,32]. The understanding of DC in the view of dynamic capability theory helps clarify the systematic logic of a series of digital practices, such as obtaining and maintaining data resources, using digital technology for data mining and making data-driven strategic decisions [16]. It not only reflects the dynamic development characteristics of capability but also displays the composition of capability elements and the synergy with other resources and capabilities of the organization. In consequence, on the basis of the existing research and the dynamic capability theory, DC is defined as a dynamic capability to achieve value co-creation and integration and co-generation with partners through the comprehensive integration of digital technology with production, operation and decision-making management, thereby realizing the whole process and all-round digital management.

The connotation of companies' DC mainly contains three aspects. Firstly, the corporation should have software and hardware to support digital technology analysis, and the all-around integration with the processing, operation and management, so that it can obtain data information in a timely manner and carry out all-process and all-around digital management. This refers to the digital technology application capability (DTAC). Secondly, the firm is capable of screening and extracting the obtained operation and management data and mining and analyzing the valuable information from it. That stands for the data information analysis capability (DIAC), which is essential for maximizing the benefits of data resources. Thirdly, the corporation can integrate and collaborate with the acquired data resources via digital technology to enhance its insight and agility and realize real-time intelligent decision-making within the organization and the sharing, co-construction, co-governance, and value co-creating of digital resources among partners. By that, we mean the digital resource collaboration capability (DRCC). These three aspects, which show the progression of DC from low to high, are predicated on the logical process of "collection-analysis-integration" of digital resources. The conceptual model of DC is displayed in Fig. 1. In light of this, DC can be measured as three dimensions of DTAC, DIAC and DRCC.

2.1.2. Green supply chain collaboration

The concept of synergy originates from the theory of synergetics in natural science, which was founded by Hermann Haken, a famous German physicist, in the 1970s. In synergetics, Haken [33] defined synergy as the collaboration between the parts of the system, so that the whole system formed a new quality of structure and characteristics that were absent at the micro-individual level. The notion of SCC was formally put forward in the mid-1990s and rapidly developed as a research hotspot in the field of supply chain management. According to Simatupang and Sridharan [34] and Simatupang and Sridharan [35], SSC refers to the cooperation of two

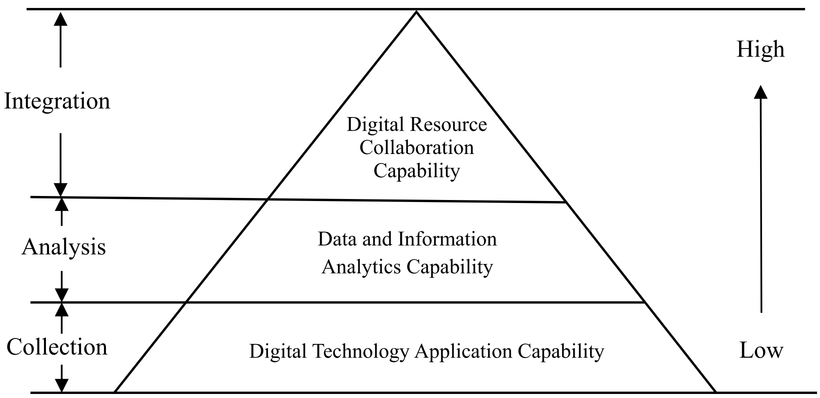

Fig. 1. The conceptual model of digital capability (**Source(s):** Authors work).

or more supply chain participants to meet customer needs and enhance their competitive advantage through information and revenue sharing and joint decision-making to achieve greater benefits than a single party's action, which is highly accepted at present. Hence, SSC is a strategically cooperative choice [36] and superior to traditional supply chain management because it views the supply chain as an organic whole and ultimately realizes the synergistic effect of "1 + 1> 2". Therefore, the essence of SSC is to facilitate communication and information sharing amongst persons as well as the sharing of successes and advantages by connecting and integrating each member of the supply chain. The goal is to establish a collaborative partnership with complementary strengths and limitations to maximize business resource utilization and finally reach a "win-win" situation.

Relying on the theory of corporate responsibility, companies must accept responsibility for the results of their operations and the obligations imposed by society as members of the community. In company operations, environmental responsibility is also a crucial consideration. Hence, the concept of GSCC has arisen from the necessity to include green ideas in a series of SSC initiatives in light of the growing severity of environmental and resource-related issues. Abdallah and Al-Ghwayeen [37] argued that GSCC referred to working with supply chain members strategically to implement green practices by information sharing and group decision-making to create a competitive advantage. Andalib Ardakani et al. [38] pointed out that GSCC incorporated eco-conceptual thinking into supply chain management, covering all stages of the life cycle from product design to final disposal. Some other studies thought that GSCC encompassed tasks like product redesign, waste and energy minimization, recycling and reverse logistics [39,40].

As a summary of the research discussed above, it is known that GSCC evolved from SSC, and the distinction between them is that GSCC aims to protect the environment and promote the sustainable development of enterprises [41]. In other words, it seeks environmental benefits while pursuing the financial gains of supply chain participants. In consequence, GSCC mandates that the shared objectives should be founded on the idea of environmental benefits and cooperative decision-making should consider the environment's influence. The resources shared by supply chain participants, such as information, knowledge and technology, are also associated with green development goals like lowering carbon emissions and pollution in the environment. Therefore, this research holds that GSCC refers to the mutual trust and cooperation between upstream and downstream companies in the supply chain to achieve economic and environmental coordination, and the synergy of information, resources and strategies to drive firms' complementary strengths and weaknesses and the efficient use of resources, which will ultimately increase the competitiveness of the whole supply chain and all members and jointly achieve sustainable development.

It is evident from the GSCC connotation that the meanings have three facets. First, in the process of transaction or cooperation, members of the green supply chain share and exchange information about business operation and management timely aiming at environmental protection and green development. The information mainly includes product demand forecasting and production information, inventory status, after-sale service, logistics and carbon emission information, etc. to realize the synchronization of upstream and downstream information. That means green information collaboration (GIC). Second, firms in green supply chain identify, draw, match, activate, integrate and reconfigure the green technology, green knowledge and other resources owned by the green supply chain, so as to form a new and more valuable core resource system, i.e. green resource collaboration (GRC). Third, members of the green supply chain come to a common green strategic goal, reach a consistent green strategic decision (including the green strategic plan, green operation business and green operation management, etc.), forge a solid strategic cooperative relationship, and create a community of interests, i.e., green strategic collaboration (GSC). Among these, GIC helps to eliminate the "bullwhip effect" in supply chains and is essential to achieving sustainable cooperation [42–44]. It is as well the "heart" and "nerve center" of GSCC [45], which can improve the efficiency of enterprise collaboration. GRC determines whether the green resources of supply chain members can be fully and effectively utilized and has an impact on the future competitive advantage of green supply chains. GRC assesses if members of the supply chain can use their green resources to their fullest and best benefit, which affects the potential competitive advantage of the green supply chain. These three elements are progressive and in a low-to-high relationship, in other words, GIC is the foundation, GRC is the further development, and GSC is the highest realm. The conceptual model of GSCC is shown in Fig. 2. Hence, GIC, GRC and GSC are taken as three dimensions to measure GSCC.

