

A study of the impact effect of digital transformation on environmental performance—Based intermediation of financing constraints

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Abstract. This paper selects A-share listed companies in China's Shanghai and Shenzhen cities from 2015 to 2022 as the research sample, and puts forward the corresponding research hypotheses and empirically tests the relationship between digital transformation and environmental performance through the fixed effect model of digital transformation and environmental performance. The results show that corporate digital transformation can improve corporate environmental performance. The driving effect of digital transformation on corporate environmental performance is more prominent in enterprises with non-dual CEO and chairman positions, state-owned and high gearing ratios. Empirical evidence is provided at the firm level for the role of digital transformation in improving environmental performance, which contributes to the synergistic development of digital greening in firms.

Keywords: digital transformation; environmental performance; financing constraints.

1. Introduction

Modern society faces increasingly serious environmental problems, such as climate change, resource depletion and environmental pollution. These problems pose serious challenges to human life and sustainable development. At the same time, certain traditional business models and operating practices have also had a negative impact on the environment, including high energy consumption, high emissions and waste of resources. In April 2024, the People's Bank of China, the National Development and Reform Commission and seven other departments jointly issued the "Guiding Opinions on Further Strengthening Financial Support for Green and Low-Carbon Development," which proposes that in the next five years, an internationally leading system of financial support for green and low-carbon development will be basically constructed. In the next five years, the international leading financial support system for green and low-carbon development will be basically constructed, the financial infrastructure, environmental information disclosure, risk management, financial products and market, policy support system and green financial standard system will be improved, the regional reform of green finance will be promoted in an orderly manner, international cooperation will be closer, and all kinds of factors and resources will be gathered to the field of green and low carbon in an orderly manner[1]. The green financial system has been improved. Enterprises, as important subjects of environmental protection, should assume the responsibility of environmental protection. In this process, environmental performance as one of the important management tools, it is necessary to focus on the driving force of corporate environmental performance, in order to better improve the ability of corporate governance of the environment.

The 14th Five-Year Plan for the Development of the Digital Economy proposes that, during the 14th Five-Year Plan period, China's digital economy will shift to a new stage of deepening application, standardized development and universal sharing. In order to cope with the new challenges of the new situation, grasp the new opportunities of digital development, expand the new space for economic development, and promote the healthy development of China's digital economy, we will continue to promote the development of China's digital economy.[2]. In today's society, with the continuous development and continuous innovation of a new generation of information technology, artificial intelligence, blockchain, cloud computing, big data, Internet of Things and other technologies continue to make new breakthroughs, digital transformation has become an important trend in the development of today's society, and digital transformation has profoundly changed every aspect of

human society, from manufacturing to the service industry, and from the agricultural to the financial sector, the application of digital technology is bringing about an unprecedented changes. Digital transformation refers to the combination of traditional business models, processes and operating methods with digital technology to improve efficiency, create value and drive innovation. Digital transformation is a major issue that the vast majority of enterprises cannot get around. In the tide of digital transformation, if you do not carry out digital transformation, enterprises are likely to be eliminated. Digital transformation can gain more market opportunities and try more business models. The arrival of digitalization has broken the information barriers and basically changed the traditional production-oriented business model, and customer-centricity has become the key for enterprises to survive in the market competition.

The 14th Five-Year Plan for National Informatization states that it is necessary to promote the construction of a green, intelligent and ecological civilization, and to promote the synergistic development of digitalization and greening.[3] The "14th Five-Year Plan" of national informationization pointed out that it is necessary to promote the construction of green wisdom ecological civilization in depth and promote the synergistic development of digitalization and greening. At present, Zhou Qing et al. based on the data of 73 counties (districts, cities) in Zhejiang Province, that the regional digital equipment, application level of the impact of innovation performance is an inverted "U" shaped relationship; Yu Lianchao et al. showed that digital transformation has a significant positive impact on the environmental performance of enterprises.[4] Yu Lianchao et al. showed that digital transformation has a significant positive impact on the environmental performance of enterprises.[5] Zhang Yao et al. showed that digital transformation has a significant positive effect on the improvement of enterprise environmental performance.[6] Li Tao et al. showed a U-shaped relationship between corporate innovation investment and environmental performance.[7] Li Tao et al. These results may be due to the different measurement methods or definitions of digital indicators.

