

Digital Transformation and Corporate Greenwashing: Unraveling the Moderating Effects of Environmental Regulation and Market Competition

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Abstract: With the impetus of the "dual carbon" objectives, China's capital market has imposed ever - stricter environmental information disclosure requirements. However, a few enterprises still resort to "greenwashing" to deal with regulatory pressures and market expectations. Meanwhile, digital transformation is an essential trend in enterprise development. Based on the panel data of A - share listed companies from 2014 to 2022, this paper delves into the impact of digital transformation on enterprises' "greenwashing" behavior and the underlying mechanisms. The empirical results indicate that digital transformation can significantly mitigate enterprises' "greenwashing" behavior, and this conclusion remains robust after a battery of robustness tests. The mechanism test reveals that environmental regulation and market competition positively moderate the relationship between digital transformation and greenwashing behavior. Moreover, the heterogeneity analysis shows that in state - owned enterprises and those with high financing constraints, digital transformation exerts a more pronounced mitigating effect on "greenwashing" behavior.

Keywords: Greenwashing, Digital transformation, Environmental regulation, Market competition, Green development

1. Introduction

With the increasing global climate change and the continuous prominence of carbon emission, governments around the world have formulated a series of emission reduction targets and policy measures. Among them, the targets of "carbon peaking" and "carbon neutrality" proposed by China, as a new emission reduction concept, have been widely concerned and recognized around the world. In 2020, the Shenzhen Stock Exchange revised the Measures for the Assessment of Information Disclosure Work of Listed Companies to incorporate ESG information disclosure into the regulatory system, marking a shift in environmental governance from voluntary disclosure to mandatory norms. However, in response to regulatory and market demands, some enterprises have adopted "greenwashing" strategies such as selective disclosure and data modification, resulting in environmental governance difficulties.

The term "greenwashing" was first proposed by American environmentalists in the 1890s and was initially summarized as "misleading communication patterns" [1]. After the 21st century, "green statements" have been frequently released, but most corporate organizations have been accused of

"inconsistent words and deeds", and this kind of "pseudo-social responsibility behavior" of enterprises in the field of environmental protection has been defined by scholars as "greenwashing" [2]. Today, "greenwashing" refers to an attempt by a company to project an image of environmental responsibility in a false, inauthentic and false way [3]. Existing studies have shown that the "greenwashing" behavior of enterprises will reduce consumers' green purchase intention [4] and damage the financial performance of enterprises [5]. In addition, as consumers are difficult to trust green marketing activities, it will further lead to increased social transaction costs and low efficiency [6]. Therefore, how to improve enterprises' "greenwashing" behavior is an urgent problem for the government and academia to study and solve.

In recent years, digital technology has advanced and been widely applied, providing new approaches for "greenwashing" governance. For example, blockchain technology can ensure the complete traceability of environmental data, and the industrial Internet of Things can monitor the real emissions of production links in real time. This has sparked academic discussion on the relationship between digital transformation and corporate "greenwashing" behavior. Most scholars believe digital transformation can enhance "greenwashing" behavior and further promote the "less talk and more action" of corporate environmental responsibility [7-9]. Conversely, some scholars hold the opposite view. For instance, case analyses reveal some digital tech companies employ digital means to conceal non-sustainable actions, achieving the purpose of "greenwashing" [10].

Existing research on digital transformation's impact on corporate "greenwashing" is limited, with insufficient analysis of the mechanisms involved. To address this, this study uses A-share listed companies from 2014 to 2022 as samples, empirically testing digital transformation's effect and its mechanisms on "greenwashing" behavior. The study's contributions include: firstly, to explore digital transformation's impact on "greenwashing", offering insights for its governance; Secondly, to analyze digital transformation's adjustment path from environmental regulation and market competition pressures; Thirdly, to examine the heterogeneity of digital transformation's impact considering ownership nature and financing constraints.

2. Theoretical analysis and hypothesis

2.1. The effect of digital transformation on corporate greenwashing

Enterprise digital transformation can effectively restrain the motivation and space of enterprise "greenwashing". First of all, the use of technologies to collect corporate environmental data in real time can reduce the possibility of data manipulation and disclose more accurate, complete and transparent corporate environmental information to the public, thus increasing the difficulty of enterprises greenwashing. At the same time, professional third-party institutions such as analysts usually focus on the enterprises after digital transformation [11], whose information mining function can further improve the information transparency of enterprises and compress the "green bleaching" space.