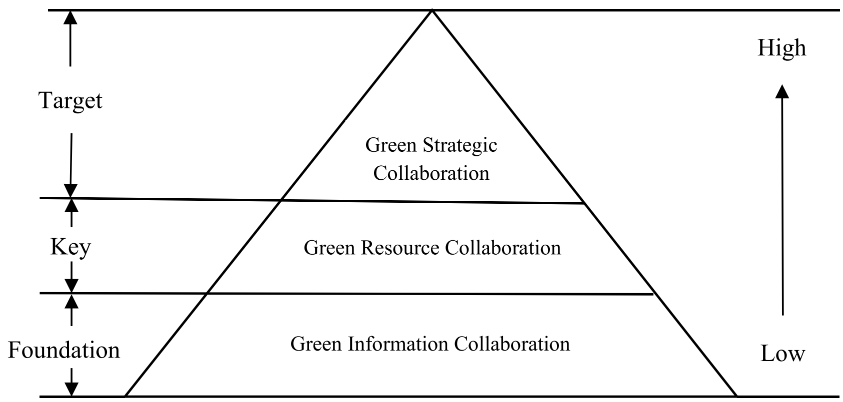

Fig. 2. The conceptual model of green supply chain collaboration (**Source(s):** Authors work).

2.1.3. Research gap

Previous studies have explored the impact of big data on corporates' innovation and green development from both theoretical and empirical perspectives. However, there are few in-depth and systematic studies on the relationship between DC and green innovation. First, most of the existing studies concentrated on the impact of big data or big data capability or digital technology on enterprises' green innovation. Few studies have examined how enterprises' DC affect green innovation from specific dimensions such as digital technology application, data information analysis and digital resource coordination. In addition, earlier research focused on the direct impacts of big data capability or digitalization on green innovation. This study explicitly explored the transmission mechanism of GSCC through the three dimensions of information collaboration, resource collaboration and strategic collaboration. Based on the connotations and dimensions of the DC and GSCC, this research thoroughly discusses the influence and transmission mechanism of DC on green innovation and explores its boundary conditions. Fig. 3 displays the research framework and theoretical model in this study.

2.2. Research hypotheses

On the grounds of the resource-based view, dynamic capability view, synergy effect and upper echelons theory, five research hypotheses related to DC, GSCC, GIP and TMEA are proposed combined with the existing literature. The overall research framework and theoretical model are displayed in Fig. 3.

2.2.1. Digital capability and green innovation performance

Green innovation, also known as eco-innovation and environmental innovation, describes the products or processes innovation that increase the value of organizations and customers while lessening their negative effects on the environment. Green innovation is a kind of innovation, which has double externalities above ordinary innovation. It can accomplish sustainable development by balancing environmental preservation with business performance, as well as lessen environmental pollution and save energy [46]. Unlike other corporations that only strive to meet the bare minimum of environmental requirements, green innovation focuses on the treatment and prevention of pollution, lowers the environmental burden of companies, and improves economic benefits through the introduction of new products and processes [47]. Based on the connotation of green innovation, this study divides GIP into two dimensions: environmental performance (ENP) and innovation performance (INP), which are used to measure the enterprises' effectiveness in environmental and innovation respectively.

According to the resource-based view and dynamic capability view, data, as a production factor of enterprises in the current digital economy, is crucial for maintaining an organization's core competitiveness [48]. As a dynamic capability that enables corporates to have long-term competitive advantages, DC can provide support for enterprises to implement green innovation [49].

DTAC makes it easier for enterprises to adopt green innovation by assisting in the collection, transfer, and sharing of data resources. On the one hand, the application of digital technology can increase the transparency of the operation and management process, assist corporations in gathering data across the entirety of the green production and operation process, and retain vast data resources to enhance and optimize business and production processes. For instance, corporations can monitor energy waste during production and understand patterns of energy consumption by installing embedded intelligent devices in machines and facilities to collect and store real-time energy parameters [50–52]. On the other hand, the application of digital technology can facilitate communication between multiple agents and create a link between businesses and consumers [53,54]. In addition, it can break down geographical and temporal barriers in production and operation [55], promote the real-time transmission and sharing of data resources and information, and

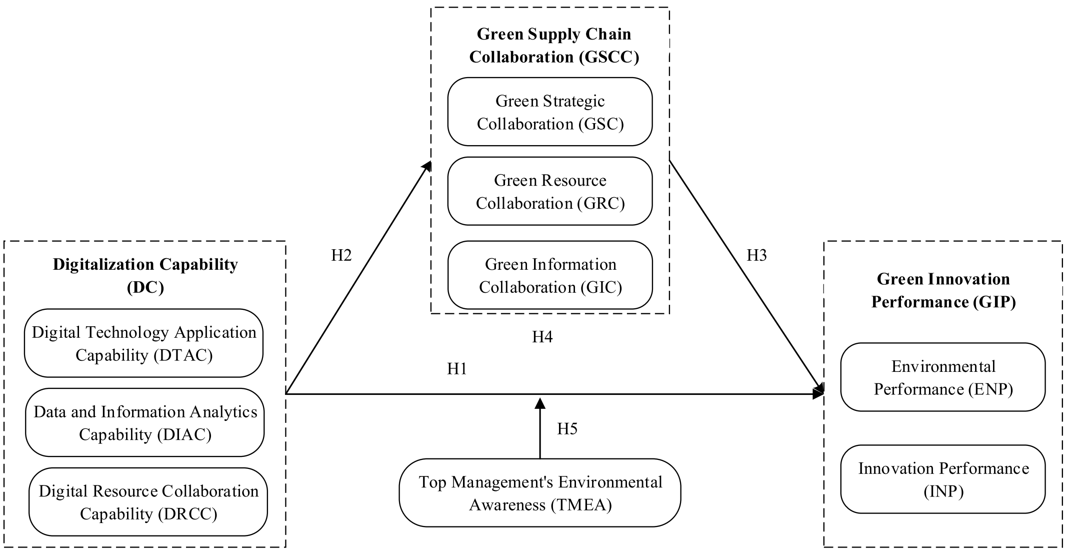

Fig. 3. Research framework and theoretical model. (**Source(s):** Authors work).

establish the groundwork for the creation of new concepts and knowledge.

DIAC can help to support companies in strengthening their capacity for green innovation and their understanding of the market. DIAC can effectively mine and analyze large amounts of data, obtain real-time insight into market changes [8,56], and discover new market opportunities. For example, thorough data analysis can be used to understand customer preferences and segment consumer behavior [53,57], which encourages corporates to identify the accurate market position of products [58]. Subsequently, the business process undergoes transformation or optimization [59], the product or services are upgraded or re-developed and produced to meet the market demand [57] and clients are provided with personalized innovation and customized demands [48].

DRCC helps to improve the ability to adapt to external changes for corporates and achieve multi-body collaborative innovation. According to the dynamic capability view, DC can be dynamically adjusted in response to the changes in the outside world [60]. For example, companies can enhance the greenness and market recognition of their products by implementing disruptive innovation, reconfiguring and integrating internal and external resources, updating production and sales strategies, and changing product characteristics in response to external market changes. They can also realize digital transformation of production and operation [61]. DRCC is beneficial for realizing the diverse interchange of multi-enterprises and the complementarity of superior resources, speeding up product design and R&D [62], and encouraging value co-creation and green innovation. DRCC enables corporates to accurately predict processing time and product quality based on real-time data [63], thus improving the timeliness, dynamism, adaptability and accuracy of innovation activities, as well as the GIP of enterprises.

Previous literature has substantiated that DC have a positive impact on green innovation [7,8,15]. Relying on the analysis presented above, the following hypothesis is put forth.

