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RESEARCH ARTICLE

Impact of Corporate ESG Performance on Open Green Innovation in the Context of Digital Transformation*

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Abstract

In the context of digital transformation, corporate environmental, social, and governance (ESG) performance plays a critical role in promoting open green innovation. Drawing on data from A-share listed companies from 2011 to 2022 in China, this paper examines the impact of ESG performance on open green innovation during the digital transformation. The results reveal that good ESG performance significantly promotes enterprises' open green innovation, and this conclusion remains valid after several robustness tests. Moreover, the positive effect is more pronounced in regions with higher levels of digital economy development and among enterprises with greater digitization. Heterogeneity analysis reveals that ESG performance more strongly promotes open green innovation in three types of enterprises: high-tech enterprises, those in high-trust regions, and those with strict financing constraints. Based on these findings, enterprises should establish modern ESG management systems, fully leverage the dividends of regional digital economy development, and actively leverage digital transformation to enhance open green innovation ecosystems and ESG capability building.

Keywords ESG performance; open green innovation; regional digital economy development; corporate digital transformation

1 Introduction

With the emergence of artificial intelligence (AI), big data analytics, and the Internet of Things (IoT), enterprises worldwide are experiencing an unprecedented wave of digital transformation. The wave of digitalization has not only reshaped how enterprises develop products, services, and delivery models, but has also fueled business model innovation, reorganized internal structures, altered managerial practices and culture, and even influenced enterprises' capability for green innovation (Cai & Zhang, 2023). In the context of both digital transformation and sustainable development, network-based open innovation has become a prominent innovation pattern. This approach emphasizes knowledge sharing and collaboration across organizational boundaries, resource integration through networks, ecosystem development, and mutually beneficial value creation. This topic has become a growing focal point in academic research and is increasingly recognized as a vital pathway

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for strengthening innovation capabilities in the digital economy era (Guan & Liu, 2016; Xia & Song, 2015). The convergence of green innovation and open innovation expands traditional innovation theory and introduces new mechanisms and pathways for innovation research. This integration incorporates environmental sustainability considerations into the open innovation framework, resulting in a new innovation model called open green innovation. Under this model, open innovation emphasizes the development of innovation networks and ecosystems, while green innovation underscores the role of enterprises in environmental protection and sustainable development. The integration of these approaches offers new insights into how innovation networks and ecosystems can support enterprises in balancing economic value creation with wider social and environmental responsibilities, thereby advancing green innovation outcomes.

Under China's national strategies of innovation-driven growth and green sustainable development, exploring the link between ESG performance and open green innovation holds significant theoretical and practical implications. Firstly, strong ESG performance and open green innovation play an important role in improving China's competitiveness in the global green economy and contribute directly to achieving national "dual carbon" targets. Secondly, at the theoretical level, this line of investigation expands existing research perspectives. At a practical level, it offers enterprises new strategic directions for integrating innovation with sustainability. Finally, as global environmental pressures intensify and competition in the green economy grows, the acceleration of corporate digital transformation has made green innovation more urgent. In this context, enterprises have to strengthen their ESG practices to enhance innovation capacity, improve competitiveness, and advance toward high-quality, sustainable development. However, existing studies have primarily examined how ESG performance influences enterprise performance or how open innovation supports innovation activities. Comparatively, fewer studies investigate the mechanisms by which ESG performance affects open green innovation. In theory, enterprises with stronger ESG performance tend to gain greater trust and support from stakeholders, which facilitates access to resources and the development of innovation networks. However, current research remains mainly focused on traditional innovation settings, with limited attention to open green innovation, particularly in the context of digital transformation. To address this gap and explore how digital transformation reshapes the relationship between ESG performance and open green innovation, this paper seeks to answer the two core research questions: (1) How does ESG performance influence enterprises' open green innovation capabilities under the digital transformation context? (2) Do regional digital economy development and corporate digital transformation moderate this relationship?

Drawing on a sample of Chinese A-share listed companies from 2011 to 2022, this paper empirically investigates the impact of ESG performance on open green innovation and the moderating roles of regional digital economy development and corporate digital transformation. It makes three key contributions. Firstly, by utilizing large-scale firm-level data, it documents this impact and elucidates the mechanisms through which

digital transformation shapes it, extending the theoretical understanding of ESG-driven innovation. Secondly, it supplements research on both the economic outcomes of ESG and the antecedents of green innovation by offering new empirical insights from an open-innovation perspective. Thirdly, the results provide practical implications for enterprises seeking to leverage digital advancements to bolster ESG governance, enhance open green innovation, and facilitate sustainable, high-quality growth.

2 Theoretical Analysis and Research Hypotheses

2.1 ESG Performance and Corporate Open Green Innovation

This paper scrutinizes the relationship from both theoretical and practical perspectives when evaluating the impact of ESG performance on corporate open green innovation. From a theoretical perspective, enhancing ESG performance transcends mere responses to external pressures or stakeholder expectations. It is also a proactive strategic choice that enables companies to seek a competitive edge and cultivate a robust green brand image. When improving ESG performance, enterprises must navigate challenges related to energy conservation, emissions reduction, social responsibility, and corporate governance. These challenges, in turn, generate a direct demand for green technologies, green products, and services. Open green innovation emerges as a model that effectively integrates internal and external resources to accelerate technological innovation and application. This approach has become a critical approach for enterprises to overcome these challenges and achieve green transformation. Thus, the pursuit of enhanced ESG performance serves both as an intrinsic motivation and a strategic guide for open green innovation within organizations. From a practical perspective, enterprises often increase investments in green innovation when improving ESG performance. These investments encompass direct expenditures on research and development as well as initiatives in green supply chain management, eco-design, and green marketing strategies. Such efforts not only strengthen internal innovation capabilities but also expand the boundaries of innovation and accelerate the commercialization of green technologies through open collaboration models such as industry–university–research partnerships and green supply chain collaborations. This phenomenon can be examined in three key dimensions.

