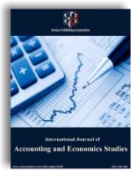
International Journal of Accounting and Economics Studies, 12 (4) (2025) 246-258

International Journal of Accounting and Economics Studies

Website: www.sciencepubco.com/index.php/IJAES
https://doi.org/10.14419/zd9jjr88
Research paper



Digital Transformation, Disclosure Quality, and Green Innovation: What Does Board Independence Matter?

Guo Jia *, Aza Azlina Md Kassim

Graduate School of Management, Postgraduate Centre, Management and Science University, Shah Alam, Selangor, Malaysia
**Corresponding author E-mail: guoj6600@163.com*

Received: July 27, 2025, Accepted: August 3, 2025, Published: August 9, 2025

Abstract

Environmental issues emerge due to rapid economic growth, and the Chinese government responds to these issues by issuing environmental regulations and providing environmental subsidies. In this case, corporations are under increasing pressure to change their production and operation models. Based on this background, corporations need to integrate sustainable practices into their operations, such as developing green innovation. In addition, digital transformation has been recognized by corporations as a critical development direction. This is attributed to the fact that digital technologies provide advanced tools and systems for monitoring, reporting, and optimizing operations. These capabilities may improve the operational efficiency of corporations, increase data transparency, and improve disclosure quality, which appears to affect the development of green innovation. This research uses the data of Chinese corporations to explore the impact of digital transformation on green innovation, analyzes disclosure quality as a mediating mechanism, and emphasizes the role of board independence.

Keywords: *Digital Transformation; Disclosure Quality; Green Innovation; Board Independence; China.*

1. Introduction

In recent years, environmental issues have become urgent issues facing countries around the world (Zhang et al., 2022). Governments around the world have increasingly incorporated sustainable development and green transformation into their national policy strategy. In this case, they have issued some related policies and regulations, such as carbon pricing in Europe (Khurshid et al., 2023), environmental taxes in OECD countries (Karlilar & Pata, 2025), and the encouragement of renewable energy resource consumption in the United Kingdom (Ramzan et al., 2023). In China, with the rapid economic growth in recent years, it is also facing serious environmental problems, which pose a significant challenge to sustainable development (Dou & Gao, 2023). The Chinese government also proposes some strategies, including the "dual carbon" goal and the 14th Five-Year Plan for industrial green development. Moreover, it is widely accepted that green innovation is the critical method to resolve this contradiction (Guinot et al., 2022). Some governments have taken immediate action. For example, the EU has proposed the Horizon Europe strategy to encourage the development of green innovation. Similarly, the Chinese government has proposed to establish and improve a market-oriented green innovation system in 2019 and 2023, respectively. Specifically, green innovation is defined as a combination of "green" and "innovation", and its purpose is to carry out technological innovation to solve environmental problems (Guinot et al., 2022). In this case, corporations need to gradually establish and improve their green innovation system. However, compared with traditional technological innovation, green innovation is characterized by high initial investment (Xiang et al., 2022), high risk (Takalo & Tooranloo, 2021), and double externalities (Li & Shi, 2022), which may mean that corporations need to bear greater cost and risk pressure in the short term. Therefore, corporations may not be willing to develop green innovation to some extent. Moreover, the digital economy has increasingly become a key driver of global economic development (Xia et al., 2024), which seems to be attributed to advancements and applications in information technology, including the Internet of Things (IoT), blockchain, big data analysis, and artificial intelligence (AI) (Zhang et al., 2022). These technologies appear to support the transformation of traditional industries towards low-carbon and green practices (Feroz et al., 2021), which may provide corporations with new development opportunities and innovation possibilities. In this case, digital transformation is considered a critical strategic approach for corporate development. For instance, IoT can be utilized to achieve intelligent management and analysis of production through device interconnection and data collection (Chen, 2020). In addition, Blockchain technology, with its decentralized and secure transparency features, may provide breakthroughs for industries, such as finance and logistics (Chen & Bellavitis, 2020). Furthermore, AI may enhance decision-making efficiency through deep learning and data analysis (Cioffi et al., 2020).

On the one hand, the popularization of digital technologies is likely to promote internal and external information exchange within corporations (Feng et al., 2022), which may effectively accelerate the diffusion of technology. In this case, it may foster the development of green innovation. On the other hand, digital transformation seems to reduce information asymmetry, which may improve disclosure quality and further promote green innovation. Specifically, from the perspective of the enterprise, by collecting information on existing production processes, corporations seem to more accurately and quickly identify opportunities for green innovation (Tang et al., 2023). In this case,

the efficiency of green innovation may be enhanced to some extent. From the external perspective, it is possible for corporations to communicate frequently with external information users by using digital platforms (Liu & Song, 2023), which may enhance their trust in the corporation. Hence, it may alleviate financing constraints for green innovation, subsequently promoting its advancement.

Although digital transformation is expected to facilitate green innovation theoretically, some studies argue that digital transformation may not significantly promote green innovation (Yin & Li, 2022; Yin & Yu, 2022). This may be attributed to different digital measurement indicators. Specifically, existing indicators for measuring digital transformation primarily include two types, one is the frequency of digital-related terms in annual reports (Feng et al., 2022; Tang et al., 2023), and the other is the frequency of digital transformation-related words divided by the total number of words in management discussion analysis (He & Su, 2022; Wang & Zhong, 2024). In this case, text mining methods are widely adopted in the existing literature to measure a firm's level of digital transformation. Although these methods can reflect a company's attention to digital issues and strategic orientation to some extent, they primarily reflect disclosure behaviour rather than actual implementation. Hence, these indicators are more likely to reflect how firms choose to communicate their digital transformation externally, rather than what they have done. Consequently, textual frequency-based measures are limited in their ability to fully capture firms' real progress in strategic planning, technological deployment, organizational restructuring, and digital outcomes. This may result in representational bias and measurement error when assessing the actual impact of digital transformation on green innovation. Therefore, this study will use six categories of indicators to provide a comprehensive assessment of digital transformation, including strategic leadership scores, technology-driven scores, organizational empowerment scores, environmental support scores, digital achievement scores, and digital application scores.

Furthermore, the existing mechanisms on the impact of digital transformation on green innovation can be divided into internal factors and external factors. Specifically, internal factors include green dynamic capacity (Zhang et al., 2023), research and development expenditure (Yin et al., 2022), top management team environmental attention (Martínez Falcó et al., 2024), and dynamic capability (Liu & Song, 2023). Financing constraints (Sreenu et al., 2025) and government subsidies (Xue et al., 2022) as external factors are proven to play a mediating role in the relationship between digital transformation and green innovation. However, relatively few studies address how internal control affects the relationship between digital transformation and green innovation (Sun & He, 2023). In addition, no one explores disclosure quality as a mediating mechanism in the relationship between digital transformation and green innovation. It is considered as the research gap. Hence, this study extends the theoretical association between internal control and the relationship between digital transformation and green innovation. Therefore, this research proposes three questions: (1) How does digital transformation affect green innovation? (2) Whether disclosure quality play a mediating role in the relationship between digital transformation and green innovation? (3) How does board independence influence the relationship between digital transformation and green innovation?

This research aims to explore how digital transformation affects green innovation, its influencing mechanism of disclosure quality, and the moderating effect of board independence as a kind of internal control mechanism in this relationship. Moreover, the National Ecological and Environmental Protection Conference was held in 2018, which indicates that green innovation is considered a critical strategy by the government. In this case, after deleting the corporations with missing data, 501 Chinese corporations between 2018 and 2022 are considered as the subject of this research. In addition, this research includes baseline regression analysis, robustness analysis, mechanism analysis, moderating effect analysis, and heterogeneity analysis. There are six parts in this research. The second part discusses the related literature. The third part describes the theoretical support and establishes the hypotheses of this research. The fourth part describes the methodology of this research, including the data, definitions of variables, and model specification. The fifth part conducts the related analyses. The last part summarizes the results and limitations of this research.

2. Literature review

2.1. Consequences of corporate digital transformation

Digital technology mainly includes big data, artificial intelligence(AI), the Internet of Things (IoT), and blockchain (Zhang et al., 2022). The employment of these technologies may optimize the organizational structure, improve decision efficiency, and facilitate sustainable development in corporations, which is defined as digital transformation.

The advantages of digital transformation for corporations have been explored in prior studies, which may be divided into three aspects. Firstly, digital transformation improves the dynamic capabilities of the corporation. Specifically, dynamic capabilities are proposed by Teece et al.(1997). It is defined as the ability of a corporation to adapt resources promptly in a continuously changing environment(Suddaby et al., 2020). In addition, Warner and Wäger(2019) also explain that corporations without digital capacity may hinder the formation of corporate dynamic capacity. In addition, this issue may be dealt with by sensing, seizing, and transforming capacity. Moreover, digital transformation provides corporations with digital tools and systems, such as big data. It seems to achieve real-data capture (Xue et al., 2022), which may facilitate corporations to analyze large volumes of data promptly and effectively. In this case, the internal and external environments appear to be identified in real time. Therefore, corporations may adjust strategies and organizational structure based on changing environments, which is considered an improvement of corporate dynamic capabilities.

