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ORIGINAL PAPER

A matter of motivation: the impact of enterprise digital transformation on green innovation

Qiuqin He[1] · Samuel Ribeiro-Navarrete[2,4] · Dolores Botella-Carrubi[3]

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Abstract
The rapid expansion of digital technology has increasingly challenged conventional knowledge in corporate green innovation. Debate surrounding whether and how enterprise digital transformation enhances green innovation outcomes is gathering pace. However, there remains no conclusive evidence, in large part because the motivation for green innovation is overlooked. Using data from Chinese publicly listed firms between 2008 and 2021, this study explores the impact of digital transformation on the underlying mechanisms and boundary conditions of green innovation through the lens of company motivations, distinguishing green innovation as substantive-driven and strategic-driven. The results reveal that digital transformation significantly impacts green innovation by strengthening the resource and knowledge bases, which is consistent with the resource-based view. However, considering the motivations of green innovation, we find that digital transformation positively affects substantive innovation, but does not affect strategic green innovation. We further explore the boundary conditions of digital transformation's effects on green innovation by analyzing the moderating effect of environmental orientation (EO) and separating EO's motivations into voluntary-driven and mandatory-driven. The results show that environmental orientation positively moderates the relationship between digital transformation and green innovation and that only voluntary-driven EO has a positive moderating effect. Our findings add new insights to the theory linking strategy decision-making to green innovation performance, with specific regard to firms' motivations.

Keywords Digital transformation · Green innovation · Environmental orientation · Motivation · Resource-based view

Mathematics Subject Classification D22 · O33 · Q55

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Extended author information available on the last page of the article

1 Introduction

Given the widespread adoption of sustainable development goals, green innovation is increasingly being regarded as the primary strategies to obtain a competitive advantage. A considerable body of literature has explored the organization drivers and outcomes of green (environmental) innovation, and the rewarding results have significantly advanced our understanding of sustainability (Boons et al. 2013; Bossle et al. 2016; Diez-Martinez et al. 2022; Lee and Suh 2022; Ortigueira-Sánchez et al. 2022; Tipu et al. 2022). In a systematic review, Bossle et al. (2013) identify external factors such as government, regulatory pressures, technological opportunities, and market demand, as well as internal factors such as environmental culture, environmental leadership, and environmental capability, as the primary drivers of eco-innovation adoption. Diez-Martinez et al. (2022) find that eco-innovation drivers are more potent in collaborative enterprises than in non-collaborative firms. Tipu et al. (2022) emphasize the impact of learning, organizational culture, and leadership on the sustainable growth of enterprises.

Due to the "double externality" (technology and environment) and high risk, regulations are among the most frequently reported drivers (Li-Ying et al. 2018). Recently, with the rapid growth of digital technology, research efforts that link digital transformation (information technology) to green innovation adoption have emerged (Melville 2010; Ardito et al. 2021; Chen et al. 2021; Feng et al. 2022; Zameer et al. 2022). Ongoing digital transformation sets enormous changes in motion for firms (Kraus et al. 2021, 2022), such as transforming the entrepreneurial ecosystem (Endres et al. 2022; Song et al. 2022), fostering entrepreneurship (Kraus 2019), updating the business model (Åström et al. 2022) and green innovation activities are not an exception. Some studies support the idea that digital transformation can stimulate green innovations, with such innovations being mediated by R&D investment, government subsidies, and income tax burden (Feng et al. 2022; Zameer et al. 2022;) and moderated by factors such as regulatory pressure, international opportunities, and ownership (Chen et al. 2021; He and Su 2022). While some findings indicate a negative interaction between digitalization and environmentalism, they were created to fulfill divergent corporate goals that may conflict due to limited organizational resources (Ardito et al. 2021). Others indicate that whether digital transformation can "empower" organizational innovation is determined by whether the enterprise's management capability meets the digital transformation strategy (Hajli 2015). Overall, the existing results are inconsistent, and the understanding of the impact of digital transformation on the underlying mechanisms and boundary conditions of green innovation is limited and sporadic, especially overlooking firms' motivations to engage in green innovation (Li-Ying et al. 2018).

Literature has categorized green innovation into two main topologies. The first classification categorizes innovations based on their level as either radical or incremental (Klimas and Czakon 2022). The second classification examines the economic benefits of green innovation and distinguishes them into process and product innovations (Rennings 2000). Motivation is a vital factor in a firm's decision to adopt green innovation practices, while the literature has given little attention to it. There is no doubt that regulation-driven and strategy-driven motivations will adopt different green innovation strategies. Under the pressure of multiple external regulations, firms may engage in green innovation activities with the motivation of adhering to environmental standards and reducing their environmental punishment, thus tending to pursue innovation in "quantity" rather than "quality" (Ramanathan et al. 2010; Li and Zhen 2016). As a strategic objective, firms will engage in more substantial innovation activities to develop the unique green innovation capability required for long-term competitive advantage (Li-Ying et al. 2018). Therefore, a question naturally arises about whether digital transformation has varying effects on green innovation based on different motivations. In other words, will firms with different motivations (regulation-driven vs. strategy-driven) leverage digital transformation to green innovation differently?

This study uses a sample of 4950 firm-year observations from Chinese A-share listed firms between 2008 and 2021 to empirically analyze how digital transformation impacts enterprises' green innovation and to respond to the above question from a resource-based view (RBV). In this study, green innovation is divided into two types based on different motivations: substantive green innovation, which tries to advance technology and acquire a competitive advantage, and strategic green innovation, which focuses on speed and quantity to meet regulatory criteria. The direct effect of digital transformation on green innovation is first investigated.

Then, the moderating effect of environmental orientation (EO) is further studied to explore whether EO plays an important boundary role in the process of enterprises promoting green innovation through digital transformation. In the context of RBV, EO has a strategic and active internal capability to integrate environmental priorities into a firm's tactical, operational, and innovative activities (Ardito et al. 2021; Zameer et al. 2022). An environmentally oriented firm typically demonstrates a persistent motivation to engage in the search for ecological activities to avoid negative environmental consequences (Graham and Potter 2015; Fiorini et al. 2018), significantly influencing firms to leverage digital transformation for green innovation. In light of this idea, this study constructs an environmental orientation index based on firms' environmental practices. Zhou et al. (2022) find enterprises selected different strategies under different environmental orientations. This study further clusters it into mandatory and voluntary EO according to the different EO's motivations.

Mandatory EO is driven by environmental regulation formulated by the government or relevant regulatory agencies. This study focuses on the *Measures for Supervisory Monitoring and Information Disclosure of Pollution Sources of Key National Monitoring Enterprises*, which have been in place since 2014 and these measures specify the substance, method, time limit, and regulatory aspects of environmental information disclosure by key polluting enterprises. The voluntary EO is motivated by firms' strategic goals, and this research focuses on ISO 14,001 certification. ISO 140,011 certification is self-initiated to improve firm reputation and social and market positioning, cut costs, and provide better environmental benefits (Fryxell and Szeto 2002; Prajogo et al. 2012).

