

Digital transformation empowers corporate environmental performance

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Abstract. Good ecological environment is both natural and economic wealth, and is related to economic and social development potential and strength of economic and social development. In the era of digital transformation, clarifying the role mechanism of digital empowerment of ecological construction can provide an important theoretical basis for building a beautiful China. This paper adopts the panel data of A-share listed companies from 2009 to 2022, and explores the influence mechanism of digital transformation on corporate environmental performance based on the mediating effect of financing constraints and the moderating effect of green technology innovation. The study finds that: digital transformation can significantly improve corporate environmental performance; financing constraints have a mediating effect in the impact of digital transformation on corporate environmental performance; green technology innovation positively moderates the impact of digital transformation on corporate environmental performance; and the heterogeneity analysis shows that digital transformation has a more significant effect on environmental performance for state-owned enterprises, non-heavily polluted enterprises, non-high-tech enterprises, and labor-intensive and technology-intensive enterprises. The promotion effect of digital transformation on environmental performance is more significant. The study focuses on the mechanism of digital transformation in the environmental performance of enterprises, which is of great significance for enterprises to utilize digital transformation to empower green development.

Keywords: digital transformation; environmental performance; financing constraints; green technology innovation.

1. Introduction

Since the reform and opening up, China's early economy to rough development mode to achieve rapid improvement, but the cost of development is a huge waste of resources and environmental damage, a variety of extremely poor environment and weather for us to sound the alarm of environmental awareness. 2023 December 27, the State Council issued on the comprehensive promotion of the construction of beautiful China's views, the views pointed out that China's economic and social development has entered the stage of accelerated Greening, low-carbon high-quality development stage, the construction of ecological civilization is still in a critical period of overlapping pressures and heavy loads, the task of building a beautiful China is still arduous, we must put the construction of a beautiful China in the construction of a strong country, the national rejuvenation of a prominent position, and unswervingly take the road of civilized development of production development, affluent life, ecological wellbeing, and build a beautiful home with a blue sky, a green earth, and a clear water.

The National Informatization Plan of the 14th Five-Year Plan in 2022 calls for "leading greening with digitization", accelerating the green and low-carbon development of the industry empowered by digital technology, "driving digitization with greening", and promoting the development of green smart terminals, green information networks, and green data centers. It also calls for "driving digitalization with greening" and promoting the development of green intelligent terminals, green information networks and green data centers. On the other hand, it is proposed to "vigorously develop new technologies and industrial systems for the integration of digital and green technologies", and to promote the symbiotic development of the digital economy and the green economy.

Based on this, how to empower green production, green transformation and green development with digital transformation has become an urgent concern for society. However, the existing research involves the impact of digital transformation on enterprise valuation (Zhang Jianjia, 2023), financial

performance (Lin Yixin, 2023), talent innovation (Liu Haorong, 2023) and marketing management (Qiao Yibin, 2023), while little is mentioned in the impact of digital transformation on the ecological environment, therefore, through this paper's research, the marginal contributions that will be realized are as follows: firstly, broadening the research perspective, focusing on the impact of digital transformation in the environmental performance of enterprises and constructing the corresponding model, which enriches the theoretical construction of digital transformation and environmental performance; second, adopting financing constraints as the mediating variable and green technology innovation as the moderating variable, specifically analyzing the mechanism of the role of digital transformation on the environmental performance of enterprises, and clarifying the motivating and influencing factors for the enhancement of the environmental performance of enterprises; third, examining Third, it examines the heterogeneous characteristics of different enterprises in the process of digital transformation affecting environmental performance, providing targeted theoretical references for the green and high-quality development of different kinds of enterprises.

2. Theoretical analysis and research hypothesis

2.1 Enterprise Digital Transformation

In today's digital era, digital transformation has gradually become an important strategic goal for enterprise competition and development, which not only affects the internal operation of enterprises, but also affects the business model of the whole industry. However, existing research has different levels of understanding of digital transformation. Digital transformation brings new resources to enterprises, but at the same time, enterprises must have the ability to effectively accumulate, integrate and develop resources in order to truly transform them into value (AMIT R & HANX, 2017); digital transformation involves both the application of digital tools to transform the core as well as the discovery and seizing of new opportunities brought about by digitalization (Furr N & Shipilov A., 2019). Overall, digital transformation should not be limited to the upgrading of a particular system or the improvement of existing technologies; it should be a systematic project, a process of comprehensive change in an organization. All industries should make efficient use of new digital technologies while eating the dividends brought by new technologies, and use big data, machine learning, cloud platforms and other methods to create a new digital business for enterprises and help them break through technical bottlenecks. The current digital transformation has become an irreversible and inevitable trend, but enterprises should also seek long-term sustainable and healthy development while accelerating the digital transformation, to make up for and improve the previous crude development in the ecological aspects of the unfinished business, and ultimately for social progress and national economy to inject a new green power.