Secondly, digital transformation has a positive influence on corporate innovation. Specifically, the increased employment of digital technologies enhances the potential for internal and external information and knowledge sharing (Xu et al., 2023). It may simplify communication procedures among internal employees, communication procedures among departments, and communication procedures between internal and external entities. Moreover, there is evidence that knowledge spillover (Proeger & Runst, 2020) and technological spillover (Miao, 2022) effects are more pronounced in digitally transformed corporations. It indicates that the simplification of communication procedures seems to strengthen cross-departmental, internal, and external cooperation. In this case, knowledge and skills in different fields are integrated, which may promote the technological progress of corporations. Moreover, Li et al.(2023) prove that digital industrialization can foster corporate innovation, and this effect is affected by the level of the region's digital industry.

Thirdly, digital transformation enhances corporate operational efficiency by improving decision-making efficiency, increasing productivity, optimizing operational processes, and enhancing resource allocation efficiency. On the one hand, due to the establishment of digital infrastructure, corporations benefit from reduced operational costs to some degree. For example, with a unified big data platform, there is enhanced information flow, which may lower the cost of inter-departmental information exchange (Mikalef et al., 2020). Additionally, the introduction of automated and intelligent systems may optimize production scale based on big data analysis (Xue et al., 2022), thereby reducing resource wastage. On the other hand, digital transformation may increase the operating revenue. Specifically, the employment of big data achieves real-time analysis of large amounts of customer information (Lin et al., 2021). It may identify customer needs, preferences, and the likelihood of repurchases. Utilizing online shopping platforms and personalized recommendations, precise marketing strategies

can be implemented (Li, 2022). It seems to increase a company's revenue. Furthermore, the utilization of digital technologies leads to the derivation of online services (Björkdahl, 2020), which may provide additional operational services to customers and create opportunities for profit growth.

However, the employment of digital transformation also seems to bring some limitations. On the one hand, there are considerable costs in the initial process of digital transformation, including technological investment, employers' training investment, and maintenance costs. Specifically, implementing digital transformation requires selecting, purchasing, and developing digital technologies (Guo & Xu, 2021). These may lead to significant technological expenses. In addition, employees need to be trained to ensure the rapid application of new technologies and systems. It indicates that the corporation needs to bear training costs and productivity losses during the training. Furthermore, corporations also need to bear maintenance costs, including technology improvement, data security maintenance, and employee retention. On the other hand, corporations need to restructure their operational processes and management systems to adapt to the level of digitalization. There is evidence that mismatched operational processes and management structures may reduce corporate efficiency and performance (Li et al., 2018). In this case, if the corporation decides to conduct digital transformation, the operational processes and management systems appear to be altered to some degree. It seems to increase the complexity of implementing digital transformation.

2.2. Influencing factors of green innovation

To improve resource efficiency and achieve sustainable development, the concept of green innovation is proposed. It is considered an important approach to achieve both economic benefits (Kraus et al., 2020) and environmental benefits (Yusliza et al., 2020). Green process innovation and green product innovation are included in this concept. Although green innovation is considered an effective way to deal with the high carbon emissions of the corporation to some degree (Castellacci & Lie, 2017). However, due to the high risks (Takalo & Tooranloo, 2021), high investments(Xiang et al., 2022), and double externalities (Li & Shi, 2022), corporations have insufficient motivation to foster green innovation. To deal with this issue, there are several studies that focus on exploring the influencing factors of developing green innovation, including external factors and internal factors.

Regarding external influencing factors, Bai and Lyu (2023) claim that the institutional environment imposes regulatory pressure on companies to develop green practices. Based on this, the effect of formal institutions and informal institutions has been discussed by scholars. For example, environmental regulations (Wu et al., 2022), green subsidies (Xia et al., 2022), and environmental taxes (Zheng et al., 2023) have a positive influence on green innovation. By contrast, informal institutions, such as the participation from non-governmental organizations (Zhang & Huang, 2023) and the attention of customers(Lin et al., 2014), also enhance green innovation. This attention from formal and informal institutions may directly affect the financing capacity of corporations. For example, Yu et al.(2021) propose that green finance policies proposed by formal institutions have a direct influence on the level of finance constraints, which may affect the external investment in green innovation.

Furthermore, concerning internal influencing factors, there is evidence that big data analysis capability (Chen & Liang, 2023), environmental awareness (Zubeltzu-Jaka et al., 2018), internal control (Ma et al., 2022), advanced technologies (Kong et al., 2016), and dynamic capability (Huang & Li, 2017). Specifically, based on the improvement of big data analysis and dynamic capability, internal and external resources can be integrated to improve green innovation (Wamba et al., 2017; Waqas et al., 2021). In addition, the higher the level of environmental awareness, the easier it is to recognize the benefits brought by green innovation (Huang et al., 2020). Furthermore, internal control seems to affect the decision-making process of the corporation directly (Ma et al., 2022). It may influence green innovation strategy, which is recognized as an organizational factor.

2.3. Research on digital transformation and green innovation

The positive relationship between digital transformation and green innovation has been proven in prior studies. The reason can be divided into three aspects. Firstly, digital transformation may integrate internal and external resources and expand the depth and breadth of green innovation information. Specifically, it is possible to establish comprehensive digital communication platforms if the corporation conducts digital transformation (Kraus et al., 2021). In addition, its establishment is likely to facilitate the communication between internal and external knowledge (Feng et al., 2022). In this case, internal researchers seem to access information about green innovation from other corporations through this platform. Moreover, transaction costs are defined as the additional costs incurred in the process of conducting economic transactions(Schmidt & Wagner, 2019). If a comprehensive digital platform is established, corporations may be able to acquire information related to green innovation without incurring additional costs or at significantly reduced costs. In this case, through digital platforms, corporations seem to engage in real-time communication and cooperation with external research institutions, suppliers, and customers at low transaction costs. It may facilitate the joint development of green technologies. Therefore, digital transformation promotes green innovation by enhancing a firm's capacity to absorb internal and external knowledge of green innovation.

Secondly, digital transformation may deal with the limitations of green innovation to some degree. Based on the existing research, the limitations of green innovation focus on two aspects, including high risks (Takalo & Tooranloo, 2021) and high investments (Xiang et al., 2022). On the one hand, the long duration and high failure rate are the primary reasons for the high risk associated with green innovation, which is likely to be decreased by digital transformation. Specifically, the application of digital platforms tends to integrate knowledge and data from various disciplines (Tang et al., 2023), which may foster interdisciplinary innovation. Simultaneously, it enables the intelligent allocation of resources, such as human capital and finances (Xue et al., 2022), which is likely to optimize the combination and utilization of these factors. The interdisciplinary and factor innovations driven by digital transformation may significantly shorten the cycle of green innovation. Moreover, digital transformation uses technologies, such as big data and artificial intelligence, to promote data forecasting in developing green innovation (Liu & Song, 2023). It may identify potential risks and provide the basis for corporations to make optimal decisions. In this case, high failure risks associated with green innovation appear to be reduced.

On the other hand, there is evidence that digital transformation may reduce financing constraints (Liu et al., 2023). Specifically, it is possible to share data related to green innovation projects in real time due to digital transformation (Cong & He, 2019), which may increase the quality of information disclosure. In this case, investors are likely to accurately assess the project by using this information (George & Schillebeeckx, 2022), which may reduce the uncertainty and risk caused by information asymmetry in the financing process. Hence, corporations may more easily obtain capital, which may address the high investment associated with green innovation to some degree. Therefore, green innovation is likely to be promoted. Thirdly, digital transformation brings the optimization of operational processes, which may provide additional resources for green innovation. Specifically, the application of digital technologies, such as the Internet of Things, enables real-time monitoring of production processes, energy consumption, and waste emissions (He et al., 2024), which may enhance resource efficiency and allow more resources to be allocated to green innovation. In this case, the development of green innovation seems

to be fostered to some extent. Moreover, opportunities to reduce resource usage and adopt more environmentally friendly alternatives seem to be identified through this real-time feedback mechanism (Zhang et al., 2024). It can be considered a key method to promote green innovation for corporations.

Although the existing research focuses on the relationship between digital transformation and green innovation in China, an increasing number of international studies have explored this relationship from various perspectives. For example, Martínez Falcó et al. (2024) found that digital transformation may promote green innovation in Spanish wineries. They have also proved that green knowledge sharing mediates, and top management environmental awareness moderates this association. In addition, Nosratabadi et al. (2023) explore how digital transformation affects social sustainability in EU-27 countries. These studies demonstrate that the role of digital technologies in promoting green innovation is not limited to China but is increasingly being validated across countries with diverse institutional contexts.

