

The Impact of Digital Transformation on Corporate Green Innovation: The Mediating Role of Corporate ESG Ratings

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Abstract. Using data from Chinese A-share listed firms during 2015-2024, this paper examines how digital transformation shapes corporate green innovation and identifies the mechanisms at play, focusing on how corporate ESG ratings mediate the relationship above. The results indicate that digitalization has a significant positive effect on green innovation, and this positive effect is stable across various robustness tests. Furthermore, ESG performance partially mediates the positive effect: digital transformation encourages green innovation both directly, and indirectly through improving firms' environmental, social, and governance performance. Additional heterogeneity tests show that the promoting effect is more evident in firms with high R&D investments, firms in heavily polluting industries, and state-owned firms. Overall, this study provides empirical evidence of how digitalization drives corporate green innovation, enabling insights for business decisions and public policy.

Keywords: Digital Transformation, Green Innovation, ESG Rating, Mediating Effect, Corporate Sustainable Development

1. Introduction

As China's economy evolves into a stage of high-quality growth, greening and decarbonizing production and social systems have become important national goals. Within this framework, ESG has been a prominent tool for evaluating overall corporate performance and how transformation strategies may work effectively to align long-term value creation with sustainable development goals [1]. However, firms often face considerable hurdles in achieving better ESG outcomes with green innovation, such as over-consumption, high emissions, and limited innovation capacity as a result of conventional modes of production [2], as well as managerial inefficiencies and information asymmetries which negatively affect both identification of environmental risks and commercialization of innovative green solutions [3]. Addressing these CSR bio and market barriers require that new pathways and driving forces be explored.

Digital technologies (such as AI, big data, and the Internet of Things (IoT)) are now core drivers embedded into the functioning of both market economics and social relations. Government planning documents, like the "14th Five-Year Plan for Digital Economy Development," note explicitly that digitalization-led transformation is a core driver towards building new competitive advantages and advancing towards low-carbon, green development. Digitalization not only provides benefits to the sustainability of traditional production processes [4], but it also enables the development of new

green products, services, and technology-driven solutions [5] that contribute to improved environmental performance. Additionally, digital transformation promotes transparency, efficiency of management practices, and strengthens corporate social responsibility and governance. These attributes suggest that digitalization has significant potential in alleviating ESG-related challenges and provoking green innovation.

As the convergence of policies and corporations accelerates, several key questions arise: Can digital transformation be an effective driver of corporate green innovation? What are the pathways of this effect? Are ESG performance providing a mediate pathway? Addressing these questions is essential for mapping out the ways digitalization may support green development, improving firms' transformation policies, and aiding policymakers.

The study makes three contributions to the scholarly literature based on its academic perspective. First, it proposes an aggregated analytical framework that creates an empirical test of the impact of digital transformation on corporate green innovation on a direct and indirect basis. In doing so, it utilizes ESG ratings as a mediator, which helps to validate the partial role of ESG ratings and how improved ESG performance supports green innovation. Second, it examines heterogeneity analyses across R&D intensity, pollution, and ownership structures, which provides evidence for variations in the impact of digitalization, depending on the organizational and industry contexts. Taken together, the contributions lead to both theoretical contributions and practical implications for policymakers to create a differentiation in order to create differentiated policy responses.

2. Theoretical analysis and research hypotheses

2.1. The impact of digital transformation on corporate green innovation

The implementation of digital technologies significantly improves organizations' capabilities to pursue green innovation based on the spread and absorption of knowledge. Although organizations may undertake radical change to the digitalization of practices, intensive usage of digital technologies facilitates better identification of new opportunities in green technology, more effective use of innovation resources, and more rapid renewal of R&D. Technologies such as big data analytics and artificial intelligence enable organizations to manage enormous amounts of environmental data in real time, identify patterns, and determine the most productive directions for innovations, and thereby improve the efficiency and relevance of green R&D. At the same time, digital transformation generates collaborative innovation platforms to break down knowledge silos within and across organizations, increasing flow, sharing and recombination of green technological knowledge. This facilitates the cross-fertilization of technological resources across different disciplines and improves the generation of systemic green innovations [6]. Through industrial internet systems and various collaborative networks, organizations can physically transcend spatial and organizational boundaries to have access to, adopt, and incorporate advanced external green practices, technologies and ideas. This form of extensive spillover and systemic integration of knowledge provides a rich base of resources and breadth of solutions for green innovation, forming an important mechanism for enabling green-integrated innovation.