First, ESG performance comprises environmental, social, and governance dimensions. In terms of environmental governance, strong ESG performance supports green innovation. Based on legitimacy theory, organizations adopting environmentally friendly strategies promote energy efficiency, pursue green technological innovation, and gain recognition from stakeholders and regulatory authorities. By proactively embracing environmental responsibilities, companies send positive signals to governments and investors (Yang et al., 2022). Addressing stakeholders' environmental expectations further helps secure support from key stakeholders, which in turn provides the necessary resources and capabilities for innovation endeavors (Wang & Wang, 2021). Existing literature supports the notion

that ESG performance positively influences the promotion of green innovation (Yan et al., 2024). When considering social governance, strong ESG performance also facilitates open innovation. In an era characterized by advanced digital and network economy, conventional models of closed innovation and rigid thought processes cannot meet the complex demands of networked, ecological, and integrative development. As such, network-based open innovation has emerged as the predominant approach. This perspective argues that innovation is not confined to a company's internal knowledge base but is also driven by external resources and partnerships embedded in broader enterprise networks (Guan & Liu, 2016; Yang et al., 2021). This reflects boundaryless resource integration and collaborative innovation dynamics.

Second, corporate open innovation is characterized by networked collaboration, ecosystem-driven complementary capability development, and the pursuit of diversified innovation opportunities. Its fundamental principle is to integrate external resources and collaborators into the enterprises' innovation network (Guan & Liu, 2016; Xia & Song, 2015). Within these informal collaboration networks, the traditional bureaucratic management structure is inadequate. ESG performance serves as a guiding value system in partner selection, a decision-making basis for constructing innovation ecosystems, and a governance foundation for incorporating networked resources (Cai & Li, 2023). Firstly, enterprises that adhere to ESG principles adopt a holistic perspective, prioritizing the overall interests of stakeholders (Qiu & Yin, 2019), including owners, employees, suppliers, consumers, and the broader community, thereby optimizing networks and resources to enhance open innovation capabilities (Yu et al., 2024). Secondly, ESG-oriented development fosters trust internally and externally, forging consensus and promoting positive resource cycles. The synthesis of previously disparate knowledge and capabilities allows enterprises to generate incremental value. Lastly, strong ESG performance reduces business risks and alleviates resource constraints during the innovation process (Zhang & Lucey, 2022).

Third, integrating open and green innovation is significantly supported by an enterprise's ESG performance. Organizations that excel in their ESG metrics signal their commitment to being proactive in environmental stewardship, social responsibility, and sound governance practices. This not only enhances their reputation but also attracts more partners, investors, and consumers, thereby providing resources and opportunities for open green innovation (Cheng et al., 2014). Enterprises with strong environmental performance typically exhibit high efficiency in resource utilization, energy consumption, and green production practices. These measures alleviate environmental burdens and optimize resource efficiency, thereby easing the implementation and maturation of green innovation (Li & Zhang, 2020). In a similar vein, excellent performance in social responsibility bolsters an enterprise's societal engagement and enhances public image. This recognition fosters support from communities and stakeholders, attracting partners to collaborative green innovation projects. Internally, it boosts employees' innovation engagement, thereby promoting internal green innovation

(Petruzzelli et al., 2011). Finally, governance performance, marked by a well-structured corporate governance system, also plays a pivotal role. A robust corporate governance framework ensures transparency in decision-making and effective risk management, and these underpin the sustainability of green strategies. Furthermore, within innovation networks, strong governance lays the foundation for equitable benefit sharing, risk allocation, and collaborative mechanisms, enhancing network efficiency and mitigating innovation risks. This, in turn, bolsters initiatives centered on open green innovation (Chen et al., 2023). The emphasis on ESG performance reflects a holistic approach to stakeholder interests, generating value for stakeholders and broadening the enterprise's resource base. From the lens of the resource orchestration theory, effective management of these resources empowers enterprises to cultivate long-term competitive advantages (Chen & Cui, 2022). As enterprises engage in open green innovation, strong ESG performance enables timely responses to external environmental demands by optimizing knowledge and resource absorption through interactions within innovation networks (Wan et al., 2022). This adept integration and utilization of resources further enhances an enterprise's capabilities in open green innovation. In line with this rationale, the following research hypothesis is proposed:

H1: Corporate ESG performance positively influences open green innovation.

2.2 The Moderating Role of the External Digital Economy Environment

The advent of digital technologies such as big data, cloud computing, and AI is reshaping the logic of traditional economic activities, business value propositions, and competition models. These advancements present unprecedented opportunities for organizations to engage in open innovation (Nambisan et al., 2018). On the one hand, the emergence of the digital economy has accelerated innovations in management methodologies and value-creation mechanisms. It has cultivated a more integrated system across enterprises, regions, and value chains, thereby strengthening interactions among innovation participants. Conversely, the digital economy has disrupted conventional innovation models in the real economy, significantly decreasing barriers to knowledge sharing and collaboration efforts among innovation actors. This transformation has given rise to distributed innovation (Hong & Ren, 2023), ultimately elevating enterprises' performance in open innovation.