3. Theoretical analysis and research hypotheses

3.1. The direct impact of digital transformation on green innovation

The digital transformation of corporations indicates the application of technology in the planning, development, production, and consumption process (Xue et al., 2022). In addition, these technologies are characterized by collecting diverse real-time data and analyzing large amounts of data (Zhang et al., 2022), such as the Internet of Things, Artificial Intelligence, and blockchain technology. On the one hand, digital transformation may mitigate information asymmetry to some extent, which is likely to foster green innovation. Specifically, internally, the use of information platforms tends to enhance the efficiency of information transmission (Liu, 2023), which indicates that the corporation tracks specific aspects of production and operations. It facilitates the implementation of their environmental strategies. In this case, the development of green innovation seems to be promoted. Externally, the application of information technology enables knowledge sharing among different departments and organizations to some degree (Feng et al., 2022), which may create knowledge spillover effects. It is likely to contribute to the development of green innovation. On the other hand, digital transformation seems to provide real-time and effective monitoring of the production process, which may promote green innovation. Specifically, there is evidence that digital technology seems to provide real-time data and analysis (Liu, 2023). It indicates that precise monitoring and management of resource usage may be achieved to some degree. In this case, opportunities for improvement and innovation appear to be identified by analyzing this data, which may drive the development of environmentally friendly products and processes. It is considered a kind of data support for green innovation. Hence, the development of green innovation may be promoted. Therefore, hypothesis 1 is established as:

H_1: Digital transformation fosters the development of green innovation.

3.2. Digital transformation, disclosure quality, and green innovation

Disclosure quality plays a mediating role in the relationship between digital transformation and green innovation. On the one hand, there is evidence that the implementation of digital transformation tends to enhance an enterprise's ability to collect and analyze large volumes of data in real-time (Zhang et al., 2024). It means that corporations seem to gain a detailed, accurate, and real-time understanding of how their production and operational processes impact the environment. In addition, disclosure quality is defined as the comprehensive performance of the completeness, accuracy, transparency, and timeliness of the information provided by the corporation (Restrepo et al., 2022). In this case, the implementation of digital transformation may be considered as an improvement in the quality of information disclosure. On the other hand, since digital platforms provide a variety of ways to publish and transmit data, the data collected and analyzed through digital technologies may be communicated more frequently and transparently with external stakeholders through digital platforms(Xue et al., 2022). It is also regarded as an enhancement in information disclosure transparency. Moreover, evidence shows that a high level of information disclosure transparency is likely to convey a responsible corporate image to the public (Martins et al., 2020), which seems to increase the trust of external stakeholders, such as investors, customers, and regulators. In addition, based on the resource-dependence theory, the development of corporations depends on external resources (Celtekligil, 2020). In this case, if there are adequate resources, the development of green innovation may be fostered. Hence, due to the high level of information disclosure quality, corporations may secure more funding and resources when engaging in green innovation. Therefore, hypothesis 2 can be established as :

H_2: Disclosure quality plays a mediating role in the relationship between digital transformation and green innovation.

3.3. The moderating role of board independence

Board independence may provide effective monitoring for the operation of a corporation, which may positively moderate the relationship between digital transformation and green innovation. Specifically, it is widely accepted that corporate governance mechanisms influence corporate social responsibility(CSR) performance (Bolourian et al., 2021). The board, as a critical mechanism of corporate governance, plays a supervisory role in the company's strategic decision-making (Kolev et al., 2019). In this case, the objectivity of the board's oversight and whether its recommendations align with shareholder interests directly impact CSR performance. Moreover, based on the principal-agent theory, the presence of independent directors is likely to mitigate agency problems between the management and shareholders (Chintrakarn et al., 2021), which implies that directors are more likely to provide objective advice. Furthermore, the development of green innovation, as a long-term strategy, is considered an aspect of CSR fulfillment and aligns with the interests of shareholders (Zhao et al., 2023). In addition, the development of green innovation is closely linked to the external reputation of the company (Chen et al., 2023). In this case, developing green innovation may respond to the expectations of shareholders and external stakeholders for the development of the company. Hence, boards with higher independence are more likely to encourage corporations to adopt digital technologies to foster green innovation. Therefore, hypothesis 3 is established as:

H_3: Board independence positively moderates the relationship between digital transformation and green innovation.

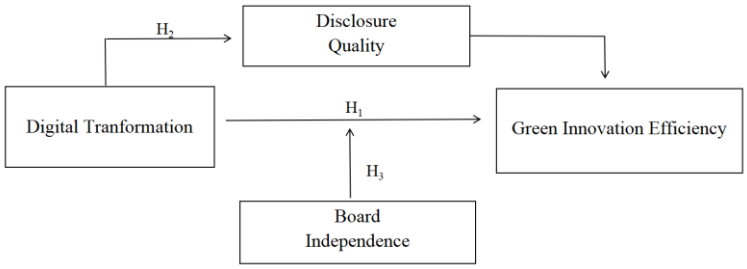


Fig. 1: Conceptual Framework.

In summary, Fig.1 describes the framework of this research. It proposes that digital transformation directly promotes green innovation efficiency (H_1). In addition, disclosure quality plays a mediating role in the relationship between digital transformation and green innovation efficiency (H_2). Furthermore, board independence is hypothesized to moderate the relationship between digital transformation and green innovation efficiency (H_3).

4. Research methodology

4.1. Source of data

The first China Green Innovation Conference was held in 2018, which indicates that green innovation was generally considered a critical strategy for corporations at that time. In this case, the data is collected from a secondary data platform from 2018 to 2022. Specifically, 2505 observations are chosen in this research. ST and *ST corporations have been excluded, as well as financial corporations and corporations with missing data are also excluded. The data on the independent variable, mediating variable, moderating variable, and control variables are collected from the China Stock Market and Accounting Research Database (CSMAR). In addition, the data of the dependent variable is collected from the Chinese Research Data Service Platform (CNRDS).

4.2. Selection of variables

4.2.1. Independent variable

Digital transformation is the independent variable of this research. Digital transformation in corporations is defined as the integration of digital technologies to reshape operational processes, products, and services. It is usually influenced by the strategic orientation of the management(Graf et al., 2019), the degree of technology adoption(Shen et al., 2022), support from internal and external environments(Wiesböck and Hess, 2022), digital achievements, and the extent of digital applications. In this case, this research uses the Digital Transformation Index to measure the level of digital transformation (Xu et al., 2024), which is jointly developed by the CSMAR team and the "Smart Business and Technology Enterprise Management" research team from the School of Economics and Management at East China Normal University. Specifically, the Digital Transformation Index combines six indexes, which are strategic leadership scores, technology-driven scores, organizational empowerment scores, environmental support scores, digital achievement scores, and digital application scores. In addition, 31 secondary indicators are included in these six indices, which may avoid the limitations associated with using a single indicator. Each indicator is extracted and quantitatively scored using a combination of machine learning and manual verification, and a comprehensive score is generated through weighted aggregation. In addition, the index is not equally weighted, but rather uses a differentiated weighting approach based on expert consultation and empirical validation. Table 1 shows the contents of the Digital Transformation Index.

Table 1: Contents of Digital Transformation Index

Index	Proportion	Secondary Indicators
Strategic leadership scores	0.3472	(a) Establishment of digital positions at the management level (b) Foresight of digital innovation orientation at the management level (c) Sustainability of digital innovation orientation at the management level (d) Digital innovation orientation at the management level (e) Intensity of digital innovation orientation at the management level
Technology-driven scores	0.162	(a) Artificial intelligence technology (b) Blockchain technology (c) Cloud computing technology (d) Big data technology
Organizational empowerment scores	0.0969	(a) Digital capital investment plan (b) Digital human resources investment plan (c) Digital infrastructure construction (d) Technological innovation base construction
Environmental support scores	0.0342	(a) Digital technology intensity of the China Securities Regulatory Commission (CSRC) industry (b) Digital capital investment intensity of the CSRC industry (c) Human capital investment intensity of the industry (d) Number of invention patents in the national economy industry (e) Research and development activities in the national economy industry (f) New product development and sales in the national economy industry (g) Optical cable density in the city (h) Mobile switch capacity in the city (i) Internet broadband access user scale in the city (j) Mobile Internet user scale in the city
Digital achievement scores	0.2713	(a) Digital innovation standard (b) Digital innovation research

		(c) Digital invention patent (d) Digital innovation qualification (e) Digital national award
Digital application scores	0.0884	(a) Technology innovation (b) Process innovation (c) Business innovation

4.2.2. Dependent variable

Green innovation is the dependent variable of this research. There are two kinds of measurement of this variable, including the input of green innovation and the output of green innovation (Xiang et al., 2022). Specifically, the input of green innovation is usually measured by the investment in green innovation (Fernández et al., 2018). In addition, the output of green innovation is usually measured by green invention patents, including the application of green invention patents (Chen & Chen, 2021) and the grants of green invention patents (Scarpellini et al., 2019). Considering that the entire process of green innovation is affected by digital transformation, there are some uncertainties during the process of green innovation. In this case, the outputs of green innovation are considered as the measurement of green innovation. In addition, there is a lag in patent granting. Hence, green innovation is measured by the application of green invention patents (Tang et al., 2023).

