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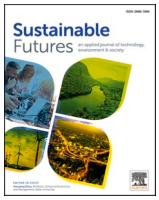

Innovation at the nexus of technology and sustainability: CEO leadership and digital transformation in China

Muhammad Kaleem Khan [a,*], Phool Hussain [b], Muhammad Jameel Hussain [c], Kathy Michael [d]

[a] Asia-Australia Business College, Liaoning University, China
[b] Faculty of Management, Prague University of Economics and Business, Jarošovská 1117/II, Jindrichuv Hradec, 377 01, Czech Republic
[c] School of Management, Northwestern Polytechnical University, China
[d] Victoria University Business School, Victoria University, Australia

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ABSTRACT

In response to escalating environmental issues, firms are urgently pursuing advanced technologies for sustainability and green innovation (greenovation). This study aims to examine the impact of digitalization on green innovation performance in Chinese firms, in light of China's growing digital economy and increasing environmental awareness. Furthermore, the study examines the moderating influence of diverse CEO characteristics on the relationship between digitization and green innovation. This study analyzes panel data comprising 21,764 firm-year observations from Chinese publicly traded companies (2008–2022) via the lenses of resource-based theory and agency theory. Research indicates a favorable correlation between digitization and green innovation, especially among experienced, well-educated, politically connected, and female CEOs. The research provides significant theoretical perspectives and practical applications for improving green innovation methods. The strong findings endure thorough validation, highlighting digitization as a crucial facilitator of corporate greenovation. These ideas are essential for navigating the realm of digital technologies about sustainability, especially in fast developing economies such as China.

1. Introduction

Environmental concerns, like the shortage of natural resources and the excessive release of carbon, have become increasingly prominent due to rapid economic expansion. To overcome these challenges, it is advisable for companies to actively pursue environmentally friendly innovation as a component of their corporate social responsibility [1]. Greenovation, a form of modernization that aims to conserve resources in addition reduce environmental pollution, facilitates firms achieve a balance between profitability and environmental responsibility [2,3]. Green innovation has turn into a crucial approach for enterprises to achieve sustainable progress and comply with environmental protection legislation [4]. The promotion of green innovation has become a decisive matter due to its ultimate significance.

The manufacturing companies are claiming that digital revolution has brought about more avenues for developing the green output in the form of energy efficient product or reduction in harmful wastes [5]. But there is a dearth of literature available to establish the link between digitalization and green innovation. China has taken place of third biggest digital economy in the world.[1] Chinese government is hugely investing on digitalization under the umbrella of its National Development Reform Commission . Here arises a question, whether this digital revolution in the economy will put the innovation of the Chinese firms on green path?

Conceptually, Digitalisation provides various advantages to a company, such as cost savings, enhanced operational productivity, and increased innovation achievement [6]. In essence, Digitalisation at the business level significantly influences modernization and entrepreneurship [7], organisational efficiency [8], and stock markets. Our primary purpose is to investigate the role of Digitalisation further, building upon the foundations established by previous investigations. We intend to investigate the advantages a firm can achieve by integrating Digitalisation into its operations, particularly in enhancing and promoting green innovation. The correlation between enterprise digitalisation and green innovation remains a contentious topic of discussion. The fundamental inquiry arises from two separate bodies of literature. Certain

* Corresponding author.
E-mail address: MuhammadKaleem.Khan@vu.edu.au (M.K. Khan).

[1] Read the news about globally digital-oriented countries https://www.ciie.org/zbh/en/news/exhibition/News/20210107/25218.html

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specialists assert that Digitalisation can facilitate and enhance green innovation. Conversely, some contend this Digitalisation could foster rivalry for rare organisational resources and interrupt green innovation [9]. Furthermore, while the influence of Digitalisation on fostering green innovation has been explored, there remains a deficiency in a comprehensive analysis of the underlying processes substantiated by sufficient observational indication [10]. The collective analysis emphasises the necessity for an in-depth investigation of the tangible advantages of digitalisation projects, particularly regarding critical decision-making plus communication methods inside organizations. Thus, the study not exclusively fills this significant inconsistency in comprehension but also possesses applicability and significance in consideration of many shareholders managing the intricacies of digitalisation implementation as well as its wider effects on organisational movement. Consequently, we embraced Digitalisation to examine its effects and processes on green innovation. Distinguished to alternative types of innovation, firms may be less driven for greenovation because of high perceived risk and considerable investment [11]. Here comes the CEO, who must make strategic decisions. Chief executive officer (CEO) is one actor who will decide whether the firm should adopt digitization and green innovation or not. They can even control the effects of digitalization on various firm level performance measures. The theoretical significance of digitalisation is substantially impacted by the practical implementation decisions of CEOs [12]. Moreover, the attributes of these CEOs, including their age, educational attainment, and gender, significantly influence the trajectory of digitalisation adoption [13], potentially resulting in enhanced greenovation. Prior research has solely examined the impact of CEO attributes on green innovation [14,15], neglecting the moderating character of CEO personal characteristics in the connection between digitalisation in addition green innovation. We aim to demonstrate how the human traits of CEOs influence corporate green innovation in this digital age. Consequently, we examined how CEO attributes influenced the connection between digitization and green innovation. The subsequent theoretical justifications for the influence of CEO learning, gender, and age on this connection are presented. Arising out age of CEOs, analyses implies that one's skill to make strong judgements doubles accompanying age and life capability [16]. Young CEOs can be more friendly with and affluent utilizing new technologies, moreover they may be further likely to visualize digitalization as a prospect to establish a back-and-forth competition. They can further be little opposed to alter than earlier CEOs [17]. Additionally, a younger CEO with a determined qualification in expertise may own a well knowledge of the possible advantages and uncertainties owned by digitalization and can be more enthusiastic to acquire the imperative capitals to execute and decreases the concern of calculated modernization [18]. The age of a CEO is a symbol of their career and experience in association to the performance of the company [19,20]. Elderly chief executive officers (CEOs) retain most competitive benefits compared to their younger counterparts, on account of their increased competence. This proficiency facilitates the conception of more prosperous strategic judgments. Elderly chief executive officers (CEOs) receive higher performance by making tentative and less assertive choices [20].

Proceeding with the CEO's education, higher education can increase understanding of the expected benefits of digitalisation, including increased competence, accuracy, and clarity [21]. The educational fulfillment of CEOs indicates their competence to use complex interpretation and creative thinking, easing the productive implementation of organisational approaches [22]. CEOs with leading education display greater openness to novel conceptions and technology, and they can retain superior proficiencies to determine the expected return on investment for digitalisation attempts. Moreover, CEOs acquiring robust analytic capabilities captured through progressive education may be more adept at calculating the endangers and challenges linked to digitalization and might be willing to formulate efficient extenuation plans [23]. Research signifies that, apart from CEO gender, female CEOs exhibit better risk-taking warning than their male colleagues [24]. This can prompt them to exercise better caution when dealing with digitalisation intentions. However, it could also encourage a focus on adopting digitalisation to mitigate risks while optimising benefits. Gender has varying effects on behavior among individuals. Even when men and women perform the identical work, their approaches differ. According to Wani and Masih [25], females exhibit greater emotional maturity and stability, are more cautious in taking risks as shown by Croson and Gneezy [26], and possess better multitasking abilities as demonstrated by Ruderman, Ohlott, Panzer, and King [27], compared to males. As a result, female CEOs are more adept at coordinating and overseeing strategy execution. According to [28], having women in leadership positions can enhance team efficiency and have positive externalities. According to Huang [29], organizations led by female CEOs have stronger balance sheets and to survive than those led by male CEOs with comparable qualities. Research indicates that, aside from CEO gender, female CEOs generally exhibit greater caution in risk-taking than their male colleagues [30]. This may prompt businesses to exercise greater caution in executing digitalisation efforts, while it could also encourage them to pursue digitalisation in a manner that mitigates risks and optimises rewards.

Moving towards CEO's Political connections, since [31–33], the research has demonstrated that a CEO's political connections have a noteworthy influence in a firm's market performance and competitive advantage. However, the method by which a CEO's political relationships influence the underlying forces of the CEO gender in business efficiency remains unknown. According to [34], enterprises with better political connections continue to benefit from external financing and product competition, despite a more equitable market environment. Piotroski & Zhang [35] suggest that corporations with significant political connections are more successful in IPOs.

Our study adds valuable contributions to the existing literature related to sustainability, green technological revolution, and CEO attributes. As a first step, it adds to what is already known about green innovation and gives proof that digitization is helpful in getting there. The study presents new empirical evidence that supports the idea that digitalization is positively related to corporate greenovation. This research fills an important gap in our understanding of how sophisticated digital technology might promote environmentally friendly innovation. Prior studies have examined factors that influence sustainable business practices for instance control and participant stress [36, 37]. However, the connection between digitalization and corporate green behavior has not been thoroughly investigated. In general, research focuses on the meaning and categorization of digital transformation [38,39] and on its economic effects [40] with less consideration given to how digital transformation affects enterprise green innovation. Our research enhances the existing body of knowledge on technology adoption by showcasing how digitalization can facilitate the implementation of environmentally friendly innovations, often known as greenovation. Our hypothesis builds upon the resource-based view (RBV) and contributes to the development of RBV theory by depicting the digitalization, as a deliberate resource, enhances reasonable benefit by enabling greenovation. The study demonstrates the advantages in performance that come with digitization, responding to the need for more investigation into the results of implementing digitalization [41]. This text explores the theoretical basis for utilizing emerging technologies such as artificial intelligence, blockchain, and data analytics to create and execute systems that increase green innovation. The inquiry encompasses the effects of modern technologies on hazard identification, evaluation, and improvement inside organisations. Secondly, the report underscores the significant economic advantages linked to the adoption of digitalisation for enhancing green innovation. Secondly, we have identified and checked the controlling nature of CEO attributes in the relationship between digitisation and green innovation. This study examines the CEO's age, education, political ties, and gender. This study adds to the existing literature on CEO characteristics by including the most important attributes of CEOs. This study provides notable

additions by demonstrating a novel aspect on the convergence of digitalisation, green innovation, and CEO individual traits. The findings embellish the perceptive of the intelligent and behavioural dimensions connected to the intimate attributes of CEOs in the framework of digitalisation, allowing for possibility the CEO's gender, age, political relations, in addition of academic qualification. This establishes the ground for understanding how sensible partialities, decision styles, and predictive sense, impacted through age, gender, governmental affiliation, and education, influence acceptance and achievement of digital efforts about green innovation. Our research uses principal-agent theory to demonstrate the substantial effects of digitalisation on green innovation across various CEO leadership frameworks. This highlights the influence of CEO traits on their feedback to new technologies, which is a topic that has acknowledged definite consideration in research on technology acceptance [42,43]. The study uses principal-agent theory to illustrate the substantial impacts of digitalization on green innovation under different CEO leadership situations. This emphasizes the impact of CEO attributes on their responses to new technologies, a subject that has been minimally explored in studies on technology adoption [42,43]. This promotes comprehension of the involvement of internal stakeholders in facilitating the use of technology for the purpose of sustainability. The findings also make a valuable contribution to the existing body of research on innovation in developing economies such as China, where the government is actively promoting effective leadership in companies [44].