H1. Digital capability has a positive impact on green innovation performance.

2.2.2. Digital capability and green supply chain collaboration

The fulfillment of supply chain collaboration (SSC) requires cross -organizational cooperation and work with partners to complete a number of supply chain management tasks such as design, R&D, procurement, production, marketing, etc. To carry out these efforts, DTAC, DIAC, and DRCC help are needed. Consequently, DC can provide strong support for GSCC [64,65].

DTAC can provide transmission and sharing channels of information, knowledge and resources for GSCC. Digital technology, like Internet Technology (IT), can be used to overcome geographic limitations [66] and promote the transmission of information, knowledge and resources among supply chain members more quickly and efficiently [67,68]. By using Internet of Things technology, companies can quickly obtain and share information about sales, production, inventory, and distribution, improving information transparency and removing information asymmetry between partners [69,70]. It contributes to the improvement of trust and understanding between supply chain participants which are essential elements of SSC [71]. The formation of a good resource-sharing relationship between enterprises is the basis for long-term cooperation [69]. By exchanging green information and resources, DC will help foster positive and cooperative relationships among green supply chain participants and improve the level of GSCC.

DIAC provides rich knowledge stock and technical resources for GSCC. According to the resource-based view, data resources are crucial strategic tools for companies to gain a competitive advantage. Through in-depth mining and joint decision-making, DIAC helps supply chain partners sort and filter massive volumes of first-hand data, extract high-value-added parts and create knowledge [8]. It helps to sustain a long-term and stable cooperation relationship between companies and to encourage the transformation of data resources into knowledge and technology for GSCC to improve its overall competitiveness [14].

DRCC provides a stable strategic alliance environment for GSCC. Through the integration and collaboration of the data resources of upstream and downstream partners in the green supply chain, the companies' boundary can be eliminated, and the strategic synergy among manufacturing firms suppliers and retailers can be effectively promoted [62], thus promoting the green supply chain members to form a whole. They share risks and cut costs together while simultaneously optimizing the major business operations of the green supply chain [72,73]. It enables organizations to reach a consistent strategic goal, make strategic decisions together [69], and form a green strategic alliance. Digital resource collaboration can help standardize and integrate supply chain processes [74], reduce transaction costs between supply chain partners, enhance the viability of engagement between various organizations [14], and lay the groundwork for SSC.

Prior research has verified that DC has a positive effect on GSCC [31,41,68]. Based on the above analysis, the following hypothesis is proposed.

H2. Digital capability has a positive impact on green supply chain collaboration.

2.2.3. Green supply chain collaboration and green innovation performance

The significance of GSCC in corporates' green innovation has come to light [75–77]. Information sharing, resource complementarity and stable cooperation among companies in the green supply chain contribute to the efficient integration and allocation of innovative resources, such as green information and green knowledge, and form the green innovation capability.

GSCC is beneficial for the exchange of green information and knowledge among its members, opening up a direct line of communication for green innovation. Corporates can communicate freely with each other upstream and downstream thanks to the supply chain's information and knowledge-sharing mechanism, which also lowers the cost of additional communication and knowledge search and avoids the issue of information asymmetry [76]. It provides convenience for the unhindered exchange of green resources, knowledge and technology. Upstream suppliers can be the source of innovative eco-design, green materials and environmental knowledge for manufacturing firms [78], by exporting green innovative technology and process knowledge and assisting manufacturing companies with green innovation R&D or green product design [79]. Downstream retailers or customers are capable of collecting consumers' feedback on the use of products, which is of great benefit for new products to overcome design defects and improve functionality [80]. Moreover, consumer groups with leading thinking tend to have forward-thinking attitudes, concepts, and value perspectives that might offer insight for green innovation [81,82].

GSCC facilitates resource sharing and complementarity among enterprises, expanding the prospects for green innovation. Resource-based theory proposes that cooperative interactions between firms aim to develop a wide range of complementary capabilities, including innovation [83]. Each company has unique superiorities in terms of resources. SSC makes it possible to achieve complementary resources and capabilities by exchanging and sharing information, knowledge, ideas, technologies and opportunities among partners, allowing enterprises to take advantage of opportunities for growth and venture into new markets [84] and generate innovative ideas that might not be realized on their own [85]. Complementary resources help corporates mobilize resources for exploratory operations and the creation of new capacity to enter new fields, thus obtaining new development potential and creating value for enterprises. Ding [76] believed that complementarity from external partners is important, because ecological innovation involves all aspects of raw materials and parts procurement, product design and production, logistics and recycling, etc. [86], which cannot be completed by a company independently. The upstream and downstream companies of the supply chain must complement resources each other to carry out collaborative innovation.

GSCC can bring stable cooperative relations and provide a favorable environment for green innovation. GSCC enables upstream and downstream firms of the green supply chain to establish strategic alliances, and these long-lasting working relationships help lessen inter-enterprise friction in the process of product innovation of SCC. Knudsen [87] researched the correlation between supply chain cooperation and product innovation and found that enhancing cooperation among supply chain firms can shorten the time to market for new products, reduce the cost of product R&D, and generate advantages over contractual relations between supply chain members [88]. Compared with horizontal enterprise alliance in product innovation, vertical product innovation of SSC can simultaneously improve the product innovation benefits of each member and the whole supply chain, which is a more effective collaborative model [89]. Therefore, GSCC can assign environmental goals and performance to each member of the supply chain in a stable and harmonious atmosphere and put all resources into the design, research and development of green products, so as to develop new products or new businesses and produce more green innovation achievements. Based on the above analysis, the following hypothesis is proposed.

H3. Green supply chain collaboration has a positive impact on green innovation performance.

2.2.4. Mediating effect of green supply chain collaboration

Through the cooperation of upstream and downstream businesses in the green supply chain, GSCC can encourage the efficient integration and exchange of digital resources. It can also offer more dependable and secure channels and support for businesses using DC to implement green innovation.

GSCC can promote the use of digital technology to integrate internal and external information and resources [90] and enhance the efficiency and capabilities of corporates' green innovation. The information-sharing behavior brought about by GSCC and the information circulation channel provided by the application of digital technology break the "information island" in the green supply chain and help realize the end-to-end information transmission [91]. According to the resource-based theory, companies cannot guarantee the renewal and increase of resources unless they successfully integrate diverse resources acquired from the outside with the intrinsic resources [92]. The resources upstream and downstream can be effectively integrated and flowed through digital technology by GSCC, allowing each member's superior resources to complement one another and quickly enhancing corporate innovation capacity and efficiency and GIP.

GSCC is conducive to the transformation of information and resources obtained by digital technology into knowledge and technology and realizing green innovation through sharing among organizations. Green innovation requires a large amount of information to provide decision support. The application of digital technology provides the basis for supply chain members to gather, store and share massive data information, and SSC can encourage the possibility of turning this data into formal development projects [93]. The high-value information is extracted from the huge amount of data collected by digital technology [94] and the knowledge is formed under the joint decision of green supply chain partners [95]. Then, the knowledge can be assimilated and digested by enterprises and transformed into valuable green knowledge or technology, through exchanging and sharing among upstream and downstream firms of green supply chain. Members of the green supply chain will exchange and learn about these green technologies or knowledge, which will enable businesses to overcome the knowledge resource gap and achieve green innovation [96].