4.2.3. Mediating variable

Disclosure quality is the mediating variable in this research. It is defined as the clarity, completeness, and accuracy of financial and non-financial information disclosed by a corporation (Restrepo et al., 2022). Considering that the evaluation indicators provided by the stock exchanges are standardized, objective, and comprehensive, disclosure quality is measured by the Shanghai Stock Exchange and Shenzhen Stock Exchange's information disclosure evaluation indicators for listed companies (Xu and Rhee, 2018).

4.2.4. Moderating variable

Board independence is the moderating variable in this research. Specifically, board independence is defined as the independence and objectivity of board members in decision-making (Chintrakarn et al., 2021). A corporation with strong board independence means that the decision made by the board is not influenced by external pressures or internal conflicts of interest (Masulis & Zhang, 2019), which appears to safeguard the interests of shareholders and other stakeholders. It is generally measured by the percentage of independent directors on the board (Neville et al., 2019)

4.2.5. Control variable

Considering that this research is to explore the relationship between digital transformation and green innovation, some variables that are not directly related to digital transformation but can still affect green innovation need to be considered. In this case, consistent with prior studies by Xue et al. (2022) and Yang et al. (2023), this study includes four control variables to account for firm-level characteristics that may influence green innovation, including firm age, operating profit margin, cash flow sufficiency, and firm size. Specifically, there is evidence showing that firm age has an influence on green innovation (He & Su, 2022). Companies with a long history may have more resources to develop green innovation than companies with a short history. In addition, the operating profit margin reflects the efficiency of a company in managing and controlling its operating costs (Mahdi & Khaddafi, 2020). Compared with a company with a lower operating profit margin, a higher operating profit margin indicates that the corporation has stronger profitability. In addition, since green innovation is associated with high initial investment and high risks, a high operation profit margin seems to provide financial resources for green innovation (Xie et al., 2022). Similarly, the level of cash flow sufficiency reflects the financial stability and capital structure of a corporation. In addition, since sufficient cash flow tends to reduce the necessity for firms to rely on external financing frequently during the process of engaging in green innovation, there is a relationship between cash flow sufficiency and green innovation (Chen et al., 2020). Furthermore, there is evidence showing that firm size has a positive influence on green innovation due to the stronger risk tolerance of large-scale corporations (He et al., 2024). In summary, the definition of variables is shown in Table 2.

Table 2: Definitions of Variables

Type of Variables	Name	Code of Variables	Definition	Literature Foundations
Dependent	Green Innovation	GI	Ln (1+green invention patent applications)	Tang et al., 2023
Independent	Digital Transformation	DT	Digital Transformation Index	Xu et al., 2024
Mediating	Disclosure Quality	DQ	Shanghai Stock Exchange and Shenzhen Stock Exchange's information disclosure evaluation indicators	Xu and Rhee, 2018
Moderating	Board Independence	BI	Number of independent directors/number of all directors	Neville et al., 2019
Control	Firm Age	AGE	Length of time the company has been established	He et al., 2024
	Operating Profit Margin	OPM	Operating profit / Operating income	Mahdi and Khaddafi, 2020
	Cash Flow Sufficiency	FLOW	Net cash flow from operations / total assets	Ma et al., 2022
	Firm Size	SIZE	Ln (Total Assets)	He et al., 2024

4.3. Model specification

To assess the direct relationship between digital transformation and green innovation (H_1), this research employs the following model:

$$GI_{i,t}=\alpha_0 + \beta_0 DT_{i,t} + Controls_{i,t} + \eta_i + \eta_t + \varepsilon_{i,t} \quad (1)$$

To examine the mediating mechanism of disclosure quality in the relationship between digital transformation and green innovation (H_2), this study uses the following models:

$$GI_{i,t}=\alpha_0 + \beta_0 DT_{i,t} + Controls_{i,t} + \eta_i + \eta_t + \varepsilon_{i,t} \quad (1)$$

$$DQ_{i,t}=\alpha_2 + \beta_1 DT_{i,t} + Controls_{i,t} + \eta_i + \eta_t + \varepsilon_{i,t} \quad (2)$$

$$GI_{i,t}=\alpha_3 + \beta_2 DQ_{i,t} + \beta_4 DT_{i,t} + Controls_{i,t} + \eta_i + \eta_t + \varepsilon_{i,t} \quad (3)$$

To explore how board independence have an influence on the relationship between digital transformation and green innovation (H_3), this research develops the following model:

$$bGI_{i,t}=\alpha_4 + \beta_3 DT_{i,t} + \beta_5 DT_{i,t} \times BI_{i,t} + Controls_{i,t} + \eta_i + \eta_t + \varepsilon_{i,t} \quad (4)$$

Which GI represents the dependent variable, which is green innovation. DT represents the independent variable, which is digital transformation. DQ represents a mediating variable, which is disclosure quality. Controls represent control variables. η_i and η_t represents industry-fixed effect and time-fixed effect. ε represents the error vector.

5. Empirical results and discussion

5.1. Descriptive statics and correlation coefficient

The results of the descriptive analysis are shown in Table 3. The number of green innovations (GI) is from 0.000 to 7.071, in addition, its average number is 1.115. It represents that there is a significant variation in the extent of green innovation among corporations. Similarly, the number of digital transformation (DT) varies widely. It distributes from 21.377 to 79.406 and its mean is 38.661. Moreover, the maximum value of disclosure quality (DQ) is 4.000 and its minimum is 0.000. In addition, its mean is 3.037. It indicates that the subjects of observation exhibit relatively high disclosure quality in this research. The percentage of independent directors (BI) is from 0.167 to 0.714 and its average number is 0.376. It shows that there is a considerable difference in board independence. Furthermore, firm age (AGE), operating profit margin (OPM), cash flow (FLOW), and firm size (SIZE) represent significant variations, which may contribute to the robustness and generalization of the results. According to Table 3, green innovation (GI) is significantly associated with digital transformation (DT) (β=0.378, $p<0.01$), which indicates that digital transformation may enhance green innovation. In addition, there is a significant and positive relationship between disclosure quality (DQ) and digital transformation (DT) (β=0.132, $p<0.01$). It means that the high level of disclosure quality seems to improve digital transformation. Moreover, green innovation is also significantly and positively associated with disclosure quality (β=0.195, $p<0.01$). It seems to verify hypothesis 1 and hypothesis 2. Furthermore, the value of correlation is almost lower than 0.5. In this case, based on the research conducted by He and Su (2022), there may be no issue with multicollinearity. In addition, based on Table 4, the value of VIF is from 1.010 to 5.270, which is not more than 10. In this case, it further shows that there is no issue with multicollinearity.

Table 3: Descriptive and Correlation Statics

Variables	Mean	Std.	Min	Max	GI	DT	DQ	BI	AGE	OPM	FLOW	SIZE
GI	1.115	1.346	0.000	7.071	—							
DT	38.661	10.932	21.377	79.406	0.378***	—						
DQ	3.037	0.690	0.000	4.000	0.195***	0.132***	—					
BI	0.376	0.056	0.167	0.714	0.075***	0.071***	-0.036*	—				
AGE	23.205	5.405	9.000	43.000	-0.041**	-0.151***	0.012	0.006	—			
OPM	-0.067	4.360	-167.762	34.367	0.021	0.036*	0.135***	-0.000	-0.015	—		
FLOW	0.044	0.077	-0.748	0.533	0.075***	-0.011	0.207***	-0.001	-0.040**	-0.071***	—	
SIZE	0.012	0.824	-29.018	8.149	0.029	0.030	0.110***	-0.001	-0.012	0.897***	0.138***	—

t statistics in parentheses; *p < 0.1, ** p < 0.05, *** p < 0.01.

Table 4: Variance Inflation Factor

Variables	VIF	1 / VIF
DT	1.050	0.951
DQ	1.090	0.918
BI	1.010	0.992
AGE	1.030	0.973
OPM	5.240	0.191
FLOW	1.090	0.922
SIZE	5.270	0.190
Mean VIF	2.250	

5.2. Baseline regression

Based on Table 5, columns (1) - (3) show the results between green innovation and digital transformation without control variables, including a random effects model, time fixed effects, and fixed effects control for both time and industry. In addition, column (4) represents the results after adding control variables. In these results, p-values are all less than 0.01, and the values of correlation are all positive. This indicates that digital transformation is significantly positively associated with green innovation. Hence, digital transformation enhances green innovation, which verifies hypothesis 1.

Table 5: Baseline Regression

Variable	(1) GI	(2) GI	(3) GI	(4) GI Model (1)
DT	0.047*** (20.440)	0.046*** (20.270)	0.057*** (23.760)	0.058*** (23.890)
AGE				0.009** (1.970)
OPM				0.010 (0.840)
FLOW				1.072*** (3.460)
SIZE				-0.036 (-0.550)
CONS	-0.685*** (-7.490)	-0.676*** (-6.610)	-0.659*** (-3.080)	-0.912*** (-3.820)
Year FE		YES	YES	YES
Industry FE			YES	YES
N	2505	2505	2505	2505
R^2	0.143	0.146	0.270	0.2744

t statistics in parentheses; ** p < 0.05, *** p < 0.01.