That will help to enhance the ecofriendly measure by the Chinese firms and design a proper track to achieve SDGs. This study deviates from all the extant studies available on similar topics. The closest study is [5], which has also explored the relationship of digitalization with green innovation of Chinese studies. However, their study has seen this relationship through the lens of absorption capacity. Whereas our study has explored this nexus in the light of resource-based view and agency cost. Moreover, our study has explored the moderation effects of CEO attributes, which makes our study distinct from all the studies on the topic of digitalization and green innovation relationship. Another relevant study is ([45]; Dukangqi [46]), but it also did not incorporate the moderating impacts of CEO attributes.

The remainder of the paper is structured as follows: Second section presents a discussion culminating in a research gap. Third part designs the methodology to conduct this research followed by results and discussion in part four. The last section presents conclusions, implications, limitations and future recommendations.

2. Literature review and hypothesis development

2.1. Digitalization – greenovation nexus

The resource-based view theory explains how organization gets sustainable competitive advantage by using its resources [47,48]. This theory considers firms' own resources and capabilities as the primary drivers of its competitive advantage rather than external factors, for example industry as suggested by Porter [49]. Digitalization is now an indispensable tool for companies in today's market [50]. Businesses may enhance their data accumulation, analysis, and use, in addition to their operations, communication, and decision-making, by way of digital technologies. Through improving productivity, incisive costs, and providing purchasers with exceptional products and services, businesses can get a back-and-forth competition through the clever use of digital technologies. An extra separating determinant for businesses may be green innovation, that is generating and executing eco-friendly goods, operations, and practices. Companies which put fund into green innovation position a larger possibility of being conspicuous from the circle, satisfying consumers' demands for eco-friendly goods and duties, staying in accordance with government authorities, and developing their public understanding.

Companies can accelerate and reduce their green innovation processes with digitalization. Sustainable commodity and solution evolution, energy utilization optimization, waste decline, and environmental impact observing are all attainable by way of digital technologies like data analytics, the Internet of Things (IoT), artificial intelligence (AI), and blockchain. With the help of digitalization, businesses may more conveniently gain and inspect large volumes of data related to their environmental depiction, identify difficulty areas, and enact visionary solutions. Businesses need to become agile, creative, and capable to shift their resource base as required so that shine in the age of digitalization and green innovation. In order to make use of digital tools for environmentally familiar innovation and stay up with technological progresses, businesses must steadily develop their digital experiences. Training staff members, encouraging an essence of creativity, building crucial alliances, adapting to switching market conditions, and assuring the environment are all contained this. Businesses and society may gain from digitization and green innovation collaboration. They can achieve sustainability aims, satisfy shareholders, reduce their impact on the surroundings, and bring economic advantage ultimately. A company's reliability, collaborator trust, and long-term profit can all be pushed when corporate ambitions are in accordance with social demands.

The digitalization has an affect greenovation. Research discloses that the digital economy is undoubtedly tied in with green innovation [51]. Green innovation is encouraged by the digital economy by bright firms to digitize their operations [52]. The digital economy further builds it permissive for companies to find and evolve green technologies. Through digitization, companies can record and determine their energy usage, acknowledging them to classify opportunities for more effective and sustainable operations (S. [53]). Additionally, the digital economy has empowered companies to build more productive marketing plannings for green products, making it easier to receive all-inclusive out about their products and services [51]. Other studies demonstrate that digital conversion can considerably facilitate incremental green innovation (Xiaoxu [5,54] disclose that organizations' digitalization and green innovation plans have been undoubtedly contributing to the swift evolution of digital technologies. Similarly, high-polluting companies' intentions to advance sustainable development and digital transformation have drawn significant concern [55].

Furthermore, Liu [56] found that digital renovation extremely improves green innovation. According to the instrument analysis, digital transformation encourages green innovation by lowering the cost of loans and raising the investment of resources for innovation. Digital transformation is a promising approach to enhance green innovation and address environmental issues in production and operation. This discussion takes us to build the following baseline hypothesis.

H1. *The digitalization fosters the greenovation.*

2.2. CEO's age

Younger and older executives typically have different risk tolerances, information-gathering and processing skills, and management experience [57]. Hambrick and Mason [20] point out that age is a proxy for experience and risk tolerance in executives. Older CEOs tend to be more cautious in evaluating strategic options for their companies since they are familiar with the industry's rules, hazards, and competition. In contrast, younger executives are more able to learn new skills and information, even though they possess comparatively less managerial experience. Consequently, young executives will be motivated to emulate peers' digital transformation plans when they create or execute their own. Fan et al. [58] found that younger CEOs are more sensitive to environmental factors and have superior abilities in processing and integrating information. Younger CEOs demonstrate more flexibility in decision-making and are more sensitive to information. Older CEOs often emphasize internal experience over external information, which reduces the remark value of outside information. Due to this, earlier executives may be less informed and comprehend information regarding

their peers' decisions. By comparison, businesses are more inclined imitate and absorb knowledge from their peers' digital conversion administrative when the percentage of younger executives in top management increases [59].

H2. *The Valuable Effects of Digital Transformation on Enterprises Green innovation is prominent in firms led by young CEOs than those with older CEOs.*

2.3. CEO education

There is a definite correlation between executive education and cognitive capacities [60–62] indicate that well educated top management are more apt to form strategic adjustments. Producing information swiftly, impartially, and thoroughly is advantageous for executives with a particular learning capacity [54]. The highly educated CEOs' aspirational mindset also facilitates corporate digital transformation. While making decisions about digital transformations, well-educated executives weigh the costs and benefits more thoroughly [63]. Furthermore, they combine internal and external knowledge to form a reasonable and scientific judgment, which prevents them from missing opportunities or taking unwarranted risks [64]. In competitive market conditions, higher-educated executives tend to react more quickly and are more perceptive to the actions and choices of their peers. Thus, well-educated top governance is more likely to reduce their strategic plans based on the strategies of their associates when executing digital transformation [65].

H3. The Positive Significance of Digitalization on Firm Green Innovation is More Pronounced in Firms with highly educated CEO.

2.4. Politically connected CEOs

Subsequently, when CEOs are politically united, digitalization impacts greenovation to some extent. The firms are more inclined to embrace green technologies, invest in green innovation, and undertake green activities [66]. *Furthermore, these firms are more likely to gain government financial aids and incentives, additional strengthening their innovation competence* [34]. *This, in turn, leads to a competitive advantage and grants them a larger market share. Furthermore, politically linked CEOs are more likely to enact political decisions that contribute to their firms, such as campaigning green policies. This can bring about a more important impact on the environment and a boost in profits for the firms. Furthermore, politically linked CEOs are more likely to receive favoritism from government leaders, making it easier for authority to do business* [67].

H4. *The Positive Effect of Digitalization on Firm Green Innovation is More obvious in Firms with politically linked CEOs.*

2.5. Female CEO

There is a contrast in attitude between male and female CEOs concerning social cooperation, risk propensities, and governance styles [68, 69]. Former studies have proved that female executives have better interpersonal abilities. Women are more likely than men to cultivate interpersonal connections and information sharing, focus more on collaboration and sharing, and create social network connections [68]. Thus, female CEOs are more likely to foster communication and collaboration among peer organizations, enhancing their ability to observe and replicate their peers' digital transformation decision-making. Additionally, research shows that female CEOs make more circumspect and risk-opposing decisions rather than male executives ([70]. As a result, organizations will be more inclined to emulate their peers' low-risk strategic decisions and risk-averse mindset when it comes to digital transformation decisions. Senior managers are more likely to use information sharing to modify their decisions when the number of women in senior management increases, thus enhancing the impact of peer organizations' digital transformations.

H5. The significant effect of Digital Transformation on Firm's Green Innovation is more evident in Firms with Female CEOs compared to Male CEOs.

3. Methodology

3.1. Data source and sample selection

The current analysis employs a panel dataset comprising all A-share businesses that were listed on the Shanghai and Shenzhen stock exchanges from 2008 to 2022. Chinese companies who are at the top of their industry have begun integrating digital transformation into their business strategy since 2007. The data on digital transformation and corporate governance attributes is sourced from the China Stock Market and Accounting Research Database (CSMAR) as well as the Chinese Research Data Service Platform (CNRDS). To assure reliable results, the calculation of variables excludes all financial enterprises, firms accompanying exclusive treatment status, and companies accompanying incomplete data. Consequently, the ultimate dataset comprises 21,764 observations of A-shared listed firm-year for analysis.

3.2. Variable measurement

3.2.1. Greenovation

The Sustainable Development Goals (SDGs) are a collection of 17 global goals set by the United Nations to achieve environment sustainably and ensure prosperity for all by 2030. Prior research, such as studies conducted by Li et al. [71] and Wu et al. [72], has defined the term "green innovation" (hence referred to as "greenovation") as patents awarded for inventions related to environmental protection. The researchers employed the quantity of green patents awarded to each company as a metric to gauge the level of green innovation within company. The justification for utilizing green patents stems from the fact that they represent a company's intention to develop environmentally friendly technology, that is essential for attaining sustainable development objectives.