2.2 Corporate environmental performance

Environmental management system certification ISO14001 defines environmental performance as: enterprises take energy saving and emission reduction as the development goal of the enterprise, and optimize the environmental elements independently, so as to realize the transformation to an environmentally friendly enterprise; and the World Commission on Sustainable Development believes that the environmental performance of enterprises can be optimized through the continuous optimization of enterprises in the production and operation process, reduce the enterprise's dependence on resources, and realize the technological transformation, which can in turn promote the sustainable and healthy socio-economic development. With the proposal of green and high-quality development, enterprises are also required to have a sense of environmental awareness and social responsibility, of which environmental performance is an important measurement standard, which not only represents the enterprise's investment in environmental protection, but also provides the basis and guidance for enterprises to achieve emission reduction and digital empowerment (Hu Weitong and Su Donglei, 2018). Currently, the industry has different standards for measuring the

environmental performance of enterprises, and there are roughly several assessment methods, such as the amount of emissions, sewage charges, responsibility scores, and comprehensive scores.

2.3 The Impact of Enterprise Digital Transformation on Environmental Performance

The theory of industrial structure optimization believes that through industrial restructuring, it can promote the national economy. The coordinated development of industries and the rationalization and advancement of industrial structure can be realized in the process of growing social demand. On the one hand, by adjusting the industrial demand and supply structure to realize the optimized allocation of resources; on the other hand, through the technological progress, the overall quality and efficiency of the industrial structure evolves to a higher level, realizing the advancedization of the industrial structure (Gan Chunhui et al., 2011, Liu Zhibiao and Kong Lingchi, 2021).

Digital transformation has the natural advantage of promoting industrial structural change. First of all, digital transformation has obvious information advantages, for example, in the management of environmental protection affairs, you can establish a database and regulatory platform and other systems to manage and track and detect the daily sewage data, in the event of data anomalies, you can provide timely warnings and take remedial measures, even after an accident has occurred, you can trace the cause of the accident through the data back to sum up the experience and optimize the management program; in addition, through digital transformation, enterprises can break down information barriers, access to external advanced technology, and share resources and experience among enterprise branches and departments. digital transformation, enterprises are able to break information barriers, access to external advanced technology, and synchronize information in a timely manner between enterprises, and between branches and departments of enterprises, and share resources and experience, which greatly improves the disadvantages of the previous information asymmetry, and also significantly reduces the cost of information exchange (BRIEL F V et al., 2018). Through the information advantages of digital transformation, the efficiency of resource utilization is significantly improved, the use of resources can quickly find the crux of the problem and accurately match it, and the factors of production can break through the limitations of time and space to reasonably flow and optimize the allocation among various departments, so as to achieve the rationalization of the industrial structure, which can reduce the waste of resources and improve the environment level (Han Yonghui et al., 2016). At the same time, in the context of digital transformation, the proportion of digital and technology-oriented enterprises will be greatly increased relative to labor- and capital-intensive industries, because the market will tend to favor manufacturing and service industries with higher factor productivity (Castellacci, 2010), realizing the advanced industrial structure, and such enterprises tend to be low in energy consumption and emissions, which are relatively harmless to the environment, and likewise contributes to the environmental performance of enterprises. Accordingly, this paper proposes the following hypotheses:

H1: Digital transformation of enterprises helps to improve their environmental performance.

2.4 Mediating effects of financial constraints

Due to the non-exclusivity of knowledge, in order to prevent the leakage of information and the outflow of technology, it is difficult for external investors to obtain R&D-related information to assess the level of the enterprise's innovation ability and the merits of the project, so investors face serious information asymmetry, which greatly increases the difficulty and cost of external financing of innovation activities, forming a financing constraint. If enterprises do not have sufficient funds to support long-term R&D expenditures, especially green innovation expenditures, in the context of digital transformation will inevitably affect the future green and sustainable development of enterprises, which will have a negative impact on the environmental performance of enterprises. Digital transformation through the "cloud platform", "big data" and other technologies, greatly reducing the information asymmetry caused by the high cost of external financing, reduce the

enterprise financing constraints. In addition, its significant resource and information advantages in the rational flow of factors, the optimal allocation of resources and alleviate the agency problem also has a better performance, which also reduces the enterprise's operating costs and agency costs (Luo Jinhui and Wu Yilong, 2021, Yu Shihai et al., 2022), and reduce the pressure on the enterprise's capital.

At the same time, digital transformation, as an important initiative in line with China's development strategy, is prone to enjoy national policy preferences when financing (Hua Junguo et al., 2022). Previous studies have also shown that government resources will be preferentially tilted to enterprises with better environmental performance, thus improving the enterprise financing environment (Yao Sheng and Zhou Min, 2017), optimizing enterprise resource allocation, and ultimately forming a virtuous cycle: with financing support, enterprises further carry out digital transformation work effectively, and enterprises are also motivated by government support to allocate more resources to environmental affairs, which continues to have a positive effect on environmental performance, and ultimately forms an intrinsic motivation to improve environmental performance through digital transformation, while enterprises are motivated by government support to continue to have a positive effect on environmental performance. The internal motivation to improve environmental performance through digital transformation is finally formed, and the financing constraint plays a bridging role in it. Therefore, this paper proposes the following hypotheses:

H2: Corporate digital transformation improves corporate environmental performance by reducing corporate finance constraints.

2.5 Moderating effects of green technology innovation

Green technology refers to the emerging technology that follows the ecological principles and ecological economic laws, reduces consumption, reduces pollution, improves ecology, promotes the construction of ecological civilization, and realizes the harmonious coexistence of human and nature (Cheng Qiongwen and Lu Siyu, 2023). At present, green technology innovation is becoming an important emerging field in the new round of global industrial revolution and scientific and technological competition.