5.3. Robustness tests

To test the effectiveness of the results, robustness tests are conducted, including the replacement of the independent variable and the dependent variable.

5.3.1. Replacement of the independent variable measurement

Drawing the study conducted by Wu (2021), the digital transformation of the corporation is divided into five aspects, including artificial intelligence technology, big data technology, cloud computing technology, blockchain technology, and digital technology applications. The research conducted by Wu (2021) uses textual analysis methods to summarize the frequency at which the mentioned five categories of related words appear in annual reports. Due to the right-skewed nature of this data, following the approach in the research conducted by Changyong et al. (2014), the measurement of digital transformation is replaced by the sum of the five categories mentioned above and takes the natural logarithm. It is represented as DT_new. This data is collected from CSMAR. Based on the results of column (1) in Table 6, DT_new is positively associated with green innovation at the significant level of 1% (β=0.031, p<0.01), which is consistent with previous results. Hence, after replacing the measurement of the independent variable, digital transformation is also positively and significantly related to green innovation.

5.3.2. Replacement of the dependent variable measurement

Following the research conducted by Tang et al. (2023), the measurement of digital transformation is replaced by the number of green patents granted plus 1 to take the natural logarithm. It is established as GI_grant. The regression results are reported in column (2) of Table 6 after substituting variables. In Table 6, the coefficient of digital transformation is 0.309, and the p-value is less than 0.01, which is consistent with previous results. It indicates that digital transformation can foster green innovation statistically. Hence, after replacing the measurement of green innovation, the previous results are also effective. Therefore, hypothesis 1 is also verified after conducting robustness tests.

Table 6: Robustness Tests

Variable	(1) GI	(2) GI_grant
DT_new	0.031*** (15.300)	
DT		0.309*** (15.300)
AGE	0.007 (1.500)	0.007 (1.500)
OPM	0.012 (2.540)	0.012 (0.950)
FLOW	0.835** (2.540)	0.835** (2.540)
SIZE	-0.033 (-0.480)	-0.033 (-0.480)
CONS	0.485** (2.000)	0.485** (2.000)
Year FE	YES	YES
Industry FE	YES	YES
N	2505	2505
R^2	0.184	0.184

t statistics in parentheses; ** p < 0.05, *** p < 0.01.

5.4. Mechanism analysis

To clarify whether disclosure quality (DQ) plays a mediating role in the relationship between digital transformation (DT) and green innovation (GI), a mechanism test has been conducted. In this research, there are two methods to test this mechanism, which are the three-step mediation analysis and the Sobel test. Specifically, Table 7 and Table 8 show the three-step mediation analysis and Sobel test, respectively.

Columns (1) - (2) of Table 7 show the results of model 2 and model 3. Model 2 shows the relationship between disclosure quality and digital transformation. The influence coefficient of digital transformation is 0.010, and its p-value is less than 0.01. It indicates that there is a positive association between disclosure quality and digital transformation at a significant level of 1%. Furthermore, Model 3 is the model that adds disclosure quality as an independent variable, which represents the association between digital transformation and green innovation, and the correlation between disclosure quality and green innovation. In the results of Model 3, the coefficient between digital transformation and green innovation is 0.277, and its p-value is less than 0.01. It shows that digital transformation is positively associated with green innovation at a significant level of 1%. In addition, there is a positive association between disclosure quality and green innovation at a significant level of 1% (β=0.055, p<0.01). Hence, combined with the results of Model 1, the three-step mediation analysis proves that disclosure quality plays a mediating role in the relationship between digital transformation and green innovation. Therefore, hypothesis 2 has been proved.

Table 7: Three-Step Mediation Analysis

Variable	(1) DQ Model (2)	(2) GI Model (3)
DT	0.010*** (7.500)	0.277*** (7.910)
DQ		0.055*** (22.74)
AGE	0.004 (1.470)	0.008* (1.760)
OPM	0.030*** (4.320)	0.002 (0.170)
FLOW	1.783*** (10.170)	0.577* (1.850)
SIZE	-0.081** (-2.170)	-0.014 (-0.220)
CONS	2.360*** (17.480)	-1.566*** (-6.270)
Year FE	YES	YES
Industry FE	YES	YES
N	2505	2505
R^2	0.1167	0.2922

t statistics in parentheses; *p < 0.1, ** p < 0.05, *** p < 0.01.

Furthermore, Table 8 shows the results of the Sobel test mediation analysis. In these results, the direct effect is positive and significant at 1% level (β=0.045, p<0.01). It indicates that digital transformation enhances green innovation. In addition, the indirect effect is also positive and significant at a 1% level (β=0.002, p<0.01). It represents that disclosure quality plays a mediating role in the relationship between digital transformation and green innovation (p<0.01). In addition, the mediating effect also indicates that the higher the level of digital transformation, the higher the disclosure quality represented and the greater the development of green innovation (β=0.002). Furthermore, Table 8 shows that the indirect effect accounts for about 5% of the total effect, which further proves the mediating mechanism of disclosure quality in the relationship between digital transformation and green innovation. Therefore, the Sobel test also verifies hypothesis 2. In summary, disclosure quality plays a mediating role in the relationship between digital transformation and green innovation.

Table 8: Sobel Test Mediation Analysis

Projects	Regression Results
Direct effect	0.045*** (19.460)
Indirect effect	0.002*** (5.061)
Total effect	0.047*** (20.464)
Indirect effect to total effect ratio	5.000%

t statistics in parentheses; *p < 0.1, ** p < 0.05, *** p < 0.01.

5.6. Moderating effect analysis

Following the analysis method employed by Lin and Xie (2024), the interaction term of DT×BI is established to prove the moderating effect of board independence (BI) in the relationship between digital transformation (DT) and green innovation (GI). Table 9 shows the results of Model 4. In these results, DT×BI is significant and positively associated with green innovation at a 5% level (β=2.530, p<0.05). It suggests that board independence positively moderates the relationship between digital transformation and green innovation, which proves hypothesis 3.

Table 9: Moderating Effect Analysis

Variables	GI Model (4)
DT	0.048*** (10.360)
DT×BI	2.530** (2.520)
AGE	0.009* (1.940)
OPM	0.010** (0.830)
FLOW	1.075 (3.470)

SIZE	-0.035 (-0.540)
CONS	-0.893*** (-3.750)
Year FE	YES
Industry FE	YES
N	2505
R^2	0.276

t statistics in parentheses; *p < 0.1, ** p < 0.05, *** p < 0.01.

5.7. Heterogeneity analysis

Heterogeneity analysis includes two analyses. Firstly, corporations are classified into manufacturing and non-manufacturing enterprises based on the industry classification standard GB/T 4754-2017 "Industry Classification of National Economy" issued by the CNBS. Secondly, based on the nature of controlling equity, companies are divided into state-owned enterprises and non-state-owned enterprises. Table 10 shows the results of the two heterogeneity analyses. Columns (1) and (2) of Table 10 describe the results of manufacturing enterprises and non-manufacturing enterprises. In specific, digital transformation (DT) is significantly and positively associated with green innovation (GI) in both manufacturing (β=0.063, p<0.01) and non-manufacturing corporations (β=0.040, p<0.01). It indicates that the impact of digital transformation on green innovation is more significant in manufacturing enterprises compared with non-manufacturing enterprises. This may be because manufacturing enterprises, as a kind of traditional industry, are more dependent on resource and energy inputs in the production process (Xia et al., 2024). In this case, with the increasing awareness of environmental protection (Shao et al., 2020), they seem to be subject to stricter environmental regulations and market pressures. In this case, manufacturing corporations have a more urgent need to optimize resource allocation, improve energy efficiency, and reduce pollution emissions through digital transformation. Hence, digital transformation plays a greater role in promoting green innovation in manufacturing corporations.

Columns (3) and (4) of Table 10 show the results of state-owned enterprises and non-state-owned enterprises. Specifically, there is a significant and positive relationship between digital transformation and green innovation in both state-owned enterprises (β=0.062, p<0.01) and non-state-owned enterprises (β=0.057, p<0.01). In addition, digital transformation has a more significant impact on green innovation in state-owned enterprises than in non-state-owned enterprises. Compared with non-state-owned enterprises, state-owned enterprises usually bear more social responsibilities, including environmental protection and sustainable development (Khan et al., 2019). In addition, state-owned corporations appear to have advantages in obtaining policy resources, financial support, and technology introduction. This may encourage these corporations to utilize digital innovation to develop green innovation. Therefore, digital transformation tends to have a stronger effect on promoting green innovation in state-owned enterprises.