3.2.2. Digitalization

This study concentrates on digital transformation. To build a digitalisation index, we employ a dictionary-based text analysis of the annual reports of publicly traded companies, like previously investigated [73]. This research integrates nine elements characterising digital transformation: big data, informatisation, digitisation, and computing, distinguishing it from the research by Boffa & Maffei, [74], which employed five keywords. The utilisation of nine keywords has led to an expansion of the scope. Subsequently, we construct an extensive digital lexicon by augmenting the fundamental terminology. Employing a model, we ascertain keywords along analogous implications to the fundamental terms in the reports. This enabled us to locate as well as enumerate supplementary vocabulary linked to the nine keywords, yielding 147 associated terms. Ultimately, we measured the degree of digitalisation by calculating the natural logarithm of the final word count plus one [75].

3.2.3. Measuring CEO attributes

CEO Gender (*CEO gender*) is measured by a dummy variable which is 1 if the firm has led by male CEO and 0 otherwise. CEO Political Connections (*CEO_pol*) is measured by a dummy variable which is equal to 1 if the firm CEO has political connections. CEO Education (*CEO_edu*) is a dummy variable which is equal to 1 if the CEO have a master's or PhD degree, 0 otherwise. CEO Age (*CEO age*) is a dummy variable which is equal to 1 if the young CEO's age is between 30 and 45 years and 0 otherwise

3.2.4. Control variables

By following previous studies [76–80], we also control for the

different variables, which may influence the relationship between digital transformation and environmental decoupling in Chinese listed firms. First, we control for the board level characteristics such as board size (total number of directors on the board), board independence (number of independent directors divided by total directors), CEO duality (dummy variable equal 1 if CEO also holds the chairman position and otherwise zero) and CEO gender (dummy variable equal 1 if CEO is a male or zero otherwise). Second, we control for the firm level characteristics such as firm profitability measure as return of assets (ROA), firm size (natural logarithm of total assets), firm age (taking the no of years since the firm is listed on stock exchange), leverage (total debt divided by total assets) and ownership concentration as shareholders owned by largest shareholder (Top 1), total capital expenditures divided by total assets (Cap_inten).

3.3. Econometric model

Our research employs a positive approach to empirically establish causal relationships, specifically examining the impact of digitalization on corporate greenovation [81]. This approach utilizes deductive reasoning, drawing on existing theories to formulate testable hypotheses [82]. Similar investigations, such as those by Khan et al. [44] and Zahid et al. [83], have utilized OLS regression with fixed effects to explore associations within comparable contexts. Other scholars have used similar methods to explore relationships of greenovation with CEO marketing experience [84], government influence on executive salary and tournament incentives [85]. Henceforward, following the relevant extant literature, following baseline OLS model with fixed effects is developed to test our hypothesis 1.

$$greenovation_{it} = \alpha + \beta_1 DIG_{it} + \beta_2 X_{it} + \omega_{year} + \omega_{Industry} + \varepsilon_{it} \quad (1)$$

In the model, $greenovation_{it}$ represents the performance of green innovation of each firm i in each year t. DIG_{it} denotes the level of digitization in the firm i. X_{it} comprises control variables that operate at the business, industry, and board levels including *board size, board ind, CEO duality, CEO gender, ROA, firm size, firm age, leverage, Top1, Cap_Inten* (see Table-A in appendix 1 for more information on variables). The vector ω_{year} represents temporal fixed effects, while $\omega_{Industry}$ is a dummy variable used to account for the influence of unobservable factors specific to the industry. ε_{it} denotes error term in the regression model, represented as E1. (1) (Table 1).

Table 1
Defining variables: Syntax and Measurement.

Syntax	Variable Name	Measurement
Independent Variable		
DIG	Digitalization	We use a dictionary-based text analysis taking nine keywords, namely big data, informatization, intelligence, robotics, Internet of Things, blockchain, automation, digitization, and cloud computing of the listed corporations' annual reports to create the digital transformation index.
Dependent Variable		
GRNV	Green Innovation (greenovation)	the count of green patents granted to a firm by the government at year (t) scaled by total patents granted in the industry at year (t)
Moderating and Control Variables		
CEO_gend	CEO Gender	A dummy variable =1 if the firm has led by male CEO and 0 otherwise
CEO_pol	CEO Political Connection	A dummy variable =1 if the firm CEO has political connections.
CEO_age	CEO Age	A dummy variable =1 if the young CEO's age is between 30 and 45 years and 0 otherwise
CEO_edu	CEO Education	A dummy variable =1 if the CEO have a master's or PhD degree, 0 otherwise
Board_size	Board Size	total number of directors on the board
Board_ind	Board Independence	number of independent directors divided by total directors
CEO_dual	CEO Duality	dummy variable equal 1 if CEO also holds the chairman position and otherwise zero
ROA	Return on Assets	The proportion of net income to total assets
Size	Firm Size	natural logarithm of total assets
Leverage	Leverage	total debt divided by total assets
Top1	Ownership Concentration	Shareholding owned by largest shareholders
Cap_Inten	Capital Intensity	total capital expenditures divided by total assets

4. Empirical findings and robustness tests

4.1. Descriptive statistics and correlation analysis

Table 2 displays descriptive data for all variables used in this study. The mean value of greenovation is 0.152(0.354), illustrating that firms in the sample are granted 0.153 average green patents. The mean value of digitalization in the total Sample of Chinese listed companies is 0.009, while the highest score is 0.056, demonstrating that the implementation of digitalization is still small, Descriptive statistics of other variables cold be found in Table 2.

Table 3's Pearson's correlation coefficients shed light on the connections between variables. The correlation coefficient of 0.026* between DIG and GRNV suggests a positive relationship, indicating that a higher level of digitalization in the organization is associated with improved greenovation. Furthermore, the coefficients of correlation between all other variables are quite small, suggesting the lack of severe problems associated with multicollinearity.

4.2. Results of baseline tests

Based on the regression results presented in Table 4, there appears to be a statistically significant positive relationship between digital transformation and corporate green innovation (GI). Specifically, the coefficient on DT is 0.901 and is highly statistically significant ($p < 0.01$). This suggests that a 1 unit increase in DT is associated with a 0.901 unit increase in GI, on average and holding all other variables constant. In other words, the findings indicate that higher levels of digital transformation within a firm are associated with higher levels of corporate green innovation. This relationship is quite strong, as indicated by the large and highly significant coefficient. Some potential explanations for this positive association could be that digital technologies enable more efficient operations, data collection, analytics, and new innovations that can reduce environmental footprints. Digital transformation may provide capabilities that allow firms to more readily develop and implement new green products, services, and processes. Overall, the results suggest digitalization facilitates and promotes corporate green innovation among Chinese firms. In summary, the regression analysis specifies fascinating empirical evidence that digital transformation has a statistically and economically notable positive affect corporate green innovation within sample of Chinese firms. The findings highlight that digitalization is an imperative antecedent and facilitator of green innovation (Table 5).

The regression analysis examines the connection between diverse firm-level traits and green innovation in the middle of a sample of Chinese firms. The results signify that digital transformation has a statistically important positive association with green innovation. Specifically, the coefficient on digital transformation is 0.901 and very important, suggesting that greater levels of digitalization inside firms are associated with expanded green innovation. This makes sense, as digital technologies can allow more effective and sustainable actions, data-driven observations, and new green innovations (Table 6).

In comparison, the analysis finds that other firm traits like board size, board liberty, CEO attributes, profitability, capacity, age, capital structure, ownership concentration, and capital depth do not demonstrate statistically important connections accompanying green innovation. For

Table 2
Descriptive statistics.

	N	Mean	Std. Dev.	min	p25	Median	p75	max
GI	21,764	0.152	0.354	0.000	0.000	0.000	0.000	1.857
GT	17,428	0.009	0.010	0.000	0.003	0.005	0.011	0.056
Board_size	21,461	9.431	2.453	5.000	8.000	9.000	11.000	18.000
Board_ind	21,461	0.377	0.063	0.250	0.333	0.364	0.429	0.583
CEO_dual	21,764	0.294	0.456	0.000	0.000	0.000	1.000	1.000
CEO_gend	21,764	0.933	0.251	0.000	1.000	1.000	1.000	1.000
CEO_pol	21,753	0.075	0.263	0.000	0.000	0.000	0.000	1.000
CEO_edu	21,764	3.427	0.897	1.000	3.000	4.000	4.000	5.000
CEO age	21,764	49.697	6.574	33.000	45.000	50.000	54.000	66.000
ROA	21,464	0.053	0.073	−0.302	0.027	0.053	0.085	0.253
Firm size	21,764	9.620	0.676	8.488	9.171	9.485	9.906	12.191
Firm age	17,948	2.206	0.861	0.000	1.792	2.398	2.890	3.466
Leverage	21,764	0.428	0.223	0.047	0.249	0.413	0.588	0.956
Top1	21,548	34.267	15.250	8.360	22.430	31.870	44.250	76.290
Cap_inten	16,375	0.051	0.049	0.000	0.015	0.037	0.071	0.234

example, the coefficient on board size is very small at 0.000 and meaningless, indicating that the size of a firm's board does not intentionally impact green innovation initiatives. Similarly, the coefficient on CEO gender is miniature and unimportant, suggesting the gender of the CEO is not basically associated with a firm's level of green innovation (Table 7).

The lack of significant relationships between green innovation and traditional firm characteristics like governance mechanisms, CEO traits, size, age, capital structure, ownership, and capital intensity are notable. It indicates that these organizational factors may not be as relevant for explaining differences in green innovation as digital transformation. Overall, the findings highlight that digitalization rather than other firm-level factors seems to be the key antecedent and enabler of corporate green innovation in this sample of Chinese companies. The results point to the potentially transformative power of digital technologies in driving sustainability outcomes (Table 8).

4.3. Impact of CEOs' attributes on the digitalization-greenovation nexus

4.3.1. Moderating effect of CEO age

To investigate whether CEO age moderates the relationship between digitalization and greenovation, we priori classified the firms on the basis of CEO age, thereby got two classes of data; one sample class where the CEO is young and another where the CEO is old aged. The findings are presented in table number 5.

