The Impact of Digital Transformation on Green Innovation -- ESG-based Intermediation

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Abstract: This paper analyzes the relationship between digital transformation and green innovation based on the data of A-share listed companies from 2019-2023. It is found that (1) digital transformation enhances the development of green innovation, which still holds after the robustness test. (2) Digital transformation promotes the development of green innovation by enhancing the level of corporate ESG index and then promoting the development of corporate green innovation. (3) Digital transformation has a more significant impact on green innovation in SOEs than in non-SOEs. The purpose of this paper is to provide references and lessons for enhancing enterprises' attention to digital transformation and promoting enterprises' green innovation development.

Keywords: corporate digital transformation, corporate green innovation, corporate ESG

1. Introduction

The Fourteenth Five-Year Plan explicitly proposes to promote the greening and decarbonization of economic and social development and to strengthen the development of the digital economy, emphasizing the dual goals of digital transformation and green development. Digital transformation is the transformation of production and operation management, as well as the application of new digital technologies to upgrade their production and business models to a new level[1]. Digital transformation innovation and development has become an important driving force for the improvement of today's enterprises, and the enhancement of the digital transformation of enterprises is conducive to the acquisition of timely and effective data, faster and more accurate decision-making, and the enhancement of the competitiveness of enterprises. Green innovation is a core competence in the process of enterprise development, which can greatly improve enterprise performance[2]. Green innovation promotes enterprises to save resource costs and improve resource utilization, which is conducive to improving the competitiveness of enterprises, and meets the public's demand for green development, which enhances the image of enterprises, improves their reputation, and raises the valuation of enterprises, and then attracts more green investors to invest in them and promote their own development.

Currently, there is an increasing abundance of academic research on the impact of digital transformation on green innovation. Scholar[3] demonstrated the facilitating effect of digital transformation on green innovation based on the mediating and threshold roles of dynamic innovation and R&D investment. Scholar[4] explored the development of green innovation through the impact of digital transformation on external governance from the perspective of external governance.

Scholar[5] focuses and explores the different degrees of facilitation of digital transformation for green innovation in industrial enterprises. Most of the academics explore the different degrees of facilitating effect of digital innovation on green innovation of different industries through different mediators from a macro perspective.

The purpose of this paper is to deepen the understanding of the different levels of promotion of digital transformation for green innovation using a micro perspective and a sample of A-share companies in 2019-2023. This paper takes enterprise ESG as a mediator, analyzes digital transformation to promote the development of green innovation level by improving enterprise ESG, and confirms that digital transformation is more significant for green innovation in state-owned enterprises by analyzing the different levels of green innovation between state-owned enterprises and non-state-owned enterprises. The conclusion of this paper is intended to provide empirical support and theoretical guidance for enterprises to pay attention to the development and implementation of digital transformation strategy, and then the level of green innovation to meet the new trend of social development.

2.   Theoretical analysis and research hypotheses

2.1.   Impact of digital transformation on green innovation

Digital transformation helps optimize green resource allocation and efficiency[6]. Digital transformation allows enterprises to use big data information to more comprehensively and accurately collect and analyze enterprise resource outflow and usage conditions. Real-time analysis of the peak and low-efficiency zones of the enterprise's demand for different green resources, and then the use of AI automation technology, automatic allocation of green resources, so that the green resources are more reasonable and efficient flow to the high-demand zone, improve the utilization rate of green resources, i.e., the digital transformation of the enterprise can optimize the allocation of resources, and adjust the efficiency of the organization to achieve the general technological innovation[7].At the same time, digital transformation enhances the green innovation ability of enterprises, on the one hand, enterprises use the high technology content characteristics of digital technology to provide elemental support for green innovation, and the organizational and institutional changes brought about by digital transformation provide sustainable development ability for enterprises to carry out green innovation and reduce the risk of green innovation[3] . On the other hand, in the era of digital intelligence, technologies such as big data, Internet of Things, cloud computing, blockchain, artificial intelligence and so on have been gradually integrated into the existing business operations and decision-making of enterprises, and the digital transformation and green technology innovation of enterprises empower each other [8]. Digital transformation enhances digital tools that can significantly improve R&D efficiency, shorten R&D cycles, accelerate the R&D process, and accelerate the development of green innovation. Through digital transformation, the use of digital tools to assess the product development cycle, predict the problems in the development of the rainy day, proactive, conducive to the promotion of the design of enterprise innovation, and the problems that will be encountered in advance to deploy and respond to further promote the development of green innovation. It can be seen that digitalization provides a solution for breaking down the barriers to green innovation[9] . At the same time, through digital transformation, it improves enterprise flexibility and better meets customer needs. The enterprise's big data analysis capability can efficiently match the consumers' personalized demand for green products with the enterprise's positioning of green products, thus enhancing the enterprise's green innovation "quantity and quality"[10] .