Secondly, the reason why enterprises choose to "greenwash" is often financial difficulties [7]. When enterprises are faced with financial crisis, in order to save costs, enterprises may try to obtain maximum economic benefits with minimum environmental costs, so as to actively or passively "greenwashing". However, digital transformation alleviates the financing constraints of enterprises and improves their financial situation in a variety of ways, thus reducing the incentive to "greenwash". For example, artificial intelligence can be used to promote the upgrading of corporate financial sharing, the systematization and precision of tax management [12], so as to make transaction behaviors more visible and transparent, enhance the digital credit of enterprises' networks, and thus reduce financing costs.

Digital technology overcomes time and space barriers, cuts labor, capital, and technology - related search and transport costs, quickly accumulates innovation factors, and greatly boosts corporate green innovation efficiency and level [13]. Enhanced green innovation enables firms to cut environmental protection costs, gain real green benefits, and weaken "green bleaching" appeal. Digital transformation improves information transparency, eases financing constraints, lifts green innovation level, curbing "greenwashing". Thus, the following hypothesis is put forward:

H1: Digital transformation can improve enterprise "greenwashing" behavior

2.2. The regulatory role of environmental regulations

Environmental regulation is a binding regulation implemented by the government, enterprises and industrial associations to prevent and control environmental pollution and improve the level of environmental governance [14]. According to Porter's hypothesis, strict and flexible environmental regulation can prompt enterprises to invest in pollution control and environment-oriented investment for the purpose of reforming product design and process flow, thus reducing compliance costs [15]. This means that under high-intensity environmental regulation, enterprises will be more active in using digital technology and resources to reduce environmental pollution. In addition, with the strengthening of the regulatory system and the implementation of the government accountability mechanism, the cost of environmental penalties for enterprises due to "greenwashing" began to be higher than the cost of environmental protection investment, so that enterprises can no longer respond negatively to environmental regulations through "greenwashing" behavior, but need to use digital technology to control pollution at the source and increase substantive environmental protection investment. When some scholars used the DID to evaluate the effect of the new Environmental Protection Law, they found that enterprises increased environmental protection investment after the implementation of the policy, which further confirmed the rationality of the above view [16]. Environmental regulation encourages enterprises to increase actual green investment, significantly improving their environmental performance [17], and reducing the necessity of "greenwashing" behavior. Thus, the following hypothesis is put forward:

H2: Environmental regulation intensity positively regulates the relationship between digital transformation and enterprise "greenwashing" behavior

2.3. The regulatory role of market competition

Market competition encourages enterprises to take information disclosure as a competitive strategy. In highly competitive industries, improving information transparency can strengthen the enterprises' competitive advantage [18]. Enterprises will use digital technology to enhance information transparency in order to enhance their market advantages. However, this increased transparency also means that competitors can quickly identify and expose greenwashing through digital platforms. Once a company's greenwashing is exposed, it will not only lose market share in a market with many alternative firms, but also face serious reputational damage.

From the perspective of signal transmission theory, information asymmetry exists in the capital market. To gain competitive advantages, enterprises will take costly actions to send signals to the market. These actions are difficult to be easily imitated by other enterprises due to their certain cost [19]. Compared with the "greenwashing" behavior, the actual investment in environmental protection has a higher cost and can better reflect the real value and long-term development ability. Therefore, in the case of intense market competition, enterprises will improve their environmental performance through digital transformation in order to gain long-term competitive advantages, rather than relying on "greenwashing" behavior to obtain short-term benefits. Thus, the following hypothesis is put forward:

H3: Market competition positively regulates the relationship between digital transformation and enterprise "greenwashing" behavior

3. Model construction

3.1. Data source and processing

This study selects Shanghai and Shenzhen A-share listed companies from 2014 to 2022 as samples, with the following processing: (1) excluding ST and financial - industry enterprises during the sample period; (2) removing enterprises with severely missing main-variable data; (3) using Stata17's winsor2 command for 1% tailing processing on continuous variables to rule out extreme values. Finally, it obtains 6456 observations from 1230 listed companies. Data are mainly from corporate annual reports, CSMAR, and CNRDS databases.