The findings illustrate that CEO age moderates the relationship between digital transformation (DT) and greenovation (GI). Specifically, firms with older CEOs exhibit a stronger positive association between DT and GI ($b = 1.600$, $p < 0.01$) compared to firms with younger CEOs ($b = 1.211$, $p > 0.10$). This suggests that the digital transformation efforts of firms led by older CEOs are more strongly linked to increases in green innovation. A potential explanation is that older CEOs with more experience may be better positioned to leverage digital technologies to create environmentally friendly innovations.

In terms of the control variables, return on assets (ROA) is positively associated with GI for firms with older CEOs ($b = 0.002$, $p < 0.01$), indicating greater profitability supports green innovation in these firms. However, ROA has a negative relationship with GI for firms with younger CEOs ($b=-0.013$, $p < 0.05$), suggesting profit motivations may deter green innovations under younger leadership. Firm size exhibits a positive association with GI across both older ($b = 0.045$, $p < 0.01$) and younger ($b = 0.026$, $p > 0.10$) CEO firms, implying larger firms engage in more green innovation, although the effect is stronger with older leadership. Leverage has a negative link to GI only for older CEO firms ($b=-0.000$, $p < 0.10$), potentially indicating higher debt levels constrain the pursuit of green innovation in these firms. The associations between GI and the other control variables of board size, independence, CEO duality, CEO gender, firm age, ownership concentration, and capital intensity are statistically insignificant (Table 9).

The findings indicate CEO age is an important contingency that strengthens the digital transformation-green innovation relationship, with older CEOs being more effective at leveraging digital technologies for environmental innovations. The results have implications for research on upper echelons theory and the role of top executives in shaping sustainability strategies.

4.3.2. Moderating effect of CEO education

To investigate whether CEO education moderates the relationship between digitalization and greenovation, we priori classified the firms on the basis of CEO education. This has divided the data into two sets, one data set is that for companies which has highly educated CEO and other dataset is from the companies which is less having CEO not having master's or PhD degree. The results are presented in table number 6.

The findings signify that CEO education level moderates the connection among digital transformation (DT) and green innovation (GI), albeit with some differences from expectations. For firms with highly educated CEOs (with masters/PhD degrees), there is a positive association between DT and GI ($b = 1.369$, $p < 0.05$). This aligns with predictions and suggests digitalization efforts in firms led by highly educated CEOs translate into greater green innovations. However, for firms with less educated CEOs (without advanced degrees), the coefficient for DT is also positive but insignificant ($b = 1.556$, $p > 0.10$). The lack of significance among less educated CEO firms is surprising, as it was expected their digitalization strategies would be less oriented toward environmental innovations.

Regarding the controls, return on assets (ROA) has a positive link to GI for highly educated CEO firms ($b = 0.001$, $p < 0.10$), indicating profitability supports green innovation in these firms. Firm size also exhibits a positive relationship with GI across both subsamples (High educ $b = 0.033$, $p < 0.05$; Low educ $b = 0.034$, $p < 0.10$), suggesting larger firms engage in more green innovations, with a slightly stronger effect for highly educated CEOs. Leverage is negatively related to GI for both groups (High educ $b=-0.000$, $p < 0.05$; Low educ $b=-0.000$, $p < 0.10$), implying higher debt constrains green innovation regardless of CEO education level. The other control variables have statistically insignificant associations with GI.

In summary, while CEO education strengthens the digital transformation-green innovation relationship as predicted, the positive coefficient for less educated CEOs is counterintuitive. Additional research on contingencies shaping this relationship is warranted. The findings contribute to upper echelons perspective by highlighting the nuanced role of CEO education in harnessing digital technologies for environmental objectives.

4.3.3. Moderating effect of CEO political connections

To investigate whether CEO political connections moderate the

Table 3
Correlation Matrix.

Variables	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)
(1) GI	1.000														
(2) DIG	0.026*	1.000													
	(0.001)														
(3) Board size	−0.004	0.013	1.000												
	(0.595)	(0.097)													
(4) Board_ind	0.012	0.004	−0.222*	1.000											
	(0.085)	(0.616)	(0.000)												
(5) CEO_dual	−0.009	0.007	−0.176*	0.095*	1.000										
	(0.196)	(0.349)	(0.000)	(0.000)											
(6) CEO_gend	0.002	−0.001	0.045*	−0.039*	0.043*	1.000									
	(0.765)	(0.918)	(0.000)	(0.000)	(0.000)										
(7) CEO_pol	0.002	−0.004	−0.024*	0.025*	0.041*	−0.030*	1.000								
	(0.793)	(0.613)	(0.001)	(0.000)	(0.000)	(0.000)									
(8) CEO_edu	−0.008	0.008	0.125*	−0.012	−0.039*	0.026*	0.120*	1.000							
	(0.226)	(0.272)	(0.000)	(0.084)	(0.000)	(0.000)	(0.000)								
(9) CEO_age	0.012	0.015	0.043*	0.019*	0.173*	0.038*	−0.042*	−0.056*	1.000						
	(0.069)	(0.045)	(0.000)	(0.007)	(0.000)	(0.000)	(0.000)	(0.000)							
(10) ROA	0.001	−0.014	−0.067*	0.003	0.040*	−0.012	0.005	−0.033*	0.023*	1.000					
	(0.921)	(0.062)	(0.000)	(0.661)	(0.000)	(0.084)	(0.478)	(0.000)	(0.001)						
(11) Firm size	0.009	0.051*	0.350*	0.003	−0.194*	0.042*	0.024*	0.212*	0.153*	−0.026*	1.000				
	(0.172)	(0.000)	(0.000)	(0.696)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)					
(12) Firm age	0.007	−0.029*	0.134*	−0.065*	−0.150*	−0.015	−0.044*	0.021*	0.042*	−0.072*	0.128*	1.000			
	(0.313)	(0.000)	(0.000)	(0.000)	(0.000)	(0.023)	(0.000)	(0.002)	(0.000)	(0.000)	(0.000)				
(13) Leverage	0.012	0.006	0.245*	−0.034*	−0.180*	0.027*	−0.032*	0.099*	0.031*	−0.307*	0.521*	0.246*	1.000		
	(0.070)	(0.408)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)			
(14) Top1	−0.012	−0.009	−0.026*	0.037*	−0.045*	−0.008	−0.018	−0.015	0.025*	0.155*	0.140*	−0.066*	0.010	1.000	
	(0.080)	(0.237)	(0.000)	(0.000)	(0.000)	(0.240)	(0.010)	(0.027)	(0.000)	(0.000)	(0.000)	(0.000)	(0.127)		
(15) Cap_inten	−0.005	−0.008	−0.067*	0.001	0.077*	0.016	−0.010	−0.073*	−0.032*	0.167*	−0.108*	−0.142*	−0.130*	0.071*	1.000
	(0.561)	(0.353)	(0.000)	(0.873)	(0.000)	(0.046)	(0.224)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	

*** $p < 0.01$, ** $p < 0.05$,.
* $p < 0.1$.

Table 4
Main Result Impact of Digital transformation and corporate green innovation.

	(1) GI
DT	0.901**
	(2.192)
Board_size	0.000
	(0.278)
Board_ind	0.048
	(1.427)
CEO_dual	−0.006
	(−1.557)
CEO_gend	0.001
	(0.208)
ROA	−0.028
	(−1.070)
Firm size	0.013
	(0.172)
Firm age	−0.002
	(−0.249)
Leverage	0.003
	(0.307)
Top1	−0.000
	(−1.405)
Cap_inten	0.023
	(0.587)
_cons	−0.037
	(−0.053)
Observations	12,168
R-squared	0.568
Firm-FE	Yes
Year FE	Yes

t-values are in parentheses.
*** $p < 0.01$,.
** $p < 0.05$, * $p < 0.1$.

Table 5
Impact of CEO Age.

	(1) Old_Age	(2) Young_Age
DT	1.600**	1.211
	(2.113)	(1.593)
Board_size	−0.002	0.001
	(−0.645)	(0.348)
Board_ind	0.008	0.064
	(0.092)	(0.597)
CEO_dual	−0.006	0.004
	(−0.572)	(0.290)
CEO_gend	0.009	−0.003
	(0.382)	(−0.112)
ROA	0.002***	−0.013**
	(4.773)	(−2.457)
Firm size	0.045***	0.026
	(3.087)	(1.503)
Firm age	0.010	0.005
	(1.221)	(0.526)
Leverage	−0.000*	−0.000
	(−1.943)	(−1.617)
Top1	−0.001***	0.000
	(−2.647)	(0.483)
Cap_inten	−0.030	−0.027
	(−0.242)	(−0.232)
_cons	−0.262*	−0.140
	(−1.794)	(−0.823)
Observations	5795	6373
R-squared	0.021	0.014
Firm-FE	Yes	Yes
Year FE	Yes	Yes

t-values are in parentheses.
*** $p < 0.01$.
** $p < 0.05$.
* $p < 0.1$.

Table 6
Impact of CEO Education.

	(1) High_Edu	(2) Low_Edu
DT	1.369**	1.556
	(2.130)	(1.620)
Board_size	−0.000	0.000
	(−0.222)	(0.029)
Board_ind	0.080	−0.061
	(1.045)	(−0.480)
CEO_dual	−0.002	0.008
	(−0.234)	(0.465)
CEO_gend	0.020	−0.053
	(1.309)	(−1.165)
ROA	0.001*	−0.043
	(1.706)	(−1.261)
Firm size	0.033**	0.034*
	(2.400)	(1.744)
Firm age	0.006	0.010
	(0.744)	(0.882)
Leverage	−0.000**	−0.000*
	(−2.051)	(−1.661)
Top1	−0.000	−0.001*
	(−0.739)	(−1.750)
Cap_inten	0.002	−0.221
	(0.017)	(−1.403)
_cons	−0.217	−0.073
	(−1.583)	(−0.357)
Observations	8451	3717
R-squared	0.011	0.032
Firm-FE	Yes	Yes
Year FE	Yes	Yes

t-values are in parentheses.
*** $p < 0.01$,.
** $p < 0.05$,.
* $p < 0.1$.

Table 7
Impact of CEO Political Connection.