In view of this, this paper captures the synergistic development of digital greening and tries to explore a series of issues such as whether digital transformation can effectively contribute to corporate environmental performance, and whether the impact varies across firms with different property rights and across firms with different capital positions. The exploration of the above issues not only helps to help understand the role of enterprise digital transformation in promoting environmental performance, but also may provide empirical assistance for the formulation of relevant policies.

Possible marginal contributions of this paper: in terms of research intention, it analyzes the relationship between digital transformation and enterprise environmental performance from the perspective of micro subjects, which enriches the relevant research and provides decision-making basis and suggestions for enterprises on how to improve their environmental performance; in terms of research content, it unfolds the theoretical analysis and empirical test on the impact of digital transformation on the environmental performance of enterprises, and at the same time combines with the impact of heterogeneity in an attempt to construct the possible existence of the two The research methodology of the study adopts the instrumental variables method and two-stage least squares method to better solve the endogeneity problem, while replacing the main variables to ensure the robustness of the conclusions, so as to provide more reliable theoretical support and empirical references for the green development of digitally empowered enterprises.

2. Theoretical analysis and research hypotheses

2.1 Digital transformation and environmental performance

The impact of enterprise digitalization on environmental performance is a complex subject, which involves changes in all aspects of the enterprise's internal aspects as well as the feedback effect of the external environment; therefore, digital transformation optimizes the daily production and operation activities of enterprises while promoting sustainable development. Digital transformation can have a

positive impact on the improvement of environmental performance through multiple paths, such as strengthening the internal control of enterprises, optimizing the internal governance environment of enterprises, increasing internal and external information communication channels, improving the transparency of corporate information, and the green innovation capability of enterprises, etc.[8] . Specifically, the impact of enterprise digital transformation on the environment is mainly reflected in the following three aspects.

First, in the digital era, business management can be improved by automating processes and optimizing resource allocation, thus promoting operational efficiency and helping companies to manage energy use more effectively and reduce energy consumption[9] . The use of digital energy management systems can provide real-time monitoring and statistics on energy use. Effective energy saving measures for energy use can not only effectively reduce energy consumption, but also reduce the adverse impact on the environment to a certain extent. At the same time, the digital transformation of enterprises can also reduce the generation of waste at the same time, improve product quality, reduce the cost of waste disposal and the negative impact on the environment. Secondly, digital transformation is of great help to enterprises in implementing refined sustainable development strategies. Real-time monitoring of environmental indicators using intelligent monitoring systems can identify and help improve environmental problems in a timely manner, improving the responsiveness and adaptability of enterprises in terms of environmental management. Digitization helps enterprises achieve refined management of the environment, and they can better understand the trends of environmental influencing factors and formulate more effective and reasonable environmental management strategies and measures. Based on historical data and various models, enterprises can forecast future energy demand, which can be used to adjust production plans and energy procurement, reducing energy consumption while reducing costs. Third, digital transformation promotes the improvement of enterprise innovation ability, which helps enterprises develop more environmentally friendly products and services. Enterprises can improve their innovation ability by strengthening the construction of innovation culture, enhancing employees' innovation awareness and innovation ability, and introducing innovative talents.[10] . Digitalization provides new ways for enterprises to solve environmental problems. Enterprises can make use of advanced digital technologies, such as artificial intelligence, big data analytics, blockchain, etc., to develop new solutions centered on digital technologies, thus reducing the environmental footprint of enterprises.

Hypothesis 1: Corporate digital transformation improves corporate environmental performance.

2.2 Intermediation of financing constraints

Digital transformation increases enterprise productivity while reducing costs. Digitization not only improves the quality of products and services and enhances market competitiveness, but also improves the financial situation of enterprises and strengthens their solvency and creditworthiness. In addition, digitization improves the level of business transparency and information disclosure, making the presentation of the enterprise's financial position, operational performance and environmental responsibility more transparent, reducing information asymmetry and increasing the trust of investors and lending institutions in the enterprise. These make enterprises more attractive and easier to attract investment and obtain loans, thus achieving the goal of easing financing constraints.