3.2. Model setting

To demonstrate the relationship between enterprise "greenwashing" and digital transformation, this paper constructs a regression model as shown in equation (1).

$$GWL_{i,t} = \alpha_0 + \alpha_1 DIGI_{i,t} + \alpha_2 X_{i,t} + Ind_i + Year_t + \varepsilon_{i,t} \quad (1)$$

Where, $GWL_{i,t}$ is the "greenwashing" degree of enterprise i in year t . $DIGI_{i,t}$ is the digital transformation level of enterprise i in year t . $X_{i,t}$ is a series of control variables. Ind_i represents the fixed effect of industry. $Year_t$ represents fixed effect of year. $\varepsilon_{i,t}$ is the random error element. α is the coefficient to be estimated. In the benchmark regression model, pay attention to the coefficient of digital transformation. If the $DIGI_{i,t}$ regression coefficient is significantly negative, it indicates that H1 in this paper is established.

According to the above theoretical analysis, the regulatory effects that may affect the improvement of enterprises' "greenwashing" behavior by digital transformation are two factors: the intensity of environmental regulation and the degree of market competition. The regulatory effect model is used to test this hypothesis, as shown in equation (2).

$$GWL_{i,t} = \gamma_0 + \gamma_1 DIGI_{i,t} + \gamma_2 MV_{i,t} + \gamma_3 DIGI_{i,t} \times MV_{i,t} + \gamma_4 X_{i,t} + Ind_i + Year_t + \varepsilon_{i,t} \quad (2)$$

Where, $MV_{i,t}$ is the regulatory variable that needs to be tested. In the regulatory effect model, pay attention to the regression coefficient in model (2). If the regression coefficient γ_3 is significant and in line with expectations, the regulatory effect is established.

3.3. Description of variables

3.3.1. Explained variables

This paper quantifies the greenwashing score of the same industry relative to enterprises as the substitute variable of enterprise greenwashing degree [20], as shown in the following formula.

$$GWL_{i,t} = \left(\frac{ER_{dis\ i,t} - ER_{dis\ Average}}{\sigma_{dis}} \right) - \left(\frac{ER_{per\ i,t} - ER_{per\ Average}}{\sigma_{per}} \right) \quad (3)$$

Where, $ER_{dis\ i,t}$ represents the environmental disclosure score of enterprise i in year t , $ER_{dis\ Average}$ represents the industry average, and σ_{dis} represents the industry standard deviation. The Bloomberg ESG score, reflecting only public ESG data disclosure, is utilized. $ER_{per\ i,t}$ represents

the actual environmental performance score of enterprise i in year t , $ER_{per\ Average}$ represents the industry average, and σ_{per} represents the industry standard deviation. The Huazheng ESG score, incorporating indicators like legal violations for a more accurate performance reflection, is adopted. $\left(\frac{ER_{dis\ i,t} - ER_{dis\ Average}}{\sigma_{dis}}\right)$ and $\left(\frac{ER_{per\ i,t} - ER_{per\ Average}}{\sigma_{per}}\right)$ respectively indicate the environmental disclosure score relative to the industry-standardized measure and the actual environmental score relative to the industry-standardized measure. A greater difference between the two implies a higher degree of corporate greenwashing.

3.3.2. Core explanatory variables

This paper constructs the enterprise digital transformation index via text analysis. Annual reports are collected, converted to text, and the business situation analysis section is extracted using Python. Based on existing literature's word segmentation dictionary [21], keyword disclosure times are counted from four aspects to reflect the digital transformation degree. Then, the word frequency data is standardized, the entropy method determines each index's weight, and finally, the DIGI index is obtained.

3.3.3. Control variables

With reference to the existing research, this paper selects variables covering the company's financial situation, governance structure and other levels [22], the above control variables are all derived from the CSMAR database. The definitions of the main variables are shown in Table 1.