At present, green technology innovation patents are mainly focused on administrative, regulatory or design areas, such as waste management; low-carbon areas, such as fossil energy carbon reduction technologies and energy storage technologies; and new energy areas, such as smart grids, nuclear energy and new energy vehicles. Through emerging technologies, enterprises are able to establish a management mode and regulation mechanism that coordinates economy, resources and environment, realize clean production with low energy consumption and low emission, as well as final and efficient pollution treatment, comprehensively improve enterprise environmental performance, and promote the construction of intelligent, green and efficient production system. However, out of the demand of enterprises to reduce production costs and improve economic efficiency, green technology innovation research and development cycle is longer and the input cost is larger, which will make enterprises give up part of their environmental performance, thus causing greater harm to the environment. If enterprises focus on green technological innovation, and take advantage of the powerful resource advantages of digital transformation: to improve the efficiency of resource integration and the optimal allocation of factors across time and space; and the information advantage: to avoid the waste of resources and pollution due to information asymmetry and information barriers, it can greatly reduce the continuous cycle of technological research and development and investment, and improve the effective supply of green intelligent equipment, clean production processes and pollution control technology (CIRIELLO R F et al., 2018, Wu Fei et al., 2021). In the impact of digital transformation on the environmental performance of enterprises, if enterprises transform the current high-input, high-consumption rough development mode and focus on green technological innovation, it will inject new momentum to achieve high-quality development that harmonizes the economy with the resources and environment. Therefore, this paper puts forward the following hypotheses:

H3: Green technology innovation positively moderates the impact of digital transformation on firms' environmental performance.

3. Study design

3.1 Sample Selection and Data Sources

This paper selects A-share listed companies from 2009 to 2022 as the research sample, in order to ensure the validity of the data, excluding ST, *ST enterprises during the sample period, excluding enterprises with key variables missing or other variables seriously missing, excluding extreme values, excluding enterprises in the financial industry, and finally obtaining the panel data which contains a total of 36,732 observations of 4,712 listed companies in the 14-year period, and part of the enterprises have data missing in part of the year. The panel data contains 36732 observations for 4712 listed companies over 14 years, with some companies having missing data for some years. The main sources of data are the database of Cathay Pacific and the annual reports of listed companies.

3.2 Description of variables

2.2.1 Explained variable: firms' environmental performance (EP)

Given that there is currently no publicly available database on corporate environmental performance in China, after considering Shen Hongtao et al.'s (2017) method of measuring corporate environmental performance in terms of both discharge concentration and total volume of discharges, as well as Yu Lianchao et al.'s (2020) method of measuring corporate environmental performance using environmental taxes and fees, it is argued that corporate environmental performance cannot be evaluated singularly from a qualitative or quantitative perspective alone, and therefore this paper draws on Li Xiaomei and Li Manman (2022), and Ma Dove et al. (2024), to construct a corporate environmental performance evaluation system from three aspects of regulatory certification, environmental protection management, and pollution management, by collecting relevant annual reports of listed enterprises during the sample period, assigning 0 points to the corresponding indexes with no mention, 1 point to the existence of a qualitative description, and 2 points to the existence of a quantitative description, and then assigning 2 points to the total score as a comprehensive score of the corporate environmental performance at both the qualitative and quantitative levels, with the larger the value indicating that the corporate environmental performance is not only from a single qualitative or quantitative perspective. The total score is used as the comprehensive score of the firm's environmental performance in both qualitative and quantitative dimensions, and the larger value indicates the higher environmental performance of the firm, the detailed criteria are shown in Table 1. In addition, we use the environmental E part of the CSI ESG score data and divide the score by 10 to replace the explanatory variables in the robust test.

Table1 Environmental Performance Evaluation System

Level 1 indicators	Secondary indicators	Tertiary indicators	Scoring criteria
Environmental performance	regulatory certification	Key Pollution Monitoring Units	(0, 1)
		Pollutant emission compliance	(0, 1)
		environmental emergency	(0, 1)
		Environmental violations	(0, 1)
		Environmental petition cases	(0, 1)
		ISO14001 certified or not	(0, 1)
		ISO9001 certified or not	(0, 1)
		Environmental Concepts	(0, 1)
		environmental objective	(0, 1)
		Environmental management system system	(0, 1)
		Environmental Education and Training	(0, 1)

environmental management	Special Environmental Action	(0, 1)
	Environmental incident response mechanisms	(0, 1)
	Environmental honors or awards	(0, 1)
	"Three simultaneous" system	(0, 1)
	Emission reduction and management of waste gas	(0, 1, 2)
pollution control	Wastewater abatement and management	(0, 1, 2)
	Dust and fume management	(0, 1, 2)
	Solid waste utilization and disposal	(0, 1, 2)
	Treatment of noise, light pollution, radiation, etc.	(0, 1, 2)
	Cleaner production implementation	(0, 1, 2)

2.2.2 Explanatory variable: digital transformation of enterprises (Dig)

From the viewpoint of existing research and practice, the major strategic decisions of enterprise digital transformation will appear more clearly in the annual reports of enterprises, indicating the future development path of enterprises, so we draw on the methods of Wu Fei et al. (2021) and Yuan Chun et al. (2021) to construct a dictionary of enterprise digital transformation terms based on semantic descriptions of national policies related to the digital economy and draw on the annual reports of listed companies with more successful digital transformations to annual reports to expand the dictionary appropriately. Relevant reports with summary nature of the enterprises studied from 2009 to 2022 are finally selected, and the text is subjected to word division and word frequency statistics, and the natural logarithm of the digitized word frequency after adding 1 is used to measure the degree of digital transformation of each enterprise.