Compared to other innovations, green technology innovations have higher R&D costs and longer R&D cycles, and in the face of financing constraints, it is more likely that funds will be used to produce non-green innovation businesses[11] . Alleviating firms' financing constraints can directly increase firms' investment in environmental performance, thereby improving their environmental performance. Here are some ways in which this could have an impact: first, financing constraints limit the ability of firms to upgrade environmental technologies and build environmental facilities. By alleviating financing constraints, firms can more easily access funds to invest in environmental technologies and facilities. Second, firms need to establish environmental management and monitoring systems to ensure that their production activities comply with relevant laws and

regulations. Easing the financing constraints of enterprises can enable them to have the funds to establish and maintain these systems, so that they can monitor and manage the environment more effectively and take the necessary measures to improve environmental performance. Thirdly, enterprises can also conduct employee training to raise environmental awareness. By alleviating the financing constraints of enterprises, enterprises can more easily conduct training and education on environmental protection for their employees, which in turn promotes the raising of awareness of environmental protection within the enterprise, and indirectly enables enterprises to improve their environmental performance. In conclusion, easing enterprise financing constraints gives enterprises stronger financial strength to invest in environmental protection technology projects and management measures, which has a positive effect on improving their environmental performance. At the same time the more severe the financing constraint, the greater the likelihood of observed poor environmental performance[12] .

Hypothesis 2: Corporate digital transformation can improve corporate environmental performance by alleviating corporate finance constraints.

3. Research design

3.1 Data sources and sample selection

In this paper, A-share listed companies in Shanghai and Shenzhen from 2015 to 2022 are used as the original sample, and the environmental performance of listed companies is measured using the China Listed Companies Environmental Research Database of Cathay Pacific (CSMAR), on the basis of the following criteria: (1) selecting non-ST stocks; (2) excluding the financial industry in the 2012 version of the industry classification of the Securities and Exchange Commission (SEC); (3) excluding the environmental management disclosure missing listed companies; (4) excluding the rest of the sample with missing data. The original word frequency of digital transformation comes from Wu Fei et al. research data, EGS related data comes from Bloomberg et al. ESG scores of enterprises, and other related research data comes from CSMAR. the final number of valid annual sample observations retained is 25,898. Stata software is used to program and get the relevant research data through calculation, and then the research data is used for data analysis.

Most current research on corporate performance uses the ESG evaluation system. ESG ratings, also known as ESG scores or ESG evaluations, provide an overall assessment of the risks, opportunities, and impacts of a given subject's sustainable development, primarily from the environmental, social, and governance perspectives[13] ESG rating is also known as ESG score or ESG evaluation. It covers a wider range of content, but this paper would like to focus on measures related to the internal environmental management of enterprises, in order to better guide enterprises in environmental governance, promote the development of green finance, and achieve the goal of sustainable development.

3.2 Measurement of variables

3.2.1 Dependent variable: firms' environmental performance^(EP)

Drawing on the research, a comprehensive scoring methodology was used to construct corporate environmental performance^(EP) indicators by utilizing Cathay Pacific's environmental research database of Chinese listed companies. The environmental performance indicators consist of the following components: (1) whether the enterprise has an environmental protection philosophy; (2) whether it has environmental protection goals; (3) whether it has adopted an environmental protection management system; (4) whether it has conducted environmental protection education and training; (5) whether it has special behaviors for environmental protection; (6) whether it has adopted an emergency response mechanism for environmental incidents; (7) whether the enterprise has a "three-simultaneity" system; (8) whether it has received honors or awards for environmental protection; (9) whether the enterprise has passed ISO14001 certification. Enterprises receive one point for each of

the above items, and zero points for not meeting them, and the summed score is used as a proxy variable for the enterprise's environmental performance (EP)[14] .

In the robustness test section, an alternative approach is used to construct the corporate environmental performance indicator. The environmental responsibility score from the Bloomberg ESG score is used as a proxy measure of environmental performance, which is named as *ESGE* .