Corporate ESG practices embody an enterprise's commitment to green innovation and value co-creation, while simultaneously acknowledging the vital roles of stakeholders, including employees, suppliers, customers, and communities. As such, ESG practices serve as an informal institutional environment that facilitates the dissemination of shared green values and advocates the advancement of green innovation. A well-developed digital economy reduces collaboration costs among organizations and stakeholders and facilitates access to external resources, which in turn improve ESG performance and open green innovation. More specifically, digital platforms and data analytics improve the efficiency of information access and sharing. Such technologies enable businesses to quickly access

the latest insights into environmental technologies, market dynamics, and policy changes. This not only promotes extensive collaboration and open sharing in the field of green innovation, but also significantly improves enterprises' responsiveness and capabilities with respect to environmental, social, and governance performance. Consequently, with seamless and uninterrupted information flows, organizations can adapt green innovation strategies in real time, further elevating their ESG performance. Thus, the availability and sharing of information under the digital economy amplify the positive effect of ESG performance on open green innovation. Moreover, the expansion of the digital economy supports organizations in accumulating digital resources. These resources encourage learning from open green innovation systems, the assimilation of external knowledge, and integration with internal knowledge to guide innovation decisions and resource distribution. Digital technologies also create spillover effects (Zhao et al., 2023). As the regional digital economy continues to develop, local businesses benefit from knowledge spillovers within the ESG-driven external innovation networks. This enhances their ability to absorb new technologies and knowledge from stakeholders.

Furthermore, by empowering technological innovation, the digital economy supports resource integration and environmental monitoring capabilities (Thompson et al., 2013), thereby stimulating green innovation (Zeng et al., 2024). Against the backdrop of rapid digital economy development, ESG-oriented enterprises can tap into green technology innovations to secure pivotal positions within digital ecosystems, control essential resources, and reshape industry structures (Tan et al., 2021). Simultaneously, intensified market competition and growing stakeholder expectations for sustainability compel businesses to improve ESG performance and green innovation strategies to maintain competitiveness. This sustainability-driven competitive landscape further propels the practice of open green innovation. Based on the aforementioned arguments, the following hypothesis is proposed:

H2: The level of regional digital economy development positively moderates the relationship between ESG performance and open green innovation.

2.3 The Moderating Role of Corporate Digital Transformation

Corporate digital transformation encompasses integrating digital technologies, such as big data, blockchain, and AI, across various facets of business operations, including product enhancement, operational optimization, management reform, strategic alignment, and business model innovation. Its primary aim is to improve overall performance, enhance competitive advantage, and facilitate comprehensive organizational transformation (Liu et al., 2020; Tao et al., 2023).

Amid intensifying global competition and heightened focus on sustainable development, digital transformation has emerged as a crucial avenue for businesses seeking to strengthen competitiveness and advance green development. Firstly, digital transformation improves corporate governance and transparency by utilizing technologies such as big

data, blockchain, and AI (Lu et al., 2023). Doing so increases information transparency and reinforces public confidence in corporate ESG strategies, which, in turn, attracts collaboration from partners, investors, and consumers toward open green innovation (Nambisan et al., 2018). Moreover, rapid information circulation encourages knowledge sharing and collaboration, lowers cooperation and transaction costs, and strengthens the positive association between ESG performance and open green innovation (Zhang & Gu, 2023). Digital transformation also broadens engagement across supply chains, partners, and customers, and supports the growth of collaborative innovation ecosystems (Tang et al., 2023). Companies can share information and resources instantaneously and accelerate the momentum of open green innovation through these digital platforms (Zhang et al., 2016). Secondly, technologies such as cloud computing and the Internet of Things not only optimize ecosystem efficiency but also enhance sustainability outcomes (Sui et al., 2024). Lastly, digital transformation has facilitated the emergence of business models grounded in the sharing economy and circular economy, both of which are inherently more sustainable (Rehman et al., 2016). These models are redefining corporate operations while improving ESG performance (Geissdoerfer et al., 2017). Additionally, digital-enabled approaches such as smart manufacturing and mass customization help businesses minimize waste and avoid overproduction, thereby reinforcing green innovation (Rüßmann et al., 2015).

To summarize, corporate digital transformation amplifies ESG performance, especially in open green innovation. Such benefits are evident in several ways, including facilitating data-driven decision-making, enhancing collaborative efficiency, integrating and optimizing innovation resources, advancing environmental monitoring and management capabilities, and fostering business model innovation. Together, these advancements contribute to improved sustainability outcomes and competitiveness while boosting an enterprise's innovation capacity. Based on the reasoning above, the following research hypothesis is proposed:

H3: Corporate digital transformation positively moderates the relationship between ESG performance and open green innovation.