Table 10: Heterogeneity Analysis

Variables	(1) Manufacturing enterprise	(2) Non-manufacturing enterprises	(3) State-owned enterprises	(4) Non-state-owned enterprises
	GI	GI	GI	GI
DT	0.063*** (21.320)	0.040*** (8.750)	0.062*** (6.370)	0.057*** (23.060)
AGE	0.017*** (2.620)	0.000 (0.020)	-0.048*** (-2.120)	0.013*** (2.640)
OPM	0.010 (0.660)	0.007 (0.340)	1.183*** (2.700)	0.009 (3.550)
FLOW	1.618*** (3.730)	0.392 (0.940)	2.163 (1.570)	1.127*** (3.550)
SIZE	-0.042 (-0.500)	-0.016 (-0.110)	-4.229*** (-2.170)	-0.031 (-0.480)
CONS	-1.537*** (-7.800)	-2.114 (-0.810)	0.070 (0.090)	-0.983*** (-3.930)
Year FE	YES	YES	YES	YES
Industry FE	YES	YES	YES	YES
N	1500	1005	270	2235
R^2	0.244	0.279	0.365	0.284

t statistics in parentheses; *p < 0.1, ** p < 0.05, *** p < 0.01.

6. Discussion and conclusions

Based on the data of China from 2018 to 2022, this research analyzes the relationship between digital transformation and green innovation, the mechanism of disclosure quality in this relationship, and the moderating effect of board independence in this relationship. In addition, two comparisons are conducted, including the comparison between manufacturing corporations and non-manufacturing corporations, and the comparison between state-owned enterprises and non-state-owned enterprises. Although this research is grounded in the context of China, the findings may be extended to other countries undergoing similar transformations, particularly in emerging or developing economies where digitalization and green innovation are jointly prioritized in national strategies. Specifically, the government often plays a critical role in promoting digitalization and green innovation in these countries, which is consistent with the context of China. In addition, they face similar structural constraints, such as resource scarcity, environmental pressure, and the urgent need for industrial upgrading. In this case, it requires firms to align digital capabilities with sustainability goals. Hence, the findings of this study are expected to provide implications for other countries.

6.1. Theoretical Implications

This research provides empirical evidence for the relationship among digital transformation, disclosure quality, and green innovation. Specifically, digital transformation is positively associated with green innovation. Moreover, the impact of digital transformation on green

innovation varies among enterprises in different industries and with different types of controlling shares. The impact of digital transformation on green innovation in manufacturing enterprises is greater than that in non-manufacturing enterprises, and the impact of digital transformation on green innovation in state-owned enterprises is greater than that in non-state-owned enterprises. In addition, disclosure quality plays a mediating role in this relationship. These indicate that digital transformation seems to enhance the capability of collecting and analyzing data, which may improve the disclosure quality to some degree. In this case, the information asymmetry seems to be decreased to some extent. In addition, based on financial constraint theory, the reduction of information asymmetry tends to mitigate financial constraints for corporations. Hence, the issue of underinvestment in green innovation seems to be alleviated to some extent, which may foster green innovation.

Furthermore, the moderating role of board independence has also been verified by this study. Specifically, the board independence positively moderates the relationship between digital transformation and green innovation. It indicates that the independence of the board of directors may effectively promote the implementation of digital transformation projects and the progress of green innovation by providing objective supervision and suggestions. Specifically, since independent directors have a strong professional background and are not influenced by the management (Masulis & Zhang, 2019), they appear to prioritize the interests of the corporation when performing their duties. In addition, it is widely accepted that green innovation is a long-term strategic goal, which is consistent with the interests of corporations (Zhao et al., 2023). In this case, independent directors may ensure that green innovation objectives are prioritized in the formulation and implementation of digital transformation strategies. Hence, the positive relationship between digital transformation and green innovation may be enhanced when board independence increases.

6.2. Practical Implication

Firstly, policymakers can design targeted support policies based on industry characteristics. For example, providing additional subsidies and rewards for digital transformation and green innovation to manufacturing and state-owned enterprises, as research indicates that digital transformation has a greater impact on green innovation in these sectors. Secondly, the government can implement measures to enhance disclosure quality, such as establishing comprehensive disclosure mechanisms and ESG rating mechanisms. It can encourage corporations to actively engage in digital transformation and foster the development of green innovation. Moreover, it aligns with the trend of ESG, which may enhance the comparability of sustainability information in international markets. Thirdly, the government can continuously emphasize the importance of independent directors and establish regulations on their proportion. Companies should actively respond to policy requirements and continuously optimize their independent director appointment systems, thereby promoting the development of green innovation.

6.3. Limitations and future research suggestions

This research has several limitations. Firstly, this research uses the stock exchange's information disclosure evaluation to measure the disclosure quality; another measurement of disclosure quality can be explored in further studies. Secondly, this study focuses on the context of China, and it uses the data of manufacturing corporations. Future research can extend the results to other countries or other industries.

Acknowledgments

The authors would like to thank all those who provided encouragement and insightful discussions during the development of this study.

References

[1] Bai, X., & Lyu, C. (2023). Environmental Information Disclosure and Corporate Green Innovation: The Moderating Effect of Formal and Informal Institutions. Sustainability, 15(7), 6169. https://doi.org/10.3390/su15076169.

[2] Björkdahl, J. (2020). Strategies for digitalization in manufacturing firms. California management review, 62(4), 17-36. https://doi.org/10.3390/su15076169

[3] Bolourian, S., Angus, A., & Alinaghian, L. (2021). The impact of corporate governance on corporate social responsibility at the board-level: A critical assessment. Journal of Cleaner Production, 291, 125752. https://doi.org/10.1016/j.jclepro.2020.125752.

[4] Celtekligil, K. (2020). Resource Dependence Theory. In: Dincer, H., Yüksel, S. (eds) Strategic Outlook for Innovative Work Behaviours. Contributions to Management Science. Springer, Cham. https://doi.org/10.1007/978-3-030-50131-0_7.

[5] Changyong, F. E. N. G., Hongyue, W. A. N. G., Naiji, L. U., Tian, C. H. E. N., Hua, H. E., & Ying, L. U. (2014). Log-transformation and its implications for data analysis. Shanghai archives of psychiatry, 26(2), 105.

[6] Chen, A., & Chen, H. (2021). Decomposition analysis of green technology innovation from green patents in China. Mathematical Problems in Engineering, 2021(1), 6672656. https://doi.org/10.1155/2021/6672656.

[7] Chen, H., Zhong, T., & Lee, J. Y. (2020). Capacity reduction pressure, financing constraints, and enterprise sustainable innovation investment: Evidence from Chinese manufacturing companies. Sustainability, 12(24), 10472. https://doi.org/10.3390/su122410472.

[8] Chen, W. (2020). Intelligent manufacturing production line data monitoring system for industrial internet of things. Computer communications, 151, 31-41. https://doi.org/10.1016/j.comcom.2019.12.035.

[9] Chen, Z., & Liang, M. (2023). How do external and internal factors drive green innovation practices under the influence of big data analytics capability: Evidence from China. Journal of Cleaner Production, 404, 136862. https://doi.org/10.1016/j.jclepro.2023.136862.

[10] Chen, Z., Hao, X., & Chen, F. (2023). Green innovation and enterprise reputation value. Business Strategy and the Environment, 32(4), 1698-1718. https://doi.org/10.1002/bse.3213

[11] Chintrakarn, P., Jiraporn, P., & Treepongkaruna, S. (2021). How do independent directors view corporate social responsibility (CSR) during a stressful time? Evidence from the financial crisis. International Review of Economics & Finance, 71, 143-160. https://doi.org/10.1016/j.iref.2020.08.007.

[12] Cioffi, R., Travaglioni, M., Piscitelli, G., Petrillo, A., & De Felice, F. (2020). Artificial intelligence and machine learning applications in smart production: Progress, trends, and directions. Sustainability, 12(2), 492. https://doi.org/10.3390/su12020492.

[13] Cong, L. W., & He, Z. (2019). Blockchain disruption and smart contracts. The Review of Financial Studies, 32(5), 1754-1797. https://doi.org/10.1093/rfs/hhz007.

[14] Dou, Q., & Gao, X. (2023). How does the digital transformation of corporates affect green technology innovation? An empirical study from the perspective of asymmetric effects and structural breakpoints. Journal of Cleaner Production, 428, 139245. https://doi.org/10.1016/j.jclepro.2023.139245.

[15] Feng, H., Wang, F., Song, G., & Liu, L. (2022). Digital transformation on enterprise green innovation: Effect and transmission mechanism. International journal of environmental research and public health, 19(17), 10614. https://doi.org/10.3390/ijerph191710614.