3.2.2 Independent variable: digital transformation(*Dig*)

Drawing on Wu Fei's method[15] , text extraction is performed on the annual reports of Chinese A-share listed companies from 2015 to 2022, and based on this, text analysis and data measurement are applied to obtain digital transformation indicators.

The digitization index was measured by performing the "inverse hyperbolic sine" transformation on the sum of word frequencies.[16] The formula is as follows The formula is as follows.

$$Dig = Ln(Dig_{number\ it} + \sqrt{(Dig_{number\ it})^2 + 1}) \quad (1)$$

In the formula Dig_{it} represents the firm i in the t the digitization index in the year, the $Dig_{number\ it}$ represents the firm's i in the t the sum of digitized word frequencies in the year. The method converts the data columns into a scaled sequence of changes and avoids being tailed when the sum of digitized word frequencies is zero. The larger the value of the index, the higher the degree of digital transformation of the enterprise.

3.2.3 Mediating variable: financing constraints(*Loan*)

The *SA* index is used to measure the financing constraints of firms(*Loan*) . Other commonly used indicators to measure corporate finance constraints are the *WW* Index and the *KZ* Index. *SA* The advantage of the Index over the *WW* Index and the *KZ* Index is that it is more exogenous, using firm size and firm age to calculate the *SA* Index.[17] The formula for calculating the Index is *SA* The formula for calculating the Index is:

$$SA = -0.737*Size + 0.043*Size^2 - 0.040*Age \quad (2)$$

where *Size* is the size of the firm expressed as the logarithm of the firm's total assets, and *Age* is the age of the firm. *SA* The larger (closer to 0^-), the smaller the firm's financing constraint(*Loan*) .

3.2.4 Control variables

With reference to the existing studies, the variables related to the basic characteristics of the company, the company's financial status and corporate governance are selected as control variables. Specifically, the following variables are included: CEO and Chairman of the Board of Directors (*Dual*) , nature of the company(*SOE*) , net profit margin of total assets(*ROA*) , gearing(*Lev*) , age of the company(*Age*) , number of board of directors(*Board*) , and proportion of independent directors(*Indep*) .

The reasons for selecting the above as control variables are mainly as follows: CEO and chairman of the board of directors, the number of board of directors and the proportion of independent directors will have an impact on the corporate governance structure and the efficiency of high-level decision-making, which will have an impact on various aspects such as the power structure, decision-making process, internal supervision mechanism and risk management, and thus affect the corporate environmental performance(*EP*) . And the nature of the firm affects the strategic choice of the firm, which in turn affects *EP* performance. Enterprises with a high return on assets have a greater financial advantage and are able to support strategies related to corporate governance, such as environmental protection and social responsibility fulfillment. Whereas lack of capital affects corporate activities, the ability to raise capital is also an important source of resource support for corporations. Meanwhile older listed companies have more sound internal mechanisms and more experience, and will have better management of environmental control.

The main variables are defined as shown in Table 1, and in order to mitigate the effects of sample outliers, continuous variables in this paper are reduced-tailed at the 1st percentile and 99th percentile.

Table 1 Definition table of main variables

Variable type	variable name	variable symbol	Variable Definition
implicit variable	Environmental performance	<i>ES</i> <i>ESGE</i>	See variable definitions for details
independent variable	Digital Transformation	<i>Dig</i>	See variable definitions for details
control variable	CEO and Chairman of the Board of Directors	<i>Dual</i>	Both = 1, otherwise = 0
	Nature of business	<i>SOE</i>	State-owned enterprises = 1, non-state-owned enterprises = 0
	Net profit margin on total assets	<i>ROA</i>	Net profit/total assets balance
	gearing	<i>Lev</i>	Total liabilities/total assets
	Age of business	<i>Age</i>	$\ln(\text{Current year} - \text{Year Listed} + 1)$
	Number of Board of Directors	<i>Board</i>	$\ln(\text{Number of Board of Directors})$
	Proportion of independent directors	<i>Indep</i>	Number of independent directors/number of board of directors
Mechanism variables	Financing constraints	<i>Loan</i>	<i>SA</i>

3.3 Modeling

To test whether corporate digital transformation improves corporate environmental performance, controlling for industry and year two-way fixed effects, the following regression model was used:

$$EP_{i,t} = \alpha_0 + \alpha_1 Dig_{i,t} + \lambda Control_{i,t} + \sum Ind + \sum Year + \varepsilon_{i,t} \quad (3)$$

where *EP* is the firm's environmental performance, *Dig* is the firm's digital transformation, *Control* is the relevant control variable, and ε is a random disturbance term.

