

Research on the Impact of Digital Transformation on Enterprise Green Innovation

Ruihan Geng

*College for International Education Cooperation, Tianjin University of Commerce, Tianjin, China
2510577822@qq.com*

Abstract: Amid escalating global climate change and environmental challenges, contemporary organizations now prioritize environmentally-conscious technological advancements as a pivotal mechanism to attain enduring ecological equilibrium. While existing studies have explored the role of digitalization on eco-friendly innovation, the mediating role of ESG score between the two is not discussed enough in the prior scholarly investigations, which is mostly from a singular viewpoint analysis and lacks systematic empirical support. This paper takes China's A-share listed companies from 2016 to 2023 as samples to explore the impact mechanism of digital transformation on corporate green innovation and introduces ESG score as a mediating variable to reveal its impact path. The findings indicate that digital transformation has a notable impact on enhancing the level of green innovation within enterprises, and ESG score serves as a moderating factor in this sequence of events. Heterogeneity test shows that digital transformation plays a more significant role in promoting green innovation in non-state-owned enterprises. This research offers an innovative viewpoint for comprehending the intrinsic linkage between the shift to digital and eco-innovative advancements and provides a theoretical basis and practical reference for enterprises to realize green transformation through digital technology.

Keywords: Digital transformation, Green innovation, ESG scoring, Mediating effect, Sustainable development

1. Introduction

Amidst the deepening challenges of worldwide climate alteration and ecological contamination, coupled with the hastened pursuit of a carbon-neutral planet, green innovation stands out as a critical avenue for firms to secure sustainable progress, thereby growing in strategic importance. Green innovation refers to the cognition, behavior and results of enterprises to improve the conception, manufacturing, and marketing of goods in order to minimize the adverse effects on the environment, improve resource utilization, and establish a competitive advantage, so as to achieve sustainable development [1]. As an important force to promote enterprise change, digital transformation has attracted increasing attention on its impact on enterprise green innovation. Enterprise digital transformation denotes the adoption and integration of digital technology into processes and analyzing data resources to promote enterprises to undergo profound changes in many aspects (such as operation process, internal structure, operation mode, external interaction mode, etc.), so as to achieve the established goals of the organization in a more efficient way [2]. At the same time, ESG is a holistic evaluation system of the three dimensions of Environmental, Social and Governance,

which comprehensively measures the corporate execution level in ecological protection, fulfillment of social responsibilities and internal management efficiency [3]. As an important indicator of a company's sustainable development ability, The ESG rating likely plays a pivotal role in the correlation between the shift to digital procedures and eco-friendly innovation. Although existing studies have paid attention to the independent impact of eco-friendly technological advancements [4] or ESG score [5] on green innovation, there are still gaps in the research on the mechanism of the two in synergistic driving green innovation, especially the mediating effect of ESG score has not been fully verified. The objective of this research is to uncover the dynamics by which corporate digitization influences eco-innovative practices, while also investigating the intermediary role that ESG ratings play in the relationship between these two phenomena. At the same time, this paper includes ESG score into the study of the relationship between digital transformation and green innovation and verifies its conduction route through the intermediary effect model, which expands the research boundary for the studies into the driving elements influencing corporate eco-innovative practices. The present study aims to offer an alternative viewpoint for comprehending the linkage between the shift to digital processes and firms' eco-friendly innovation initiatives, offer conceptual guidance to businesses to achieve green transformation in the era of digital economy, and provide theoretical basis and practical reference for improving ESG evaluation system and digital transformation policy and promoting enterprise green transformation.

2. Theoretical analysis and research postulation

In the era of digital economy, digital transformation has become a key driver for enterprises to achieve sustainable development. Digital transformation can not only enhance the fundamental competitive advantage of companies, but more importantly, it provides a strong support for promoting green innovation [6]. First of all, digital transformation provides a direct resource and technology foundation for enterprises' green innovation by reducing costs, optimizing resource allocation efficiency and strengthening technology research and development investment [7]. Secondly, digital means can strengthen the efficiency of knowledge integration, improve the internal governance mechanism of enterprises, enhance internal control, and thus provide a key propelling catalyst for the cultivation and implementation of green innovation [8]. Concurrently, shift to digitalization can stimulate the green innovation vitality of micro market players, promote the alteration in quality and variation in efficiency of enterprises' green innovation, so as to realize the ecological transformation and advancement of corporation, as well as fostering their green innovative capabilities [9]. In addition, by alleviating financing limitations, digitalization can additionally advance green innovation, reducing principal-agent costs and improving corporate environmental and social responsibility levels [10], so as to attain mutual prosperity between financial gains and environmental impacts. Based on this, the following hypothesis is proposed:

H1: Digital transformation has a profound influence on enterprise green innovation.