3 Research Plan

3.1 Research Sample and Data Sources

This paper utilizes A-share listed companies in China from 2011 to 2022 as the research sample. The main datasets include ESG ratings from Sino-Securities Index Information Service (Shanghai) Co., Ltd. (referred to as Sino-Securities Index Information Service), the China Stock Market & Accounting Research Database (referred to as CSMAR), and the *China City Statistical Yearbook*. In accordance with established research guidelines, entities within the financial and insurance sectors, as well as ST-designated enterprises and observations with incomplete data, were excluded from the analysis. Continuous variables at the 1st and 99th percentiles underwent winsorization to mitigate the impact of extreme outliers.

3.2 Variable Construction

3.2.1 Dependent Variable: Open Green Innovation (OGI)

Open green innovation merges the principles of open innovation with those of green innovation, and its measurement encapsulates both dimensions. Building on the method developed by Cai and Zhang (2023), open innovation is quantified through joint-invention patent counts, while green innovation is measured using green patent counts. To effectively represent the convergence of both concepts, this paper defines open green innovation as the number of jointly filed green patents. To further reduce the potential influence of outliers, the natural logarithm of the variable "green joint patent counts + 1" is used.

3.2.2 Independent Variable: ESG Performance (ESG)

This paper uses ESG ratings from the Sino-Securities Index Information Service, as adopted by Wang et al. (2022). This data source is selected for its broad coverage, frequent updates, and contextual relevance to Chinese enterprises. The Sino-Securities Index Information Service ESG system comprises nine levels and provides quarterly ratings. Enterprises are awarded scores from 1 to 9, with one being the lowest and nine the highest. The annual ESG value is calculated as the average of quarterly ratings.

3.2.3 Moderating Variables: Regional Digital Economy Development (RDL) and Corporate Digital Transformation (DT)

This paper quantifies regional digital economy development using a composite index proposed by Zhao et al. (2020). The index is derived using principal component analysis. It incorporates indicators such as broadband access per 100 residents, the employment share within IT and software services, per capita telecommunications volume, mobile subscriptions per 100 residents, and the Digital Inclusive Finance Index. Corporate digital transformation is assessed using methodologies established by Wu et al. (2021) and Hu et al. (2023). The analysis uses an automated Python-based web-scraping technique to extract keywords related to "digital transformation" from annual reports. A higher frequency of those keywords indicates greater engagement in digital transformation initiatives.

To manage significant variations in textual frequency, the analysis employs the natural logarithm of "word frequency + 1."

3.2.4 Control Variables

The model includes the following control variables: enterprise size (*Size*), enterprise age (*Age*), current ratio (*CurrentRatio*), return on assets (*ROA*), growth (*Growth*), operating cash flow (*CashFlow*), board size (*BoardSize*), board diligence (*BoardMeeting*), shareholding percentage of the largest shareholder (*Top*1), ownership type (*Soe*), and CEO duality (*Dual*). The detailed definitions for each variable are presented in Table 1.

Table 1
Variable Definitions

Variable type	Variable name	Symbol	Definition
Dependent variable	Open green innovation	*OGI*	The logarithm of the number of joint green patent applications filed by the company in the current year plus one
Independent variable	ESG performance	*ESG*	The Sino-Securities Index Information Service ESG quarterly rating is converted to a 1–9 scale and averaged annually
Moderator	Regional digital economy development	*RDL*	A composite index constructed via principal component analysis
	Corporate digital transformation	*DT*	The logarithm of the digital transformation keyword frequency based on text analysis plus one
Control variable	Enterprise size	*Size*	The natural logarithm of a company's total assets
	Enterprise age	*Age*	The natural logarithm of the company's listed years
	Current ratio	*CurrentRatio*	The ratio of current assets to current liabilities
	Return on Assets	*ROA*	The ratio of total profit to net sales
	Enterprise's growth	*Growth*	The annual growth rate of total operating revenue
	Operating cash flow	*CashFlow*	Net operating cash flow divided by total assets
	Board size	*BoardSize*	The natural logarithm of the total number of board members
	Board diligence	*BoardMeeting*	The natural logarithm of the number of board meetings
	Shareholding percentage of the largest shareholder	*Top*1	The ratio of shares held by the largest shareholder to total company share capital
	Nature of business	*Soe*	Assigned a value of 1 for state-owned enterprises, and 0 otherwise
	CEO	*Dual*	Assigned a value of 1 if the roles of Board Chair and CEO are held by the same person, and 0 otherwise

3.3 Model Specification

To evaluate the influence of ESG performance on open green innovation and to evaluate the moderating roles of regional digital economy development and corporate digital

transformation, the following regression models are formulated:

$$OGI_{it} = \alpha_0 + \alpha_1 ESG_{it} + \sum_k \theta_k Control_{kit} + \mu_i + \eta_t + \varepsilon_{it}. \quad (1)$$

$$OGI_{it} = \beta_0 + \beta_1 ESG_{it} + \beta_2 MV_{it} + \beta_3 ESG_{it} \times MV_{it} + \sum_k \delta_k Control_{kit} + \mu_i + \eta_t + \varepsilon_{it}. \quad (2)$$

In the two models, subscript i denotes the individual enterprises, and t denotes the respective year. *OGI* serves as the dependent variable representing open green innovation efforts, while *ESG* represents the key independent variable assessing *ESG* performance. The moderating variables, defined as *MV*, encompass both *RDL* and *DT*. *Control* includes the aforementioned control variables. The terms μ_i and η_t capture enterprise-level and year-level fixed effects, respectively, while ε_{it} represents the error term.