In summary, the hypothesis of this paper is formulated

H1: Digital transformation can enhance green innovation.

2.2. The mediating role of ESG

First, digital transformation has implications for ESG. Digital transformation drives the management of ESG objectives, and enterprises must pay attention to environmental protection and responsibility bearing in order to realize long-term development[11] . By formulating, implementing, and monitoring the process of ESG goal landing, ESG will develop in the right direction of the goal, and then promote the realization and development of ESG goals. According to Scholar[12] digital transformation enhances the transparency of internal information of enterprises, facilitates the monitoring of internal information accuracy and the standardization of the use of information, which in turn significantly enhances the efficiency of enterprises in handling ESG-related information and the quality of information disclosure[13] . Enterprises can better track and analyze ESG performance, prescribe the right remedy, reflect it more accurately and comprehensively in ESG reports, enhance the transparency of ESG reports, which in turn enhances their credibility and is conducive to the enhancement of the enterprise's reputation. Through digital transformation, enterprises have successfully reduced information asymmetry, thereby significantly improving their ESG performance[14] .

Enterprises practicing the ESG concept pay more attention to and pursue the overall interests of stakeholders[15] . Further, as today's society for green development and environmental protection awareness, the importance of green innovation for enterprise development is becoming more and more important, the overall interests of the enterprise development needs to be closely linked to the enhancement of the enterprise to promote the enterprise for the importance of green innovation and willingness. At the same time, the development of ESG is conducive to the enhancement of the overall staff and stakeholders to work for the common goal. Good ESG performance requires corporate managers to increase trust and connections with other stakeholders[16] . Mutual trust among all parties promotes coordinated development, which is conducive to the development of good corporate decision-making and provides support and guarantee for the process of corporate green innovation. In addition, enterprises perform well in ESG information disclosure, and relevant government financial policies such as tax incentives and financial subsidies are constantly tilted to enterprises[17] . Providing resources, technology and financial support for the development of enterprise green innovation, so that enterprises can devote themselves to the research of enterprise green innovation, and then promote the further development of green innovation.

H2: ESG has a mediating role in digital transformation and corporate green innovation.

3. Model Construction

3.1. Data sources and processing

In this paper, A-share firms are selected as a sample from 2019-2023 with the following treatments: (1) exclude ST firms during the sample period; (2) exclude the financial industry (the 2012 version of the industry classification of the Securities and Futures Commission (SFC)). Finally, 5,317 one-year observations of enterprises are obtained, covering 74 industries. Data from CSMAR database, CNRDS database.

3.2. Modeling

Based on the above theoretical analysis, this paper sets the benchmark model (1) to test the impact of digital transformation on green innovation of enterprises. The subscripts i, j and t in the period denote the enterprise, industry and year, respectively.$PAT_{i,t}$ is the level of green innovation of enterprise i in year t, $DIG_{i,t}$ is the degree of digital transformation of enterprise i in year t, and $Controls_{i,t}$

represents a series of control variables. This paper controls for the industry effect Indj and the year effect Yeart. Ei,j,t is a randomized disturbance term.

$$PATi,t=\alpha0+\alpha1DIGi,t+Controlsi,t+Indj+Yeart+\varepsilon i,j,t \qquad (1)$$

This paper sets the mediation model (2) (3) to test the mediation effect of ESG. ESGi,t denotes the ESG of enterprises, if β1 and φ2 are significant, it indicates that the mediation effect of green technological innovation is established. On this basis, if φ1 is significant, it indicates the existence of partial mediation effect of green technology innovation, otherwise it is full mediation effect.

$$ESGi,t =\beta0+\beta1DIGi,t+Controlsi,t+Indj+Yeart+\varepsilon i,j,t \qquad (2)$$

$$PATi,t = \varphi0+\varphi1DIGi,t+\varphi2ESGi,t+ Controlsi,t+Indj+Yeart+\varepsilon i,j,t \qquad (3)$$

3.3. Description of variables

(1) Enterprise Digital Transformation (DCG)

This paper draws on the practice of Scholar[18] to construct enterprise digital transformation index statistics based on the frequency statistics of digital transformation words adopted in the annual reports of listed companies, and conducts data processing due to the characteristic of "right skewness" of the data.

(2) Corporate Green Innovation (PAT)

In this paper, we use the cnrds database to analyze the value of ln taken as the sum of the number of independent applications for single green inventions in the year plus the number of independent applications for green innovations in the year plus 1.

(3) ESG

In this paper, we measure the ESG performance of companies through the CSI ESG rating system and assign ESG performance values of 1-9.