This study is essential and timely, given China's rapid development of the digital economy and the achievement of the sustainable development goals of "carbon peak" by 2030 and "carbon neutral" by 2060. The empirical findings contribute to a better understanding of how to use digital technology to foster green innovation in enterprises, which will be critical in combating global climate change and environmental degradation. The study contributes to the literature in several ways. First, unlike previous studies that divided green innovation into process innovation and product innovation (Awan et al. 2021), this paper investigates the motivation for innovations in depth and divides green innovation into substantive and strategic green innovation. The findings show that digital transformation has a significant positive impact on green innovation but only on substantive, not strategic, green innovation. Second, we investigate the moderating effect of EO to explore the boundary conditions of enterprises' digital transformation that affect green innovation. This study constructs an environmental orientation index based on firms' environmental practices rather than constructing one based on questionnaire measurements. The result indicates that EO has a positive moderating effect on the relationship between digital transformation and green innovation, no matter substantive or strategic green innovation. Third, we further divide EO into mandatory and voluntary EO, each with its own motivation. Our finding is interesting. Although EO positively moderates the relationship between digital transformation and green innovation, only voluntary EO has this effect. Our findings indicate that identifying the motivation to engage in green innovation is critical for further understanding the boundary conditions under which digital transformation boosts green innovation activities. The results have important implications for emerging economies in promoting digital transformation and green innovation.

2 Theoretical background and hypothesis development

2.1 Theoretical background: resource-based view

The resource-based view (RBV) of the firm serves as the theoretical framework for our study in terms of leveraging digital transformation for firms' green innovation strategies. A large amount of studies contributes to the literature on firms' green innovation grounded in a resource-based view. Ziegler and Nogareda (2009) examine the impact of environmental management systems (EMS) on technological environmental innovations based on RBV. Meyskens and Carsrud (2013) empirically examine the role of partnership diversity in nascent green-technology ventures based on RBV. Lee and Min (2015) examines the impact of green R&D investment for eco-innovation on environmental and financial performance based on RBV. Li et al. (2017) investigates how external legitimacy pressure and internal business profitability affect green innovation using institutional theory and RBV. Sahoo et al. (2022) examine the connections between a firm's big data management activities, green manufacturing practices, and sustainable business performance from resource-based and dynamic capabilities perspectives. Using the resource-based view and the behavioral theory of the firm, Yang and Jiang (2023) investigate the impact of buyers' environmental attitudes on enterprises' green innovation.

According to RBV, resources are viewed as integrated combinations of assets and capabilities, with assets referring to organizational attributes that a firm can acquire, develop, nurture, and leverage for strategic goals and capabilities referring to collections of collective knowledge and expertise that are used through organizational processes (Srivastava et al. 2001). A firm gains a sustainable competitive advantage from unique resources that are valuable, rare, inimitable, and non-substitutable (VRIN) (Barney 1991). VRIN resources help firms form and exploit opportunities (Ferreira et al. 2019), making firms much more likely to innovate and achieve favorable innovation results (AlzamoraRuiz et al. 2021; Barroso-Castro et al. 2022).

With increasing environmental uncertainty and dynamic changes in market competition, companies might be forced to reconfigure not only their unique resources but also their entire resource set. Therefore, the concept of dynamic capabilities is proposed by Teece et al. (1997), who emphasize firms' ability to integrate, build, and reconfigure internal and external resources to address rapidly changing environments. Scholars have attempted to explain the impact mechanism of digital transformation on the green innovation of enterprises based on dynamic capability theory and resource-based theory (Feng et al. 2022). Digital transformation could enhance firms' sensing capabilities, help them identify and capitalize on emerging opportunities in their internal and external environments, and further reconfigure their resources to develop new green products, new green process technology, and green services to gain a green competitive advantage (Chen and Tian 2022).

Dynamic capabilities focus on continuous actions by adding, modifying, or reconfiguring resources or competences, and competitive advantage stems not only from the capabilities themselves but also from the resource configurations they create (Barney et al. 2001). That is, RBV offers an integrated perspective on how bundles of assets and (dynamic) capabilities promote green innovation strategy decisions. Therefore, we adopt it as a theoretical background to explore the boundary conditions of the impact of digital transformation on green innovation.

2.2 Hypothesis development

2.2.1 The effect of digital transformation on a firm's green innovation

Eco-innovation, environmental innovation, and sustainable innovation are synonymous with green innovation (Boons et al. 2013). Green innovation, in general, can be defined as new or modified processes, techniques, practices, systems, and products that aim to prevent or reduce environmental damage, increase recycling, enhance regulatory environments, and boost ecological, economic, and social performance (Rennings 2000). The most noticeable trait is that green innovation produces positive environmental externalities, discouraging private firms from dedicating resources to associated activities. Although the general trend is to advocate for it, the proportion of firms adopting green development strategies is still small due to resource constraints. Compared with other innovations, green innovations require a higher resource commitment and a more complex combination of resources (Zhang and Walton 2017). Adopting digital transformation can be a powerful motivator for green businesses.

Digital transformation has no universally acknowledged definition. In this study, digital transformation refers to reshaping an organization to take advantage of valuable existing strategic resources in new ways using next-generation information and communication technologies such as AI, IoT, blockchain, cloud computing, and big data (Westerman et al. 2014; Pagoropoulos et al. 2017). A firm's adoption of digital transformation entails the incorporation of digital technology into its existing enterprise management system to achieve organizational structure change, business process enhancement, and the promotion of the process of reshaping the manner of value creation, which offers a new solution for green innovation.

Digital transformation could promote green innovation in several ways. First, digital technology modifies the organizational structure and enhances business processes, which can effectively improve firms' resource utilization efficiency (Zhang et al. 2021). In other words, digital transformation can reduce operating costs and sales costs with an efficiency improvement, generating a resource-saving effect that allows firms to allocate more resources to green innovation.

Second, digital transformation has the potential to reinvent existing and novel knowledge as well as reconfigure firm resources to meet the requirements of green innovations (Nambisan et al. 2019; Gil-Alana et al. 2020; Giusti et al. 2020). Using digital twins, for instance, firms amass vast quantities of production and operation data, which have become the most valuable strategic resource. Massive amounts of data can be fully utilized by digital technology, such as cloud computing and big data analytics, to seize the new trend of the market and new opportunities, which could support green innovation. By mining production data, firms may innovate their production processes and products, thereby increasing energy efficiency and reducing environmental damage. With consumption data, firms may capture weak signals from consumers' changing consumption patterns, as increasing consumer environmentalism enforces green product innovation (Zhang and Zhu 2019).

Third, a firm that adopts digitalization can make its organization more flexible and reactive, which could smoothly help share goals, shared knowledge, and mutual respect within the organization (Claggett and Karahanna 2018; Ardito et al. 2021). With a digitized work process, multiple people can access information and talent simultaneously and can make full use of the knowledge and information to fulfill goals such as green development. For a specific technology, for example, the IoT will increase the connected environment by developing partnerships that could create innovative solutions for the problems encountered in green innovation (Saarikko et al. 2017).

Thus, we propose the following hypothesis:

H1 Digital transformation promotes a firm's green innovation.

Generally, the underlying assumption of firms' motivation to engage in innovative activities is that they want to bring about technological progress and competitive advantage. Tong et al. (2014), however, discover that enterprises' innovation activity, as assessed by patent applications, is occasionally strategic. In other words, innovation is merely a tactic for accommodating government regulations and oversight. In response to the growing emphasis on environmental protection and green growth, the Chinese government has enacted a number of pollution control legislations. With this regulatory pressure, a company is likely to pursue green innovation's quantity and velocity to comply with the law and government. Thus, we distinguish between substantive and strategic green innovations. The former seeks to advance technology and gain a competitive advantage, whereas the latter emphasizes speed and quantity.

Firms engaged in substantial green innovation, being ahead of competitors, frequently have no prior art to exploit and market-accessible know-how (Li-Ying et al. 2018). Digital transformation facilitates the extraction of meaningful information from massive market and operational data, which identify complementary resources and capabilities and enhance the technical knowledge base for substantial green innovation. Digitalization creates an organization structure that is more flexible, which could facilitate interorganizational learning, information sharing with knowledge partners, and the cocreation of new practices. These are essential for the exploration of cutting-edge technology, which is required for substantial green innovation. External stakeholders, such as external R&D partners, who can offer new insights and solutions for complex green innovation operations, benefit from digital transformation.