Table 1: Main variable definitions and descriptions

Category of Variables	Variable name	Notation	Measure
Explained variables	The extent to which companies "greenwash"	GWL	The difference between the environmental disclosure score and the actual score relative to standardized measures.
Explanatory variables	Digital transformation index	DIGI	The word frequency digital transformation is weighted by entropy weight method
	Business size	Size	Log the total assets by adding one
	Corporate leverage levels	Lev	Asset-liability ratio
	Corporate profitability	Roa	Net profit/total assets
	Enterprise development ability	Grow	Operating revenue growth rate
	Ownership concentration	Top	Number of shares held by the largest shareholder/total number of shares
Control variables	Age of business	Age	Year of observation minus year of listing plus one takes logarithm
	Cash flow ratio	Cash	Net cash flow from operating activities/total assets
	Two jobs in one	Dual	A value of 1 is assigned if the chairman and general manager are the same person, otherwise 0
	Industries	Ind	Control industry
	Year	Year	Year of control

4. Analysis of empirical results

4.1. Descriptive statistics

From Table 2, we find that the median value of the "greenwashing" behavior (GWL) of the explained variable enterprises was -0.506, lower than 0, indicating that a small number of enterprises had greenwashing behavior in the sample. Further analysis of digital transformation level (DIGI) shows

that the mean value of DIGI is at a low level, reflecting that most enterprises are still in the initial stage of digital application, while its standard deviation is large, indicating that there are significant differences in the level of digital transformation among enterprises. In addition, the statistical results of other variables are all within a reasonable range.

Table 2: Descriptive statistics of main variables

Variable name	Sample number	Mean	Standard	Min	Median	Max
GWL	6456	-0.464	1.222	-3.290	-0.506	2.841
DIGI	6456	1.553	2.321	0	0.795	14.540
Size	6456	23.450	1.234	20.110	23.350	26.340
Lev	6456	0.474	0.188	0.062	0.487	0.879
Roa	6456	0.047	0.057	-0.227	0.040	0.200
Grow	6456	0.157	0.334	-0.523	0.105	2.086
Top	6456	0.370	0.158	0.084	0.357	0.737
Age	6456	2.479	0.727	0	2.708	3.332
Cash	6456	0.065	0.065	-0.136	0.061	0.245
Dual	6456	0.211	0.408	0	0	1

4.2. Baseline regression

Column (1) of Table 3 presents baseline regression results for digital transformation and corporate greenwashing, controlling for industry and year fixed effects. The digital transformation coefficient (-0.051, significant at the 1% level) suggests it effectively inhibits corporate greenwashing, verifying H1.

4.3. Robustness test

In order to test the robustness of the baseline regression results, the following three methods are adopted in this paper. First, replace the core explanatory variable. By referring to existing studies and using text analysis method, the total word frequency of keywords in enterprise annual reports was counted from the other four aspects and logarithmic processing was carried out to construct enterprise digital transformation level index [23]. The coefficient of Digital is still significantly negative, indicating that digital transformation does have an inhibitory effect on enterprises' "greenwashing"; Second, shorten the sample period. Given the huge impact of COVID-19 on all sectors of society, including digital transformation and greenwashing by enterprises, there may be significant differences in the data for this period, leading to bias in model estimates. Therefore, in this paper, data after the epidemic year of 2020 are excluded for regression, and the results are shown in column (3). The regression coefficient's significant 1% level negative value reaffirms the conclusion's robustness. Third, control variables were included. Based on prior research, Board size and Big4 audit status were added to the benchmark regression [24]. Column (4) results still support the conclusion that digital transformation can reduce corporate greenwashing.

Table 3: Baseline regression and robustness test

	GWL			
	(1)	(2)	(3)	(4)
DIGI	0.051*** (0.009)		0.054*** (0.013)	0.053*** (0.009)
Digital		0.027*		

Table 3: (continued)

		(0.015)		
_cons	2.907*** (0.389)	2.747*** (0.389)	2.763*** (0.500)	1.784*** (0.503)
Control variables	Yes			
Ind/Year	Yes			
N	6456	6456	4128	6456
adj. R2	0.057	0.053	0.053	0.085

Note: The regression coefficient is outside the brackets, the robust standard error is inside the brackets, * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$, the same below.

4.4. Adjustment effect test

4.4.1. Intensity of environmental regulation

In the test of the regulatory effect of environmental regulations (column (2) of Table 4), the proportion of the amount of waste gas and wastewater pollution treatment in the industrial output value of the year where the listed company is located is measured [25]. The results show that DIGI and DIGI×Reg coefficients have the same significant signs, confirming the positive regulatory effect of environmental regulation, consistent with H2.

4.4.2. Degree of market competition

In view of the influence mechanism of market structure (column (4) of Table 4), the Herfindahl index (HHI) is selected to measure industry concentration. The index value measures industry concentration and inverse competition. Empirical results show that DIGI and DIGI×HHI coefficients are opposite and significant, indicating that industry competition positively moderates the DIGI-greenwashing link, supporting H3.