4 Empirical Analysis

4.1 Descriptive Statistics

Table 2 presents the descriptive statistics of the main variables used in this paper. The minimum value of *OGI* is 0.000, the maximum is 6.621, the mean is 0.497, and the median is 0.000. These statistics underscore a predominantly low level of open green innovation among sampled enterprises, as evidenced by the fact that over half of the enterprises did not obtain any open green innovation patents. In terms of ESG performance, the mean score of *ESG* stands at 3.917. This score reflects a minimum of 0.000 and a maximum of 6.250 and suggests a moderate level of overall ESG performance across enterprises. The result is consistent with an approximate B-level rating in the evaluation framework.

Table 2

Descriptive Statistics of Main Variables

Variable	*N*	*M*	*SD*	*Mdn*	*Min.*	*Max.*
OGI	13,141	0.497	0.901	0.000	0.000	6.621
ESG	13,141	3.917	1.162	4.000	0.000	6.250
Size	13,141	21.944	1.065	21.829	19.652	26.915
Age	13,141	1.790	0.853	1.946	0.000	3.367
CurrentRatio	13,141	2.900	2.900	1.896	0.292	17.774
ROA	13,141	0.043	0.068	0.046	–0.301	0.204
Growth	13,141	0.302	0.741	0.133	–0.740	7.141
CashFlow	13,141	0.050	0.067	0.048	–0.188	0.245
BoardSize	13,141	2.206	0.163	2.303	1.792	2.565
Top1	13,141	31.461	13.651	29.600	8.380	74.300
BoardMeeting	13,141	2.334	0.332	2.303	1.609	3.178
Soe	13,141	0.048	0.214	0.000	0.000	1.000
Dual	13,141	0.399	0.490	0.000	0.000	1.000

4.2 Main Effect Test

Table 3 presents empirical findings on the impact of ESG performance on open green innovation. In column (1), the regression results include only the core explanatory variable, *ESG*. The analysis yielded a positive, statistically significant coefficient. Column (2) introduces the complete set of control variables and confirms that *ESG* retains its significance at the 1% level. Column (3) further accounts for both the enterprise and year fixed effects. The *ESG* coefficient remains positive and highly significant. This result reinforces the conclusion that ESG performance has a robust, statistically significant positive influence on open green innovation. From an economic perspective, holding other conditions constant, a one-unit enhancement in ESG performance correlates with a 1.6% increase in open green innovation. These findings underscore the critical role ESG performance plays in driving open green innovation within enterprises.

Table 3

Baseline Regression Results: The Impact of ESG Performance on Open Green Innovation

	(1)	(2)	(3)	(4)	(5)	(6)
ESG	0.086***	0.072***	0.016***			
	(12.85)	(10.82)	(2.60)			
E				0.151**		
				(2.17)		
S					0.129**	
					(2.54)	
G						0.000
						(0.00)
Size		0.227***	0.071***	0.069***	0.066***	0.070***
		(25.73)	(5.19)	(4.94)	(4.71)	(5.01)
Age		–0.225***	–0.002	–0.013	–0.013	–0.011
		(–20.30)	(–0.10)	(–0.50)	(–0.49)	(–0.41)
CurrentRatio		–0.016***	0.003	0.002	0.002	0.002
		(–5.34)	(1.19)	(0.57)	(0.54)	(0.52)
ROA		0.058	0.040	0.078	0.068	0.078
		(0.45)	(0.45)	(0.79)	(0.68)	(0.79)
Growth		0.016	–0.014**	–0.013	–0.013	–0.013
		(1.51)	(–2.04)	(–1.50)	(–1.49)	(–1.57)
CashFlow		–0.318**	–0.059	–0.031	–0.026	–0.032
		(–2.56)	(–0.62)	(–0.31)	(–0.26)	(–0.32)
BoardSize		0.048	0.048	0.057	0.051	0.056
		(1.00)	(0.85)	(0.95)	(0.85)	(0.92)
*Top*1		–0.003***	0.000	0.000	0.000	0.000
		(–4.46)	(0.06)	(0.14)	(0.22)	(0.22)

(*To be continued*)

(*Continued*)

	(1)	(2)	(3)	(4)	(5)	(6)
BoardMeeting		0.071***	–0.022	–0.026	–0.026	–0.027
		(2.95)	(–1.10)	(–1.22)	(–1.22)	(–1.24)
Soe		0.025	0.022	0.027	0.029	0.029
		(0.68)	(0.64)	(0.76)	(0.81)	(0.80)
Dual		0.030*	–0.018	–0.020	–0.020	–0.020
		(1.93)	(–1.11)	(–1.16)	(–1.16)	(–1.16)
Constant	0.159***	–4.521***	–1.174***	–1.673***	–1.535***	–1.082***
	(5.79)	(–22.74)	(–3.78)	(–3.98)	(–4.20)	(–2.69)
Firm fixed effects	No	No	Yes	Yes	Yes	Yes
Year fixed effects	No	No	Yes	Yes	Yes	Yes
n	13,141	13,141	13,141	12,202	12,202	12,202
Adj. R^2	0.012	0.082	0.654	0.656	0.656	0.656