Strategic green innovation to meet regulations comprises very straightforward issues (Parker 2000). To comply with environmental regulations, strategic green innovation can be accomplished by employing eco-friendly materials such as recyclable materials, enhancing the process, introducing energy-saving equipment, and decreasing the consumption of resources and energy (Xie et al. 2015). Companies can find solutions in existing resources and technologies, and they typically license or acquire preexisting technology to avoid R&D risk (Li-Ying et al. 2018). In this process, digital transformation plays a limited role in comparison to significant green innovation. As stated before, digital transformation can be used to create opportunities to improve and expand a firm's operations and product offerings (Nambisan et al. 2019). This study holds that a firm with such an orientation gains a competitive advantage through green innovation. Thus, we propose the following hypothesis:

H2 Digital transformation promotes a firm's substantive green innovation rather than its strategic green innovation.

2.2.2 The moderating effect of environmental orientation

A firm's strategic orientation reflects efforts to create and implement the proper behaviors and actions to attain the superior performance of the business (Adams et al. 2016). Environmental orientation can be interpreted as a pro-environmental strategic orientation that manifests a firm's philosophy of operating in a sustainable manner (Banerjee 2002). Environmental orientation shows a firm's attitude toward environmental conservation and influences firm's connections with external stakeholders, including suppliers, communities, and the government (Feng et al. 2018). The core of EO is a kind of strategic ability (Zameer et al. 2022). A firm with an environmental orientation tends to allocate resources to tactical, operational, and innovative activities to meet internal eco-friendly values (Ardito et al. 2021). This mindset will be reflected in the firm's culture and strategy, influencing its products, procedures, and practices (Adams et al. 2016). Hence, environmentally oriented firms will make full use of the role of digital technology in green innovation, just as they leverage employees proactively to process information with environmental protection in mind (Kang and He 2018). Suppose a firm develops a solid environmental orientation. In this case, managers will apply digital technology to integrate internal and external resources and increase the efficiency of resource conversion, which could contribute to reducing production pollution, such as toxic and harmful emissions (Jiang et al. 2018). Furthermore, some firms use digital transformation as part of an ecological orientation strategy (de Sousa Jabbour et al. 2018), which could upgrade the new generation of manufacturing processes. That is, enterprises will utilize digital resources and digital technology in the design, building, production, and utilization of a green innovation program to achieve strategic objectives. Meanwhile, with an environmental orientation, digital transformation could be a potent auxiliary tool for strengthening employee relationships, forming a consensus on environmental protection, exchanging environmental knowledge, and then maximizing human capital for green innovation.

Thus, we propose the following hypothesis:

H3 Environmental orientation positively moderates the effect of digital transformation on firms' green innovation, irrespective whether it is substantive green innovation or strategic green innovation.

Some scholars have divided EO into two categories: internal and external EO (Zhang et al. 2022). The former describes the enterprise's ethical standards, commitments, and environmental values, while the latter describes how aware and responsive the enterprise is to the environmental needs of stakeholders (Banerjee 2002). This research contends that there is a significant distinction in the motivations of these two environmental orientations. Internal EO is the manifestation of corporate values, which are developed spontaneously by the organization and incorporated into corporate culture and strategy. External EO is mainly shaped by the external environment and formed passively, which is frequently influenced by external environmental legislation and consumer environmentalism. This study splits EO into voluntary and mandatory EO based on their respective motivations to evaluate the moderating effect of EO on the relationship between digital transformation and green innovation.

González-Benito and González-Benito (2005) found that a firm pursues ISO 14,001 certification in response to ethical and competitive motivations and that the firm's portfolio of environmental motivations does not change considerably after certification. Firms associate ISO 14,001 certification with other advantages attributed to environmental proactivity. As a result, this study regards ISO 14,001 certification as a voluntary EO, which is often seen as a strong sign of a firm's dedication to environmental protection (Potoski and Prakash 2005; Quan et al. 2023). ISO 14,001 is a voluntary environmental regulation certified by a third party as an Environmental Management System (EMS). It provides a specified environmental protection standard to assist businesses in improving their environmental management (Rennings et al. 2006), and it focuses on supporting businesses in developing an effective environmental management system. It allows firms to have more room for innovation. According to Bu et al. (2020), enterprises' optional ISO 14,000 environmental certification helps enhance their innovation output. The ISO 14,001 standard often requires enterprises to restructure their existing production and operating modes to adopt a new approach to pollution prevention, product management, and sustainable development through green innovation. A firm that has voluntarily certified itself is more likely to embrace digital transformation for green innovation. That is, in firms that have achieved ISO 14,001 certification, digital transformation has a stronger impact on green innovation.

In accordance with the motivation of actively pursuing morality and competitive advantage, another motivation of EO is to pursue legality when confronted with stringent environmental restrictions (González-Benito and González-Benito 2005). Against the backdrop of "carbon peaking and carbon neutrality" targets in China, significantly polluting manufacturing businesses face stricter environmental protection scrutiny and environmental protection information disclosure. Therefore, if an enterprise is a key pollution monitoring unit, it must disclose environmental information in response to a mandatory EO. When compared to other firms, Du et al. (2017) found that highly polluting enterprises are more subject to public and investor attention, as well as environmental-related legal procedures or conflicts. High-polluting enterprises requiring the mandatory disclosure of environmental information are more likely to increase their environmental investment, improve their environmental performance, and subsequently improve their relationships with stakeholders. This disclosure system can potentially compel enterprises to boost their investment in innovation, develop new goods, enhance new technology, and adopt new energy sources. According to Al-Tuwaijri et al. (2004), corporate environmental information disclosure significantly improves business performance. As a result, we infer that enterprises that are required to disclose environmental information will use more digital technology to achieve green innovation and that digital transformation will have a higher

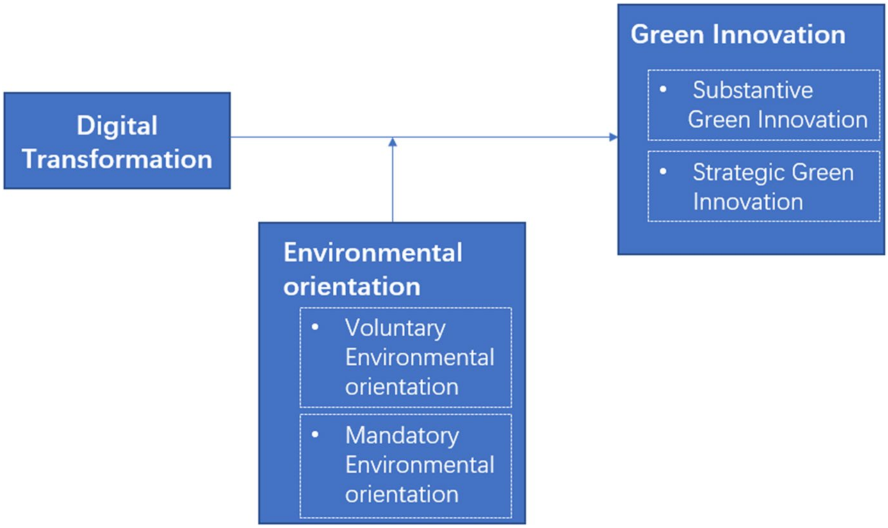

Fig. 1 The conceptual model

impact on green innovation in key polluting enterprises than in others. Thus, we propose the following hypothesis:

H4a Voluntary EO positively moderates the effect of digital transformation on firms' green innovation, regardless whether it is substantive green innovation or strategic green innovation.