2.2.3 Intermediate variables: financing constraints (SA)

At present, the academic community for the measurement of financing constraints mainly includes a single index, KZ index, WW index to, SA index, FC index four, but a single index is difficult to comprehensively measure the degree of corporate financing constraints, the other indices also have a lot of endogenous financial variables, such as cash flow, leverage, etc., compared to this paper, this paper selects the method of Hadlock & Pierce (2009), which is based on corporate financial reports to classify the type of corporate financing constraints. Based on the enterprise financial report to classify the type of enterprise financing constraints, only the enterprise size (Size) and enterprise age (Age) two variables with little change over time and has a strong exogenous construction of the SA index, and is relatively robust. Where Size is the natural logarithm of the firm's total assets (in millions of dollars) and Age is the year of observation minus the year of the firm's inception, $SA = -0.737 * Size + 0.043 * Size^2 - 0.040 * Age$.

2.2.4 Moderating variable: green technological innovation (Gti)

Drawing on the practice of Cheng Qiongwen et al. (2023), and Ma Ling et al. (2024), the number of green technology patent applications is more representative of the level of green technology innovation of enterprises than the number of granted patents, considering that patent applications are time-consuming, and the number of patent applications is used to measure the level.

2.2.5 Control variables

This paper controls for the following variables: gearing (Lev), firm growth (Growth), net asset margin (Roa), net cash content of operating income (Cash), equity concentration (Tophold), age (Age), and also controls for the effect of industry (Indutry) and year (Year).

A detailed description of the explanatory variables, explanatory variables, mediating variables, moderating variables, and control variables involved in this paper is shown in Table 2.

Table 2 Variable description table

Variable type	variable name		Variable Measurement
explanatory variable	Corporate environmental performance	EP	Total evaluation system score (see table 1 for details)
explanatory variable	Digital Transformation	Dig	$\ln(\text{digitized word frequency} + 1)$
intermediary variable	Financing constraints	SA	SA index
moderator variable	Green Technology Innovation	Gti	Number of patent applications for green technologies
	gearing	Lev	Total liabilities/total assets
	Corporate Growth	Growth	(Amount of operating income for the current period of the year - Amount of operating income for the same period of the previous year) / (Amount of operating income for the same period of the previous year)
control variable	Net interest rate on assets	Roa	Net profit/total assets balance
	Net cash content of operating income	Cash	(Net cash flows from operating activities)/(Total operating income)
	shareholding concentration	Tophold	Shareholding ratio of the largest shareholder
	(a person's) age	Age	$\ln(\text{year of observation} - \text{year of incorporation})$
	sector	Industry	virtual variable
	particular year	Year	virtual variable

3.3 Modeling

To verify the impact of digital transformation on corporate environmental performance, the following benchmark regression model (1) is constructed according to hypothesis 1:

$$EP_{i,t} = \alpha + \beta Dig_{i,p} + \lambda controls_{i,t} + Industry + Year + \varepsilon_{i,t} \quad (1)$$

To verify the mediating effect of financing constraints in the impact of enterprise digital transformation on environmental performance, model (2) and model (3) are constructed according to hypothesis 2:

$$SA_{i,t} = \alpha_1 + \beta_1 Dig_{i,p} + \lambda_1 controls_{i,t} + Industry + Year + \varepsilon_{1i,t} \quad (2)$$

$$EP_{i,t} = \alpha_2 + \beta_2 Dig_{i,p} + aSA_{i,t} + \lambda_2 controls_{i,t} + Industry + Year + \varepsilon_{2i,t} \quad (3)$$

To verify the moderating effect of green technology innovation in the impact of enterprise digital transformation on environmental performance, model (4) and model (5) are constructed according to hypothesis 3:

$$EP_{i,t} = \alpha_3 + \beta_3 Dig_{i,p} + \theta Gti_{i,t} + \lambda_3 controls_{i,t} + Industry + Year + \varepsilon_{3i,t} \quad (4)$$

$$EP_{i,t} = \alpha_4 + \beta_4 Dig_{i,p} + \theta_1 Gti_{i,t} + \theta_2 dG + \lambda_4 controls_{i,t} + Industry + Year + \varepsilon_{4i,t} \quad (5)$$

Where Dig represents the degree of enterprise digital transformation, EP represents the level of enterprise environmental performance, SA represents the level of enterprise financing constraints, Gti represents the level of enterprise green technological innovation, dG is the interaction term

($dG = Dig * Gti$), and ε is the random perturbation term, Industry and Year are industry and year dummy variables, and i and t represent individuals and enterprises, respectively.