GSCC may establish a stable environment for green innovation and offer dependable assurance for resource integration and information exchange. The application of digital technology provides an unobstructed channel for information exchange for upstream and downstream members in the supply chain [90], while GSCC further ensures the timeliness of information acquisition and the reliability of information sources by establishing vertical relationships among partners [97]. Without trust and understanding of each other, supply chain partners can hardly share critical information [98]. The effective integration and collaboration of data resources in the supply chain depend on the good cooperative relationship among supply chain members. A stable cooperative relationship fosters business exchanges and deep communication among corporates, which in turn encourages the creation of knowledge pertaining to particular goals and fosters the collaborative innovation of various entities in the process of problem-solving [32]. It is conducive to integrating and utilizing complementary resources, encouraging enterprises to transform creative knowledge and achievements into more green new products or services [99].

To sum up, GSCC serves as a link between DC and GIP, and it is beneficial for enterprises to give full play to the role of DC. Therefore, the following hypothesis is proposed.

H4. Green supply chain collaboration plays a mediating role in the impact of digital capability on green innovation performance.

2.2.5. Moderating effect of top management's environmental awareness

According to upper echelons theory, the background traits, thinking patterns, cognition and values of corporate executives have an important impact on the strategic choice and behavioral decisions of an organization [100,101]. Managers will recognize and evaluate possibilities and challenges from the outside world based on their own experiences, preferences, and cognitive processes, among other factors [102]. Therefore, various managers interpret identical regulations and settings differently, and this will ultimately show up in the way that businesses behave. TMEA is the tangible representation of their environmental cognition, which reflects the perception of senior managers on environmental issues and motivates them to engage in environmentally friendly practices with positive attitudes and emotions [103]. Senior managers with a strong awareness of environmental responsibility can recognize the urgency and necessity of pollution prevention and control, make full use of DC to obtain various resources and identify market opportunities, and integrate resources and capabilities actively [104]. Thus, pollution emissions can be minimized and environmental goals can be achieved through green innovation [105].

First, the stronger the environmental awareness of the executives, the more they can make full use of the resources brought by the DC of the corporation and carry out green innovation actively for the benefit. Senior managers with a high awareness of environmental protection will take the initiative to pay attention to environmental policies, legislation, and industry advancements [105]. The application of digital technology facilitates and expedites the collecting of this kind of information [106]. Hence, under the direction of TMEA, companies will fully utilize digital technology to obtain various information and resources pertaining to green and environmental protection and extract more valuable information through DIAC [56]. The rational allocation of resources and knowledge absorption can be achieved through the collaboration of digital resources [107], and more green products and services can be developed and produced to improve environmental and innovation performance.

Second, leaders who care more about the environment will be better able to recognize and capitalize on the business opportunities created by the DC, prompting the enterprise to invest more resources in green innovation. More market prospects have resulted from a significant shift in how businesses develop and create value due to the usage of digital technology [8]. Senior managers are more likely to recognize possible advantages and market prospects for green innovation the more environmentally conscious they are [22,108]. It is beneficial to promote senior managers to have a stronger sense of responsibility and enthusiasm for green innovation and integrate green innovation into the strategic level [102] so that they are willing to invest more human and material resources [109] and green resources [110] in green innovation activities. In consequence, the opportunity will be seized to carry out green innovation and meet the environmental needs of the market [111].

As a form of cognitive awareness, TMEA can accurately represent the value effect of DC on GIP. In other words, the greater the level of environmental consciousness among executives, the greater the beneficial influence of DC on GIP. Consequently, the following hypothesis is put out.

H5. Top management's environmental awareness plays a positive moderating role in the impact of digital capability on green innovation performance.

3. Research methodology

3.1. Data collection and sampling

The object of this study is the manufacturing industry, so the interviewees should be managers related to purchasing, processing, operation or environment, health and safety management in manufacturing firms. They should be familiar with the digital technology or data analysis capabilities used in the production and operation, the collaborative business with upstream and downstream enterprises in the supply chain, and the performance of the corporation in terms of environment and innovation. Make sure anonymity when answering the investigation and provide a confidential statement to participants. The data collection process lasted about four months, from February to May of 2023.

Considering the challenge of random sampling, snowball sampling is used in this study [112]. The specific sampling processes are as follows. First, the initial investigation enterprises are determined through three channels, including 1) manufacturing firms that have cooperative relations with our workplace; 2) qualified corporates through our tutor's introduction and recommendation; and 3) appropriate companies recommended by classmates, friends and relatives. The senior, middle or first-line managers in these investigation enterprises were selected as the initial respondents. Subsequently, questionnaires were sent to the initial respondents. The survey data collection method of Asadi et al. [113] was adopted to send questionnaires to potential respondents. Each questionnaire was sent out via a tracking email, and a link to a website was included for interviewees to complete the online survey. If there is no response, send reminders. Hence, two rounds of emails were sent to possible responders. Our contact information was also included in the email so that the confusion raised by some interviewees was also clarified via email or phone. Next, we stayed in contact with the original respondents, who assisted us in spreading the questionnaire by recommending it to friends or relatives who work for other manufacturing companies. Finally, 400 questionnaires were released by email and online, and 382 of them were responded to. After removing 24 unavailable (incomplete or blank) questionnaires, 358 valid questionnaires remained for additional examination. The recovery rate was 89.5 %.

We fully consider the uniformity of the distribution of the surveyed enterprises in the region and industry to ensure that the sample has a certain representativeness. The sample companies are spread across more than ten provinces in mainland China, covering Beijing, Hebei, Shanghai, Zhejiang, Jiangsu, Guangdong, Fujian, Hubei, Chongqing, Shaanxi, etc. which are in Northern, Eastern, Southern, Central and Western regions. In terms of industry distribution, the surveyed corporates are spread across a wide range of industries covering electrical machinery and equipment, computer and communication equipment, automobile and other transportation equipment, special and general equipment, agricultural and sideline products and food, textile and apparel and other manufacturing industries. Of these, the automobile and other transportation equipment industries account for a relatively large number of samples (32.7 %). In terms of firm size, small and medium-sized enterprises with 100–500 people take up most of the samples (31.8 %). In the eyes of firms' ownership, private enterprises are the main body of sample data collection (33.2 %). From the view of firm age, there are more companies with 6–10 years (43.0 %). Judging from the basic information of the respondents, there are more men (59.2 %) than women and the largest number of people hold bachelor's degrees (45 %). The majority have working experience of 3–5 years (40.2 %) and are middle managers (57.3 %). Table 1 gives descriptive information about the surveyed enterprises and respondents.

3.2. Instrument and measures

The questionnaire survey was used to collect data to test the proposed hypotheses. To ensure the validity of the content, we used the following steps to design the measurement scale. Initially, an extensive literature review was conducted on studies related to DC, GSCC, and GIP (see Section 2). After that, senior experts in the manufacturing industry were invited to review and make modifications to the initial questionnaire based on the literature, which included extracting the mature scale items from studies by Gadenne et al. [114], Cao and Zhang [45], Wong et al. [115], Raut et al. [116], Benzidia et al. [31], Akhtar et al. [41] and other scholars. At last, the revised version was distributed to 20 companies for a preliminary, small-scale survey to test the reliability and validity of the questionnaire. On the grounds of the test results, the questionnaire was adjusted and revised to form the final formal questionnaire.

The final questionnaire consists of two sections. The first part is the basic information of the surveyed enterprises and individuals, including firms' ownership, size, age, turnover, industry and the interviewee's job position and experience. The second part includes three modules of DC, GSCC and GIP, with a total of 41 measurement questions. The DC module is measured from three dimensions of DTAC, DIAC and DRCC. The GSCC module is measured from three dimensions of GSC, GRC and GIC. The GIP is measured from two

Table 1
Characteristics of the respondents.