H4b Mandatory EO positively moderates the effect of digital transformation on firms' green innovation, regardless whether it is substantive green innovation or strategic green innovation.

Figure 1 provides a conceptual model illustrating the hypothesized links between all the investigated constructs for reference.

3 Empirical strategy

3.1 Sample and data

Since 2008, Chinese e-commerce has entered a boom period, and Chinese enterprises are undergoing large-scale digital transformation and online transactions, which provide compelling empirical evidence. Additionally, considering the availability of most variables' data, the paper constructs an unbalanced panel model by using data from the statements issued by A-share firms listed on the Main Board, Growth Enterprise Board, and Small and Medium Enterprise Board of the Chinese

Table 1 The content of EO index

Item	Content
EPtConcept	Disclose the company's environmental protection concept, environmental policy, environmental management organizational structure, circular economy development mode, green development, etc. If so, EPtConcept = 1, otherwise, 0
EPGoal	Disclose the company's past and future environmental protection goals If so, EPGoal = 1, otherwise, 0
EPManSysSchema	Disclose that the company has formulated a series of management systems, such as relevant environmental management systems, systems, regulations, and responsibilities. If so, EPManSysSchema = 1, otherwise, 0
EPEduTrain	Disclose information about the company's participation in environmental education and training. If so, EPEduTrain = 1, otherwise, 0
EPSpecialAct	Disclose the company's involvement in special environmental protection, environmental protection, and other social welfare activities. If so, EPSpecialAct = 1, otherwise, 0
EnvEventEmergMech	Disclose the company's establishment of an emergency response mechanism for major environmental-related emergencies, the emergency measures it has taken, and the treatment of pollutants, etc. If so, EnvEventEmergMech = 1, otherwise, 0
EPHonorReward	Disclosure of honors or awards received by the company in environmental protection. If so, EPHonorReward = 1, otherwise, 0
ThreeSimultaneity	Disclose the firm's implementation of the "three Simultaneities" system. If so, ThreeSimultaneity = 1, otherwise, 0

Three simultaneities system means pollution prevention and control facilities in a construction project must be designed, built, and put into operation concurrently with the main project

stock markets between 2008 and 2021. The data were obtained from the China Stock Market & Accounting Research Database (CSMAR) and the Chinese Research Data Services Platform (CNRDS). Due to the different financial treatments, we pretreat the raw data by deleting samples (1) in finance or insurance industries; (2) with special treatment having an ST/*ST/S/SST mark; and (3) that are unable to offset debts with assets. We also deleted the samples with missing data and the samples with less than 3 years of observations. Finally, we obtain a sample with 4950 firm-year observations. To eliminate the influence of extreme values, all continuous variables are winnowing at 1%. Table 1 displays the descriptive statistics for the main variables.

3.2 Variable measurement

3.2.1 Dependent variables

Green Innovation (GreTotal). The number of patent applications is the ultimate manifestation of the enterprise's innovation resource input and utilization efficiency, and patent application data will be more stable, reliable, and timely than grant data (Li and Zheng 2016; Li-Ying et al. 2018). As a result, the number of green patent applications filed by the listed firm in the current year is used as a proxy variable for green innovation in this paper. In particular, the total number of green innovations is equal to the natural logarithm of (1 + green invention patent applications + green utility model patent applications).

This paper distinguishes substantive from strategic green innovation based on different motivations, which are difficult to identify with objective data. According to the definition above, we identify the behavior of enterprises applying for high-tech green invention patents as substantive green innovation (GreInvia) and the behavior of enterprises applying for low-tech green utility model patents as strategic green innovation (GreUmia). Specifically, it equals the natural logarithm of (1 + green invention patent applications) and the natural logarithm of (1 + green utility model patent applications).

CNRDS is the source of all green innovation data. The database uses the division standard of green patents by following the Green Patent Standard of the World Intellectual Property Administration. The original data come from the Chinese National Intellectual Property Administration.

3.2.2 Independent variables

Enterprise Digital Transformation (DT). In existing research, two measurement methods are commonly used: (1) dummy variables that describe whether companies have digital transformation based on their investment in digital transformation or the results of digital transformation and (2) text analysis to measure the degree of digital transformation of enterprises by the frequency of terms related to digital transformation in specific text materials; the higher the frequency, the better the digital transformation's performance (Feng et al. 2022). This study applies the text analysis approach, as the former primarily assesses whether the enterprise has undergone digital transformation, which is very likely to result in an overestimation of the enterprise's level of digital transformation. This study focuses on firms' use of next-generation information technologies. According to Gong and Ribiere (2021), we account for the occurrence frequency of keywords involving artificial intelligence, big data, cloud computing, blockchain, and digital technology application. DT equals the natural logarithm of (1 + the occurrence frequency of keywords related to digital transformation). CSMAR is the source of digital transformation data.

3.2.3 Moderating variables

Environmental orientation (EO). As we stated before, an environmentally oriented firm places great emphasis on internal ecological practices. Therefore, we construct an EO index using information about enterprises' environmental management disclosure data (Table 2).

To comprehensively evaluate corporate environmental practices, EO is calculated by the mean of the above eight items, which equals

Table 2 Definition of main variables

Variable type	Variable name	Variable short name	Variable measurement
Dependent variable	Green innovation	GreTotal	Log (1 + green invention patent applications + green utility model patent applications)
	Substantive green innovation	GreInvia	Log (1 + green invention patent applications)
	Strategic green innovation	GreUmia	Log (1 + green utility model patent applications)
Independent variable	Digital transformation	DT	Log (1 + the occurrence frequency of keywords related to digital transformation)
Moderate variable	Environmental orientation	EO	$\frac{1}{8}$ (EPtConcept + EPGoal + EPManSysSchema + EPEduTrain + EPspecialAct + EnvEventEmergMech + EPHonorReward + ThreeSimultaneity)
	Mandatory environmental orientation	MdEO	MdEO = 1 represents the key pollution monitoring units by the administration, which should provide mandatory disclosure of environmental information, otherwise 0
	Voluntary environmental orientation	VtEO	VtEO= 1 represents a firm that has obtained the ISO 14001 certification, which is voluntary environmentally oriented, otherwise it is not
Control variable	Firm size	size	Log (the number of employees)
	Firm age	firmage	Log (the year of data collection date—the year of firm establishment date)
	Return on total assets	roa	Net profit / total assets
	Leverage	doa	Total debts / total assets
	Capital intensity	capitalintensity	Total assets / operating income
	Growth	growth	The growth rate of operating income
	Concurrent Position	ConcurrentPosition	The value is one if the chairman and CEO are the same person and 0 otherwise
	Largest Holder Rate	LargestHolderRate	The percentage of the largest shareholder
	Board size	board	Log (the number of board directors)
	Herfindahl Index	HHI	The sum of each firm's sales squared share to total sales in the same industry

The keywords are related to Artificial intelligence, blockchain, cloud computing, big data, and digital technology applications

$$\begin{aligned}\text{EO}_{\text{it}} = \frac{1}{8}(&\text{EPtConcept}_{\text{it}} + \text{EPGoal}_{\text{it}} \\ &+ \text{EPManSysSchema}_{\text{it}} + \text{EPEduTrain}_{\text{it}} + \text{EPSpecialAct}_{\text{it}} \\ &+ \text{EnvEventEmergMech}_{\text{it}} + \text{EPHonorReward}_{\text{it}} + \text{ThreeSimultaneity}_{\text{it}})\end{aligned} \tag{1}$$

The larger the value is, the stronger the orientation.