Additionally, the process of digital transformation provides encouragement for green innovation via reductions in innovation costs and risks. Cloud services and digital twin systems provide low-cost simulated environments in which new green technologies can be tested many times, which greatly reduces trial-and-error costs incurred during research and development. In this way, firms can improve products and processes virtually with little consumption of materials or energy resources used, which leads to lower capital needs [7]. By allowing firms to explore reality through

virtual testing, this process not only reduces financial risk but also drives motivation to invest in speculative green technologies that have promise but unknowns, thus stimulating exploratory innovation.

It is also important that the inherent characteristics of digital transformation, such as efficiency, sustainability and traceability heavily match the demands of green development, so digital features promote organizations to implement digital capabilities along the dimensions of eco-friendly product design, production optimization and low-carbon supply chain management, which expands both the scope and depth of green innovation outcomes [8].

Hypothesis 1: Digital transformation exerts a positive effect on corporate green innovation.

2.2. The mediating role of ESG ratings

Through the incorporation of environmental, social, and governance results, ESG ratings serve as a vital link between digital transformation and corporate green innovation. To begin with, digital technology adoption improves the firms' ability to collect and analyze environmental data, facilitating the sophistication of environmental management. This supports compliance with disclosure requirements and performance measures associated with the "E" dimension of ESG ratings [9]. Greater ESG scores signal positively to investors and stakeholders about the quality of firms' sustainability performance and may provide firms with access to supportive policies and sustainable financing resources, enabling a direct influx of capital toward green technology development [10].

Second, digitalization enhances governance through improved data-driven decision-making and intelligent risk management. This results in more rational resource allocation and a more targeted investment in green innovation projects. These improvements in governance represent a fundamental element of ESG assessment and contribute to improved ESG scores [11].

Moreover, enhanced ESG performance facilitates an organizational context that combines external scrutiny, with an internal desire, to shift managers attention toward long-term value creation and sustainability. In this context, firms are encouraged to convert their digital capabilities into real innovation outputs which improve and sustain their ESG performance. Therefore, digital transformation, through its ESG performance, indirectly enhances green innovation capability, as well.

Hypothesis 2: ESG ratings mediate the relationship between digital transformation and corporate green innovation.

3. Model construction

3.1. Data sources and processing

This study draws its sample from Chinese A-share listed companies spanning 2015 to 2024. The sample selection follows a three-step procedure: first, the omission of ST and *ST firms; second, the exclusion of financial institutions; and third, a 1% and 99% winsorization of all continuous variables to control for outliers. The required data were obtained from the Wind, CNRDS, and CSMAR databases, culminating in an unbalanced panel of 5,427 distinct firms, which corresponds to 37,524 firm-year observations.

3.2. Variable definitions

3.2.1. Dependent variable

Corporate green innovation is measured by the number of green patent applications [12], following established research practice. Specifically, the total number of green invention patents and green utility model patents is calculated. Additionally, it applies a logarithmic transformation after adding one to reduce right-skewness.

3.2.2. Independent variable

The recurrence of digitalization-related terms appearing in firms' annual reports proxies digital transformation [13], consistent with prior literature. Keywords span five dimensions: big data, blockchain, artificial intelligence, cloud computing, and applications of digital technologies. The total frequency is summed and then log-transformed after adding one.

3.2.3. Mediating variable

ESG performance is represented by the average annual Huazheng ESG rating. The Huazheng system, specifically designed for Chinese firms, evaluates corporate environmental, social, and governance practices using publicly available data and assigns ratings ranging from AAA to C on a percentage-based scale.