Table 4: Test of DIGI effect

	Intensity of environmental regulation		Degree of market competition	
	(1)	(2)	(3)	(4)
DIGI	0.052*** (0.009)	0.055*** (0.009)	0.052*** (0.009)	0.049*** (0.009)
Reg	-23.882 (15.459)	27.947* (15.642)		
DIGI×Reg		9.872* (5.836)		
HHI			1.080* (0.635)	1.268** (0.644)
DIGI×HHI				0.234* (0.130)
_cons	2.978*** (0.393)	2.980*** (0.393)	2.899*** (0.394)	2.875*** (0.394)
Control variables	Yes			
Ind/Year	Yes			
N	6436	6436	6436	6436
adj. R2	0.058	0.059	0.057	0.058

4.5. Heterogeneity test

4.5.1. Property right nature

Column (1) (2) of Table 5 demonstrate that digital transformation significantly inhibits "greenwashing" in state-owned enterprises, yet not in non-state-owned ones. This discrepancy likely stems from differing levels of government supervision. This result may result from the difference in government supervision intensity between the two types of enterprises. Since most soes are directly controlled by the government, their digital systems need to be forced to connect to the government environmental protection platform to realize real-time pollution data sharing, which limits the management's manipulation space. However, non-state-owned enterprises are less subject to direct supervision pressure, and digital technology is more used to improve production efficiency, so they have relatively large space to manipulate environmental protection data.

4.5.2. Financing constraints

Some enterprises usually face higher external financing costs due to problems such as asymmetric information and insufficient collateral. Digital transformation can alleviate this problem by improving supply chain transparency and financial data credibility, allowing companies with high financing constraints to allocate more internal funds to substantive environmental investments. In this paper, the absolute SA index value measures corporate financing constraints, and the sample is split into high and low financing constraint groups at the median [26]. Financing constraint heterogeneity is analyzed, with results in Table 5, columns (3)-(4). The absolute regression coefficient is significantly larger for high - constraint firms, indicating digital transformation more effectively reduces "greenwashing" in such firms.

Table 5: Heterogeneity test

	(1)State-owned Enterprises	(2) Non-state- owned enterprises	(3) Enterprises with high financing constraints	(4) Enterprises with low financing constraints
DIGI	0.096*** (0.014)	-0.016 (0.012)	0.078*** (0.013)	0.030** (0.013)
_cons	4.032*** (0.558)	2.282*** (0.598)	3.875*** (0.558)	2.431*** (0.621)
Control variables	Yes			
Ind/Year	Yes			
N	3402	3054	3228	3228
adj. R2	0.080	0.064	0.086	0.056
p value	0.000		0.001	

Note: The P-value of the coefficient difference is calculated from the estimated Chow test of the interaction term model.

5. Conclusions

Based on 2014 - 2022 data from Shanghai and Shenzhen A - share listed companies, this paper empirically studies the impact and mechanism of digital transformation on corporate "greenwashing". The findings are: (1) Digital transformation can significantly improve enterprises' "greenwashing" behavior; (2) The moderating effect test shows that both environmental regulation and industry competition positively influence the relationship between enterprise digitalization and greenwashing behavior. (3) Heterogeneity analysis indicates digital transformation more effectively reduces

"greenwashing" in state-owned and high-financing-constraint enterprises. Based on these findings, the following recommendations are proposed:

First, enterprises should leverage digital transformation as the core engine to propel high-quality development. They need to harness technological innovation, apply digital technology to green governance, and achieve a win-win of economic and social benefits.

Second, the government should increase its support for digital transformation and encourage enterprises to speed up the process of digitization through policy guidance and financial support. In the process of formulating and implementing environmental regulations, the government needs to balance "strength" and "flexibility", and maintain the coordinated development of environmental regulations and enterprise digitalization. In addition, the government needs to promote fair competition in the market, especially strengthen anti-monopoly law enforcement, so as to enhance the environmental governance effect of digital transformation.

Last, based on the heterogeneity of enterprises, increase the supply of "greenwashing" governance systems for differentiated enterprises. For example, we should encourage state-owned enterprises to play a leading role in digital transformation and green governance, and increase financial support for green governance of enterprises with high financing constraints.

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