Mandatory environmental orientation (MdEO). Since 2014, China has had laws in place requiring key monitoring companies to self-monitor and disclose information. The regulation specifies the substance, method, time limit, and regulatory aspects of environmental information disclosure by key polluting enterprises. Businesses that fail to disclose information as required will face penalties from the competent environmental protection department. That is, high-polluting enterprises' environmental performance will be exposed to investors, consumers, governments, and other stakeholders, putting significant pressure on environmental practices. We believe that the key pollution monitoring units under the administration should provide mandatory disclosure of environmental information, as they are engaged in environmental practices under greater regulatory pressure. As a result, we assign a mandatory EO value of 1 to the important pollution monitoring enterprises and a value of 0 otherwise.

Voluntary environmental orientation (VtEO). ISO 14,001 is an Environmental Management System (EMS) certified by a third party. It provides a specified environmental protection standard to assist businesses in improving their environmental management (Rennings et al. 2006), and it focuses on supporting businesses in developing an effective environmental management system. Certification is applied by enterprises proactively and with strong flexibility and autonomy. ISO 14,001 certification is often seen as a strong sign of a firm's dedication to environmental protection (Quan et al. 2023). Consequently, we evaluate the enterprise's environmental orientation based on its ISO 4001 certification status. If the enterprise has the certification, it has a voluntary EO and VtEO = 1; otherwise, it does not and VtEO = 0.

3.2.4 Control variables

The control variables are taken from prior studies examining factors that affect green innovation (Song and Yu 2018; Aboelmaged and Hashem 2019; Feng et al. 2022). First, we control for several firm characteristics. Firm size (size) is measured by the natural logarithm of employees. Firm age is measured by the natural logarithm of the year of data collection date minus the year of firm establishment date. Return on total assets (roa) is measured by net profit/total assets. Leverage (doa) is measured by total debt/total assets. Capital intensity (capitalintensity) is measured by total assets/operating income. Growth (growth) is measured by the growth rate of operating income.

Second, we control the impact of corporate governance. Concurrent Position (ConcurrentPosition) is a dummy variable, and it takes the value of one if the chairman and CEO are the same person and 0 otherwise. LargestHolderRate is measured by the percentage of the largest shareholder. Board size (board) is measured by the natural logarithm of the number of board directors.

Third, we use the Herfindahl Index (HHI) to control industry competition. The HHI equals the sum of each firm's sales squared share to total sales in the same industry. A higher HHI means less competition. Year, industry, and province fixed effects are included as well.

3.3 Empirical model

To investigate the effect of a firm's digital transformation on its green innovation, we construct the following model.

$$\mathrm{GreTotal_{it}/GreInvia_{it}/GreUmia_{it}} = \alpha_0 + \alpha_1 DT_{it} + \sum \alpha_j controls_{it} + \sum Year + \sum Industry + \sum Province + \epsilon_{it} \quad (2)$$

In Model (2), $\mathrm{GreTotal_{it}}$,$\mathrm{GreInvia_{it}}$,$\mathrm{GreUmia_{it}}$ represent i firm's total green innovation, substantive green innovation, and strategic green innovation in t year, respectively. DT_{it} represents the core independent variable, ifirm's digital transformation in year t. $controls_{it}$ include firms' characteristics, corporate governance, and industry-level factors. *Year*, *Industry*,*Province* represent three fixed effects.

To investigate the moderating effect of environmental orientation on the relationship between a firm's digital transformation and its green innovation, we construct the following model.

$$\mathrm{GreTotal_{it}/GreInvia_{it}/GreUmia_{it}} = \beta_0 + \beta_1 DT_{it} + \beta_2 EO_{it} + \beta_3 DT_{it} \times EO_{it} + \sum \beta_j controls_{it} + \sum Year + \sum Industry + \sum Province + \epsilon_{it} \quad (3)$$

$$\mathrm{GreTotal_{it}/GreInvia_{it}/GreUmia_{it}} = \beta_0 + \beta_1 DT_{it} + \beta_2 MdEO_{it} + \beta_3 DT_{it} \times MdEO_{it} + \sum \beta_j controls_{it} + \sum Year + \sum Industry + \sum Province + \epsilon_{it} \quad (4)$$

$$\mathrm{GreTotal_{it}/GreInvia_{it}/GreUmia_{it}} = \beta_0 + \beta_1 DT_{it} + \beta_2 VtEO_{it} + \beta_3 DT_{it} \times VtEO_{it} + \sum \beta_j controls_{it} + \sum Year + \sum Industry + \sum Province + \epsilon_{it} \quad (5)$$

In Model (3), EO_{it} is the moderating variable, representing i firm's total level of environmental orientation in t year. In Models (4) and (5), $MdEO_{it}$ and $VtEO_{it}$ represent the mandatory and voluntary environmental orientations of i firm in year t, respectively. The other variables are the same as those in Model (2). Detailed variable definitions and measures are presented in Sect. 3.2.

Table 3 Descriptive statistics

Variable	Obs	Mean	Std. dev.	Min	Max
GreTotal	4950	1.3437	1.1181	0	5.0434
GreInvia	4950	0.9998	1.0548	0	4.8283
GreUmia	4950	0.7244	0.8960	0	3.7612
DT	4950	2.3616	1.2114	0.6931	5.2417
EO	4950	0.2175	0.2557	0	1
MdEO	4950	0.2071	0.4052	0	1
VtEO	4950	0.3220	0.4673	0	1
firmage	4950	2.8305	0.3441	1.7918	3.4965
size	4950	8.0381	1.2897	5.4972	11.5605
roa	4950	0.0389	0.0619	− 0.2572	0.1909
doa	4950	0.4276	0.1871	0.0690	0.8598
capitalintensity	4950	2.1687	1.3256	0.4962	8.1756
Growth	4948	0.1717	0.2892	− 0.4494	1.3914
ConcurrentPosition	4923	0.3088	0.4620	0	1
LargestHolderRate	4950	32.2606	14.8264	7.2600	72.1500
board	4950	2.1135	0.2005	1.6094	2.6391
HHI	4950	0.1112	0.0951	0.0287	0.6032

4 Empirical results

4.1 Descriptive statistics

Table 3 shows the descriptive statistics for the main variables.GreTotal, GreInvia, and GreUmia have means of 1.3437, 0.9998, and 0.7244, respectively. It shows that, on average, our sample of firms has 1.3437 green patents, 0.9998 green invention patents, and 0.7244 green utility model patents each year. On average, substantive green innovation exceeds strategic green innovation. For the variable we are concerned about, DT has a mean of 2.3616. The moderating variables EO, MdEO, and VtEO have means of 0.2175, 0.2071, and 0.3220, respectively, indicating that firms' environmental orientation is relatively low on average.