3.2.4. Control variables

In line with earlier studies on green innovation, several firm-level characteristics are controlled for: managerial shareholding ratio, Tobin's Q, firm age, leverage, return on assets, cash flow ratio, and firm size.

3.3. Model specification

To assess the effect of digital transformation (Dig) on green innovation (GI)—the dependent variable—we estimate the following baseline regression model:

$$GI_{it} = \alpha_0 + \alpha_1 Dig_{it} + \sum Controls_{it} + \sum Ind_t + \sum Year_i + \varepsilon_{it} \quad (1)$$

To conduct a deeper analysis of ESG performance as a mediating variable, the following set of mediation models is constructed:

$$ESG_{it} = \beta_0 + \beta_1 Dig_{it} + \sum Controls_{it} + \sum Ind_t + \sum Year_i + \varepsilon_{it} \quad (2)$$

$$GI_{it} = \gamma_0 + \gamma_1 ESG_{it} + \sum Controls_{it} + \sum Ind_t + \sum Year_i + \varepsilon_{it} \quad (3)$$

In the equations, subscript *i* refers to the industry, and *t* the year. This research incorporates industry (Ind) and year (Year) effects to control for potential bias. with $\sum Controls_{it}$ representing a series of control variables.

4. Empirical analysis

4.1. Descriptive statistics

As shown in Table 1, the descriptive statistics for the core variables are documented. Corporate green innovation (GI) has a mean of 0.380, a median of 0, and a maximum of 3.710. This indicates that most firms demonstrate relatively limited output in terms of green technology innovation. More than half of the sample has not yet produced substantive green patents, while only a small proportion shows remarkable innovation activity. This pattern can largely be explained by the long development cycles and substantial investment requirements associated with green technologies, leaving many enterprises in a stage of technological accumulation rather than active commercialization.

As indicated in the data, digital transformation (Dig) records a mean of 1.770, a median of 1.610, and an upper bound of 5.280, showing a right-skewed distribution. This suggests that although the general level of digitalization is moderate, only a minority of firms have achieved a relatively advanced stage of transformation, while the majority are still experimenting with early-stage digital practices. For ESG ratings, the mean equals 73.15, the median stands at 73.34, and the variation is low, as reflected in a standard deviation of 5.510, reflecting relatively narrow variation among firms. Such results imply that ESG performance has become increasingly standardized across industries, in line with the growing importance of ESG frameworks in China.

Table 1. Descriptive statistics results

Variable	Observations	Mean	Std. Dev.	Min	Median	Max
GI	37214	0.380	0.790	0	0	3.710
Dig	37341	1.770	1.410	0	1.610	5.280
MSR	37344	14.71	19.62	0	2.250	68.56
TobinQ	28073	2.050	1.950	0	1.460	10.86
Age	31502	12.13	8.010	0	10	34
Lev	28073	0.430	0.210	0.0600	0.420	0.940
ROA	28824	0.0400	0.0700	-0.290	0.0400	0.200
CFR	37344	0.0500	0.0700	-0.160	0.0500	0.240
Size	37340	22.30	1.290	19.98	22.09	26.37
ESG	36125	73.15	5.510	56.16	73.34	86.69

4.2. Baseline regression

The fundamental regression analysis, presented in Table 2, indicates a statistically significant and positive impact of digital transformation on corporate green innovation. All models include year and industry fixed effects. The first specification in Column (1) excludes control variables and shows a robust positive relationship for the Dig variable, which reached significance at the 1% level. The analysis does not change in Column (2) after including particular firm-level control variables. For example, the coefficient on Dig is 0.0530, which still maintains significance at the 1% level. This means, more specifically, that an increase of one-unit of digital transformation raises green innovation by 0.0530 units, which means Hypothesis 1 is confirmed.