	(1) Pol_Co	(2) No_Pol_Co
DT	1.329**	2.488
	(2.130)	(1.445)
Board_size	0.000	−0.005
	(0.061)	(−0.770)
Board_ind	0.051	−0.137
	(0.754)	(−0.557)
CEO_dual	−0.002	−0.000
	(−0.175)	(−0.010)
CEO_gend	0.005	−0.053
	(0.331)	(−0.861)
ROA	0.001	−0.028
	(1.086)	(−0.108)
Firm size	0.030**	0.102***
	(2.306)	(2.860)
Firm age	0.005	0.024
	(0.681)	(1.262)
Leverage	−0.000***	−0.001
	(−3.360)	(−1.086)
Top1	−0.000*	0.001
	(−1.833)	(0.583)
Cap_inten	−0.019	−0.224
	(−0.220)	(−0.602)
_cons	−0.157	−0.743**
	(−1.209)	(−2.043)
Observations	1590	10,578
R-squared	0.010	0.090
Firm-FE	Yes	Yes
Year FE	Yes	Yes

t-values are in parentheses.
*** $p < 0.01$,.
** $p < 0.05$,.
* $p < 0.1$.

Table 8
Impact of Female CEO.

	(1) F_CEO	(2) M_CEO
DT	1.406**	1.950
	(2.336)	(0.714)
Board_size	0.000	−0.002
	(0.062)	(−0.361)
Board_ind	0.023	0.324
	(0.346)	(1.215)
CEO_dual	−0.001	0.028
	(−0.165)	(0.604)
ROA	0.001	−0.496**
	(1.431)	(−1.985)
Firm size	0.033***	0.056
	(2.587)	(1.477)
Firm age	0.006	0.018
	(0.859)	(0.690)
Leverage	−0.000***	−0.001*
	(−3.512)	(−1.809)
Top1	−0.000*	0.000
	(−1.741)	(0.038)
Cap_inten	−0.108	0.880**
	(−1.280)	(2.010)
_cons	−0.170	−0.544
	(−1.331)	(−1.318)
Observations	1401	10,767
R-squared	0.011	0.104
Firm-FE	Yes	Yes
Year FE	Yes	Yes

t-values are in parentheses.
*** $p < 0.01$,.
** $p < 0.05$,.
* $p < 0.1$.

Table 9
Univariate.

Obs	4256		4256		
	Mean	SD	Mean	SD	p-value
Boardsize	9.374	−2.46009	9.488	−2.44521	<0.001
Board_Ind	0.378	−0.06183	0.377	−0.06392	0.74
CEO_Duality	3230	−29.60 %	3166	−29.10 %	0.42
CEO_Gender	10,144	−93.10 %	10,151	−93.40 %	0.32
ROA1	0.053	−0.07342	0.052	−0.07276	0.24
Firm_size	9.55	−0.65497	9.69	−0.69013	<0.001
L_Firmage2	1.378	−0.10257	1.377	−0.10257	0.31
Leverage	0.418	−0.22454	0.438	−0.22011	<0.001
Top1	34.093	−15.0906	34.442	−15.4062	0.092
CapInten	0.052	−0.05226	0.051	−0.05038	0.2

Data are presented as mean (SD) for continuous measures, and n (%) for categorical measures.

relationship between digitalization and greenovation, we priori classified the firms based on CEO political connections. This has divided the data into two sets, one data set is that for companies which has politically connected CEO and other dataset is from the companies which is having not-politically connected CEO. The results are presented in table number 7.

The findings show that CEO political connections moderate the bond between digital transformation (DT) and green innovation (GI). For firms with politically connected CEOs, there is a positive association between DT and GI ($b = 1.329$, $p < 0.05$). This suggests digitalization efforts in politically connected firms lead to greater green innovation, perhaps due to the CEOs' ability to secure governmental resources and policies to support environmental objectives. In contrast, for firms without politically connected CEOs, the coefficient for DT is positive but insignificant ($b = 2.488$, $p > 0.10$), indicating the digital transformation-green innovation link is weaker when firms lack political ties at the upper echelons.

Looking at the control variables, firm size exhibits a positive relationship with GI for both subsamples (Politically connected $b = 0.030$, $p < 0.05$; Not politically connected $b = 0.102$, $p < 0.01$). This shows larger firms engage in more green innovation, with a stronger magnitude for firms without political CEO connections. Leverage has a negative association with GI only for politically connected firms (b=−0.000, $p < 0.01$), suggesting higher debt constrains green innovation specifically when CEOs have political ties. The other controls do not have statistically significant relationships.

The results provide support for upper echelons theory by demonstrating CEO political connections strengthen the translation of digitalization into environmental innovations. However, the lack of significance for firms without politically tied CEOs is unexpected and warrants additional investigation. The findings have practical implications regarding the value of political networks at the executive level for harnessing digital technologies to promote green innovation.

4.3.4. Moderating effect of female CEO

To investigate whether CEO gender moderates the correlation between digitalization and green innovation, we priori classified the firms on the basis of female CEO. This has divided the data into two sets, one data set is that for companies which has female CEO and other dataset is from the companies which is having male CEO. The results are presented in table number 8.

The findings indicate that CEO gender moderates the relationship between digital transformation (DT) and green innovation (GI). For firms with female CEOs, there is a positive association between DT and GI ($b = 1.406$, $p < 0.05$). This suggests that digitalization efforts in firms led by female CEOs lead to greater green innovation. In contrast, for firms with male CEOs, the coefficient for DT is positive but insignificant ($b = 1.950$, $p > 0.10$), implying the digital transformation-green innovation link is weaker when the CEO is male. A potential explanation is that female executives may be more attuned to stakeholder demands for sustainability and effectively leverage digital technologies to develop eco-friendly innovations.

In terms of the controls, firm size exhibits a positive relationship with GI for female CEO firms ($b = 0.033$, $p < 0.01$) but an insignificant association for male CEO firms. This indicates larger firm size promotes green innovation when the CEO is female. Leverage has a negative link to GI for both subsamples (Female b=−0.000, $p < 0.01$; Male b=−0.001, $p < 0.10$), suggesting higher debt constrains green innovation regardless of CEO gender. The other controls do not have statistically significant relationships.

Overall, the findings provide support for upper echelons theory by showing CEO gender is an important contingency that strengthens the translation of digital transformation efforts into environmental innovations. However, the unexpected insignificance for male CEO firms merits further investigation. The results have practical implications regarding the value of gender diversity at the executive level for harnessing digital technologies to foster green innovation.

4.4. Robustness tests: PSM and entropy balancing

To address the potential issue of selection bias, which may be a result of firms with specific attributes reducing environmental decoupling practices and possibly having more digital transformation for the sake of enhancing their legitimacy, we employ the propensity score matching (PSM) technique. We conduct one-to-one nearest neighbor matching with a caliper distance of 0.01 to identify a subset of firms without digital transformation (the control group). These control group firms exhibit similar characteristics, including board size, board independence, CEO duality, CEO gender, ROA, firm size, firm age, leverage and top1, when compared to our sample of firms with digital transformation (the treatment group).

The research revealed several significant relationships. Most explanatory variables exhibit a positive and statistically significant

effect on sustainability, indicating that higher levels of technology, CEO leadership, and digital transformation innovation promote the progress and implementation of sustainable development. Enhance the scholarly rigor and comprehensiveness; this relates to the discussion segment of my research project. Summary statistics, comparing the characteristics of both the control and treatment groups, are presented in Table 10. Subsequently, we estimate our baseline regressions using this matched subset. We present the findings in Table 10 column 1, which also confirms that digital transformation reduces the environmental decoupling, and these findings are similar with primary findings.

PSM is a technique that is frequently employed in accounting and finance literature for the purpose of sample matching. However, a considerable quantity of observations is lost during the matching procedure. To mitigate the loss of prospective observations, we employ an entropy balancing method. To compare the observations in the treatment group to those in the control group, entropy balancing re-weights the values across multiple dimensions. Like propensity score matching and other balancing methods, entropy balancing permits the balancing of multiple covariates with minimal observational loss, thereby preserving valuable data [86]. Therefore, we also employ entropy balancing and presented the results in column 2 of Table 10, which shows similar findings with main findings. For the reverse causality, we employ two stage Heckman model and present the findings in column 3 of Table 10, which also confirm the primary findings. After they employ different econometric techniques, and their findings confirm our findings are robust.

Table 10
PSM, Entropy balancing and Heckman.

	(1) PSM	(2) Entropy	(3) Heckman
DT	1.132***	0.004*	0.931***
	(2.760)	(1.708)	(2.585)
Board_size	0.002	0.000	0.001
	(1.170)	(0.334)	(0.663)
Board_ind	0.076	0.062	0.027
	(1.638)	(1.608)	(0.363)
CEO_dual	0.005	−0.000	0.006
	(0.842)	(−0.074)	(0.393)
CEO_gend	−0.007	0.004	0.002
	(−0.616)	(0.461)	(0.195)
ROA	0.015	0.034	0.004
	(0.258)	(1.103)	(0.080)
Firm size	0.009	0.012*	0.016*
	(1.107)	(1.831)	(1.678)
Firm age	−0.006	−0.001	−0.008
	(−0.208)	(−0.052)	(−0.336)
Leverage	0.026*	0.017	0.009
	(1.656)	(1.385)	(0.451)
Top1	−0.000	−0.000	−0.000**
	(−1.568)	(−1.531)	(−2.029)
Cap_inten	−0.039	−0.052	−0.030
	(−0.688)	(−1.046)	(−0.628)
lambda	–	–	0.204
			(0.479)
_cons	−0.023	−0.048	−0.255
	(−0.268)	(−0.680)	(−0.917)
Observations	8512	12,168	12,168
R-squared	0.014	0.009	0.010
Firm-FE	Yes	Yes	Yes
Year FE	Yes	Yes	Yes

t-values are in parentheses.
*** $p < 0.01$.
** $p < 0.05$.
* $p < 0.1$.