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

Columns (4) to (6) of Table 3 delineate the impact of the three ESG sub-dimensions on open green innovation. The environmental dimension (*E*) is shown to significantly enhance open green innovation by fostering resource efficiency and alleviating ecological pressure. The social dimension (*S*) contributes to this advancement by strengthening corporate social responsibility and enhancing public perception, which, in turn, attracts more partners and external resources. In contrast, the governance dimension (*G*) is pivotal in enhancing the overall corporate performance and innovation capacity. The regression analysis indicates that it does not have a direct and significant effect on open green innovation. Corporate governance primarily emphasizes the refinement of internal structures, transparency in decision-making, and the fortification of stakeholder relations. Although these elements lay a robust institutional foundation and create a favorable environment for innovation activities, they lack direct influence over the mechanisms driving open green innovation. Conversely, the improvements brought about by governance mechanisms typically emerge gradually. This necessitates an accumulation of effects on innovation capacity and organizational performance before these impacts become observable. In contrast, open green innovation mandates that businesses respond swiftly to environmental and market changes, capitalize on emerging opportunities, and adapt their innovation strategies flexibly. As such, the influence of corporate governance is less likely to yield immediate or direct outcomes in accelerating open green innovation.

4.3 Moderating Effect Test

Table 4 presents an overview of the results of the moderating effect analysis.

Table 4
Results of the Moderating Effect Analysis

	(1)	(2)	(3)
ESG	–0.078	–0.034	–0.020***
	(–1.32)	(–1.40)	(–2.63)
RDL	–2.511*		
	(–1.73)		
ESG × *RDL*	0.162*		
	(1.77)		
*DT/DT_*1	–0.059*	0.242***	
	(–1.71)	(8.13)	
ESG × *DT/DT_*1	0.018**	0.022***	
	(2.19)	(3.34)	
Constant	0.431	–1.366*	–0.632**
	(0.46)	(–1.76)	(–2.09)
Control variables	Yes	Yes	Yes
Firm fixed effects	Yes	Yes	Yes
Year fixed effects	Yes	Yes	Yes
n	9,730	5,087	11,790
Adj. R^2	0.674	0.699	0.711

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

In Table 4, column (1) introduces *RDL* alongside an interaction term between *ESG* and *RDL* (*ESG* × *RDL*) within the baseline regression model. The interaction term displays a coefficient of 0.162, significant at the 10% level. This result indicates that regional digital economy development significantly moderates the relationship between ESG performance and open green innovation. In other words, the impact of ESG performance on open green innovation is greater in regions with more advanced digital economies.

In column (2) of the same table, the analysis incorporates *DT* as the moderating variable. Building on the baseline model, *DT* and the interaction term (*ESG* × *DT*) are included. The interaction term yields a coefficient of 0.018, significant at the 5% level. This implies that corporate digital transformation positively reinforces the relationship between ESG performance and open green innovation. Column (3) of Table 4 utilizes the number of digital-economy-related patent applications (*DT_*1) as an alternative metric for corporate digital transformation. The interaction coefficient between *ESG* and *DT_*1 stands at 0.022, significant at the 1% level. This finding offers compelling evidence that elevated levels of digital transformation significantly amplify the positive influence of ESG performance on open green innovation.

4.4 Heterogeneity Analysis

A detailed heterogeneity analysis was performed, examining from three perspectives.

Initially, following the National Bureau of Statistics of China's *High-Technology (Manufacturing) Industry Classification (2017)*, sample enterprises were divided into high-tech and non-high-tech groups to conduct separate regression analyses. As illustrated in columns (1) and (2) of Table 5, the positive impact of ESG performance on open green innovation is statistically significant within the high-tech enterprise category. In contrast, the *ESG* coefficient for the non-high-tech sample remains statistically insignificant. High-tech companies exhibit heightened awareness and have adopted a proactive approach toward ESG considerations. This could be primarily attributed to their proactive approach, technology-intensive nature, and innovation-driven characteristics. These companies are more adept at adopting and integrating ESG frameworks into their open innovation processes, and they utilize advanced technologies to expedite green innovations. By contrast, non-high-tech enterprises typically have weaker technological infrastructures and exhibit limited motivations for innovation. This hampers their ability to integrate ESG strategies into their meaningful green innovation practices. Furthermore, these enterprises often face constraints on resources and expertise, which impede the execution of an effective ESG strategy, resulting in weaker outcomes in both scope and depth compared with high-tech counterparts. Therefore, the facilitating role of ESG performance in fostering open green innovation is more evident among high-tech enterprises.

Table 5

Results of Heterogeneity Analysis

	(1) High-tech enterprises	(2) Non-high-tech enterprises	(3) High regional trust level	(4) Low regional trust level	(5) High financing constraints	(6) Low financing constraints
ESG	0.017**	0.012	0.030***	0.002	0.031***	0.002
	(2.28)	(1.12)	(3.34)	(0.19)	(2.98)	(0.26)
Constant	–1.707***	–0.551	–0.532	–2.008***	–1.929***	–0.226
	(–4.04)	(–1.18)	(–0.90)	(–3.92)	(–4.12)	(–0.44)
Control variables	Yes	Yes	Yes	Yes	Yes	Yes
Firm fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
Year fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
n	9,367	3,706	6,296	6,451	6,481	6,231
Adj. R^2	0.653	0.650	0.662	0.688	0.656	0.675

Note. *t*-values are reported in parentheses.