4.2 Main result

4.2.1 Enterprise digital transformation and green innovation

We begin by examining the impact of digital transformation on several types of green innovation using an ordinary least square (OLS) estimator. We control some firm and industry characteristics that influence green innovations in the regression model, but there are still some unobservable factors. The year, industry, and province dummy variables are used to control the omitted variable problem. Table 4 shows the results in Columns (1) to (3). Firms with zero green invention patent applications account for 33.84%, whereas zero green utility model patent

Table 4 The impact of digital transformation on firms' green innovation

Variables	(1) GreTotal	(2) GreInvia	(3) GreUmia	(4) GreTotal	(5) GreInvia	(6) GreUmia
	OLS	OLS	OLS	Tobit	Tobit	Tobit
DT	0.0928***	0.1283***	– 0.0106	0.1149***	0.1796***	– 0.0205
	(0.0143)	(0.0142)	(0.0113)	(0.0262)	(0.0309)	(0.0285)
Firmage	– 0.0263	0.0238	– 0.0851**	– 0.0560	– 0.0267	– 0.1402
	(0.0483)	(0.0481)	(0.0402)	(0.0960)	(0.1117)	(0.1016)
Size	0.2585***	0.2530***	0.1602***	0.2892***	0.3209***	0.2224***
	(0.0155)	(0.0154)	(0.0124)	(0.0324)	(0.0367)	(0.0344)
roa	1.5489***	1.3165***	0.9807***	2.1394***	2.0553***	2.0715***
	(0.2275)	(0.2170)	(0.1949)	(0.4073)	(0.4763)	(0.5258)
doa	0.6526***	0.5294***	0.5446***	0.7651***	0.7229***	0.9254***
	(0.0922)	(0.0910)	(0.0749)	(0.1722)	(0.2008)	(0.2007)
Capital intensity	0.0458***	0.0442***	0.0377***	0.0556**	0.0552**	0.0671***
	(0.0116)	(0.0113)	(0.0095)	(0.0218)	(0.0268)	(0.0256)
Growth	– 0.1219***	– 0.0887**	– 0.0772**	– 0.1590**	– 0.1118	– 0.1570**
	(0.0467)	(0.0451)	(0.0393)	(0.0624)	(0.0722)	(0.0729)
Concurrent position	– 0.0256	– 0.0225	0.0262	– 0.0576	– 0.0641	– 0.0081
	(0.0297)	(0.0293)	(0.0246)	(0.0554)	(0.0650)	(0.0655)
Largest holder rate	0.0027***	0.0016	0.0021**	0.0036*	0.0026	0.0046**
	(0.0010)	(0.0010)	(0.0008)	(0.0020)	(0.0024)	(0.0023)
board	0.0142	0.1111	– 0.0841	– 0.0079	0.1515	– 0.1200
	(0.0753)	(0.0752)	(0.0618)	(0.1578)	(0.1791)	(0.1782)
HHI	0.0442	– 0.0689	0.3287	– 0.3661	– 0.6576	– 0.0798
	(0.3146)	(0.3380)	(0.2595)	(0.4357)	(0.5925)	(0.5499)
Constant	– 1.4464***	– 1.6911***	– 1.2226***	– 1.5225***	– 2.1496***	– 3.4746***
	(0.3647)	(0.3708)	(0.3073)	(0.5879)	(0.6911)	(0.8598)
Year	√	√	√	√	√	√
Industry	√	√	√	√	√	√
Province	√	√	√	√	√	√
Observations	4,921	4,921	4,921	4,921	4,921	4,921
R2(Pseudo R2)	0.3725	0.3055	0.3471	0.166	0.129	0.173

Robust standard errors in parentheses ***$p<0.01$, **$p<0.05$, *$p<0.1$; Controls are the same as those displayed in Table 4

Data source: calculated by the authors based on CSMAR and CNRDS

applications account for 47.33% of our sample. It has obvious truncation characteristics. We also provide Tobit estimates, and the results are shown in Columns (4) to (6) in Table 4. All regressions use robust standard errors to eliminate heteroskedasticity and are estimated using Stata 16.

In Columns (1) and (3) of Table 4, the coefficient on DT is positive and statistically significant at a 1% level. Both the OLS and Tobit estimations support Hypothesis H1. According to the RBV, a firm's resources and capabilities provide the foundation for implementing green innovation. Digital transformation can aid in creating a smooth knowledge network that allows different knowledge sources to interact and develop new knowledge for green innovation (De Marchi 2012). Digital transformation can also aid resource reconfiguration and efficiency improvement in firms, thereby providing a resource foundation for green innovation (Zhang et al. 2021).

In Columns (2) and (5) of Table 4, the coefficients on DT are positive and statistically significant at a 1% level, whereas they are negative and statistically insignificant in Columns (3) and (6). The findings support Hypothesis H2. The public may respond more positively to green technologies as environmental knowledge grows, resulting in a better possibility for market success and competitive advantage (Kunapatarawong and Martnez-Ros 2016). The primary goal of a firm that embraces digital transformation is to acquire a competitive advantage.

Table 5 Robustness check with lagged independent variables

Variables	(1) GreTotal	(2) GreInvia	(3) GreUmia	(4) GreTotal	(5) GreInvia	(6) GreUmia
	OLS	OLS	OLS	Tobit	Tobit	Tobit
L.DT	0.1114***	0.1574***	– 0.0208	0.1418***	0.2189***	– 0.0316
	(0.0191)	(0.0190)	(0.0154)	(0.0320)	(0.0361)	(0.0368)
Controls	√	√	√	√	√	√
Year	√	√	√	√	√	√
Industry	√	√	√	√	√	√
Province	√	√	√	√	√	√
Observations	2,859	2,859	2,859	2,859	2,859	2,859
R2(Pseudo R2)	0.4459	0.3742	0.4097	0.197	0.164	0.206
L2.DT	0.1055***	0.1547***	– 0.0322*	0.1202***	0.1954***	– 0.0674*
	(0.0235)	(0.0235)	(0.0190)	(0.0342)	(0.0400)	(0.0409)
Controls	√	√	√	√	√	√
Year	√	√	√	√	√	√
Industry	√	√	√	√	√	√
Province	√	√	√	√	√	√
Observations	2,057	2,057	2,057	2,057	2,057	2,057
R2(Pseudo R2)	0.3852	0.3326	0.3929	0.157	0.132	0.179

Note: Robust standard errors in parentheses ***$p<0.01$, **$p<0.05$, *$p<0.1$; Controls are the same as those displayed in Table 4

Data source: calculated by the authors based on CSMAR and CNRDS

With the same goal, digital transformation positively impacts substantive green innovation rather than strategic green innovation.

4.3 Robustness checks

This study employs three strategies to test the robustness of the effect of digital transformation on green innovation to ensure that it is more reliable. The first approach uses explanatory variables in lag phase I. Given that the impact of enterprises' digital transformation may be delayed, the lag phase of variables may eliminate the influence of mutual causality. The second option is to use the application of digital technology as an alternative variable to replace the measuring method of explanatory variables. The instrumental variable technique is the third method. To address the endogeneity problem, this paper uses the generally utilized number of urban mobile phones and the number of urban internet broadband access users as instrumental variables.

4.3.1 Results with lagged digital transformation

The higher the level of green innovation, the more resources and capabilities firms with a digital transformation strategy will have. There is a potential mutual causality between digital transformation and green innovation, which generates an endogeneity problem. To avoid this problem, we lag the digital transformation by one to two periods, referring to Chen et al. (2021). Existing research also shows that computerization has a time lag effect on firm productivity and output (Brynjolfsson and Hitt 2003). Enterprise digital transformation is likewise a time-consuming investment with a lag in impacts. As shown in Table 5, the coefficients on DT are positive in Columns (1), (2), (4), and (5) at a 1% significance level for both one-period

Table 6 Robustness check with different measurement of DT

Variables	(1) GreTotal	(2) GreInvia	(3) GreUmia	(4) GreTotal	(5) GreInvia	(6) GreUmia
	OLS	OLS	OLS	Tobit	Tobit	Tobit
DT_new	0.0804***	0.1287***	− 0.0176	0.0881***	0.1712***	− 0.0297
	(0.0174)	(0.0177)	(0.0145)	(0.0290)	(0.0357)	(0.0312)
Controls	√	√	√	√	√	√
Year	√	√	√	√	√	√
Industry	√	√	√	√	√	√
Province	√	√	√	√	√	√
Observations	3945	3945	3945	3945	3945	3945
R2(Pseudo R2)	0.3311	0.2882	0.3324	0.140	0.113	0.151

Note: Robust standard errors in parentheses *** $p<0.01$, ** $p<0.05$, * $p<0.1$; Controls are the same as those displayed in Table 4

Data source: calculated by the authors based on CSMAR and CNRDS

and two-period lagged digital transformation. The coefficients on DT is negative and insignificant in Columns (3) and (6) for one-period lagged digital transformation, while significant at the 10% level for two-period lagged digital transformation. Both the magnitudes and the directions of the coefficients are quite similar to those provided in Table 4. The results are generally robust with lagged explanatory variables.