The digital evolution of companies serves as a crucial mechanism for advancing enduring growth. By integrating digital technologies into all aspects of their operations, companies can improve their environmental, social and governance (ESG) performance [11] by increasing the efficiency of innovation and optimizing the allocation of resources. Digital transformation can not only optimize production processes and reduce energy consumption, but also help companies better meet their ESG responsibilities by improving transparency and risk management. In addition, digital transformation can also improve ESG performance [12] by mitigating agency conflicts and enhancing internal governance, which in turn drives companies to better fulfill their environmental, social and governance responsibilities. At the same time, as an important external governance mechanism of enterprises, media attention can strengthen the positive promoting effect of digital transformation on ESG performance through supervision and reputation mechanism [12]. The increase of both negative

and positive reports can arouse the public's attention to the ESG performance of enterprises, thus prompting enterprises to pay more attention to ESG responsibility and take positive actions to improve ESG performance. The ESG performance of business venture can also foster advancement of the quality of green innovation by improving the internal capital acquisition ability, attracting talents and strengthening the external social supervision [13]. Arising from this, the following conjectures are put forth:

H2: ESG scores act as a facilitator between digital transformation and green innovation.

3. Research Design

3.1. Sample selection and data source

Within the confines of this scholarly article, Chinese listed companies from 2016 to 2023 are selected as the research objects, and the samples are screened as follows: Companies labeled as ST or ST* are not included; listed financial firms are excluded; and firms with incomplete data are also omitted. To mitigate the impact of outliers on the study findings, the key continuous variables were trimmed at the 1st and 99th percentiles. Digital transformation data, green innovation data and ESG rating data of enterprises were collated through annual reports, and other financial data were collected from CSMAR database.

3.2. Definition of variables

3.2.1. Enterprise green innovation

According to the research of Wang Xin and Wang Ying [14], green innovation 1(GI1) is the number of green inventions applied independently in the current year + the number of green utility models applied independently in the current year +1, and the logarithm is taken; Green innovation 2(GI2) is the number of green inventions independently applied for that year +1 and take logarithm.

3.2.2. Digital transformation

Digital Transformation (DCG). Referring to the research of Wu Fei et [15] al., the total word frequency of digital transformation keywords in corporate annual reports is measured by natural logarithm after adding 1.

3.2.3. ESG score

With its comprehensive coverage dimension, high frequency updating mechanism and localization features, the ESG rating system of Huazheng has been widely adopted in academic and practical fields, and its evaluation results are both scientific rigor and empirical support reliability. Therefore, this paper selects the ESG rating score of Huaseng to measure the ESG performance of enterprises.

3.2.4. Control variables

In order to control the influence of other factors on enterprise green innovation, the following variables will be managed within the scope of this study: asset SIZE (SIZE), which is the natural logarithm of total assets; The equity ownership percentage of the primary shareholder. (TOP), it represents the fraction of the total shares held by the largest shareholder; Financial leverage (LEV), which is total liabilities/total assets; DUAL, where the chairman and general manager are both 1, otherwise 0; Return on assets (ROA), which is net profit/total assets; The size of the BOARD, expressed as the logarithm of the aggregate number of directors; And equity checks and balances

(BAN), the ratio of the sum of shareholdings of the second to fifth largest shareholders to that of the largest shareholder.

Table 1: Definitions of variables

Variable name	Variable symbol	Variable description
Digital transformation	DCG	Digital word frequency total +1 take logarithm.
ESG representation	ESG	China Securities ESG rating score.
Green Innovation 1	GI1	Number of green inventions filed independently for the year + number of green utility models filed independently for the year +1, taking logarithm
Green Innovations 2	GI2	Number of green inventions filed independently that year +1 and take logarithm.
Size of assets	SIZE	Apply the natural log transformation to the total assets.
The shareholding ratio of the largest shareholder	TOP	The largest shareholder's holding represents a fraction of the overall share count.
Financial leverage	LEV	Total liabilities divided by total assets.
Two jobs in one	DUAL	Chairman and general manager concurrently take 1, otherwise 0.
Asset profitability ratio	ROA	The quotient of net profit and total assets.
Board size	BOARD	Take logarithms of the overall count of board directors.
Equity checks and balances	BAN	2nd to 5th largest shareholder holding / 1st largest shareholder holding.
Attribute of ownership rights	SOE	Assign a value of 1 for enterprises owned by the state and 0 for all others.
Annual	Year	Annual fixed effect
profession	Ind	Industry fixed effect