Table 2. Baseline regression results

	(1)	(2)
	GI	GI
Dig	0.0791*** (0.00351)	0.0530*** (0.00523)
MSR		0.0000262 (0.000376)
TobinQ		0.00528 (0.00410)
Age		-0.00841*** (0.000932)
Lev		0.264*** (0.0393)
ROA		0.405*** (0.102)
CFR		0.277*** (0.0993)
Size		0.175*** (0.00635)
Ind		Yes
Year		Yes
_cons	-0.0462 (0.0614)	-3.950*** (0.171)
N	37186	19392
R ²	0.143	0.205
adj. R ²	0.141	0.201

4.3. Robustness tests

To ensure the reliability of the baseline findings, two robustness checks are conducted. First, an alternative proxy for digital transformation is employed. In line with earlier studies, the share of technology-oriented intangible assets in the digital domain(Dig_IA) is used as a substitute gauge [14]. Column (1) of Table 3 shows a significantly positive coefficient of 0.150 at the 1% level, consistent with the baseline outcomes. Second, to mitigate potential bias arising from the COVID-19 pandemic during 2020–2021, these two years are excluded from the sample. Column (2) reports a coefficient of 0.0496 for Dig, still significantly positive at the 1% level, while the control variables exhibit no material changes compared with the baseline model. Taken together, the robustness tests verify that the relationship between digital transformation and corporate green innovation is resilient to alternative measures and sample adjustments, thus enhancing the reliability of the core results.

Table 3. Robustness test results

	(1)	(2)
	GI	GI
Dig_IA	0.150*** (0.0298)	
Dig		0.0496*** (0.00572)
MSR	0.000137 (0.000377)	-0.000284 (0.000413)
TobinQ	0.00584 (0.00411)	0.00335 (0.00473)
Age	-0.00845*** (0.000933)	-0.00815*** (0.00102)
Lev	0.250*** (0.0394)	0.253*** (0.0428)
ROA	0.390*** (0.103)	0.433*** (0.113)
CFR	0.243** (0.0995)	0.250** (0.108)
Size	0.187*** (0.00632)	0.174*** (0.00705)
Ind	Yes	Yes
Year	Yes	Yes
_cons	-4.147*** (0.171)	-3.888*** (0.189)
N	19394	15581
R ²	0.202	0.203
adj. R ²	0.198	0.198

4.4. Mediation effect tests

Table 4 reports the results of the mediation effect test through ESG ratings. The first path, shown in Column (1), indicates a substantial positive impact of digital transformation on ESG ratings (Dig coefficient = 0.148, significant at 1%). In the second step, Column (2) demonstrates that even after controlling for the influence of ESG (coefficient = 0.0158, significant at 1%), digital transformation (Dig) retains a significant direct effect on green innovation. This evidence affirms that ESG ratings function as a partial mediating channel linking digital transformation to corporate green innovation.

Table 4. Mediating effect test results

	(1)	(2)
	ESG	GI
Dig	0.148*** (0.0341)	0.0530*** (0.00528)
MSR	0.00634*** (0.00244)	-0.0000644 (0.000378)
TobinQ	0.0483* (0.0269)	0.00406 (0.00418)
Age	-0.0770*** (0.00607)	-0.00718*** (0.000944)
Lev	-6.118*** (0.258)	0.369*** (0.0406)
ROA	8.028*** (0.686)	0.292*** (0.107)
CFR	1.112* (0.653)	0.251** (0.101)
Size	1.963*** (0.0414)	0.145*** (0.00678)
ESG		0.0158*** (0.00113)
Ind	Yes	Yes
Year	Yes	Yes
_cons	26.36*** (1.110)	-4.379*** (0.175)
N	19079	19079
R ²	0.212	0.214
adj. R ²	0.208	0.210

4.5. Heterogeneity analysis

4.5.1. R&D intensity heterogeneity

As shown in Columns (1) and (2) of Table 5, the estimated coefficient of Dig is 0.0821 for high R&D intensity firms, while it is 0.0222 for low R&D intensity firms, with both results significant at the 1% level. The stronger effect observed in the high-R&D group suggests that firms with greater absorptive capacity and stronger technological foundations are better positioned to translate digital transformation into enhanced green innovation outcomes.