Attributes	Category	Frequency	Percentage (%)
Gender	Male	212	59.2
	Female	146	40.8
Education	Middle school/high school education and below	31	8.7
	Associate degree	64	17.9
	Bachelor's degree	161	45.0
	Master's degree and above	102	28.5
Experience	Less than 3 years	30	8.4
	3–5 years	144	40.2
	6–10 years	129	36.0
	More than 10 years	55	15.4
Position	Senior managers	67	18.7
	Middle managers	205	57.3
	First-line managers	86	24.0
Firm's ownership	State-owned	81	22.6
	Collective	16	4.5
	Private	119	33.2
	Joint venture	67	18.7
	Foreign	75	20.9
Industry	Electrical machinery and equipment	64	17.9
	Computer and communication equipment	49	13.7
	Automobile and other transportation equipment	117	32.7
	Special and general equipment	40	11.2
	Agricultural and sideline products and food	24	6.7
	Textile and apparel industry	44	12.3
	Others	20	5.6
Annual revenue	Less than 1 million	94	26.3
	1-10 million	89	24.9
	10-50 million	112	31.3
	50 -100 million	39	10.9
	More than 100 million	24	6.7
Firm size (Number of employees)	Less than 50	73	20.4
	50–100	68	19.0
	100–500	114	31.8
	500–2000	68	19.0
	More than 2000	35	9.8
Firm Age (Length of time in business)	Less than 3 years	27	7.5
	3–5 years	62	17.3
	6–10 years	154	43.0
	11–20 years	74	20.7
	More than 20 years	41	11.5

dimensions of ENP and INP. Each dimension has multiple measurement questions. Each response is given on a five-point Likert scale ranging from 1 = strong disagreement to 5 = strong agreement [113,117,118]. The structure of the questionnaire and the measurement items of each variable are described in detail in Appendix 1.

In this study, AMOS software was used for confirmatory factor analysis (CFA) in Section 4.1 to test the validity of the questionnaire. Then, SPSS software was adopted to verify the main effect in Section 4.2 and PROCESS was employed to test the mediating and moderating effects.

4. Data analysis and results

4.1. Assessment of reliability and validity

This study first tested the reliability of the questionnaire and then used confirmatory factor analysis (CFA) to test the validity of the questionnaire. The test results are displayed in Table 2. According to previous literature, Cronbach's alpha and combined reliability (CR) were used to test the reliability of the questionnaire. Generally speaking, when the Cronbach's alpha coefficient of the scale is greater than 0.7, the reliability of the scale is good [15,119]. As can be seen from Table 2, Cronbach's alpha coefficient and CR of all variables of this model are greater than the recommended threshold of 0.70, indicating that each variable has a strong reliability.

AMOS22.0 is used to conduct the CFA to determine the adequacy of the measurement model. Generally, consider χ^2/df, the goodness of fit index (GFI), comparative fit index (CFI), Tuck- Lewis index (TLI), incremental fit index (IFI) and root mean square error of approximation (RMSEA), as fit indices of the model. It was generally believed that χ^2/df was less than 3, GFI, CFI, TLI and IFI were greater than 0.9, and RMSEA was less than 0.08, indicating that the model was well-fitted [8,112,118]. Table 4 shows the values of these indicators for four measurement models (DC, GSCC, GIP and TMEA), which are all within the acceptable range. Therefore, the

Table 2
Constructs reliability and validity tests.

Constructs	Items	Factor Loading	Cronbach's Alpha	CR	AVE	Mean	SD
Digital Technology Application Capability	DTAC1	0.767	0.893	0.842	0.516	3.535	0.510
	DTAC2	0.661					
	DTAC3	0.685					
	DTAC4	0.742					
	DTAC5	0.732					
Data and Information Analytics Capability	DIAC1	0.647	0.839	0.811	0.518	3.647	0.503
	DIAC2	0.752					
	DIAC3	0.745					
	DIAC4	0.731					
Digital Resource Collaboration Capability	DRCC1	0.703	0.837	0.819	0.530	3.633	0.494
	DRCC2	0.768					
	DRCC3	0.702					
	DRCC4	0.738					
Green Strategic Collaboration	GSC1	0.735	0.884	0.848	0.528	3.586	0.493
	GSC2	0.741					
	GSC3	0.682					
	GSC4	0.771					
	GSC5	0.701					
Green Resource Collaboration	GRC1	0.723	0.879	0.843	0.518	3.592	0.486
	GRC2	0.682					
	GRC3	0.732					
	GRC4	0.685					
	GRC5	0.773					
Green Information Collaboration	GIC1	0.734	0.886	0.850	0.532	3.598	0.491
	GIC2	0.689					
	GIC3	0.779					
	GIC4	0.722					
	GIC5	0.721					
Environmental Performance	ENP1	0.669	0.856	0.804	0.508	3.650	0.492
	ENP2	0.671					
	ENP3	0.762					
	ENP4	0.743					
Innovation Performance	INP1	0.758	0.854	0.823	0.539	3.665	0.476
	INP2	0.778					
	INP3	0.678					
	INP4	0.718					
Top Management's Environmental Awareness	TMEA1	0.767	0.766	0.854	0.539	3.591	0.473
	TMEA2	0.706					
	TMEA3	0.724					
	TMEA4	0.701					
	TMEA5	0.769					

Note: CR=Composite Reliability; AVE = Average Variance Extracted.

measurement model fits the data adequately.

Next, factor loading coefficients and average variance extraction (AVE) were used to test the convergent validity. The test results are displayed in Table 2. Through factor analysis, the factor load corresponding to each factor item is above 0.5, and the AVE of each construct are greater than the recommended value of 0.50 [120]. Finally, to evaluate the discriminative validity, the criterion of Fornell and Larcker (1981) is adopted, where the square root value of the AVE of each construct exceeds the correlation coefficient of the variable and other constructs. In Table 3, the diagonal is the square root value of AVE, which exceeds the non-diagonal (correlation coefficient between variables), indicating that the discriminant validity of the model is appropriate on all scales.

4.2. Testing the hypotheses

Hierarchical multiple regression analysis was used in this investigation to verify the main effect. SPSS PROCESS macro and bootstrap methods were used to analyze the mediating effect and the moderating effect. Rialti et al. [121], Waqas et al. [15], Edwin Cheng et al. [29], Q. Zhao et al. [122] and others also applied this method and verified its effectiveness. Before regression analysis, potential multicollinearity problems were taken into consideration. Variance inflation factors (VIF) were computed and the results were all less than 10, indicating that there was no serious multicollinearity in the data [123]. Then, standardized transformations of independent, dependent, and moderating variables were conducted to mitigate the potential harm of multicollinearity [124]. The results of regression analysis are shown in Table 5.

4.2.1. Direct effect test

Models 1 and 2 were used to test the direct effects. From model 1 to model 2, R^2 increased by 0.882, and the explanatory power of the model was enhanced. In Model 1, we examined the direct relationship between DC and GIP. In the regression analysis, the GIP was taken as the dependent variable, while the firm's size, age and annual revenue were taken as the independent variables. The regression results showed that the fit degree R^2 is too small to fully explain the GIP. On the basis of model 1, DC was added to model 2 as an independent variable. Regression results indicated that DC has a significant positive impact on GIP ($\beta = 0.433$, $p < 0.001$). Therefore, hypothesis H1 is true.