[16] Fernández, Y. F., López, M. F., & Blanco, B. O. (2018). Innovation for sustainability: the impact of R&D spending on CO2 emissions. Journal of Cleaner Production, 172, 3459-3467. https://doi.org/10.1016/j.jclepro.2017.11.001.
[17] Feroz, A. K., Zo, H., & Chiravuri, A. (2021). Digital transformation and environmental sustainability: A review and research agenda. Sustainability, 13(3), 1530. https://doi.org/10.3390/su13031530.
[18] George, G., & Schillebeeckx, S. J. (2022). Digital transformation, sustainability, and purpose in the multinational enterprise. Journal of World Business, 57(3), 101326. https://doi.org/10.1016/j.jwb.2022.101326.
[19] Graf, M., Peter, M., & Gatziu-Grivas, S. (2019). Foster strategic orientation in the digital age: A methodic approach for guiding SME to a digital transformation. In Business Information Systems Workshops: BIS 2018 International Workshops, Berlin, Germany, July 18–20, 2018, Revised Papers 21 (pp. 420-432). https://doi.org/10.1007/978-3-030-04849-5_37 .
[20] Guinot, J., Barghouti, Z., & Chiva, R. (2022). Understanding green innovation: A conceptual framework. Sustainability, 14(10), 5787. https://doi.org/10.3390/su14105787.
[21] Guo, L., & Xu, L. (2021). The effects of digital transformation on firm performance: Evidence from China's manufacturing sector. Sustainability, 13(22), 12844. https://doi.org/10.3390/su132212844
[22] He, J., & Su, H. (2022). Digital transformation and green innovation of Chinese firms: The moderating role of regulatory pressure and international opportunities. International Journal of Environmental Research and Public Health, 19(20), 13321. https://doi.org/10.3390/ijerph192013321.
[23] He, Q., Ribeiro-Navarrete, S., & Botella-Carrubi, D. (2024). A matter of motivation: the impact of enterprise digital transformation on green innovation. Review of Managerial Science, 18(5), 1489-1518. https://doi.org/10.1007/s11846-023-00665-6.
[24] Huang, S. Z., Chau, K. Y., Chien, F., & Shen, H. (2020). The impact of startups' dual learning on their green innovation capability: The effects of business executives' environmental awareness and environmental regulations. Sustainability, 12(16), 6526. https://doi.org/10.3390/su12166526.
[25] Karlilar, S., & Pata, U. K. (2025, February). Determinants of material footprint in OECD countries: The role of green innovation and environmental taxes. Natural resources forum, 49(1), 100-115, https://doi.org/10.1111/1477-8947.12379.
[26] Khan, F. U., Zhang, J., Usman, M., Badulescu, A., & Sial, M. S. (2019). Ownership reduction in state-owned enterprises and corporate social responsibility: perspective from secondary privatization in China. Sustainability, 11(4), 1008. https://doi.org/10.3390/su11041008.
[27] Khurshid, A., Rauf, A., Qayyum, S., Calin, A. C., & Duan, W. (2023). Green innovation and carbon emissions: the role of carbon pricing and environmental policies in attaining sustainable development targets of carbon mitigation—evidence from Central-Eastern Europe. Environment, Development and Sustainability, 25(8), 8777-8798. https://doi.org/10.1007/s10668-022-02422-3.
[28] Kolev, K. D., Wangrow, D. B., Barker III, V. L., & Schepker, D. J. (2019). Board committees in corporate governance: A cross-disciplinary review and agenda for the future. Journal of Management Studies, 56(6), 1138-1193. https://doi.org/10.1111/joms.12444.
[29] Kraus, S., Jones, P., Kailer, N., Weinmann, A., Chaparro-Banegas, N., & Roig-Tierno, N. (2021). Digital transformation: An overview of the current state of the art of research. Sage Open, 11(3), https://doi.org/10.1177/21582440211047576.
[30] Kraus, S., Rehman, S. U., & García, F. J. S. (2020). Corporate social responsibility and environmental performance: The mediating role of environmental strategy and green innovation. Technological forecasting and social change, 160, 120262. https://doi.org/10.1016/j.techfore.2020.120262.
[31] Li, L., Su, F., Zhang, W., & Mao, J. Y. (2018). Digital transformation by SME entrepreneurs: A capability perspective. Information Systems Journal, 28(6), 1129-1157. https://doi.org/10.1111/isj.12153.
[32] Li, S., Gao, L., Han, C., Gupta, B., Alhalabi, W., & Almakdi, S. (2023). Exploring the effect of digital transformation on Firms' innovation performance. Journal of Innovation & Knowledge, 8(1), 100317. https://doi.org/10.1016/j.jik.2023.100317.
[33] Li, W. (2022). Big Data precision marketing approach under IoT cloud platform information mining. Computational intelligence and neuroscience, 2022(1), 4828108. https://doi.org/10.1155/2022/4828108.
[34] Lin, B., & Xie, Y. (2024). Impacts of digital transformation on corporate green technology innovation: Do board characteristics play a role?. Corporate Social Responsibility and Environmental Management, 31(3), 1741-1755. https://doi.org/10.1002/csr.2653.
[35] Lin, H., Zeng, S. X., Ma, H. Y., Qi, G. Y., & Tam, V. W. (2014). Can political capital drive corporate green innovation? Lessons from China. Journal of cleaner production, 64, 63-72. https://doi.org/10.1016/j.jclepro.2013.07.046.
[36] Lin, R. H., Chuang, W. W., Chuang, C. L., & Chang, W. S. (2021). Applied big data analysis to build customer product recommendation model. Sustainability, 13(9), 4985. https://doi.org/10.3390/su13094985.
[37] Liu, M., Li, H., Li, C., & Yan, Z. (2023). Digital transformation, financing constraints and enterprise performance. European Journal of Innovation Management, 28(4), 1472-1497. https://doi.org/10.1108/EJIM-05-2023-0349.
[38] Liu, X. (2023). Enterprise digital transformation and green innovation. Industrial Engineering and Innovation Management, 6(2), 8-17. https://doi.org/10.23977/ieim.2023.060202.
[39] Liu, Y., & Song, P. (2023). Digital transformation and green innovation of energy enterprises. Sustainability, 15(9), 7703. https://doi.org/10.3390/su15097703.
[40] Ma, X., Ock, Y. S., Wu, F., & Zhang, Z. (2022). The effect of internal control on green innovation: corporate environmental investment as a mediator. Sustainability, 14(3), 1755. https://doi.org/10.3390/su14031755.
[41] Mahdi, M., & Khaddafi, M. (2020). The influence of gross profit margin, operating profit margin and net profit margin on the stock price of consumer good industry in the Indonesia stock exchange on 2012-2014. International Journal of Business, Economics, and Social Development, 1(3), 153-163. https://doi.org/10.46336/ijbesd.v1i3.53.
[42] Martínez Falcó, J., Sánchez-García, E., Marco-Lajara, B., & Akram, U. (2024). Digital transformation and green innovation performance: unraveling the role of green knowledge sharing and top management environmental awareness. Internet Research. https://doi.org/10.1108/INTR-11-2023-1016.
[43] Martínez Falcó, J., Sánchez-García, E., Marco-Lajara, B., & Akram, U. (2024). Digital transformation and green innovation performance: unraveling the role of green knowledge sharing and top management environmental awareness. Internet Research. https://doi.org/10.1108/INTR-11-2023-1016.
[44] Martins, A., Gomes, D., & Branco, M. C. (2020). Managing corporate social and environmental disclosure: An accountability vs. impression management framework. Sustainability, 13(1), 296. https://doi.org/10.3390/su13010296.
[45] Masulis, R. W., & Zhang, E. J. (2019). How valuable are independent directors? Evidence from external distractions. Journal of Financial Economics, 132(3), 226-256. https://doi.org/10.1016/j.jfineco.2018.02.014.
[46] Miao, Z. (2022). Industry 4.0: technology spillover impact on digital manufacturing industry. Journal of Enterprise Information Management, 35(4/5), 1251-1266. https://doi.org/10.1108/JEIM-02-2021-0113.
[47] Mikalef, P., Krogstie, J., Pappas, I. O., & Pavlou, P. (2020). Exploring the relationship between big data analytics capability and competitive performance: The mediating roles of dynamic and operational capabilities. Information & Management, 57(2), 103169. https://doi.org/10.1016/j.im.2019.05.004.
[48] Neville, F., Byron, K., Post, C., & Ward, A. (2019). Board independence and corporate misconduct: A cross-national meta-analysis. Journal of Management, 45(6), 2538-2569. https://doi.org/10.1177/0149206318801999.
[49] Nosratabadi, S., Atobishi, T., & Hegedűs, S. (2023). Social sustainability of digital transformation: Empirical evidence from EU-27 countries. Administrative Sciences, 13(5), 126. https://doi.org/10.3390/admsci13050126.
[50] Proeger, T., & Runst, P. (2020). Digitization and knowledge spillover effectiveness—Evidence from the "German Mittelstand". Journal of the Knowledge Economy, 11(4), 1509-1528. https://doi.org/10.1007/s13132-019-00622-3.
[51] Ramzan, M., Razi, U., Quddoos, M. U., & Adebayo, T. S. (2023). Do green innovation and financial globalization contribute to the ecological sustainability and energy transition in the United Kingdom? Policy insights from a bootstrap rolling window approach. Sustainable Development, 31(1), 393-414. https://doi.org/10.1002/sd.2399.
[52] Restrepo, L. F., Tellez-Falla, D., & Godoy-Bejarano, J. (2022). Information disclosure quality and firm value: empirical evidence for an emerging integrated market. Academia Revista Latinoamericana de Administración, 35(3), 345-365. https://doi.org/10.1108/ARLA-05-2021-0109