4. Empirical analysis

4.1 Descriptive statistics

After eliminating the extreme values, descriptive statistics of the core variables are carried out, and the results are shown in Table 3. As can be seen in Table 3, the minimum value of the enterprise environmental performance is 0, the maximum value is 25, and the standard deviation is 4.578, so the environmental performance has a large difference among enterprises, and the mean value is 5.220, which indicates that the overall level of the environmental performance of the enterprise is low; the minimum value of the enterprise's degree of digital transformation is 0, and the maximum value is 5.011. The standard deviation is 1.408, so the degree of digital transformation has a large difference between enterprises, and the average value is 1.405, indicating that the overall level of enterprise environmental performance is low; the observation of the control variables, the balance sheet ratio, growth, net asset interest rate of each enterprise also has differences.

Table 3 Descriptive statistics

variant	sample size	average value	(statistics) standard deviation	minimum value	maximum values
EP	36,732	5.220	4.578	0	25
Dig	36,732	1.405	1.408	0	5.011
Lev	36,732	0.411	0.206	0.011	1.548
Growth	36,732	0.143	0.303	-1.309	2.003
Roa	36,732	0.039	0.072	-1.856	0.786
Cash	36,732	0.097	0.193	-1.997	1.888
Tophold	36,732	0.345	0.150	0.018	0.900
Age	36,732	2.821	0.394	0	4.159

4.2 Benchmark regression results

A two-way fixed-effects model is used to conduct a multiple regression on the digital transformation and environmental performance of enterprises, and the results are shown in Table 4. As shown in Table 4, column (1) is the regression result without any control variables and with only the core explanatory variables, and the regression coefficient is 0.118 with the fixed effect of industry and year, and it is significant at 1% level; and column (2) is the regression result with the introduction of the basic control variables, and the regression coefficient is 0.089 and significant at the 1% level, again with industry and year fixed. This shows that digital transformation has a significant positive effect on corporate environmental performance, and an increase of Dig by one standard deviation increases EP by 0.125 units, i.e., digital transformation helps to improve corporate environmental performance, and H1 is proved.

Table 4 Benchmark regression results

	(1)	(2)
variant	EP	EP
Dig	0.118*** (5.86)	0.089*** (4.48)
Lev		3.682*** (31.00)
Growth		-0.236*** (-3.27)

Roa		6.118*** (18.70)
Cash		0.708*** (6.26)
Tophold		1.749*** (12.12)
Age		0.240*** (3.90)
Constant	0.638** (2.11)	-2.559*** (-7.51)
Observations	36,732	36,732
R-squared	0.269	0.295
INDUSTYR	YES	YES
YEAR	YES	YES
F test	0	0
r2_a	0.267	0.294
F	145.2	155.2

4.3 Robustness Tests

To verify the reliability of the results, the following robustness tests were done in this paper, as shown in Table 5. ① Control for individual effects. In order to exclude the interference of individual-level factors that do not change over time on the results, the individual fixed-effects model is used, as shown in columns (1) and (2), which are the regression results of only the basic explanatory variables and the regression results after adding control variables, and the regression coefficients are 0.966 and 0.121, respectively, and they are all significant at 1% level, which indicates that after controlling for the individual effects, the effect of digital transformation on the enterprise's environmental performance improvement is still significant, and H1 is proved. The regression coefficients are 0.966 and 0.121 respectively, and both are significant at the 1% level, indicating that after controlling for individual effects, the effect of digital transformation on the environmental performance of enterprises is still significant, and H1 is proven. (ii) Replacement of explanatory variables. The environmental E score in the CSI ESG corporate score is used to measure the level of corporate environmental performance after dividing the score by 10. As shown in columns (3) and (4), the regression coefficients are 0.050 and 0.046 respectively, and both are significant at the 1% level, the H1 hypothesis still holds, indicating that the model is more robust. (iii) Lagged explanatory variables. Considering that the impact of digital transformation on corporate environmental performance may have a time lag, which causes endogeneity problems in the model, the core explanatory variable Dig is lagged by one period and regressed again, and the results, as shown in Column (5), are still significant, which proves once again that the H1 hypothesis is more robust, and that the digital transformation of the enterprise helps to improve the environmental performance of the enterprise.

Table 5 Robustness test results

	(1)	(2)	(3)	(4)	(5)
variant	EP	EP	E	E	EP
Dig	0.966*** (31.10)	0.121*** (3.81)	0.050*** (13.75)	0.046*** (12.62)	
Lev		-0.156 (-0.64)		0.508*** (23.20)	3.859*** (29.04)
Growth		0.038 (0.70)		-0.071*** (-5.40)	-0.295*** (-3.68)
Roa		1.256*** (4.02)		0.634*** (10.58)	6.850*** (19.06)

Cash		-0.059 (-0.69)		0.043** (2.07)	0.701*** (5.46)
Tophold		-0.247 (-0.53)		0.159*** (5.98)	1.915*** (11.88)
Age		5.374*** (31.73)		-0.001 (-0.09)	0.259*** (3.55)
L. Dig					0.070*** (3.17)
Constant	3.864*** (88.60)	-10.010*** (-18.76)	6.222*** (112.98)	5.905*** (93.98)	-2.395*** (-6.23)
Observations	36,732	36,732	36,024	36,024	31,134
R-squared	0.072	0.205	0.130	0.144	0.296
Number of id	4,712	4,712			
INDUSTYR	YES	NO	YES	YES	YES
YEAR	NO	NO	YES	YES	YES
ID	NO	YES	NO	NO	NO
F test	0	0	0	0	0
r2_a	0.0716	0.205	0.128	0.142	0.294
F	967.3	227.1	57.66	61.29	133.4

Note: Missing data in some samples when replacing explanatory variables for regressions results in fewer data in columns (3) and (4); lagging explanatory variables by 1 period results in fewer observations in column (5).