In order to test whether digital transformation can improve firms' environmental performance through financing constraints, controlling for industry and year two-way fixed effects, the following linkage model is used to conduct a joint test of the mechanism's role:

$$EP_{i,t} = \beta_0 + \beta_1 Dig_{i,t} + \beta_2 Loan_{i,t} + \beta_3 Control_{i,t} + \sum Ind + \sum Year + \varepsilon_{i,t} \quad (4)$$

$$Loan_{i,t} = \alpha_0 + \alpha_1 Dig_{i,t} + \alpha_2 Control_{i,t} + \sum Ind + \sum Year + \omega_{i,t} \quad (5)$$

Where *EP* denotes firms' environmental performance, *Dig* is firms' digital transformation, *Loan* is the level of firms' financing constraints, *Control* is also a relevant control variable, and ε and ω are random disturbance terms.

4. Analysis of empirical results

4.1 Descriptive statistics

Table 2 demonstrates that the mean of corporate environmental performance is 1.940, the median is 1, the minimum and maximum values are 0 and 9 respectively, and the variance is 2.060, which indicates that the corporate performance of different firms is indeed different and has some differences. The mean of enterprise digital transformation is 2, the median is 1.820, the minimum and maximum values are 0 and 5.860 respectively, and the variance is 1.650, which indicates that the digital transformation of different enterprises is different and has some differences.

Table 2 Descriptive statistics

Variable	N	Mean	SD	Min	p50	Max.
EP	25898	1.940	2.060	0	1	9
Dig	25898	2	1.650	0	1.820	5.860
Loan	25898	-3.870	0.240	-4.470	-3.870	-3.210
ESGE	7782	12.210	14.430	0	7.610	58.710
Dual	25898	0.310	0.460	0	0	1
SOE	25898	0.310	0.460	0	0	1
ROA	25898	0.030	0.070	-0.350	0.040	0.210
Lev	25898	0.410	0.200	0.060	0.400	0.940
Age	25898	2.630	0.590	1.100	2.710	3.500
Board	25898	2.100	0.190	1.610	2.200	2.640
Indep	25898	0.380	0.050	0.330	0.360	0.570

4.2 Analysis of baseline regression results

Regression with model (3), the results are shown in Table 3. when no control variables are added and industry and year fixed effects are controlled, the regression coefficient of enterprise digital transformation and environmental performance is 0.0946, which is significantly positive at the 1% level; when control variables are added, and industry and year fixed effects are controlled, the coefficient of enterprise digital transformation and environmental performance becomes 0.0812, and is at the 1% level significantly positive. The above results indicate that enterprise digitalization can promote environmental performance, and hypothesis 1 is verified.

Table 3 Benchmark regression analysis

	(1) EP	(2) EP
Dig	0.095*** (0.009)	0.081*** (0.009)
Dual		-0.136*** (0.026)
SOE		0.593*** (0.031)
ROA		3.505*** (0.167)
Lev		1.260*** (0.067)
Age		0.129*** (0.025)
Board		1.208*** (0.076)
Indep		2.309*** (0.265)
Ind	Yes	Yes
Year	Yes	Yes

_cons	0.132 (0.172)	-4.639*** (0.290)
N	25898	25898
R ²	0.188	0.249
adj. R ²	0.186	0.247

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

4.3 Mechanism analysis

To test whether digital transformation can improve firms' environmental performance through financing constraints, models (4) and (5) are used to jointly test the role of mechanisms. The results of the mechanism regression are shown in Table 4, from column (3) of Table 4, the coefficient of digital transformation is 0.0790 and significantly positive at the 1% level, indicating that digital transformation can significantly improve environmental performance. The coefficient of financing constraint(*Loan*) is 0.813, which is also significantly positive at 1% level, and because the larger *SA* is (the closer it is to 0^-), the smaller the enterprise financing constraint(*Loan*) is, so the enterprise financing constraint(*Loan*) is negatively correlated with the environmental performance of the enterprise, i.e., reducing the enterprise financing constraints can improve the environmental performance of the enterprise. In summary, digital transformation can improve enterprise environmental performance by alleviating financing constraints, and the above results verify hypothesis 2.