*** $p < 0.01$. ** $p < 0.05$.

This paper uses survey data from Zhang and Ke (2002) to measure regional variations in social trust levels and to conduct a comparative analysis of these differences. Columns (3) and (4) of Table 5 indicate that the positive correlation between ESG performance and

open green innovation is statistically significant in regions exhibiting relatively high levels of social trust. In contrast, this relationship becomes insignificant in areas with lowered social trust levels. In regions marked by higher social trust, inter-enterprise collaboration and communication become more effective, thereby facilitating the implementation of ESG-related initiatives and enhancing the integration and sharing of green innovation resources. In such environments, enterprises are motivated to actively engage in open green innovation, driven by the innovation opportunities that arise in a high-trust environment. Conversely, in regions characterized by low social trust, both cooperation costs and perceived risks escalate, which diminishes enterprises' willingness to pursue collaborative ventures. At the same time, issues such as information asymmetry and inequitable resource allocation further hinder the effective integration of green innovation resources, limiting firms' experimentation and implementation. Thus, the influence of ESG performance on promoting open green innovation is more pronounced among enterprises situated in regions with higher levels of social trust.

Finally, the extent of financing constraints emerges as a pivotal factor influencing enterprises' investment in innovation. Strong ESG performance can effectively alleviate financing constraints. Consequently, for enterprises experiencing significant financing pressure, robust ESG performance is more likely to catalyze open green innovation. Following Pan et al. (2019), this paper employs the KZ Index to quantify enterprises' financing constraints. The findings presented in columns (5) and (6) of Table 5 illustrate that the positive impact of ESG performance on open green innovation is significantly more substantial among enterprises facing high financing constraints. This suggests that strong ESG performance not only helps in garnering stakeholder support but also alleviates financing barriers, thereby fostering open green innovation.

4.5 Robustness Tests

This paper employs five robustness verification methods. First, the total number of jointly filed green invention patents serves as an alternative metric for open innovation. The regression outcomes are detailed in column (1) of Table 6. Second, ESG ratings from the National Institution for Finance & Development of the Chinese Academy of Social Sciences (*CNRDS-ESG*) are incorporated to replace the existing Sino-Securities Index Information Service ESG dataset and address potential discrepancies arising from different ESG rating systems and methodologies. Results are shown in column (2) of Table 6. Third, the sample is restricted to the period from 2011 to 2019 to mitigate potential biases introduced by public health incidents. The results are reported in column (3) of Table 6. The fourth robustness check involves re-clustering standard errors at the company level, with results documented in column (4) of Table 6. Lastly, to enhance model control and reduce the risk of omitted-variable bias, additional control variables, including audit opinion (*Opinion*), institutional ownership (*INST*), and the Herfindahl–Hirschman Index (*HHI_A*), are introduced. The results of this analysis are displayed in column (5) of Table 6. Across all robustness tests, the

evidence consistently affirms that the positive relationship between ESG performance and open green innovation is both stable and reliable.

Table 6
Robustness Test Results

	(1)	(2)	(3)	(4)	(5)
ESG	0.017***		0.025***	0.016**	0.016***
	(3.73)		(3.41)	(2.23)	(2.70)
CNRDS-ESG		0.001*			
		(1.73)			
Opinion					0.010
					(0.28)
HHI_A					–0.049
					(–1.06)
INST					–0.002***
					(–3.38)
Constant	0.273***	–1.243***	–1.178***	–1.174***	–1.376***
	(14.91)	(–3.99)	(–3.12)	(–2.83)	(–4.25)
Control variables	Yes	Yes	Yes	Yes	Yes
Firm fixed effects	Yes	Yes	Yes	Yes	Yes
Year fixed effects	Yes	Yes	Yes	Yes	Yes
n	13,124	13,124	9,730	13,124	12,964
Adj. R^2	0.637	0.653	0.673	0.653	0.654

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

4.6 Endogeneity Test

Open green innovation capacity has emerged as a fundamental component of corporate sustainability strategies, potentially exerting a significant positive effect on ESG performance. Specifically, enterprises that possess stronger capabilities in open green innovation are more likely to demonstrate better ESG performance. However, it is essential to recognize that ESG ratings are influenced by a variety of factors, including intrinsic business characteristics, such as the embeddedness of corporate culture and employees' capacity for learning and adaptation. These attributes are likely interconnected with the enterprises' performance in green innovation initiatives. Organizations characterized by a strong cultural foundation and heightened learning capabilities typically exhibit greater proactivity in addressing social responsibility, which can lead to improved ESG evaluations. Given these dynamics, empirical findings may be subject to endogeneity issues, including selection bias, reverse causality, and omitted-variable bias. To mitigate these concerns, this paper uses instrumental variables alongside propensity score matching (PSM) to produce a more robust analysis. Table 7 reports the results.

Table 7
Endogeneity Test Results

	(1) First stage	(2) Second stage	(3) PSM
ESG		0.180***	0.016***
		(2.60)	(2.85)
IV	0.365***		
	(9.41)		
Control variables	Yes	Yes	Yes
Firm fixed effects	Yes	Yes	Yes
Year fixed effects	Yes	Yes	Yes
n	13,124	13,124	13,111

Note. *t*-values are reported in parentheses.
*** $p < 0.01$.