5. Impact mechanism test

5.1 Mediated effects test

Table 6 Mediating effects of financial constraints

	(1)	(2)	(3)
variant	EP	SA	EP
Dig	0.089*** (4.48)	0.001** (1.98)	0.084*** (4.28)
SA			3.279*** (21.81)
Lev	3.682*** (31.00)	0.050*** (12.25)	3.517*** (29.74)
Growth	-0.236*** (-3.27)	-0.011*** (-4.28)	-0.201*** (-2.81)
Roa	6.118*** (18.70)	0.023** (2.03)	6.042*** (18.59)
Cash	0.708*** (6.26)	0.019*** (4.88)	0.645*** (5.74)
Tophold	1.749*** (12.12)	0.068*** (13.63)	1.526*** (10.62)
Age	0.240*** (3.90)	-0.599*** (-282.24)	2.204*** (20.25)
Constant	-2.559*** (-7.51)	-2.168*** (-184.25)	4.550*** (9.68)
Observations	36,732	36,732	36,732
R-squared	0.295	0.766	0.304
INDUSTYR	YES	YES	YES

YEAR	YES	YES	YES
F test	0	0	0
r ² _a	0.294	0.766	0.303
F	155.2	1212	160.4

Column (2) shows that the regression coefficient is 0.001 and significant at the 5% level, indicating that digital transformation can reduce the financing constraints of enterprises (the SA value is negative, and the larger the value, the smaller the financing constraints); Column (3) shows that the regression coefficient of SA on the environmental performance of enterprises is significantly positive at the 1% level ($\alpha=3.279$), and the effect of digital transformation on environmental performance is also significant ($\beta_2 = 0.084$, $P = 1\%$) indicating that financing constraints have a mediating effect in the role of digital transformation to improve corporate environmental performance, H2 is proved.

5.2 Moderating effects test

Table 7 Moderating effects of green technology innovation

	(1)	(2)	(3)
variant	EP	EP	EP
Dig	0.089*** (4.48)	0.065*** (3.27)	0.060*** (3.00)
Gti		0.027*** (20.34)	0.023*** (10.83)
dG			0.002* (1.93)
Lev	3.682*** (31.00)	3.480*** (29.35)	3.474*** (29.29)
Growth	-0.236*** (-3.27)	-0.214*** (-2.99)	-0.213*** (-2.97)
Roa	6.118*** (18.70)	5.857*** (17.99)	5.844*** (17.94)
Cash	0.708*** (6.26)	0.703*** (6.25)	0.699*** (6.21)
Tophold	1.749*** (12.12)	1.677*** (11.68)	1.683*** (11.73)
Age	0.240*** (3.90)	0.261*** (4.28)	0.258*** (4.23)
Constant	-2.559*** (-7.51)	-2.464*** (-7.27)	-2.454*** (-7.24)
Observations	36,732	36,732	36,732
R-squared	0.295	0.303	0.303
INDUSTYR	YES	YES	YES
YEAR	YES	YES	YES
F test	0	0	0
r ² _a	0.294	0.301	0.301
F	155.2	159.5	158.0

Column (2) shows that the effect of green technology innovation level on firms' environmental performance is significantly positive ($\theta = 0.027$, $P = 1\%$); Column (3) shows that the regression coefficient of the interaction term dG on firms' environmental performance is 0.002 and is significant at the 10% level, indicating that green technology innovation positively moderates the impact of digital transformation on firms' environmental performance, and H3 is proved.

6. Heterogeneity analysis

In order to further discuss the heterogeneous impact of digital transformation on the environmental performance of enterprises, this paper will regress the overall sample of the studied enterprises in terms of the nature of ownership, the level of pollution, and the level of science and technology in groups, and the regression results are shown in Tables 9 and 10.

6.1 Analysis of ownership heterogeneity

Considering that the strategic objectives and business methods of enterprises may differ due to the nature of ownership, the overall sample is divided into non-state-owned enterprises and state-owned enterprises to explore whether there is heterogeneity in the impact of digital transformation on the environmental performance of enterprises.

As shown in columns (1) and (2) of Table 9, the regression coefficients are 0.071 and 0.162, respectively, and both are significant at the 1% level, so Dig has a significant contribution to the environmental performance of both non-state and state-owned enterprises, and the contribution to state-owned enterprises is more significant. From the descriptive statistics, we get that the average Dig level of non-state and state-owned enterprises is 1.551 and 1.144 respectively, and in general, the level of digital transformation of non-state enterprises is higher than that of state-owned enterprises; the average EP level of non-state and state-owned enterprises is 4.899 and 5.793 respectively, and in general, the level of state-owned enterprises' environmental performance is higher than that of non-state enterprises. In the context of accelerating the reform of state-owned enterprises, state-owned enterprises have gained more policy support, emerging industries are accelerating, traditional industries are struggling to upgrade, and have a broader development space in digital transformation; at the same time, state-owned enterprises have a greater social responsibility, and more stringent environmental regulation, which makes state-owned enterprises have more motivation in the process of the development of digital transformation and has a more significant role in promoting the level of environmental performance. The promotion effect is more significant.