Table 4 Mechanism analysis results

	(1) EP	(2) Loan	(3) EP
Dig	0.081*** (0.009)	0.003*** (0.001)	0.079*** (0.009)
Loan			0.813*** (0.054)
Control	Yes	Yes	Yes
Ind	Yes	Yes	Yes
Year	Yes	Yes	Yes
_cons	-4.639*** (0.290)	-3.301*** (0.033)	-1.956*** (0.340)
N	25898	25898	25898
R ²	0.249	0.299	0.256
adj. R ²	0.247	0.297	0.253

4.4 Robustness tests

4.4.1 Substitution of explanatory variables

The model was re-regressed by replacing the environmental performance indicators. Here the model is re-regressed by replacing *EP* with *ESGE*. Table 5 shows the results of replacing variables, after adding control variables and fixed effects, the coefficient of enterprise digital transformation and environmental performance is 0.851 and significantly positive at 1% level. It indicates that enterprise digital transformation does significantly improve environmental performance, and the results are consistent with the baseline regression results, while proving the robustness of the model.

Table 5 Replacement of explanatory variables

	ESGE
Dig	0.851*** (0.114)
Dual	0.149

	(0.368)
SOE	1.662***
	(0.362)
ROA	27.37***
	(2.651)
Lev	11.31***
	(0.923)
Age	-1.791***
	(0.395)
Board	5.472***
	(0.852)
Indep	18.78***
	(2.995)
Ind	Yes
Year	Yes
_cons	-24.92***
	(3.337)
N	7782
R ²	0.291
adj. R ²	0.283

4.4.2 Explanatory variables lagged by one period

Lagging the explanatory variables by one period, the results, as shown in Table 6, show that the coefficient between firms' digital transformation and environmental performance is 0.080 and significantly positive at the 1% level. Digital transformation still significantly improves firms' environmental performance, proving the robustness of the model.

Table 6 Explanatory variables lagged one period

	EP
L. Digw	0.080***
	(0.010)
Control	Yes
Ind	Yes
Year	Yes
_cons	-4.885***
	(0.329)
N	20772
R ²	0.245
adj. R ²	0.242

4.5 Endogeneity test

This paper finds that digital transformation significantly improves firms' environmental performance. Although the results remain significant after the robustness test, there may be an omitted variable problem, i.e., the baseline model may have omitted some factors that affect both digital transformation and environmental performance. Therefore, the two-stage least squares method (*2sls*) is used to correct the initial model. Drawing on the idea of Huo Chunhui et al. this paper adopts the mean value of the degree of digital transformation of the same province and cohort (*meanDig*) as an instrumental variable to deal with the endogeneity problem. Tailoring of the 1st percentile and the 99th percentile is also carried out.

Table 7 Two-stage least squares method

	first	two
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VARIABLES	Dig	EP
meanDig	0.014*** (11.48)	
Dig		0.779*** (5.71)
Control	Yes	Yes
Ind	Yes	Yes
Year	Yes	Yes
Constant	-0.848*** (-3.75)	-4.042*** (-10.96)
Observations	24,841	24,841
F-test	131.700	
R-squared	0.410	0.066

As can be seen in Table 7, the coefficient of the instrumental variable(*meanDig*) is 0.014, which is significant at the 1% level. The significantly positive coefficient of the instrumental variable indicates that local companies are also more digitally transformed when there is a higher percentage of the mean value of digital transformation in the same province and cohort, which is consistent with expectations. In addition, $F=131.700 > 10$, indicating that there is no weak instrumental variable problem. After using the instrumental variable method, the coefficient of *Dig* is 0.779, which is significant at the 1% level. It indicates that the digitization of firms after considering the endogeneity problem still significantly improves environmental performance, indicating that Hypothesis 1 is valid and the conclusion is robust.