In line with the methodology proposed by Li et al. (2024), this paper uses the annual regional-average ESG performance of enterprises within the same province and year as the instrumental variable (*IV*). Addressing the relevance criteria, businesses within the same region and year are subject to similar industrial policies and market environments, thereby creating a correlation in ESG performance metrics across these enterprises. For exogeneity, it is crucial to note that the ESG performance of other enterprises in the same region does not directly influence the open green innovation capabilities of a focal enterprise. Further validation of the instrumental variable indicates strong statistical adequacy: The LM test yields a *p*-value of 0, suggesting no concerns about under-identification. Additionally, the Cragg-Donald Wald F statistic is reported at 88.57, reinforcing the absence of weak-instrument issues. These findings collectively support the suitability and validity of using regional ESG averages as an instrumental variable. As presented in column (1) of Table 7, the coefficient associated with the *IV* is significantly positive. In column (2), the analysis continues to demonstrate that ESG performance exerts a significant positive effect on open green innovation.

Based on the framework by Peng et al. (2024), this paper subsequently divides businesses into treatment and control groups based on the annual industry-level median of ESG performance. Enterprises with ESG performance values at or above the industry median are classified into the treatment group, while those below the median are assigned to the control group. To estimate propensity scores, matching variables such as enterprise size, liquidity ratio, growth capacity, operating cash flow, board size, board diligence, most significant shareholder ownership, and CEO duality are employed through a Logit regression model, accompanied by radius matching. Post-matching analysis indicates that the differences in covariates between the treatment and control groups are no longer statistically significant. Regression analyses conducted on the matched sample yield results shown in column (3) of Table 7, which remain consistent with earlier findings and further affirm that ESG performance significantly promotes open green innovation.

5 Conclusions and Implications

Open green innovation is the confluence of open and green innovation and serves as a pivotal mechanism for enterprises seeking to achieve sustainable development. Using data from A-share-listed enterprises from 2011 to 2022, this paper empirically examines the influence of ESG performance on open green innovation. Furthermore, it evaluates the moderating effects of regional digital economy development and corporate digital transformation. The findings reveal that, firstly, ESG performance has a statistically significant positive effect on open green innovation. Specifically, a one-unit increase in ESG performance corresponds to a 1.6% increase in open green innovation output. This result demonstrates that strong ESG performance improves enterprises' capacity to access external resources and build collaborative relationships, thereby facilitating advancements in green innovation. Secondly, the development of the regional digital economy plays a significant moderating role in the relationship between ESG performance and open green innovation. A well-developed digital economy reduces cooperation costs, enhances information accessibility, and strengthens resource integration, collectively thereby amplifying the positive effect of ESG performance on green innovation outcomes. Thirdly, corporate digital transformation significantly strengthens the relationship between ESG and open green innovation. Digital transformation improves transparency, optimizes resource allocation, supports collaborative innovation efforts, and promotes new business models, thereby strengthening enterprises' capabilities in open green innovation. Fourthly, heterogeneity analysis further highlights that the influence of ESG performance is neither uniform nor linear. It varies among enterprises based on differing internal conditions and external environments. For high-technology enterprises, the combination of innovation-intensive characteristics and higher ESG requirements enhances their competitiveness in global supply chains. It attracts partners focused on sustainability and green development, thereby strongly supporting open green innovation. Furthermore, in regions with high social trust, the positive effect of ESG performance is more pronounced, as high-trust environments reduce uncertainty and promote deeper collaboration and more efficient knowledge flows. Finally, for enterprises facing high financing constraints, ESG performance becomes a form of "soft capital" that enhances credibility, reduces information asymmetry, attracts investment, and significantly accelerates open green innovation.

The theoretical framework developed in this research explains how ESG performance enhances open innovation capacity and clarifies the mechanisms through which both regional digital economy environments and enterprise-level digital transformation influence one another. The digital economy provides an enabling context for open innovation, allowing businesses to expand channels for knowledge acquisition, access global innovation networks, and engage deeply with knowledge flows. Simultaneously, enterprises' digital transformation enhances their capacity to manage internal and external knowledge resources, improving innovation efficiency and facilitating synergy among human, technological, and capital factors. Under the combined influence of external digital ecosystems and internal digital transformation capabilities, both the breadth and depth of open innovation expand. This shift

requires enterprises to move beyond traditional, closed R&D-dominant models and embrace more flexible, multi-layered, cross-boundary open innovation networks.

From the perspective of open green innovation system building and ESG capability development, this paper offers the following managerial implications.

First, enterprises should establish modern ESG management systems to leverage ESG performance as a driver of open green innovation. Businesses should integrate ESG principles into core production and operations activities, proactively assume ESG responsibilities, and effectively balance business development with environmental, social, and governance considerations. They should also remain attentive to stakeholder expectations and safeguard their interests, cultivate an open green innovation mindset, and establish strong bilateral and multilateral relationships with suppliers, consumers, investors, government agencies, and non-governmental organizations.

Second, enterprises should capitalize on the opportunities brought by regional digital economy development to strengthen innovation networks. This includes improving interaction mechanisms among network actors, enhancing coordination and coupling across participants, and fostering a green, open, co-creative, shared, and symbiotic open green innovation ecosystem. Through innovation networks, enterprises can accelerate knowledge sharing, enabling new technologies and knowledge from suppliers, customers, and governmental actors to flow into the organization.

Third, enterprises should proactively leverage digital transformation to enhance ESG capabilities and strengthen open green innovation systems. By embedding digital technologies within green innovation systems, enterprises can create innovation networks, enhance supply chain knowledge spillovers and coordination, and improve overall ESG performance.

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