[53] Scarpellini, S., Portillo-Tarragona, P., & Marin-Vinuesa, L. M. (2019). Green patents: a way to guide the eco-innovation success process?. Academia Revista Latinoamericana de Administración, 32(2), 225-243. https://doi.org/10.1108/ARLA-07-2017-0233.
[54] Schmidt, C. G., & Wagner, S. M. (2019). Blockchain and supply chain relations: A transaction cost theory perspective. Journal of Purchasing and Supply Management, 25(4), 100552. https://doi.org/10.1016/j.pursup.2019.100552.
[55] Shao, S., Hu, Z., Cao, J., Yang, L., & Guan, D. (2020). Environmental regulation and enterprise innovation: a review. Business strategy and the environment, 29(3), 1465-1478. https://doi.org/10.1002/bse.2446
[56] Shen, L., Zhang, X., & Liu, H. (2022). Digital technology adoption, digital dynamic capability, and digital transformation performance of textile industry: Moderating role of digital innovation orientation. Managerial and Decision Economics, 43(6), 2038-2054. https://doi.org/10.1002/mde.3507
[57] Sreenu, N. (2025). Digital finance and green technology innovation in India: exploring the role of financing constraints. Quality & Quantity, 1-26. https://doi.org/10.1007/s11135-025-02291-8.
[58] Suddaby, R., Coraiola, D., Harvey, C., & Foster, W. (2020). History and the micro-foundations of dynamic capabilities. Strategic Management Journal, 41(3), 530-556. https://doi.org/10.1002/smj.3058.
[59] Sun, Y., & He, M. (2023). Does digital transformation promote green innovation? A micro-level perspective on the Solow Paradox. Frontiers in Environmental Science, 11, 1134447. https://doi.org/10.3389/fenvs.2023.1134447.
[60] Tang, M., Liu, Y., Hu, F., & Wu, B. (2023). Effect of digital transformation on enterprises' green innovation: empirical evidence from listed companies in China. Energy Economics, 128, 107135. https://doi.org/10.1016/j.eneco.2023.107135.
[61] Teece, D. J., Pisano, G., & Shuen, A. (1997). Dynamic capabilities and strategic management. Strategic management journal, 18(7), 509-533. https://doi.org/10.1002/(SICI)1097-0266(199708)18:7<509::AID-SMJ882>3.0.CO;2-Z.
[62] Wamba, S. F., Gunasekaran, A., Akter, S., Ren, S. J. F., Dubey, R., & Childe, S. J. (2017). Big data analytics and firm performance: Effects of dynamic capabilities. Journal of business research, 70, 356-365. https://doi.org/10.1016/j.jbusres.2016.08.009.
[63] Wang, X., & Zhong, X. (2024). Digital transformation and green innovation: firm-level evidence from China. Frontiers in Environmental Science, 12, 1389255. https://doi.org/10.3389/fenvs.2024.1389255.
[64] Waqas, M., Honggang, X., Ahmad, N., Khan, S. A. R., & Iqbal, M. (2021). Big data analytics as a roadmap towards green innovation, competitive advantage and environmental performance. Journal of Cleaner Production, 323, 128998. https://doi.org/10.1016/j.jclepro.2021.128998
[65] Warner, K. S., & Wäger, M. (2019). Building dynamic capabilities for digital transformation: An ongoing process of strategic renewal. Long range planning, 52(3), 326-349. https://doi.org/10.1016/j.lrp.2018.12.001.
[66] Wiesböck, F., & Hess, T. (2020). Digital innovations: Embedding in organizations. Electronic Markets, 30(1), 75-86. https://doi.org/10.1007/s12525-019-00364-9.
[67] Wu, F., Fu, X., Zhang, T., Wu, D., & Sindakis, S. (2022). Examining whether government environmental regulation promotes green innovation efficiency—evidence from China's Yangtze river economic belt. Sustainability, 14(3), 1827. https://doi.org/10.3390/su14031827.
[68] Wu, F., Hu, H., and Lin, H. (2021). Enterprise digital transformation and capital market performance: Empirical evidence from stock liquidity. Management World, 37 (7), 130–144.
[69] Xia, H., Ye, P., Jasimuddin, S. M., & Zhang, J. Z. (2024). Evolution of digital transformation in traditional enterprises: Evidence from China. Technology Analysis & Strategic Management, 36(9), 2014-2034. https://doi.org/10.1080/09537325.2022.2124909.
[70] Xia, L., Baghaie, S., & Sajadi, S. M. (2024). The digital economy: Challenges and opportunities in the new era of technology and electronic communications. Ain Shams Engineering Journal, 15(2), 102411. https://doi.org/10.1016/j.asej.2023.102411
[71] Xia, L., Gao, S., Wei, J., & Ding, Q. (2022). Government subsidy and corporate green innovation-Does board governance play a role?. Energy Policy, 161, 112720. https://doi.org/10.1016/j.enpol.2021.112720.
[72] Xiang, X., Liu, C., & Yang, M. (2022). Who is financing corporate green innovation?. International Review of Economics & Finance, 78, 321-337. https://doi.org/10.1016/j.iref.2021.12.011.
[73] Xie, X., Hoang, T. T., & Zhu, Q. (2022). Green process innovation and financial performance: The role of green social capital and customers' tacit green needs. Journal of Innovation & Knowledge, 7(1), 100165. https://doi.org/10.1016/j.jik.2022.100165.
[74] Xu, C., Sun, G., & Kong, T. (2024). The impact of digital transformation on enterprise green innovation. International Review of Economics & Finance, 90, 1-12. https://doi.org/10.1016/j.iref.2023.11.001 .
[75] Xu, H., & Rhee, C. S. (2018). Corporate governance structure and accounting information disclosure quality: Evidence from Shenzhen stock exchange in China. Asian International Studies Review, 19(1), 99-116. https://doi.org/10.1163/2667078X-01901005
[76] Xu, J., Yu, Y., Zhang, M., & Zhang, J. Z. (2023). Impacts of digital transformation on eco-innovation and sustainable performance: Evidence from Chinese manufacturing companies. Journal of Cleaner Production, 393, 136278. https://doi.org/10.1016/j.jclepro.2023.136278
[77] Xue, L., Zhang, Q., Zhang, X., & Li, C. (2022). Can digital transformation promote green technology innovation?. Sustainability, 14(12), 7497. https://doi.org/10.3390/su14127497.
[78] Yang, Y., Zhu, Y., Li, Y., Zheng, Z., & Han, Y. (2023). The effect of CEO succession on green technology innovation: the mediating effect of earnings management. Environment, Development and Sustainability. https://doi.org/10.1007/s10668-023-04203-y.
[79] Yin, S., & Yu, Y. (2022). An adoption-implementation framework of digital green knowledge to improve the performance of digital green innovation practices for industry 5.0. Journal of Cleaner Production, 363, 132608. https://doi.org/10.1016/j.jclepro.2022.132608.
[80] Yin, S., Zhang, N., Ullah, K., & Gao, S. (2022). Enhancing digital innovation for the sustainable transformation of manufacturing industry: a pressure-state-response system framework to perceptions of digital green innovation and its performance for green and intelligent manufacturing. Systems, 10(3), 72. https://doi.org/10.3390/systems10030072.
[81] Yu, C. H., Wu, X., Zhang, D., Chen, S., & Zhao, J. (2021). Demand for green finance: Resolving financing constraints on green innovation in China. Energy policy, 153, 112255. https://doi.org/10.1016/j.enpol.2021.112255.
[82] Yusliza, M. Y., Yong, J. Y., Tanveer, M. I., Ramayah, T., Faezah, J. N., & Muhammad, Z. (2020). A structural model of the impact of green intellectual capital on sustainable performance. Journal of Cleaner Production, 249, 119334. https://doi.org/10.1016/j.jclepro.2019.119334.
[83] Zhang, G., Gao, Y., & Li, G. (2023). Research on digital transformation and green technology innovation—evidence from China's listed manufacturing enterprises. Sustainability, 15(8), 6425. https://doi.org/10.3390/su15086425
[84] Zhang, H., Wu, J., Mei, Y., & Hong, X. (2024). Exploring the relationship between digital transformation and green innovation: The mediating role of financing modes. Journal of Environmental Management, 356, 120558. https://doi.org/10.1016/j.jenvman.2024.120558.
[85] Zhang, M., & Huang, M. (2023). Study on the impact of informal environmental regulation on substantive green innovation in China: Evidence from PITI disclosure. Environmental Science and Pollution Research, 30(4), 10444-10456. https://doi.org/10.1007/s11356-022-22868-2.
[86] Zhang, Q., Yang, M., & Lv, S. (2022). Corporate digital transformation and green innovation: A quasi-natural experiment from integration of informatization and industrialization in China. International Journal of Environmental Research and Public Health, 19(20), 13606. https://doi.org/10.3390/ijerph192013606.
[87] Zhao, J., Qu, J., Wei, J., Yin, H., & Xi, X. (2023). The effects of institutional investors on firms' green innovation. Journal of Product Innovation Management, 40(2), 195-230. https://doi.org/10.1111/jpim.12652
[88] Zheng, Q., Li, J., & Duan, X. (2023). The impact of environmental tax and R&D tax incentives on green innovation. Sustainability, 15(9), 7303. https://doi.org/10.3390/su15097303.