3.3. Model design

To ascertain hypothesis one, which posits that the conversion to digital processes markedly influences corporate eco-innovation, model (1) will be used for analysis:

$$GI = \beta_0 + \beta_1 DCG + Controls + Year + Ind + \varepsilon \quad (1)$$

In Model 1, GI is the explained variable, indicating the degree of green innovation within the enterprise, with DCG serving as the predictor variable, reflecting the degree of enterprise digital

transformation. Controls is the set of control variables, Year is the annual fixed effect, Ind is the industry fixed effect, and ε is the error term.

$$ESG = \beta_0 + \beta_1 DCG + Controls + Year + Ind + \varepsilon \quad (2)$$

$$GI = \beta_0 + \beta_1 DCG + \beta_3 ESG + Controls + Year + Ind + \varepsilon \quad (3)$$

To examine the intermediary role of the ESG rating, models (2) and (3) will be sequentially developed from model (1) to conduct the investigation.

4. Empirical analysis

4.1. Descriptive statistics

Table 2: Descriptive statistics

Variable	N	Mean	SD	Min	p50	Max
DCG	24383	1.780	1.410	0	1.610	5.040
ESG	24071	73.37	4.920	58.18	73.48	84.63
GI1	24388	0.390	0.830	0	0	6.850
GI2	24388	0.270	0.690	0	0	6.330
SIZE	24388	22.45	1.300	20.03	22.26	26.44
LEV	24388	0.430	0.200	0.0700	0.420	0.910
TOP	24388	32.59	14.46	8.090	30.17	72.11
SOE	24388	0.330	0.470	0	0	1
BAN	24388	0.780	0.610	0.0400	0.620	2.820
DUAL	24388	0.290	0.460	0	0	1
ROA	24388	0.0300	0.0700	-0.310	0.0300	0.200
BOARD	24387	2.100	0.200	1.100	2.200	2.890

N is the number of observations for each variable; Mean is the mean of each variable; SD is the standard deviation of each variable, which measures how discrete the data is; Min is the minimum value of each variable; p50 is the median of each variable, representing the value in the middle after sorting the data; Max is the maximum value for each variable.

According to the data in the table, the average value of digital transformation (DCG) is 1.780, and the data range is 0 to 5.040, showing a large range of variation. The median value is 1.610, which is close to the average value, suggesting that the distribution of the data is more symmetrical and the greater the value, the higher the degree of digital transformation of the enterprise. The standard deviation of enterprise ESG score is 4.920, the minimum value is 58.18, and the maximum value is 84.63, indicating that there are differences in the ESG score of different enterprises; The minimum value of enterprise green innovation (GI) data is 0, the maximum value is 6.850, and the mean value is 0.390, and the larger the value is, the higher the enterprise green innovation degree is. The distribution of other control variables was also in a reasonable range.

4.2. Baseline regression

Table 3: Baseline regression

	(1) GI1
DCG	0.0489*** (0.00448)
SIZE	0.146***

Table 3: (continued).

	(0.00496)
LEV	0.185***
	(0.0320)
TOP	-0.000339
	(0.000501)
BAN	-0.0264**
	(0.0113)
DUAL	0.0251**
	(0.0110)
ROA	0.536***
	(0.0775)
BOARD	0.104***
	(0.0261)
_cons	-3.464***
	(0.128)
Year	Yes
Ind	Yes
<i>N</i>	24382
<i>R</i> ²	0.189
adj. <i>R</i> ²	0.186

Standard errors in parentheses

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

The benchmark regression results show the relationship between enterprise digital transformation (DCG) and enterprise green innovation (GI) under fixed year effect and industry fixed effect. As can be seen from the results in the table, the coefficient of digital transformation (DCG) is 0.0489, greater than 0 and significant at 1% level, suggesting that the shift to digital processes exert a considerable beneficial effect on corporate green innovation (GI). This strongly proves that enterprise digital transformation can markedly enhance the degree of corporate eco-innovation, thus verifying the validity of hypothesis H1.

4.3. Intermediation effect

Table 4: Intermediation effect

	(1) ESG	(2) GI1
DCG	0.239***	0.0460***
	(0.0265)	(0.00452)
SIZE	1.363***	0.121***
	(0.0292)	(0.00521)
LEV	-5.106***	0.289***
	(0.189)	(0.0328)
TOP	0.0269***	-0.000846*
	(0.00294)	(0.000503)
BAN	0.316***	-0.0321***
	(0.0663)	(0.0113)

Table 4: (continued).