4.2.2. Mediating effect test

The mediation effect test in this study was carried out in accordance with Model 4 in PROCESS v2.16 for SPSS compiled by Hayes [125]. We used 5000 bootstrap samples and 95 % confidence intervals [121], and all test results were displayed in Tables 5 and 6.

In order to test hypotheses H2, H3 and H4, GSCC was taken as the dependent variable and DC was added to the independent variable under the control of firms' age, size, and annual revenue. From the results of model 3 and model 5 in Tables 5 and it could be seen that the confidence interval of DC was [0.205,0.493], which did not contain 0. Hence, DC had a significant impact on GSCC ($\beta = 0.349$, $p < 0.001$), and hypothesis H2 was verified. When the dependent variable was GIP, the confidence interval of GSCC was [0.603,0.708], devoid of 0. In consequence, GSCC had a significant impact on GIP ($\beta = 0.656$, $p < 0.001$), and hypothesis H3 was confirmed. At the same time, the confidence interval of DC was [0.146,0.262], which did not contain 0. It meant that DC still had a significant effect on GIP in the case of GSCC as the mediating variable ($\beta = 0.204$, $p < 0.001$). As a result, GSCC played a partial mediating role between DC and GIP, supporting the validity of hypothesis H4. As can be seen from Table 6, direct effect (0.204) and intermediate effect (0.229) account for 47.113% and 52.887 % of the total effect (0.433) respectively.

4.2.3. Moderating effect test

Similar to the test of mediating effect, the test of moderating effect was conducted according to Model 5 in PROCESS v2.16 for SPSS compiled by Hayes [125]. The sample size of Bootstrap was 5000 and the confidence level was 95 % uniformly. The test results are shown in Table 5.

For testing hypothesis H5, GIP was taken as a dependent variable. DC was taken as an independent variable, TMEA was taken as a

Table 3
Inter-correlation and descriptive statistics.

Constructs	DTAC	DIAC	DRCC	GSC	GRC	GIC	ENP	INP	TMEA
Digital Technology Application Capability (DTAC)	0.718								
Data and Information Analytics Capability (DIAC)	0.271***	0.720							
Digital Resource Collaboration Capability (DRCC)	0.253***	0.283***	0.728						
Green Strategic Collaboration (GSC)	0.249***	0.296***	0.309***	0.719					
Green Resource Collaboration (GRC)	0.227***	0.304***	0.283***	0.313***	0.720				
Green Information Collaboration (GIC)	0.173***	0.286***	0.275***	0.326***	0.322***	0.730			
Environmental Performance (ENP)	0.217***	0.254***	0.236***	0.276***	0.287***	0.296***	0.713		
Innovation Performance (INP)	0.176***	0.179***	0.199***	0.262***	0.274***	0.285***	0.294***	0.734	
Top Management's Environmental Awareness (TMEA)	0.187***	0.232***	0.237***	0.274***	0.317***	0.279***	0.231***	0.224***	0.734

Note: *** represent $p < 0.001$, ** represent $p < 0.01$, * represent $p < 0.05$.

Table 4
Test results of the goodness-of-fit for the measurement model.

Fit index	DC	GSCC	GIP	TMEA
χ^2/df	2.198	2.907	1.549	1.309
GFI	0.947	0.917	0.980	0.993
CFI	0.973	0.952	0.993	0.996
TLI	0.966	0.942	0.989	0.992
IFI	0.973	0.952	0.993	0.996
RMSEA	0.058	0.073	0.039	0.029

moderating variable, and interaction terms between DC and TMEA were gradually added while controlling firms' age, size and annual revenue. From model 4 in Tables 5 and it could be seen that the interaction term between DC and TMEA had a significant impact on GIP ($\beta = 0.079$, $p < 0.001$), which indicated that the stronger the TMEA, the more significant the positive relationship between DC and GIP. Therefore, the TMEA positively moderates the positive relationship between DC and GIP, which means hypothesis H5 is valid.

For the sake of further explaining the moderating effect of TMEA, two groups were divided: the high group took the mean value of TMEA plus a standard deviation as the baseline and the low one took the mean value of TMEA minus a standard deviation as the baseline. A simple slope test was carried out in Fig. 4. The findings demonstrate that when the level of TMEA is low, the positive effect of DC on the enterprise's GIP is weak. When the level of TMEA is high, the positive effect of DC on the enterprise's GIP is strong. It indicates that the effect of DC on the enterprise's GIP is progressively growing as the degree of TMEA improves. That is, the TMEA plays a positive moderating role between DC and GIP.

5. Discussion

5.1. *Theoretical implications*

The emergence of the digital economy has led to a growing significance for digital resources, and digitalization offers robust backing for environmentally conscious innovation. Therefore, it is of great theoretical significance to explore the mechanism of DC on green innovation.

The significant positive impact of DC on GIP is further verified through empirical research. This conclusion validates the findings of the studies conducted by Benzidia et al. [31] and Li and Shen [46]. It also verifies that GSCC is a key factor for corporates' green innovation, which is consistent with previous research conclusions [78,126,127]. Nevertheless, prior studies have hardly examined the antecedent variables of GSCC from the perspective of DC. While some research has indicated that information technology is the basis of GSCC [41], the specific mechanism of DC on GSCC has not been deeply explored. This study explores in detail the significant positive impact of DC on GSCC from three dimensions of DTAC, DIAC, and DRCC. It enriches the existing research findings on GSCC. When using the scale to investigate, it may be affected by the subjective factors of the respondents, leading to the deviation of the measurement. In the future, multiple rounds of questionnaire design, data collection and testing can be carried out to further increase the robustness of the scale.

This study reveals how DC is influenced by GSCC to attain superior GIP, extending and complementing existing research findings. Despite the fact that numerous studies have examined the association between DC and GIP [8,15], few studies have analyzed the impact path of DC on GIP in the view of GSCC. There is little literature to measure the GSCC from three perspectives of GSC, GRC and GIC. The findings indicate that GSCC has a partial mediating effect between DC and GIP. The direct effect of DC on GIP makes up 37.024 % of the total effect, while the indirect effect accounts for 62.976 %. It implies that DC can not only directly affect the GIP, but also indirectly influence the GIP through GSCC. Even though the bootstrap approach and PROCESS have been used in many studies, it is still worthwhile to investigate whether the direct and indirect effect ratios produced in this study are entirely consistent with the results of other methods. Generally speaking, it enriches and broadens the research findings on digitalization and green innovation and offers a more thorough evaluation of the impact of DC and GSCC on green innovation.

This research demonstrates the moderating effect of TMEA on the impact of DC on GIP, enriching the upper echelons' literature on boundary conditions. Previously, more research concentrated on the direct impact of TMEA as an antecedent variable on green innovation [24,128]. However, few studies have examined the role of TMEA as a moderating variable in the relationship between digitalization and green innovation [129]. Based on the upper echelons theory, it highlights the critical role of top managers in fostering green innovation in the view of environmental awareness, which not only makes up for the lack of attention paid to top managers in current studies on digitalization and ecological innovation but also expands the role of the variable of TMEA in green innovation. It offers a fresh avenue for investigation into the connection between digitization, green innovation, and the TMEA.

5.2. *Practical implications*

This study highlights the critical role of DC in enterprises' green innovation, explores the transmission mechanism of GSCC, and emphasizes the significance of TMEA. These findings provide valuable guidance for manufacturing companies on how to use DC more effectively to achieve environmental benefits and innovation performance. Three significant practical ramifications of the study exist.