(4) Control variables

Referring to previous research on green innovation[6][19][20] , this paper selects the following control variables: firm size, firm years of experience, owner's education, cash flow level, gearing ratio, and return on total assets, as defined in Table 1

Table 1: Definition of variables

variant	variable symbol	Variable Interpretation
Enterprise Digital Transformation	DCG	Ln (digital transformation keyword word frequency +1)
Corporate Green Innovation	PAT	Ln (number of single green inventions filed independently in the year plus number of green innovations filed independently in the year + 1)
Corporate ESG	ESG	Huazheng ESG Rating Data
Enterprise size	Size	Ln (total business assets)
Years in business	Age	Time difference from the year of the date of incorporation of the enterprise to the year t
Degree of business owner	Edu	Bachelor's degree and above is assigned a value of 1, otherwise 0
Cash flow levels	Cash	Net cash flows from operating activities/total assets

Table 1: (continued).

gearing	Level	Ratio of liabilities to assets
return on total assets	ROA	Ratio of net profit to total assets

4. Empirical analysis

4.1. Descriptive analysis

The mean value of enterprise PAT is 0.41, the maximum value is 6.62, and the minimum value is 0. There is a large difference in the selected samples, which may be influenced by government policies, internal strategies of enterprises and other factors. The overall education level of enterprise owners is at a high level, which is conducive to the digital transformation of enterprises, providing abundant talents and knowledge, and promoting the rapid transformation and development of enterprises. The average value of enterprise gearing ratio is at the normal level, at a moderate level of indebtedness, with low financial risk, but high volatility, indicating that the enterprise's capital structure is changing greatly, probably due to enterprise expansion, industry cyclical fluctuations, etc. When the gearing ratio reaches the maximum value of 92%, the enterprise needs to pay attention to the financial risk. The average value of enterprise ROA 0.03 indicates that each unit of assets to obtain 3% net profit, the overall profitability is average, ROA volatility is large, certain period of time there is a debt situation, may be due to the need for large-scale capital investment in the development of the early stage, and the results of the development of the results of the need for a long period of time to reflect. Enterprise cash flow level at 15%, relatively low level, the enterprise may face certain liquidity pressure, the minimum value of negative operating cash flow serious loss situation, high business risk, but the maximum value is too high, cash flow also exists failure to timely and reasonable use of the situation, may miss a good opportunity to develop, not fully invested in the development of the business is not conducive to the operation of the enterprise.

Table 2: Descriptive analysis

Variable	N	Mean	SD	Min	p50	Max.
DCG	14244	1.940	1.390	0	1.950	5.040
PAT1	14244	0.410	0.850	0	0	6.620
PAT2	14244	7138	4129	0	7138	14285
ESG	14244	4.230	1.020	1	4	8
Size	14244	22.44	1.320	20.01	22.24	26.54
Level	14244	0.420	0.200	0.0600	0.420	0.920
ROA	14244	0.0300	0.0800	-0.320	0.0400	0.220
Cash	14244	0.150	0.540	-0.470	0.0100	4.100
Age	14244	21.68	6.090	8.330	21.42	38.50
Edu	14244	0.870	0.330	0	1	1

4.2. Benchmark regression

According to the benchmark regression data in Table 3, the coefficient of digital transformation is 0.0859, with positive significance, indicating that digital transformation has a positive and significant impact on green innovation, and every 1% increase in the degree of digital transformation increases the level of green innovation by 8.59%, so the digital transformation enhances green innovation, and Hypothesis H1 is verified. For the control variables, the level of cash flow and the education of business owners have no significant effect on green innovation. The coefficient of enterprise years of

experience is negative and significant above 1% level, which indicates that the growth of enterprise years of experience is not favorable to the development of green innovation level. The enterprise size, gearing ratio, and return on total assets are significantly positive, indicating that the larger the enterprise size, the higher the gearing ratio, and the higher the return on total assets, the higher the level of green innovation of the enterprise.

Table 3: Benchmark regression and Mediated effects test

	(1) PAT1	(2) ESG	(3) ESG
DCG	0.0859 ***	0.0909 ***	0.0815 ***
	(0.00501)	(0.00566)	(0.00569)
Size	0.119 ***	0.270 ***	0.257 ***
	(0.00622)	(0.00702)	(0.00708)
Level	0.339 ***	-1.266 ***	-1.303 ***
	(0.0424)	(0.0479)	(0.0478)
ROA	0.749 ***	1.959 ***	1.877 ***
	(0.101)	(0.114)	(0.114)
Cash	-0.00250	-0.00439	-0.00412
	(0.0129)	(0.0146)	(0.0145)
Age	-0.0157***	-0.00905 ***	-0.00733 ***
	(0.00117)	(0.00132)	(0.00132)
Edu	0.00167	0.00973	0.00955
	(0.0208)	(0.0235)	(0.0234)
PAT1			0.109 ***
			(0.00942)
_cons	-2.251***	-1.345 ***	-1.099 ***
	(0.130)	(0.146)	(0.147)
N	14244	14244	14244
adj. R2	0.078	0.177	0.185

Standard errors in parentheses
* p < 0.1, ** p < 0.05, *** p < 0.01

4.3. Mediated effects test

As shown in Table 3, digital transformation is significant to ESG at the 9% level, and for every 1% increase in digital transformation, ESG increases by 0.0909. Adding ESG to the benchmark regression model as shown in column (3), the coefficient of digital transformation is positive and significant at 0.0815, which is reduced compared with the original coefficient of 0.0859, which can be seen that ESG has a mediating role in digital transformation and green innovation. Both digital transformation enhances green innovation by enhancing ESG. Hypothesis H2 is verified.