5. Analysis and corroboration

5.1. Discussion on principal finding

Given the significance of China as the largest developing economy and being in the list of top countries which emit GHG emissions [87], The eco-environmental policies in China are of great importance. Chinese enterprises must prioritize greenovation to outperform competitive firms and attain sustainable, higher quality of economic growth [84]. China needs to focus on both, i.e. digitization and greenovation. The fundamental premise of this study is that the process of digitalization allows enterprises to ameliorate their performance in green innovation. This research investigates the links between firms' AIA (Absorptive Capacity, Innovation Ability) and greenovation (green innovation) by analyzing a sample of A-share Chinese listed enterprises from 2008 to 2017, based on the Resource-Based View (RBV) theory of enterprise. The empirical investigation validated the hypothesis that a greater implementation of artificial intelligence is correlated with a higher degree of greennovation. The finding supports previous study that indicates the importance of adopting smart technology in promoting environmentally friendly performance [88–90]. In addition, our findings align with the research conducted by Gan, Liu, Qiao, and Zhang [91], who discovered the positive impact of adopting industrial robots on green innovation. Similarly, Xing Liu, Liu, and Ren [92] observed an increase in green innovation resulting from the comprehensive use of digital technologies, as indicated by digital transformation.

In addition, our study additionally re-investigated the previously observed DIG-GRN nexus in the contexts of varying CEO characteristics including CEO age, CEO political affiliation, CEO education and gender. The study discovered that the impact of DIG on green innovation is more noticeable in the leadership of older CEOs than to younger CEOs. A potential explanation is that older CEOs with more experience may be better positioned to leverage digital technologies to create environmentally friendly innovations. In this vein, we do not agree with the studies of Jentoft, [93] that claims that earlier persons may express inferior expertise with technology and be little tend to adopt change. Earlier CEOs have more competitive benefits than younger ones on account of their collected expertise, that aids in making more determined strategic judgments (Wei et al., 2005). While analyzing the moderating impact of CEO learning, the study finds that DIG's positive effects on greenovation are more prominent when the firm is led by well skilled CEO, owning degree in masters or PhDs. In confirming earlier derived results, [21] this study certifies and substantiates the discoveries. Our research empirically illustrated that higher education builds up understanding of the potential benefits of digital transformation (DT), containing increased productivity, accuracy, and clarity. CEOs with deep analytical abilities captured through higher education might be more adept at classifying the risks and argues of DT and are more apt to elaborate efficient mitigation strategies [94].

While investigating the impact of politically linked CEOs on DIG-Greenovation nexus, the study finds that digitalization efforts in politically linked firms bring about better green innovation, possibly on account of the CEOs' ability to obtain governmental resources and policies to support environmental purposes. In contrast, for firms outside politically akin CEOs, digital revolution-green innovation link is weaker when firms require political ties at the superior echelons. These conclusions are in accordance with Fisman and Wang [32], Giannetti et al. [33], and Cao et al., who reported that CEO's governmental links have an important impact in a firm's market performance and competitive advantage; and benefit from outside financing and commodity race, regardless of a more equitable market ecosystem

Furthermore, consistent with H5, the gender of the CEO positively affects the cooperation between DIG and Greenovation. This indicates that the advantageous effect of digital transformation on green innovation is profound when a woman fills the CEO position, A potential clarification is that women may present different leadership approach

that prioritizes teamwork and conversation, that can improve a complex DIG [28]. Correspondently, male CEOs can prioritize preserving the current situation and show hesitancy to accept new technologies, accordingly, undermining internal control. Female CEOs may exhibit greater sensitivity to the human aspects of change and are more inclined to evaluate the effects of digital transformation on personnel and overall organisational success [95].

5.2. Implications of findings

The study presents several important implications for corporate stakeholders and scholars. It highlights that digitalization has the potential to promote greenovation, suggesting that this impact should be strategically harnessed. The influence of digitalization in promoting greenovation can be embellished by appointing CEOs with appropriate traits. When determining corporate greenovation, it is necessary to consider distinct aspects, including technological, organizational, and institutional aspects.

Our conclusions encourage scholars to consolidate the developing digital transformation into their research on firm-level accounting, monetary, and governance aspects. As technological upgrading considerably influences business practices and consequences, scholars need to support guidance on governing these advancements on the way to sustainable results.

Numerous practical complications emerge for ministry officials, lawmakers, and business leaders. Government officers should aid the corporate sector's assimilation of digitalization into their practices. This demands continuous government support by way of technical assistance, subsidies, in addition financial aid. Additionally, it is essential to support collaboration between academia, industry, and other shareholders to encourage and implement technical solutions for green innovation. Spending in educational and training programs is crucial to expand a proficient workforce qualified of effectively using digital technology for environmentally friendly innovation. Raising knowledge and disseminating information about the advantages of technological progress in reducing carbon emissions as well as enhancing environmental sustainability is also essential.

The findings propose crucial observations for managers aiming to enhance the effect of digital transformation on green innovation. Firm managers are urged to entirely adopt and invest in digitization to embellish green innovation performance. This is essential to set up capital allocation towards the research and development of digital technologies, processes, and tools that help green practices. Improving an inventive organizational culture that boosts exploration and application of digital technologies for green innovation is also predominant. Moreover, cooperating with digital technology firms as well as researchers can facilitate the creation of tailored digital solutions personalized to address specialized environmental challenges and promote sustainable development.

The organizations should acknowledge that the profile and characteristics of the CEO play a crucial role in deciding whether investments in digitalization really translate into better sustainability effects. The outcomes clearly reveal CEO essence like older age, higher education, political links, and female gender strengthen the digitalization-green innovation connection. This implies firms need to intently check out if the orientation and abilities of their top executive are helpful for harnessing digital capabilities for environmental innovations, and account for this when making leadership selections. The organizations should execute mechanisms to equip CEOs with the strategic mentality required to utilize digital technologies for sustainability, based on their definite attributes. For instance, targeted training programs and advisory boards with environmental professionals can help compensate for limitations of younger or less experienced CEOs regarding green innovation. Firms may need to design incentive structures to motivate CEOs to utilize digital advancements for eco-friendly purposes, rather than individual performance. Finally, the findings indicate policymakers aiming to leverage digital transformation for sustainability ends must consider how executive characteristics across industries influence environmental outcomes. Broader ecosystem policies may need to account for leadership profiles shaping the strategic direction of digitalization initiatives. Realizing the promise of digital technologies for green innovation relies heavily on appointing and empowering leaders who impart strategic orientation toward sustainability objectives.

5.3. Conclusion, limitations and suggestions for future studies

This research aimed at exploring digitalized greenovation. Specifically, this study has investigated whether digitalization fosters green innovation. Moreover, various prominent CEO attributes moderate this relationship or not. For this purpose, data set of Chinese firms were employed, and data were priori classified based upon the CEO attributes. The results of panel data estimations revealed the following conclusion: Digitalization has the potential to bring positive effect on green innovation; This relationship is more pronounced in the firms which are led by older, highly educated, politically connected and female CEOs.

Our work acknowledges significant limitations and identifies avenues for future research. Firstly, our conceptual framework was empirically tested solely on Chinese firm data, potentially introducing sampling biases despite robustness checks. Furthermore, our study focused exclusively on listed Chinese enterprises, overlooking unlisted firms that may exhibit different financial performances and behaviors across various industries. Including unlisted enterprises would provide a more comprehensive understanding [96].

Additionally, our study's measurement of digitalization using Textual Analysis on MD&A sections of annual reports raises notable concerns. It is vital to recognize that firms might strategically craft narratives in their public statements to enhance perceptions of digital prowess and corporate legitimacy [97]. To address this issue, future research should explore alternative data collection and validation techniques, integrating the qualitative along with quantitative methodologies. Case studies could also offer valuable insights.

Moreover, caution is warranted in interpreting our study's findings regarding the moderating role of CEOs in the correlation between digitalization and greenovation. The impact of green innovation initiatives alongside digitalization could be influenced by various internal and institutional factors beyond CEO attributes [98]. Existing literature underscores the importance of rigorous internal and external monitoring mechanisms in optimizing the consequences of digitalization on green innovation.

Lastly, given that our study focused on Chinese enterprises, generalizing our findings requires caution. Digitalization's impact may differ significantly across regions due to varying institutional frameworks and regulatory environments. China's leadership in digital economy and stringent environmental measures may not mirror conditions in other nations. Therefore, replication and extension of our research in diverse global contexts are encouraged to assess the applicability of our findings under varied circumstances.

Furthermore, exploring how the nexus between digitization and greenovation differs between state-owned and privately owned firms, and whether advancements in digitalization mitigate greenwashing behaviors, presents intriguing avenues for future research.(Fig. 1)

CRediT authorship contribution statement

Muhammad Kaleem Khan: Writing – original draft, Conceptualization. **Phool Hussain:** Writing – review & editing, Writing – original draft. **Muhammad Jameel Hussain:** Formal analysis, Data curation. **Kathy Michael:** Resources.

Declaration of competing interest

Authors declare no conflict of interest.

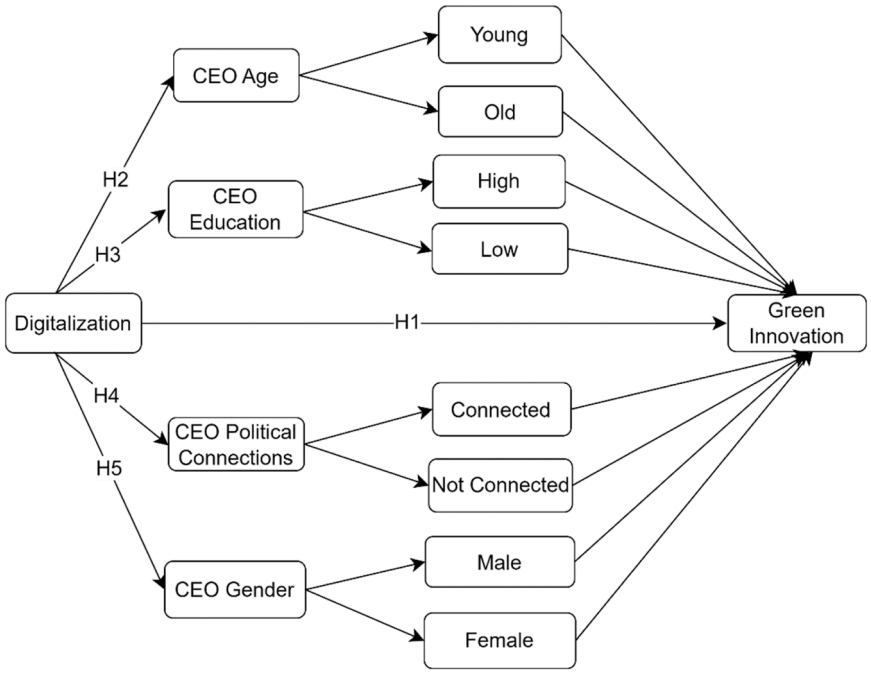

Fig. 1. Research Framework.