6.2 Heterogeneity analysis of pollution levels

Considering that there will be differences in production methods and handling of environmental problems due to different pollution levels, the overall sample is divided into non-heavily polluted enterprises and heavily polluted enterprises to explore whether there is heterogeneity in the impact of digital transformation on the environmental performance of enterprises. The classification criteria refer to the 14 heavily polluted industries announced by the Ministry of Environmental Protection, and according to the SEC's 2012 guidelines for classifying listed companies, the industry codes of listed companies are obtained after matching: B06-B12,C13,C15,C17,C19,C22,C25-C32,D44,D45.

As shown in columns (3) and (4) of Table 9, the regression coefficients are 0.104 and 0.192, respectively, and they are all significant at the 1% level, so Dig has a significant promotion effect on the environmental performance of non-heavily polluted and heavily polluted enterprises, and the promotion effect is more significant for heavily polluted enterprises. From the descriptive statistics, the average Dig level of non-heavily polluted and heavily polluted enterprises is 1.736 and 0.711, respectively, and the degree of digital transformation of non-heavily polluted enterprises is significantly higher than that of heavily polluted enterprises; the average EP level of non-heavily polluted and heavily polluted enterprises is 4.268 and 7.210, respectively, and in general, the level of environmental performance of heavily polluted enterprises is higher than that of non-heavily polluted enterprises. The reason is that in the assessment of environmental performance in this paper, heavy polluting enterprises, due to the specificity of their production, inevitably have to disclose more relevant information in the annual report, so their environmental performance level is significantly greater than that of non-heavily polluting enterprises. Also due to the specificity of its production, with the help of digital transformation, heavy pollution in clean production, pollution management, etc. can have a stronger technical support, which in turn reduces the cost of production and promotes

the construction of intelligent green production system, so the impact of the digital transformation of heavy pollution enterprises on the environmental performance of enterprises is more significant.

6.3 Heterogeneity analysis of science and technology levels

Considering the fact that the degree of transformation and business areas will vary due to different levels of technology, the overall sample is divided into non-high-tech enterprises and high-tech enterprises to explore whether there is heterogeneity in the impact of digital transformation on the environmental performance of enterprises. The classification criteria refer to the method of Peng Hongxing and Mao Xinxu (2017), and companies with listed company industry codes C25-C29, C31, C32, C34-C41, 163-165, and M73 are defined as high-tech enterprises after matching in accordance with the classification guidelines of listed companies of the Securities and Exchange Commission (SEC) 2012.

As shown in columns (5) and (6) of Table 9, the regression coefficients are 0.105 and 0.074, respectively, and both are significant at the 1% level, so Dig has a significant promotion effect on the environmental performance of non-high-tech and high-tech enterprises, and the promotion effect is more significant for non-high-tech enterprises. From the descriptive statistics, the average Dig level of non-high-tech and high-tech enterprises is 1.207 and 1.534 respectively, which is obviously higher than that of non-high-tech enterprises in terms of the degree of digital transformation of high-tech enterprises; the average EP level of non-high-tech and high-tech enterprises is 4.940 and 5.403 respectively, which indicates that non-high-tech enterprises have a higher level of environmental performance than high-tech enterprises in general. Since high-tech enterprises are themselves technology-oriented business strategies with digital and intelligent management concepts and production equipment, relatively speaking, non-high-tech enterprises have more space and potential for development under digital transformation, and therefore the improvement of environmental performance is more significant.

Table 8 Results of heterogeneity test1

	(1)	(2)	(3)	(4)	(5)	(6)
	non-municipal	government owned	non-heavy pollution	heavy pollution	non-high tech	high tech
variant	EP	EP	EP	EP	EP	EP
Dig	0.071*** (3.12)	0.162*** (4.29)	0.104*** (5.10)	0.192*** (3.87)	0.105*** (3.23)	0.074*** (2.96)
Lev	3.234*** (21.94)	3.372*** (16.02)	3.781*** (29.22)	3.798*** (15.26)	3.160*** (17.09)	3.992*** (25.69)
Growth	-0.013 (-0.15)	-0.509*** (-3.99)	-0.161** (-2.11)	-0.625*** (-3.88)	-0.191* (-1.78)	-0.263*** (-2.71)
Roa	5.884*** (16.43)	7.014*** (9.77)	5.252*** (14.94)	7.898*** (11.09)	5.610*** (10.80)	6.302*** (14.83)
Cash	0.879*** (6.10)	0.586*** (3.25)	0.720*** (6.24)	0.554* (1.95)	0.562*** (3.96)	0.964*** (5.25)
Tophold	0.212 (1.20)	2.817*** (11.05)	1.309*** (8.28)	2.629*** (8.89)	1.481*** (6.85)	1.924*** (9.94)
Age	0.275*** (3.82)	-0.252** (-2.12)	0.270*** (4.12)	0.126 (0.93)	-0.190* (-1.96)	0.487*** (6.10)
Constant	-2.315*** (-4.41)	-1.692*** (-3.39)	-1.693*** (-5.10)	1.980*** (3.91)	-0.843** (-2.06)	0.925** (2.31)
Observations	23,533	13,199	24,847	11,885	14,524	22,208
R-squared	0.285	0.352	0.230	0.239	0.295	0.296
INDUSTYR	YES	YES	YES	YES	YES	YES
YEAR	YES	YES	YES	YES	YES	YES
F test	0	0	0	0	0	0