4.4. Robustness Tests

In order to ensure the reliability of the regression results, this paper adopts the value of taking ln for the sum of the number of independent applications for single green inventions plus 1 for the year as a measure of the replacement variable in the cnrds database for the robustness test. As shown in Table 4, the coefficient of digital transformation is positive and significant, and digital transformation can enhance green innovation, which again proves the conclusion of the benchmark regression.

Table 4: Robustness test and Heterogeneity analysis

	(1) PAT2	(2) PAT1	(3) PAT1
DCG	134.3 ***	0.110 ***	0.0787 ***
	(25.05)	(0.0121)	(0.00539)
Size	34.31	0.140 ***	0.108 ***
	(31.07)	(0.0127)	(0.00780)
Level	-1967.2 ***	0.0877	0.428 ***
	(211.8)	(0.0971)	(0.0464)
ROA	-2009.5 ***	0.675**	0.767 ***
	(504.8)	(0.290)	(0.104)
Cash	-318.8 ***	0.00804	-0.00490
	(64.36)	(0.0420)	(0.0130)
Age	56.06 ***	-0.00927 ***	-0.0185***
	(5.835)	(0.00263)	(0.00133)
Edu	22.79	0.0198	-0.00275
	(104.0)	(0.0696)	(0.0209)
_cons	5810.5 ***	-2.819 ***	-1.982 ***
	(647.8)	(0.288)	(0.163)
N	14244	3682	10562
adj. R2	0.015	0.073	0.078

4.5. Heterogeneity analysis

Based on the different nature of property rights, as shown in Table 4 for green innovation, based on the digital transformation of state-owned enterprises for green innovation is more significant, this difference may be due to (1) policy support and government orientation: the government, in the process of promoting green development, may be through financial subsidies, tax incentives, green credit and other policies will be more policy support for state-owned enterprises and resources tilted, so that state-owned enterprises are more likely to to obtain government support, so as to promote their green innovation. (2) Social responsibility and public interest: Compared with non-SOEs, SOEs bear more social responsibility, especially in green development. Therefore, SOEs pay more attention to green innovation in digital transformation and are willing to invest more resources in the R&D and application of environmentally friendly technologies. (3) Capital investment and risk-taking: SOEs' advantages in funding and capital enable them to take greater risks and make more innovative attempts. Although digital transformation requires a large initial investment, SOEs can quickly advance the research and development of green technologies and green products with their strong financial support.

5. Conclusion

This paper empirically demonstrates the mechanism of digital transformation on green innovation based on the data of 2019-2023 A-share listed companies. (1) Digital transformation promotes the development of green innovation, and every 1% increase in the degree of digital transformation increases the level of green innovation by 8.59%. (2) ESG plays a mediating role in digital transformation and green innovation. (3) Compared with non-state-owned enterprises, the digital transformation of state-owned enterprises has a more significant impact on green innovation.

Based on the above conclusions, this paper gives the following recommendations: for enterprises, enterprises should pay attention to the development of digital transformation, clarify the objectives

of digital transformation, take into account market trends and future development trends of the industry, and promote the formulation, implementation and development of digital transformation strategies. The establishment of a digital transformation leadership team, the senior leadership within the enterprise to strengthen the importance of digital transformation, support, encourage and make policy adjustments to the development of digital transformation, the recruitment of digital transformation-related talent, while strengthening their own learning related professional knowledge, to provide intellectual support for digital transformation. Establishment of digital transformation infrastructure construction and access to relevant advanced technologies. For the government, by formulating long-term digital transformation strategies, such as the 14th Five-Year Plan, etc., to show the direction for the digital transformation of enterprises. Provide policy support, strengthen tax benefits, financial subsidies and other incentives to encourage enterprises to innovate and develop, reduce the cost of enterprise innovation, improve the enthusiasm of enterprises, and promote digital transformation. Through cooperation between the government and enterprises, build a platform for enterprises, strengthen exchanges and cooperation between enterprises in different industries, realize enterprise resource sharing, data circulation, and common facilities, so that resources flow to more useful sectors and improve the efficiency of resource utilization.

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