Data availability

Data are available on CSMAR database.

References

[1] G. Eweje, M. Sakaki, CSR in Japanese companies: perspectives from managers, Bus. Strategy. Environ. 24 (7) (2015) 678–687.
[2] G. Lian, A. Xu, Y. Zhu, Substantive green innovation or symbolic green innovation? The impact of ER on enterprise green innovation based on the dual moderating effects, J. Innov. Knowl. 7 (3) (2022) 100203.
[3] X. Xie, T.T. Hoang, Q. Zhu, Green process innovation and financial performance: the role of green social capital and customers' tacit green needs, J. Innov. Knowl. 7 (1) (2022) 100165.
[4] M. Shahzad, Y. Qu, S.U. Rehman, A.U. Zafar, Adoption of green innovation technology to accelerate sustainable development among manufacturing industry, J. Innov. Knowl. 7 (4) (2022) 100231.
[5] J. Ning, X. Jiang, J. Luo, Relationship between enterprise digitalization and green innovation: a mediated moderation model, J. Innov. Knowl. 8 (1) (2023) 100326.
[6] J. Selimović, A. Pilav-Velić, L. Krndžija, Digital workplace transformation in the financial service sector: investigating the relationship between employees' expectations and intentions, Technol. Soc. 66 (2021) 101640.
[7] H. Wen, Q. Zhong, C.-C. Lee, Digitalization, competition strategy and corporate innovation: evidence from Chinese manufacturing listed companies, Int. Rev. Financ. Anal. 82 (2022) 102166.
[8] S. Chouaibi, G. Festa, R. Quaglia, M. Rossi, The risky impact of digital transformation on organizational performance–evidence from Tunisia, Technol. Forecast. Soc. Change 178 (2022) 121571.
[9] L. Ardito, S. Raby, V. Albino, B. Bertoldi, The duality of digital and environmental orientations in the context of SMEs: implications for innovation performance, J. Bus. Res. 123 (2021) 44–56.
[10] J.A. Cano, A. Londoño-Pineda, M.F. Castro, H.B. Paz, C. Rodas, T. Arias, A bibliometric analysis and systematic review on E-marketplaces, open innovation, and sustainability, Sustainability. 14 (9) (2022) 5456.
[11] M.K. Khan, Y. He, U. Akram, S. Zulfiqar, M. Usman, Firms' technology innovation activity: does financial structure matter? Asia-Pacific J. Financ. Stud. 47 (2) (2018) 329–353.
[12] M.K. Khan, C. Huo, R.M.A. Zahid, U.S. Maqsood, The automated sustainability auditor: Does artificial intelligence curtail greenwashing behavior in Chinese firms? Bus. Strateg. Environ. 33 (8) (2024) 9015–9039.
[13] M. Altarawneh, R. Shafie, R. Ishak, CEO characteristics: a literature review and future directions, Acad. Strat. Manage. J. 19 (1) (2020) 1–10.
[14] M. Huang, M. Li, Z. Liao, Do politically connected CEOs promote Chinese listed industrial firms' green innovation? The mediating role of external governance environments, J. Clean. Prod. 278 (2021) 123634.
[15] M. Javed, F. Wang, M. Usman, A.A. Gull, Q.U. Zaman, Female CEOs and green innovation, J. Bus. Res. 157 (2023) 113515.
[16] H.-W. Huang, E. Rose-Green, C.-C. Lee, CEO age and financial reporting quality, Account. Horiz. 26 (4) (2012) 725–740.
[17] A. Edmans, T. Gosling, D. Jenter, CEO compensation: evidence from the field, J. financ. econ. 150 (3) (2023) 103718.
[18] M. Olanrewaju, The Impact of Entrepreneurship Education On Improving Small and Medium-size Enterprises (SMEs) Performance in Kwara and Oyo States, Nigeria, 2024.
[19] D.C. Hambrick, Upper Echelons theory: An update, 32, Academy of Management Briarcliff Manor, NY, 2007, pp. 334–343, 10510.
[20] D.C. Hambrick, P.A. Mason, Upper echelons: The organization As a Reflection of Its Top Managers, 9, Academy of Management Review, 1984, pp. 193–206.
[21] F. Sarto, S. Saggese, R. Viganò, M. Mauro, Human capital and innovation: mixing apples and oranges on the board of high-tech firms, Manage. Decis. 58 (5) (2019) 897–926.
[22] A. Davila, G. Foster, Management control systems in early-stage startup companies, Account. Rev. 82 (4) (2007) 907–937.
[23] B. Ndulu, E. Stuart, S. Dercon, P. Knaack, Driving Digital Transformation: Lessons from Seven Developing Countries, Oxford University Press, 2023, p. 241.
[24] R. Varma, R. Bommaraju, S.S. Singh, Female chief marketing officers: when and why do their marketing decisions differ from their male counterparts'? J. Market. Res. 60 (6) (2023) 1154–1176.
[25] M.A. Wani, A. Masih, Emotional maturity across gender and level of education, Int. J. Indian Psychol. 2 (2) (2015) 63–72.
[26] R. Croson, U. Gneezy, Gender differences in preferences, J. Econ. Lit. 47 (2) (2009) 448–474.
[27] M.N. Ruderman, P.J. Ohlott, K. Panzer, S.N. King, Benefits of multiple roles for managerial women, Acad. Manage. J. 45 (2) (2002) 369–386.
[28] G. Tate, L. Yang, Female leadership and gender equity: evidence from plant closure, J. financ. econ. 117 (1) (2015) 77–97.
[29] S.K. Huang, The impact of CEO characteristics on corporate sustainable development, Corp. Soc. Responsib. Environ. Manage 20 (4) (2013) 234–244.
[30] X. Liu, S. Cui, C. Du, E.R. Brisker, How to make ladies take higher risk? Female executives and corporate risk-taking in China: board social capital and marketization, Int. J. Manage. Finance (2024).
[31] X. Cao, M. Lemmon, X. Pan, M. Qian, G. Tian, Political promotion, CEO incentives, and the relationship between pay and performance, Manage. Sci. 65 (7) (2019) 2947–2965.
[32] R. Fisman, Y. Wang, The mortality cost of political connections, Rev. Econ. Stud. 82 (4) (2015) 1346–1382.
[33] M. Giannetti, G. Liao, X. Yu, The brain gain of corporate boards: evidence from China, J. Finance 70 (4) (2015) 1629–1682.
[34] Y. Bai, S. Song, J. Jiao, R. Yang, The impacts of government R&D subsidies on green innovation: evidence from Chinese energy-intensive firms, J. Clean. Prod. 233 (2019) 819–829.
[35] J.D. Piotroski, T. Zhang, Politicians and the IPO decision: the impact of impending political promotions on IPO activity in China, J. Financ. Econ. 111 (1) (2014) 111–136.
[36] N. Ahmad, Z. Ullah, H.B. Ryu, A. Ariza-Montes, H. Han, From corporate social responsibility to employee well-being: navigating the pathway to sustainable healthcare, Psychol. Res. Behav. Manage (2023) 1079–1095.
[37] S.H.A. Shah, M. Fahlevi, K. Jamshed, N. Aman, N. Rafiq, K. Jermsittiparsert, M. Aljuaid, Sustaining the earth: unraveling the synergy of workplace spirituality,