4.6 Heterogeneity analysis

4.6.1 Internal decision-making

From columns (1) and (2) in Table 8, we can see the results of the heterogeneity test of the CEO and chairman of the board of directors in two positions, the coefficients of the two positions and non-two positions are 0.0446 and 0.101 respectively, and they are all significantly positive, but the coefficients of the non-two positions are larger, so we carry out the Zou test test to see if there is a difference between the coefficients of the two subsample groups, and by the Zou test in Table 8, it shows that there are two groups with a significant difference. It shows that digital transformation has a more prominent role in promoting the environmental performance of non-dual-employee firms compared to dual-employee firms with CEOs and chairmen.

In a non-dual-job enterprise, there is a clear division of responsibilities between the CEO and the chairman of the board, so that the CEO can focus more on business operations and strategy development, while the chairman of the board can focus more on overseeing and guiding the overall development of the company. This means that when it comes to digital transformation, companies don't have to suffer from the fragmentation of executive responsibilities, and they can invest more material, human and financial resources. These additional resource investments can accelerate the process of digital transformation, leading to faster improvements in the company's environmental performance. At the same time, decision-making mechanisms are likely to be more efficient and flexible in non-dual-job enterprises. This helps firms to make faster decisions on digital transformation and increase the speed of implementation of related programs. This flexibility and efficiency enables companies to better respond to environmental challenges and take more proactive measures to protect the environment while improving environmental performance. In addition to this, in a non-dual-job enterprise, the CEO and chairman can each focus on their own areas with more in-depth expertise. This combination of expertise can provide more comprehensive and specialized guidance for digital transformation and help companies make greater progress in environmental performance.

4.6.2 Nature of property rights

Columns (3) and (4) in Table 8 show the test of heterogeneity of different property rights, in the test results show that the coefficients of SOEs and non-SOEs are significantly positive and 0.143 and 0.0541 respectively, the coefficients of SOEs are larger than those of non-SOEs, and meanwhile, at the level of 1%, Zou's test shows that there is indeed a significant difference between the two groups. This implies that the digital transformation of enterprises is more significant in improving the environmental performance of state-owned enterprises compared with non-state-owned enterprises.

First, compared with non-SOEs, SOEs are more active in promoting digital transformation due to more government support and easier access to resources. Second, SOEs usually bear more social responsibility and are subject to stricter regulation, so SOEs tend to use digital transformation as an effective way to optimize resource allocation and strengthen social responsibility. Moreover, faced with increasingly stringent environmental protection laws and policies, SOEs must take more proactive environmental measures to fulfill their social responsibilities and protect the environment. In this sense, as SOEs are able to obtain more financial support for their digital transformation, they will also have more funds to spend on improving all aspects of the environment, thus effectively improving their environmental performance. In addition, the government will provide SOEs with more incentives and subsidies such as tax breaks to encourage digital transformation and improve environmental performance. Since the management of SOEs tends to focus more on long-term development and social responsibility, the management of SOEs will be more motivated and determined in promoting the improvement of their environmental performance. In this way, the government can contribute more to the protection of the ecological environment while promoting the reform and development of state-owned enterprises.

4.6.3 Financial situation of the enterprise

The gearing ratios were grouped with a cut-off point of 0.5, with firms with gearing ratios below 0.5 being those with low gearing ratios and firms with gearing ratios above 0.5 being those with high gearing ratios.

From columns (5) and (6) in Table 8, we can get the results of the heterogeneity test of different gearing ratios, it is not difficult to see that the coefficients of enterprises with high gearing ratios and those with low gearing ratios are 0.145 and 0.0384 respectively and are all significantly positive, and the coefficients of enterprises with high gearing ratios are larger, while at the 1% level, the Zou test shows that there is indeed a difference between the two groups. It indicates that the enhancement of environmental performance by enterprise digital transformation is more obvious in enterprises with high gearing ratio.