4.3.2 Alternative measurement for digital transformation

Text analysis can better capture the use of new-generation information technologies such as artificial intelligence, blockchain, cloud computing, and big data in Chinese listed firms by analyzing the frequency of terms linked to digital transformation in specific text materials. However, it is a pedigree notion, and different researchers have varied classifications of the secondary statistical caliber of digital transformation. To reduce measurement errors and make the results more reliable, we utilize an alternate measurement for digital transformation (DT_new) constructed by Wu et al. (2021). As shown in Table 6, the coefficients on DT_new are positive in Columns (1), (2), (4), and (5) at a 1% significance level, while they are insignificant in Columns (3) and (6). Both the magnitudes and the directions of the coefficients are quite similar to those provided in Table 4. With alternative measurements, the results still support Hypotheses H1 and H2.

4.3.3 Results based on the instrument variable (IV) approach

Information disclosure may influence the measurement of enterprise digital transformation based on annual reports, resulting in an endogeneity problem. When there

Table 7 Robustness check with the instrument variable (IV) approach

Variables	(1) GreTotal	(2) GreInvia	(3) GreUmia
	IV	IV	IV
DT	0.1473***	0.2155***	– 0.0262
	(0.0339)	(0.0471)	(0.0194)
Controls	√	√	√
Year	√	√	√
Industry	√	√	√
Province	√	√	√
Observations	1,501	866	2,835
R2	0.4340	0.4022	0.4090
Sargan	2.70632	6.9100	0.8697
Sargan p	0.4392	0.1407	0.6474

Robust standard errors in parentheses *** $p<0.01$, ** $p<0.05$, * $p<0.1$; Controls are the same as those displayed in Table 4

Data source: calculated by the authors based on CSMAR and CNRDS

Table 8 The moderating effect of environmental orientation

Variables	(1) GreTotal	(2) GreInvia	(3) GreUmia	(4) GreTotal	(5) GreInvia	(6) GreUmia
	OLS	OLS	OLS	Tobit	Tobit	Tobit
DT	0.0512***	0.0906***	– 0.0268**	0.0674**	0.1415***	– 0.0599*
	(0.0166)	(0.0165)	(0.0130)	(0.0305)	(0.0353)	(0.0344)
EO	– 0.2430*	– 0.1425	– 0.1388	– 0.2607	– 0.0489	– 0.2558
	(0.1384)	(0.1373)	(0.1088)	(0.2130)	(0.2417)	(0.2244)
DT*EO	0.2285***	0.2106***	0.0873**	0.2633***	0.2165**	0.2124**
	(0.0573)	(0.0573)	(0.0411)	(0.0972)	(0.1064)	(0.0993)
Controls	√	√	√	√	√	√
Year	√	√	√	√	√	√
Industry	√	√	√	√	√	√
Province	√	√	√	√	√	√
Observations	4921	4921	4921	4921	4921	4921
R2 (Pseudo R2)	0.3771	0.3113	0.3479	0.168	0.131	0.174

Robust standard errors in parentheses ***$p<0.01$, **$p<0.05$, *$p<0.1$; Controls are the same as those displayed in Table 4

Data source: calculated by the authors based on CSMAR and CNRDS

is a suspicion of a correlation between the explanatory variables and the regression error term, the IV approach is a popular estimation strategy. We employ the first-order lag term of the primary explanatory variables, the number of urban mobile phones and the number of urban internet broadband access users, as instrumental variables for the endogenous test. The weak instrumental variable test and the overidentification test suggest that the instrumental factors chosen in this investigation are reasonable and effective. As shown in Table 7, the coefficients on DT are positive in Columns (1) and (2) at a 1% significance level but insignificant in Column (3) with an IV approach. Despite the magnitudes of the coefficients, the results are quite similar to those provided in Table 4. The results still support Hypotheses H1 and H2.

5 Moderating effect analysis

The above regression analysis demonstrates that digital transformation positively influences a company's green innovation. However, it has no effect on strategic green innovation and only affects substantive green innovation. This subsection investigates the moderating effect of environmental orientation on enterprises' green innovation to gain a better understanding of the boundary conditions under which digital transformation influences green innovation.

Table 9 The moderating effect of voluntary environmental orientation

Variables	(1) GreTotal	(2) GreInvia	(3) GreUmia	(4) GreTotal	(5) GreInvia	(6) GreUmia
	OLS	OLS	OLS	Tobit	Tobit	Tobit
DT	0.0618***	0.1052***	-0.0301**	0.0795***	0.1541***	– 0.0655**
	(0.0159)	(0.0157)	(0.0126)	(0.0284)	(0.0331)	(0.0330)
VtEO	– 0.1965***	– 0.1546**	– 0.1071**	– 0.2161**	– 0.1489	– 0.2242**
	(0.0619)	(0.0613)	(0.0497)	(0.0905)	(0.1068)	(0.1019)
DT*VtEO	0.0927***	0.0694***	0.0577***	0.1036***	0.0733*	0.1273***
	(0.0247)	(0.0247)	(0.0181)	(0.0385)	(0.0434)	(0.0427)
Controls	√	√	√	√	√	√
Year	√	√	√	√	√	√
Industry	√	√	√	√	√	√
Province	√	√	√	√	√	√
Observations	4921	4921	4921	4921	4921	4921
R2(Pseudo R2)	0.3746	0.3068	0.3486	0.167	0.130	0.175

Robust standard errors in parentheses ***$p < 0.01$, **$p < 0.05$, *$p < 0.1$; Controls are the same as those displayed in Table 3

Data source: calculated by the authors based on CSMAR and CNRDS

5.1 The moderating effect of environmental orientation

Table 8 shows the results of the environmental orientation's moderating impact on the relationship between digital transformation and green innovation. The results are reported in Columns (1) to (3) using OLS estimates and Columns (4) to (6) using Tobit estimates. The coefficients on DT*EO are positive across all estimations, as shown in Table 6, indicating that the positive impact of digital transformation is mitigated when a firm has a higher environmental orientation. Hypothesis 3 is supported. A firm with an environmental orientation is more likely to employ resources and increase its capacity to achieve internal ecological goals. Our findings align with those of de Sousa Jabbour et al. (2018) since digital transformation is more likely to be viewed as a part of an environmental orientation strategy than a competition for a firm's internal resource allocation (Ardito et al. 2021). It should be noted that the DT*EO coefficients for strategic green innovation are positive at a 1% significance level. Although digital transformation has no significant impact on strategic green innovation, it can also promote strategic green innovation when a firm has a stronger environmental orientation.