responsible leadership, and pro-environmental behavior in Pakistan's SMEs, Psychol. Res. Behav. Manage (2023) 3075–3093.
[38] Bresciani, S., Huarng, K.-H., Malhotra, A., & Ferraris, A. (2021). Digital transformation as a springboard for product, process and business model innovation. In (Vol. 128, pp. 204–210): Elsevier.
[39] R. Sundaram, D.J. Ziade, D.E. Quinn, Drivers of change: an examination of factors that prompt managers to enforce changes in business, Int. J. Manage. 11 (5) (2020).
[40] H.-T. Tsou, J.-S. Chen, How does digital technology usage benefit firm performance? Digital transformation strategy and organisational innovation as mediators, Technol. Anal. Strateg. Manage 35 (9) (2023) 1114–1127.
[41] M.M. Mariani, I. Machado, V. Magrelli, Y.K. Dwivedi, Artificial intelligence in innovation research: a systematic review, conceptual framework, and future research directions, Technovation 122 (2023) 102623, https://doi.org/10.1016/j.technovation.2022.102623.
[42] V.Z. Chen, J. Li, D.M. Shapiro, X. Zhang, Ownership structure and innovation: an emerging market perspective, Asia Pacific J. Manage. 31 (1) (2014) 1–24, https://doi.org/10.1007/s10490-013-9357-5.
[43] T. Liang, Y.-J. Zhang, W. Qiang, Does technological innovation benefit energy firms' environmental performance? The moderating effect of government subsidies and media coverage, Technol. Forecast. Soc. Change 180 (2022) 121728, https://doi.org/10.1016/j.techfore.2022.121728. -121728.
[44] M.K. Khan, R. Zahid, A. Saleem, J. Sági, Board composition and social & environmental accountability: a dynamic model analysis of Chinese firms, Sustainability. 13 (19) (2021) 10662.
[45] J. He, H. Su, Digital transformation and green innovation of Chinese firms: the moderating role of regulatory pressure and international opportunities, Int. J. Environ. Res. Public Health 19 (20) (2022) 13321.
[46] D. Li, W. Shen, Can corporate digitalization promote green innovation? The moderating roles of internal control and institutional ownership, Sustainability. 13 (24) (2021) 13983.
[47] R.W. Coff, Human Assets and Management dilemmas: Coping with Hazards On the Road to Resource-Based Theory, 22, Academy of Management Review, 1997, pp. 374–402.
[48] C.E. Helfat, A. Kaul, D.J. Ketchen Jr, J.B. Barney, O. Chatain, H. Singh, Renewing the resource-based view: new contexts, new concepts, and new methods, Strateg. Manage J. (2023).
[49] M.E. Porter, Competitive strategy, Measur. Bus. Excell. 1 (2) (1997) 12–17.
[50] E. Martínez-Caro, J.G. Cegarra-Navarro, F.J. Alfonso-Ruiz, Digital technologies and firm performance: the role of digital organisational culture, Technol. Forecast. Soc. Change 154 (2020) 119962.
[51] S. Luo, N. Yimamu, Y. Li, H. Wu, M. Irfan, Y. Hao, Digitalization and sustainable development: how could digital economy development improve green innovation in China? Bus. Strategy. Environ. 32 (4) (2023) 1847–1871.
[52] Qiao, P., Liu, S., Fung, H.-G., & Wang, C. (2023). Corporate green innovation in a digital economy. *Available at SSRN 4525084*.
[53] S. Jiang, Y. Li, N. You, Corporate digitalization, application modes, and green growth: evidence from the innovation of Chinese listed companies, Front. Environ. Sci. 10 (2023) 1103540.
[54] R. Liu, C. Li, M. Huo, The impact of chief executive officer turnover on strategic change: a model of mediating effect and joint moderating effect, China Finance Rev. Int. 13 (4) (2023) 633–666.
[55] Z. Zhu, Y. Tan, Can green industrial policy promote green innovation in heavily polluting enterprises? Evidence from China, Econ. Anal. Policy. 74 (2022) 59–75.
[56] X. Liu, Enterprise Digital Transformation and Green Innovation, Indust. Eng. Innov. Manage. 6 (2) (2023) 8–17.
[57] N. Shen, Z. Zhuo, Mediation effect of product diversification on the relationship between top management team heterogeneity and firm value in China, Chinese Manage. Stud. 17 (1) (2023) 130–151.
[58] J. Fan, Z. Tao, J. Oehmichen, H. van Ees, CEO career horizon and corporate bribery: a strategic relationship perspective, Asia Pacific J. Manage. (2023) 1–17.
[59] Z. Yang, Y. Zhou, Beggars cannot be choosers? How experiential and vicarious learning direct problemistic search at firm internationalization, Manage. Int. Rev. (2023) 1–36.
[60] D. Bendig, R. Wagner, E.P. Piening, J.N. Foege, Attention to Digital innovation: exploring the impact of a chief information officer in the top management team, MIS Quart. 47 (4) (2023).
[61] I.C. Dewi, Examining the influence of CEO characteristics and brand image on performance of food and beverages MSMEs in Indonesia: the mediating role of competitive advantage, Int. J. Bus., Law, Educ. 4 (2) (2023) 1030–1051.
[62] M.F. Wiersema, K.A. Bantel, Top management team demography and corporate strategic change, Acad. Manage. J. 35 (1) (1992) 91–121.
[63] S. Angelopoulos, E. Bendoly, J.C. Fransoo, K. Hoberg, C.X. Ou, A. Tenhiala, Digital transformation in operations management: fundamental change through agency reversal, J. Oper. Manage. (2023). Forthcoming.
[64] A. Gottesman, M.R. Morey, Does a better education make for better managers? An empirical examination of CEO educational quality and firm performance, An Empirical Examination of CEO Educational Quality and Firm Performance (April 21, 2006), Pace Univ. Finance Res. Pap.(2004/03) (2006).
[65] Å. Johnsen, Strategic planning in turbulent times: still useful? Public Policy. Adm. 38 (4) (2023) 445–465.
[66] Y. Zheng, Q. Zhang, Digital transformation, corporate social responsibility and green technology innovation-based on empirical evidence of listed companies in China, J. Clean. Prod. 424 (2023) 138805.
[67] R. Xu, Y. Shen, M. Liu, L. Li, X. Xia, K. Luo, Can government subsidies improve innovation performance? Evidence from Chinese listed companies, Econ. Model. 120 (2023) 106151.
[68] K.M. Turetsky, J.P. Curley, A.B. Carter, V. Purdie-Greenaway, Explaining the gender gap in negotiation performance: social network ties outweigh internal barriers, J. Soc. Issues 79 (1) (2023) 50–78.
[69] X. Zhang, X. Du, Industry and regional peer effects in corporate digital transformation: the moderating effects of TMT characteristics, Sustainability. 15 (7) (2023) 6003.
[70] C. Proença, M. Augusto, J. Murteira, Political connections and banking performance: the moderating effect of gender diversity, Corp. Gover.: Int. J. Bus. Soc. 20 (6) (2020) 1001–1028.
[71] Q. Li, U.S. Maqsood, R.A. Zahid, et al., Regulating CEO pay and green innovation: moderating role of social capital and government subsidy, Environ. Sci. Pollut. Res. 31 (2024) 46163–46177. https://doi.org/10.1007/s11356-023-26641-x.
[72] J. Wu, B. Liu, Y. Zeng, H. Luo, Good for the firm, good for the society? Causal evidence of the impact of equity incentives on a firm's green investment, Int. Rev. Econ. Finance 77 (2022) 435–449, https://doi.org/10.1016/j.iref.2021.10.013.
[73] K. Fossheim, J. Lund-Tønnesen, Digitalization of public sector organizations over time: the applicability of quantitative text analysis, Int. Rev. Administ. Sci. 90 (2) (2024) 318–335.
[74] E. Boffa, A. Maffei, Development and application of an Integrated Business Model framework to describe the digital transformation of manufacturing-a bibliometric analysis, Prod. Manuf. Res. 11 (1) (2023) 2164952.
[75] Z. Yang, W. Hu, J. Shao, Y. Shou, Q. He, How does digitalization alter the paradox of supply base concentration? The effects of digitalization intensity and breadth, Int. J. Oper. Prod. Manage., (ahead-of-print) (2023).
[76] A.A. Gull, N. Hussain, S.A. Khan, R. Mushtaq, R. Orij, The power of the CEO and environmental decoupling, Bus. Strategy. Environ. (2023).
[77] M.J. Hussain, G. Tian, A. Ashraf, M.K. Khan, L. Ying, Chief executive officer ability and corporate environmental sustainability information disclosure, Bus. Ethics, Environ. Responsib. 32 (1) (2023) 24–39, https://doi.org/10.1111/beer.12485.
[78] C. Marquis, C. Qian, Corporate social responsibility reporting in China: symbol or substance? Organiz. Sci. 25 (1) (2014) 127–148.
[79] S. Sauerwald, W. Su, CEO overconfidence and CSR decoupling, Corp. Gover.: Int. Rev. (2019), https://doi.org/10.1111/corg.12279.
[80] J. Yue, Y. Li, Media attention and corporate greenwashing behavior: evidence from China, Financ. Res. Lett. 55 (2023) 104016.
[81] G. Burrell, G. Morgan, Sociological Paradigms and Organisational analysis: Elements of the Sociology of Corporate Life, Routledge, 2019.
[82] M. Saunders, P. Lewis, A. Thornhill, Research Methods For Business Students, Pearson education, 2009.
[83] R.A. Zahid, U.S. Maqsood, S. Irshad, M.K. Khan, The role of women on board in combatting greenwashing: a new perspective on environmental performance, Bus. Ethics, Environ. Responsib. (2023).
[84] H. Huang, Y. Chang, L. Zhang, CEO's marketing experience and firm green innovation, Bus. Strategy. Environ. (2023), https://doi.org/10.1002/bse.3413.
[85] X. Zhao, G. Zhou, Z. Rezaee, Tournament incentives and corporate social responsibility performance, J. Account., Audit. Finance 38 (4) (2023) 934–963.
[86] J.L. McMullin, B. Schonberger, Entropy-balanced accruals, Rev. Account. Stud. 25 (1) (2020) 84–119.
[87] Y. Wang, Y. Qiu, Y. Luo, CEO foreign experience and corporate sustainable development: evidence from China, Bus. Strategy. Environ. 31 (5) (2022) 2036–2051.
[88] X. Hao, Y. Li, S. Ren, H. Wu, Y. Hao, The role of digitalization on green economic growth: does industrial structure optimization and green innovation matter? J. Environ. Manage 325 (2023) 116504 https://doi.org/10.1016/j.jenvman.2022.116504.
[89] J. Li, Can technology-driven cross-border mergers and acquisitions promote green innovation in emerging market firms? Evidence from China, Environ. Sci. Pollut. Res. 29 (19) (2022) 27954–27976, https://doi.org/10.1007/s11356-021-18154-2.
[90] X. Xie, Y. Han, T.T. Hoang, Can green process innovation improve both financial and environmental performance? The roles of TMT heterogeneity and ownership, Technol. Forecast. Soc. Change 184 (2022) 122018, https://doi.org/10.1016/j.techfore.2022.122018.
[91] J. Gan, L. Liu, G. Qiao, Q. Zhang, The role of robot adoption in green innovation: evidence from China, Econ. Model. 119 (2023) 106128, https://doi.org/10.1016/j.econmod.2022.106128.
[92] X. Liu, F. Liu, X. Ren, Firms' digitalization in manufacturing and the structure and direction of green innovation, J. Environ. Manage 335 (2023) 117525, https://doi.org/10.1016/j.jenvman.2023.117525.
[93] E.E. Jentoft, Technology and older adults in British loneliness policy and political discourse, Front. Digit. Health 5 (2023) 1168413.
[94] Gargani, G. (2023). Harnessing the power of data analytics to drive business value: implementation for Ferrero International Sa of A D&A and continuous monitoring model to prevent financial fraud (Doctoral dissertation, Politecnico di Torino).
[95] C. Cummings, T. O'Neil, Do Digital Information and Communications Technologies Increase the Voice and Influence of Women and girls. *A rapid Review of the Evidence*, Overseas Development Institute, 2015.

[96] D. Yao, R. Ding, J. Chen, Y. Liao, Bridging the financing gap for unlisted science and technology-based SMEs in China: a comprehensive evaluation framework, J. Knowl. Econ. 1-59 (2024).
[97] D. Bendig, C. Schulz, L. Theis, S. Raff, Digital orientation and environmental performance in times of technological change, Technol. Forecast. Soc. Change 188 (2023) 122272, https://doi.org/10.1016/j.techfore.2022.122272. -122272.
[98] Q. Zhou, S. Wang, X. Ma, W. Xu, Digital technologies and corporate green innovation: opening the "black box" of resource orchestration mechanisms, Sustain. Account., Manage. Policy J. (2024).