DUAL	0.142** (0.0651)	0.0229** (0.0111)
ROA	9.089*** (0.465)	0.365*** (0.0800)
BOARD	-0.398*** (0.154)	0.108*** (0.0263)
ESG		0.0189*** (0.00110)
_cons	39.93*** (0.753)	-4.233*** (0.136)
Year	Yes	Yes
Ind	Yes	Yes
<i>N</i>	24065	24065
<i>R</i> ²	0.210	0.199
adj. <i>R</i> ²	0.207	0.196

Standard errors in parentheses

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

The purpose of mediating effect analysis is to explore whether the impact of the independent factor on the outcome factor is realized through some mediating variable. In this paper, ESG score is taken as the intermediary variable, and the data analysis results in the table show that corporate digital conversion (DCG) exerts a favorable and notable effect on the firm's ESG rating, which in turn significantly boosts the level of the company's green innovation (GI). It shows that ESG score can be used as an intermediary variable to influence the level of environmental innovation within enterprises. It also shows the validity of H2 hypothesis.

4.4. Robustness test

Table 5: Robustness test

	(1) GI2	(2) GI1	(3) GI1
DCG	0.0489*** (0.00378)	0.0422*** (0.00887)	0.0534*** (0.00512)
SIZE	0.132*** (0.00418)	0.172*** (0.00887)	0.136*** (0.00631)
LEV	0.110*** (0.0270)	-0.0909 (0.0606)	0.284*** (0.0377)
TOP	-0.000373 (0.000422)	-0.00321*** (0.000924)	0.000401 (0.000616)
BAN	-0.0162* (0.00948)	-0.101*** (0.0249)	-0.00238 (0.0128)
DUAL	0.0234** (0.00930)	0.132*** (0.0303)	0.0249** (0.0119)
ROA	0.358*** (0.0653)	0.455** (0.183)	0.607*** (0.0844)
BOARD	0.0570***	0.206***	0.0114

Table 5: (continued).

	(0.0220)	(0.0484)	(0.0312)
_cons	-3.026***	-4.042***	-3.027***
	(0.108)	(0.211)	(0.177)
Year	Yes	Yes	Yes
Ind	Yes	Yes	Yes
<i>N</i>	24382	8162	16220
<i>R</i> ²	0.168	0.257	0.184
adj. <i>R</i> ²	0.165	0.249	0.179

Standard errors in parentheses

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

In the robustness test, we first adopt the method of variable substitution, specifically, we replace the GI1 variable in the baseline regression with the GI2 variable to observe whether the regression result is still significant. The outcomes of the analysis indicate that substituting GI2 for GI1 does not alter the direction and statistical significance of the pivotal variables' coefficients. The coefficients for digital transformation (DCG) remain substantially positive and statistically significant at the 1% level both prior to and following the substitution. The robustness checks reinforce the findings of the initial regression analysis, demonstrating that regardless of whether GI1 or GI2 is employed as the variable, the impact of a firm's degree of digitalization on green innovation is pronounced and consistent.

4.5. Heterogeneity test

In the heterogeneity test, the samples were divided into two groups according to the property rights of enterprises: state-owned enterprises (SOE=1) and privately-owned or other non-publicly owned enterprises (SOE=0), and the relationship between enterprise digital transformation (DCG) and enterprise green innovation (GI) was examined respectively. The data presented in the table reveals that the process of digital conversion (DCG) exerts a notable favorable influence on green innovation (GI) within both state-owned and private firms. Furthermore, the table's findings suggest that the coefficient for the first category is relatively low, signifying that the digital conversion (DCG) among the second category of private enterprises has a more profound effect on corporate green innovation (GI).

5. Conclusion

The study investigates the influence of corporate digitalization on eco-innovation and examines the intermediary function of ESG ratings in this relationship. Through an empirical study of the data of Chinese listed companies from 2016 to 2023, we arrive at the following conclusions: First, enterprises' digitalization has a notable favorable effect on green innovation. This conclusion is further verified in the robustness test, which proves the robustness and reliability of the results. Secondly, ESG ratings serve as a crucial intermediary factor between digital transformation and firms' green innovative capabilities. It is found that digital transformation can significantly improve the ESG score of enterprises, and the improvement of ESG score further promotes the ecologically-friendly innovation of enterprises. The outcomes of mediation effect analysis also confirm the significance of ESG score as a mediator variable. Furthermore, the outcomes of the heterogeneity examination indicate that the shift towards digital processes exerts a notable beneficial influence on eco-innovation within both state-controlled and private firms. Nevertheless, the influence of digital transformation on eco-innovation is more profound within private enterprises, potentially linked to their greater focus on innovation and technological advancements in the face of market rivalry.

To sum up, the findings of this paper provide a new perspective for understanding the relationship between digital transformation and green innovation of enterprises and furnish a theoretical foundation and practical guidance for advancing enterprises' green transformation. In subsequent investigation, the differences and commonalities of corporations in different industries, regions and sizes in digitalization and eco-innovation, as well as the specific mechanism of ESG score in it, can be further explored, so as to provide scientific basis for formulating more effective sustainable development strategies and policies.

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