r ² _a	0.282	0.347	0.228	0.236	0.291	0.295
F	96.15	75.63	94.98	92.84	75.48	245.6
P-value for coefficient difference		0.000		0.000		0.000

Note: P-values for differences in coefficients between groups were obtained by the chow test.

6.4 Analysis of factor-intensive heterogeneity

Considering that the development paths and business strategies of enterprises may differ due to different factor intensities, the overall sample is divided into labor-intensive, capital-intensive and technology-intensive enterprises to explore whether there is heterogeneity in the impact of digital transformation on the environmental performance of enterprises, and the regression results are shown in Table 10.

As shown in Table 10, the regression coefficients of the digital transformation of labor-intensive and technology-intensive enterprises on environmental performance are 0.108 and 0.106 respectively, and both are significant at the 1% level, so Dig has a significant effect on the environmental performance of these two kinds of enterprises, but the effect on capital-intensive enterprises is not significant. The reason may be that capital-intensive enterprises are relatively slow to reflect the market, and the main business funds occupied too much, and for the R & D capital investment is insufficient, is still in the transformation and upgrading stage, so the impact of digital transformation is not significant or very small.

Table 9 Results of heterogeneity test2

	(1)	(2)	(3)
	labor-intensive	capital-intensive	technologically intensive
variant	EP	EP	EP
Dig	0.108*** (3.23)	0.002 (0.03)	0.106*** (4.07)
Lev	2.993*** (15.26)	4.006*** (12.46)	4.371*** (25.68)
Growth	-0.161 (-1.39)	-0.537*** (-2.66)	-0.265** (-2.54)
Roa	4.770*** (8.97)	8.758*** (9.29)	6.381*** (13.52)
Cash	0.400*** (2.59)	0.864** (2.45)	1.142*** (6.08)
Tophold	1.183*** (5.02)	3.116*** (8.20)	1.637*** (7.91)
Age	-0.002 (-0.02)	0.170 (0.99)	0.450*** (5.33)
Constant	-0.913** (-2.16)	-4.772*** (-6.03)	0.776*** (2.60)
Observations	12,197	6,543	17,391
R-squared	0.311	0.279	0.237
INDUSTYR	YES	YES	YES
YEAR	YES	YES	YES
F test	0	0	0
r ² _a	0.308	0.275	0.236
F	94.45	76.34	168.5

7. Conclusions and Implications of the Study

Taking the data of A-share listed companies from 2009 to 2022 as the research samples, this paper theoretically analyzes and empirically tests the impact of digital transformation on corporate environmental performance, the mediating effect of financing constraints therein, and the moderating role of green technology innovation. The results of the study show that: firstly, digital transformation has a significant positive effect on corporate environmental performance, and this positive effect has a lag effect, that is, the level of digital transformation in the previous year has the same significant positive effect on corporate environmental performance; secondly, there is a mediating effect of financing constraints in the process of digital transformation affecting green innovation performance, that is, digital transformation can reduce the level of financing constraints of the enterprise, and then promote the enterprise environmental performance; third, green technology innovation plays a positive moderating role in the impact of digital transformation on enterprise environmental performance; fourth, there is obvious heterogeneity in the digital transformation on enterprise environmental performance, specifically, the promotion is more obvious in state-owned enterprises, non-heavily polluted enterprises, non-high-tech enterprises, labor-intensive enterprises, and technology-intensive enterprises.

Based on the findings of the study, the following insights are drawn: first, enterprises should accelerate digital transformation, especially state-owned enterprises, non-polluting enterprises and non-high-tech enterprises that have greater potential for digital development, and should actively introduce new technologies such as artificial intelligence, big data and blockchain, to promote the improvement of corporate environmental performance, and facilitate the symbiotic development of the digital economy and the green economy; second, enterprises should enhance information transparency and mitigate high external financing costs caused by information asymmetry. Secondly, enterprises should enhance information transparency to alleviate the high external financing costs caused by information asymmetry, and at the same time flexibly utilize the information and resource advantages of digital transformation to reduce internal operating costs and agency costs, alleviate financing constraints, and thus promote the improvement of environmental performance; thirdly, enterprises should reasonably allocate resources to ensure long-term and stable capital expenditures for green technological innovation, so as to safeguard the level of environmental performance of the enterprises; fourthly, the government should further improve the supportive policies to motivate enterprises to vigorously carry out the development of the digital economy and green economy. Fourth, the government should further improve the support policies to encourage enterprises to vigorously carry out digital transformation activities, alleviate the financial pressure on enterprises, and then support enterprises to steadily carry out green innovation activities to promote the continuous improvement of enterprise environmental performance.

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