5.2 The role of voluntary environmental orientation

Table 9 shows the results of the voluntary EO's moderating effect on the relationship between digital transformation and green innovation. The results are reported

Table 10 The moderating effect of mandatory environmental orientation

Variables	(1) GreTotal	(2) GreInvia	(3) GreUmia	(4) GreTotal	(5) GreInvia	(6) GreUmia
	OLS	OLS	OLS	Tobit	Tobit	Tobit
DT	0.0948***	0.1339***	– 0.0122	0.1168***	0.1894***	– 0.0234
	(0.0152)	(0.0152)	(0.0120)	(0.0272)	(0.0326)	(0.0294)
MdEO	– 0.0990	– 0.0368	– 0.1009	– 0.1121	– 0.0116	– 0.1160
	(0.0797)	(0.0775)	(0.0650)	(0.1142)	(0.1309)	(0.1318)
DT*MdEO	– 0.0385	– 0.0562	– 0.0078	– 0.0433	– 0.0936	0.0008
	(0.0361)	(0.0357)	(0.0275)	(0.0531)	(0.0599)	(0.0614)
Controls	√	√	√	√	√	√
Year	√	√	√	√	√	√
Industry	√	√	√	√	√	√
Province	√	√	√	√	√	√
Observations	4921	4921	4921	4921	4921	4921
R2(Pseudo R2)	0.3754	0.3082	0.3490	0.167	0.130	0.174

Robust standard errors in parentheses *** $p<0.01$, ** $p<0.05$, * $p<0.1$; Controls are the same as those displayed in Table 4

Data source: calculated by the authors based on CSMAR and CNRDS

in Columns (1) to (3) using OLS estimates and Columns (4) to (6) using Tobit estimates. As shown in Table 9, the coefficients on DT*VtEO are significantly positive. The results support H4a. Voluntary EO motivates proactive environmental initiatives to achieve a competitive advantage over other competitors and the concept of sustainable development (González-Benito and González-Benito 2005). Enterprises that have achieved ISO 14,001 certification have implemented an internal environmental management system, allowing digital transformation to have a more significant impact on (substantive) green innovation. The more advanced the firm's information system (IS) is, leading to a greater integration of the different activities and processes of the organization, the more effective the IS's contribution to environmental management practices (Fiorini et al. 2018). Digital transformation could be a key driver that leads to better management of the environment and more green innovations.

5.3 The role of mandatory environmental orientation

Table 10 shows the results of the mandatory EO's moderating effect on the relationship between digital transformation and green innovation. The results are reported in Columns (1) to (3) using OLS estimates and Columns (4) to (6) using Tobit estimates. Unexpectedly, the coefficients on DT*MdEO are not statistically significant across all estimations, as shown in Table 9, indicating that whether the enterprise is a mandatory EO or not the impact of digital transformation on enterprise green innovation have no significant difference. Our empirical results cannot support H4b. The likely explanation is that China's current green credit policy may directly or indirectly restrict the credit of highly polluting businesses, increase their financing costs, and subject them to severe financial restraints. Although high-polluting enterprises' mandatory disclosure of environmental information is supervised by stakeholders such as the government, investors, and consumers, they tend to allocate limited resources to low-risk projects and find solutions in existing resources and technologies to comply with environmental regulations (Li-Ying et al. 2018), as opposed to relying on digital transformation, which requires large investments and is fraught with uncertainty.

6 Discussions and conclusions

This study first explores the impacts of digital transformation on green innovation by using a sample of Chinese publicly listed firms between 2008 and 2021 based on the RBV. Then, we further differentiate between substantive and strategic green innovation and fully discuss the impact of digital transformation on green innovation with different motivations. Finally, we explore the boundary conditions of the effects of digital transformation on green innovation by analyzing the moderating effect of EO and EO driven by distinct motivations (voluntary EO vs. mandatory EO). Our findings contribute to filling major gaps in the literature on digital transformation and the drivers of enterprises' green innovation and therefore have several theoretical and practical implications.

6.1 Theoretical implication

First, we contribute to the literature on the connection between digital transformations and a firm's green innovation activities (Ardito et al. 2021; Chen et al. 2021; He and Su 2022; Rubio– Andrés et al. 2022). Specifically, we contribute to the development of theory by providing empirical support for additional research into how businesses exploit digital transformation for green innovation (Khanin et al. 2022). Several studies have attempted to establish a connection between digital transformation and the adoption of green innovation, while ignoring firms' motivations to engage in green innovation (Li-Ying et al. 2018) and how these motivations influence the relationship between digital transformation and green innovation. The results reveal that digital transformation significantly impacts green innovation by strengthening the resource and knowledge bases, which is consistent with the resource-based view. When we further differentiate between substantive and strategic green innovation, we find that digital transformation positively affects substantive innovation, not strategic, green innovation.

Second, we employ a novel measurement and a unique perspective to explore boundary conditions in the process of firms fostering green innovation through digital transformation. Specifically, we study the moderating effect of environmental orientation and create an environmental orientation index based on enterprises' environmental practices, which is typically derived from questionnaire responses (Ardito et al. 2021). Questionnaires are a frequent method for evaluating environmental orientation, but they are always susceptible to subjectivity. Environmental orientation is a fundamental business principle that guides enterprise environmental practice (Zameer et al. 2022). In accordance with this perspective, this study offers an alternative measurement by constructing an EO index using objective environmental practices. The moderating effect analyses indicate that environmental orientation positively moderates the relationship between digital transformation and green innovation.

According to the motivations of the various EOs, this study further categorizes mandatory and voluntary EO. Zhou et al. (2022) found firms choose different strategies under distinct environmental orientations. Some scholars have split EO into internal and exterior types (Zhang et al. 2022). Nonetheless, EO can be motivated by a variety of factors. We examine two sorts of motivation: those driven by environmental rules, i.e., mandatory EO, and those motivated by the firm's strategic goals, i.e., voluntary EO. The results show only voluntary EO has a positive moderating effect. The stronger the firm's (voluntary) environmental orientation is, the larger the impact of digital transformation on green innovation. Our results indicate that firms can maximize the influence of digital transformation on green innovation only if they are motivated by environmental consciousness and the desire to acquire a competitive advantage.

6.2 Practical implications

The results have several policy implications. First, digital transformation can foster green innovation, which provides compelling evidence to encourage enterprises that have not yet undergone digital transformation or those with a low digital transformation level to implement reforms, achieve the dual goals of digital transformation and green development, and boost enterprise competitiveness. Second, our results show that digital transformation only has a positive influence on substantive green innovation, while voluntary EO has a positive moderating effect. It is vital to actively assist businesses in forming the concept of environmental protection, and it is necessary for businesses to have a clear understanding that environmentally friendly innovation is the key to obtaining a competitive edge in the future. Only in this way can a spontaneous environmental orientation be formed, the role of digital transformation in promoting green development be maximized, and the "double carbon" objective be attained.

6.3 Limitations and further research directions

There are several limitations to this study that point to future research options. To begin, further investigation is encouraged to develop a more precise measurement of digital transformation. Second, this research examines the overall digital transformation. Different types of digital technology may have various effects. In the future, the dimensions of digital transformation should be further investigated. This study mainly discusses the boundary conditions of digital transformation affecting green innovation, and more potential mechanisms need to be further explored in the future.

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Data availability The data that support the findings of this study are available from the corresponding author upon request.

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Authors and Affiliations

Qiuqin He[1] · Samuel Ribeiro-Navarrete[2,4] · Dolores Botella-Carrubi[3]

✉ Qiuqin He
20190090@hznu.edu.cn

Samuel Ribeiro-Navarrete
samuelribeironavarrete@gmail.com

Dolores Botella-Carrubi
dbotella@omp.upv.es

1 School of Economics, Hangzhou Normal University, Hangzhou, China

2 ESIC University, Madrid, Spain

3 Universitat Politècnica de València, Valencia, Spain

4 University of Economics and Human Sciences, Warsaw, Poland