Initially, the findings of empirical studies highlight the importance of DC in improving the GIP. Hence, manufacturing companies

Table 5
Results for hierarchical and bootstrap regression analyses.

Variables	Dependent variable: GIP										Dependent variable: GSCC		
	Model 1	Model 2			Model 3			Model 4			Model 5		
	β	β	LLCI	ULCI	β	LLCI	ULCI	β	LLCI	ULCI	β	LLCI	ULCI
Firm Age	0.052	−0.012	−0.041	0.017	−0.016	−0.040	0.008	−0.026	−0.049	0.003	0.056	−0.015	0.026
Firm size	−0.077	−0.006	−0.032	0.020	0.000	−0.021	0.022	0.002	−0.018	0.023	−0.009	−0.027	0.010
Annual revenue	0.011	−0.008	−0.035	0.018	0.006	−0.016	0.028	0.001	−0.020	0.022	−0.018	−0.037	0.001
DC		0.433***	0.397	0.469	0.204***	0.146	0.262	0.199***	0.085	0.315	0.349***	0.205	0.493
GSCC					0.656***	0.603	0.708	0.252***	0.110	0.394			
TMEA								0.230***	0.132	0.327			
DC × TMEA								0.079***	0.054	0.103			
R^2	0.013	0.895			0.928			0.936			0.943		
F	1.531	757.451***			805.7638***			729.627***			956.69***		

Notes: *** represent $p < 0.001$, ** represent $p < 0.01$, * represent $p < 0.05$; β: regression weight estimate; p: p-value; LLCI: lower limit confidence interval; ULCI: upper limit confidence interval; R^2: multiple squared correlation indicating the percentage of variance explained.

Table 6
Decomposition results of the total effect, direct effect and mediation effect.

Type	Effect	BootSE	BootLLCI	BootULCI	Relative effect
Total effect	0.433	0.018	0.397	0.469	–
Direct effect	0.204	0.029	0.146	0.262	47.113%
Indirect effect	0.229	0.011	0.207	0.251	52.887%

Notes: SE: standard error; LLCI: lower limit confidence interval; ULCI: upper limit confidence interval.

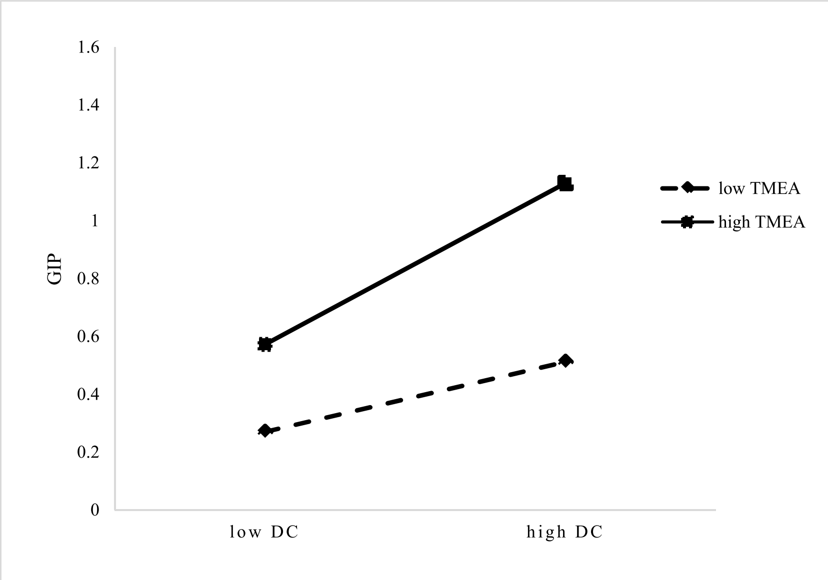

Fig. 4. Moderating effect of TMEA on the relationship between DC and GIP.

should keep up with the rapid development of the digital economy and continue to invest in DC to improve their environmental performance. Examples of DC initiatives include the implementation of digital transformation, the introduction of digital technology or data analysis tools, the construction of digital platforms, and the deep integration of operation and digital technology. This is consistent with the current goals and achievements of enterprises' digital transformation [130,131]. Simultaneously, the implementation of digital transformation can encourage firms to carry out green technology, product and process innovation. In the current digital economy era, manufacturing companies should formulate more accurate digital implementation plans, carry out business digitization and build digital platforms [132]. They should also enhance their data analysis and mining capabilities to enable real-time intelligent decision-making and foster more conducive conditions for green innovation. In conclusion, companies are encouraged to diversify their strategies with digital strategies to enhance their competitiveness [122].

Secondly, the research emphasizes that GSCC plays a partial mediating role between DC and GIP. It means that manufacturing corporates should pay more attention to the strategy of SCC and make full use of digital technology to foster information and knowledge sharing, resource integration and strategic alliance between upstream and downstream companies in the supply chain, so as to promote business, technology and strategic synergy. The partners in the supply chain should jointly formulate energy conservation and emission reduction programs and cooperatively deal with environmental issues, which help to lower environmental pollution and improve environmental performance. At the same time, it is conducive to collaborative innovation that corporates make full use of digital resources to conduct technology research jointly, optimize business processes, and form a community of interests with supply chain partners.

Thirdly, this study highlights the positive moderating effect of TMEA on DC and GIP. It indicates that manufacturing corporations and the board should pay more attention to applicants' environmental awareness when selecting executive candidates. In addition, enterprises should actively raise managers' awareness of environmental issues and pay closer attention to them. Managers should receive regular training on environmental protection knowledge to help them stay up to date on the latest environmental laws, regulations and related policies. They should also be made more aware of the risks and benefits of environmental protection as well as their sense of responsibility for it. The managers should be encouraged to drive companies to give full play to the value of DC, so that digital technologies and resources can be fully used in environmental practices, such as updating production plans, improving production methods, formulating appropriate environmental targets and programs according to the obtained data, or applying digital technologies to green technology, product and process innovation. At last, the objective of eco-friendly and sustainable development of enterprises has been achieved.

According to the above practical enlightenment, there are a few recommendations for manufacturing enterprises. The digital transformation should be promoted aggressively to enhance firms' digital capabilities. Digital technologies such as blockchain, Internet of Things and Artificial Intelligence need to be invested more and integrated with businesses' production and operation in an all-round way to improve their digital resource mining, management and analysis capabilities. Ultimately, it helps companies make real-time intelligent decisions. Furthermore, manufacturers should collaborate with upstream and downstream enterprises in the supply chain and make full use of modern digital technology to share information, knowledge and resources with them. They work together to find solutions to environmental issues, conduct green technology R&D and optimize business processes to achieve collaborative innovation. In addition, it is imperative to foster the environmental consciousness of top managers by training programs on environmental knowledge, laws and regulations. They need to be encouraged to employ digital technology to carry out green innovation, foster green development and achieve environmental goals.