Enterprises with high debt ratios tend to pursue cost-saving approaches in the production process. Advancing digital transformation in response to the situation can optimize energy consumption and reduce emissions with advanced automation and intelligent technologies. Enterprises introduce data-driven decision-making tools to be aware of the current environmental conditions and achieve better energy saving and emission reduction effects. Enterprises can also collect and analyze large amounts of real-time data, so that they can have a clear understanding of the environmental management. For enterprises with high gearing ratio, the use of data analysis can be part of the potential environmental problems to achieve a clear understanding of the solution to effectively reduce the environmental problems brought about by the management costs and risks. Meanwhile, for enterprises with high gearing ratio, in order to maintain long-term competitiveness and stability, it is more necessary to implement long-term sustainable development strategy for environmental management.

Table 8 Heterogeneity analysis

	(1) double- hatting EP	(2) Non-dual incumbency EP	(3) state enterprise EP	(4) non-state enterprise EP	(5) Levco EP	(6) low level EP
Dig	0.045***	0.101***	0.143***	0.054***	0.145***	0.038***

	(0.014)	(0.011)	(0.018)	(0.010)	(0.017)	(0.010)
Control	Yes	Yes	Yes	Yes	Yes	Yes
Ind	Yes	Yes	Yes	Yes	Yes	Yes
Year	Yes	Yes	Yes	Yes	Yes	Yes
_cons	-	-	-	-	-	-
	4.610***	-4.714***	-5.536***	-3.132***	3.664***	-4.252***
	(0.585)	(0.344)	(0.504)	(0.375)	(0.533)	(0.347)
N	8153	17745	8034	17864	8697	17201
R2	0.254	0.247	0.273	0.225	0.254	0.253
adj. R2	0.246	0.243	0.265	0.221	0.246	0.249
Coefficient difference	0.000		0.000		0.000	
p-value						

Note: Coefficient difference p-values are based on Chow test,* $p < 0.1$,** $p < 0.05$,*** $p < 0.01$

5. Conclusion

Deepening the construction of green and intelligent ecological civilization and promoting the synergistic development of digitalization and greening remains our goal. This paper provides certain experience and basis for digitalization-enabled enterprise green development. With the non-ST non-financial stock data of listed companies in Shanghai and Shenzhen from 2015 to 2022, based on theoretical analysis and using the fixed effect model, the impact of enterprise digital transformation on environmental performance is studied, and three main conclusions are drawn: first, enterprise digital transformation can improve enterprise environmental performance. Second, enterprise digital transformation can improve enterprise environmental performance by alleviating enterprise financing constraints. Third, the effect of enterprise digital transformation on corporate environmental performance effect is more significant in enterprises with non-dual-occupation, state-owned, and high gearing ratio. In addition, the results remain robust after this paper conducts a robustness test on the benchmark regression as well as dealing with endogeneity issues. Based on the above findings, the following recommendations are made.

First, a digital transformation incentive mechanism should be established to continuously promote the digital transformation of enterprises. Promoting the digital transformation of enterprises can not only increase operational efficiency, but also improve their environmental performance. The government can encourage enterprises to accelerate digital transformation by formulating corresponding incentive policies, such as subsidies or tax breaks. Second, increase financial support to ease financing constraints. By easing financing constraints, enterprise digital transformation can improve corporate environmental performance. In promoting digital transformation, the government can provide more financial support to ease corporate financing constraints and improve corporate environmental performance. Third, for enterprises with non-dual-occupation, state-owned, and high gearing ratios, customized digital transformation policies should be formulated and support should be increased. In non-dual-occupation, state-owned, and high gearing enterprises, the impact of digital transformation on corporate environmental performance is more significant, and to address this characteristic, the government can take different measures for enterprises of different natures, perhaps making the policy more effective. Fourth, the regulatory framework needs to be improved. It is necessary to improve the regulatory framework for digital transformation, standardize the application of digital technology and data management, and ensure the smooth promotion of digital transformation, as well as to improve the environmental regulatory mechanism and effectively monitor the impact of enterprises on the environment.

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