4.5.2. Pollution intensity heterogeneity

The coefficients found in Columns (3) and (4) indicate that firms in pollution-intensive industries have a coefficient of 0.0505 and companies in industries with lower pollution have 0.0452, significant at the 1% level. The stronger coefficient for pollution-intensive firms suggests that stricter environmental regulation and potentially more opportunities for performance improvement enhance the benefits of digitalization for green innovation.

4.5.3. Ownership heterogeneity

In Columns (5) and (6), it is observe that the coefficients of Digi are 0.0601 for state owned enterprise (SOEs), and 0.0516 for non-SOEs. Both coefficients are statistically significant at 1% significance level. The larger coefficient in SOEs may reflect that those businesses frequently receive government subsidies and play a role in achieving national strategic goals (for instance, carbon neutrality goals) that support their digital transformation to align more closely with environmental goals.

Table 5. Heterogeneity test results

	(1)	(2)	(3)	(4)	(5)	(6)
GI	R&D Investment Heterogeneity		Pollution Level Heterogeneity		Ownership Heterogeneity	
	High R&D	Low R&D	Heavy-Polluting	Non-Heavy-Polluting	State-Owned	Non-State-Owned
Dig	0.0821***	0.0222***	0.0505***	0.0452***	0.0601***	0.0516***
CV	Yes	Yes	Yes	Yes	Yes	Yes
Ind/Year	Yes	Yes	Yes	Yes	Yes	Yes
N	8526	9506	5914	12007	5707	13077
R ²	0.202	0.210	0.226	0.221	0.287	0.200
adj. R ²	0.195	0.202	0.215	0.215	0.276	0.195

5. Conclusion

The empirical analysis yields the following results: (1) Companies who digitally transform their processes have significantly greater green innovation capabilities. This relationship is robust in various tests including alternate measures and sample restrictions; (2) ESG ratings act as a partial mediation, suggesting that digital transformation stimulates innovation, both directly and indirectly, by enhancing ESG performance; (3) Heterogeneity analysis suggests that effects are stronger among high R&D companies, heavy-polluting companies, and SOEs, illustrating the moderating roles of resource availability, regulatory pressures, and environmental conditions.

These results, taken together, indicate that digital transformation both enables green innovation through technology and provides a sustainable route by improving ESG performance. This assists in broadening the theoretical understanding of capability-building in green innovation and provides real-world evidence of how digital technology can facilitate sustainable development at the micro-level.

The policy implications derived from this study are threefold:

(1) Corporate level: Firms should work to incorporate digital transformation with regards to green innovation. This means combination digital instruments with green development paths for firms, and

expanding the integration of AI, big data, and IoT in environmental performance management, environmentally focused process innovation, product innovation and ESG systems to achieve full digital- based green development, for example, big data can be used advantageously to manage ESG standards.

(2) Government level: Policymakers should improve the design of incentive and regulatory frameworks. Potential measures include preferential tax policies, green credit support, and dedicated funding to encourage digital-green transitions, alongside stricter ESG disclosure requirements in high-emission sectors. Moreover, differentiated policies can guide SOEs to take a leading role and assist SMEs in overcoming financial and capacity barriers.

(3) Investor and market level: The ability to recognize ESG value should be enhanced. Investors should pay attention to both digital transformation and ESG performance when identifying firms with genuine green innovation potential, thereby channeling capital toward sustainable sectors. Rating agencies, meanwhile, should refine ESG evaluation systems by integrating digitalization indicators to more accurately capture firms' long-term sustainability capacity.

In summary, promoting the integration of digital transformation and ESG practices is not only vital for strengthening firms' green innovation capabilities and competitiveness but also serves as an important micro-foundation for realizing high-quality economic advancement and achieving the dual carbon objectives.

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