6. Conclusion and direction for future study

The growth of businesses has been negatively impacted by the rising environmental waste. In China, although the manufacturing industry has grown quickly and achieved great strides recently, the environmental issues are still very severe. Digital technology has significantly increased the effectiveness of information processing and resource use in enterprises, and digitalization has demonstrated tremendous possibilities in fostering green innovation. Therefore, this study attempts to identify the transmission mechanism and boundary conditions for enterprises to implement green innovation by DC relying on digital technologies, so as to enhance their environmental performance and achieve green development. Based on resource-based theory, dynamic capability theory and upper echelons theory, this paper reveals the impact mechanism of DC on GIP from the perspective of GSCC and TMEA, constructs a theoretical model of "digital capability-green supply chain collaboration-green innovation performance", and conducts an empirical test based on the Chinese manufacturing enterprises. The findings demonstrate that DC significantly improves GIP and has an indirect effect on GIP through GSCC. The direct and indirect effects of DC on GIP accounted for 37.024 % and 62.976 % of the total effect respectively. The TMEA can positively moderate the effect of DC on GIP, that is, the higher the TMEA, the more conducive to the role of DC and the improvement of corporates' GIP. This study incorporates DC, GSCC and TMEA in the investigation of corporates' green innovation, highlighting the positive impact of DC and GSCC on green innovation and the role of GSCC and TMEA on DC and GIP. It offers a fresh framework for comprehending digitalization and green innovation.

Overall, the findings of this study are significant and have a positive impact on enterprises to improve their GIP and competitive advantage. Theoretically, this work reveals the path of the interaction between DC and GIP, fills the research gap on the transmission mechanism between DC and green innovation from the perspective of GSCC, and offers a theoretical reference for the research on DC and green innovation. Practically speaking, it provides ideas for manufacturing corporates to enhance their environmental and innovation performance. It also offers guidance on how to carry out digital transformation and engage in supply chain collaborative innovation. All of that will ultimately contribute to the sustainable and prosperous development of the manufacturing industry.

There are certain limitations, which open the way for further in-depth research in the future, although they provide valuable insights. First, the digitalization of corporations involves many factors such as daily operation, organization mode, resource capability, etc. However, the measurement dimensions and scales set in this study are insufficient to encompass all of DC. It is still up for debate how to measure DC more effectively and comprehensively. Future research may consider using a combination of objective indicators and subjective evaluation to characterize the DC of enterprises. Second, while the DC is affected by several factors, our study solely examined the impact mechanism of DC on GIP from the standpoint of TMEA. Future research can make a further study on the impact of DC and GIP in different environmental contexts, such as environmental institutional support or competition intensity. Exploring these additional contexts will provide a more comprehensive understanding of the relationship between environmental factors and organizational performance. Third, the empirical research in this work is limited to samples from the Chinese manufacturing industry. In the current wave of the global digital revolution, whether digitalization plays a universal role in enterprises' green innovation, whether digitalization also plays a crucial role in green innovation in other countries, and how to play the role are all questions worthy of further discussion.

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Data availability statement

We have shared all research data in the article.

CRediT authorship contribution statement

Wen Cheng: Writing – original draft, Validation, Project administration, Methodology, Funding acquisition, Conceptualization. **Qian Li:** Writing – review & editing, Validation, Funding acquisition, Conceptualization. **Qunqi Wu:** Supervision, Resources, Formal analysis. **Fei Ye:** Visualization, Software, Data curation. **Yahong Jiang:** Visualization, Investigation.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Appendix. Items used to measure the constructs and their sources

Construct	Items		Sources
Digital Capability (DC)			
Digital Technology Application Capability (DTAC)	DTAC 1	Our company has applied digital technology in product design, development and production.	[117] [133] [41]
	DTAC 2	Our company has applied digital technology in various logistics links such as procurement, transportation, warehousing, delivery, etc.	
	DTAC 3	Our company has applied digital technology in product marketing.	
	DTAC 4	Our company has applied digital technology in customer management.	
	DTAC 5	Our company has applied digital technology in supplier management.	
Data and Information Analytics Capability (DIAC)	DIAC 1	Our company can quickly separate valuable information from large amounts of data.	[116] [31]
	DIAC 2	Our company can use analytical tools and algorithms to conduct in-depth analysis of data.	
	DIAC 3	Our company can understand customer preferences and predict customer behavior through in-depth analysis.	
	DIAC 4	Our company can visualize the obtained data information.	
Digital Resource Collaboration Capability (DRCC)	DRCC 1	Our company can leverage digital resources for real-time intelligent decision-making.	[116] [68]
	DRCC 2	Our company can leverage digital resources to optimize business processes with partners.	
	DRCC 3	Our company can leverage digital resources for technology development and innovation with partners.	
	DRCC 4	Our company can leverage digital resources to form a common value chain with partners.	
Green Supply Chain Collaboration (GSCC)			
Green Strategic Collaboration (GSC)	GSC 1	Our company maintains long-term and stable cooperative relations with upstream and downstream partners.	[45] [134]
	GSC 2	Our company has achieved a common strategic goal of environmental protection with upstream and downstream partners.	
	GSC 3	Our company has formulated strategic plans for green production, sales, research and development jointly with upstream and downstream partners.	
	GSC 4	Our company has made strategic decisions and developed solutions to problems jointly with upstream and downstream partners.	
	GSC 5	Our company has formed a common coordination mechanism in terms of costs, benefits and risks with upstream and downstream partners.	
Green Resource Collaboration (GRC)	GRC 1	Our company has shared equipment, technology, talent and other resources with upstream and downstream partners.	[135] [45]
	GRC 2	Our company has made full use of existing green resources to expand the business field with upstream and downstream partners.	
	GRC 3	Our company has developed new green resources in new business fields jointly with upstream and downstream partners.	
	GRC 4	Our company has developed new products or provided new services using new green resources jointly with upstream and downstream partners.	
	GRC 5	Our company has obtained new green resources from the outside to grow existing business fields jointly with upstream and downstream partners.	
Green Information Collaboration (GIC)	GIC 1	Our company has shared knowledge and information related to green technologies with upstream and downstream partners.	[136] [137]
	GIC 2	Our company has shared knowledge and information related to green production and processing with upstream and downstream partners.	
	GIC 3	Our company has shared experience, knowledge and information related to green product operations and management with upstream and downstream partners.	
	GIC 4	Our company has shared knowledge and information related to green product marketing with upstream and downstream partners.	
	GIC 5	Our company has shared the latest research reports and trends in the industry with upstream and downstream partners.	
Green Innovation Performance (GIP)			
Environmental Performance (ENP)	ENP 1	The emissions of wastewater, exhaust gas and solid waste in our company have decreased significantly in the past three years.	[41] [115]

(*continued on next page*)

(*continued*)

Construct	Items		Sources
	ENP 2	The consumption of harmful substances in our company has been decreasing in the past three years.	
	ENP 3	The energy consumption of our company has been decreasing for the past three years.	
	ENP 4	The number of regulations imposed on our company has decreased significantly due to environmental problems in the past three years.	
Innovation Performance (INP)	INP 1	Our company can develop new products or services more quickly than its peers.	[138]
	INP 2	Our company can bring new products or services to market faster than its peers.	[139]
	INP 3	Our company's products and technology have more obvious competitive advantages than its peers.	
	INP 4	The improvement and innovation of our company's products or business processes have a better market response than its peers.	
Top Management's Environmental Awareness (TMEA)	TMEA 1	The top management of our company attaches great importance to the adverse impact of the company on the environment.	[114] [140]
	TMEA 2	The top management of our company attaches great importance to environmental protection.	
	TMEA 3	The top management of our company are very clear about the environmental protection measures of this industry.	
	TMEA 4	The top management of our company believes that green and environmental protection behavior can improve the company's productivity.	
	TMEA 5	The top management of our company believes that green and environmental protection behavior can increase the company's profits.	

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