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Are Green Finance Policies Facilitating the Digital Transformation of Companies?

—Empirical Evidence of Pilot Policies in Low-Carbon Cities

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Abstract

The digital transformation of enterprises is one of the important ways to promote energy saving and emission reduction, thereby helping China achieve its goals of carbon peak and carbon neutrality from a micro perspective. Most of the existing literature focuses on the impacts of low-carbon city pilot policies on enterprises' carbon emission reduction and green technology innovation capabilities, while the role of enterprise digital transformation has been relatively overlooked. This paper uses panel data of Chinese listed companies from 2000 to 2022 as a sample and employs empirical methods such as the fixed-effects model, propensity score matching (PSM), and difference-in-differences (DID) to investigate the impact and mechanisms of low-carbon city pilot policies on enterprise digital transformation. The study finds that the low-carbon city pilot policy positively promotes enterprise digital transformation, and this conclusion remains robust after a series of robustness tests and endogeneity treatments. Mechanism analysis reveals that the policy can promote digital transformation by alleviating firms' financing constraints, while government capacity plays a positive moderating role in this relationship. Further heterogeneity analysis shows that the low-carbon city pilot policy has a more significant effect on the digital transformation of technology-intensive firms, non-heavy-polluting firms, and firms in the growth and maturity stages. This paper enriches the research on the mechanisms of enterprise digital transformation under the new era and provides empirical evidence for the top-level design of green finance policies and the realization path of promoting enterprise emission reduction and greening to build a Beautiful China under the conditions of the new development paradigm.

Keywords

Low-Carbon City Pilot Policy, Enterprise Digital Transformation, Double-Difference Modeling

1. Introduction

Against the backdrop of intensifying global climate change and a deepening consensus on sustainable development, the state is paying increasing attention to environmental governance and pollution emissions. In recent years, China has issued a number of policies and programs on environmental issues, such as the "carbon peak and carbon neutral" target for 2020. Meanwhile, the report of the 20th National Congress of the CPC clearly pointed out the need to "adhere to sustainable development" and "unswervingly follow the path of civilized development with productive development, affluent living and ecological well-being"; also clearly stated the need to "adhere to sustainable development". The "Fourteenth Five-Year Plan for National Economic and Social Development and Vision 2035" and the Outline of the Fourteenth Five-Year Plan for National Economic and Social Development and the Vision 2035 also explicitly propose the formulation of an action program to peak carbon emissions by 2030. The promulgation of green policies such as these marks the comprehensive transformation of the economic and social development model towards green and low-carbon. As a core policy tool to achieve the "dual-carbon" goal, the green financial system has become a key driving force for industrial structure optimization and technological innovation by guiding the flow of capital to low-carbon areas. The pilot low-carbon city policy has been implemented in batches since 2010, forcing local governments and enterprises to actively explore low-carbon development paths through mechanisms such as financial subsidies, green credit incentives, and carbon emissions trading.

In addition, from the perspective of high-quality urban development, low-carbon transformation and digital upgrading are its core pillars. On the one hand, as the main carrier of carbon emissions, the city's industrial layout, energy structure and governance model directly affect the realization of the "dual-carbon" goal; on the other hand, the digital economy and the construction of smart cities require the city to reconfigure the efficiency of resource allocation by means of digitization, and enterprises, as the micro-body of the urban economic system, play a key role in the high-quality development of cities and also play a crucial role in the process of China's carbon peak and carbon neutrality goals. In particular, through digital transformation, enterprises can not only effectively reduce carbon emissions and optimize industrial structure but also significantly improve social productivity. Therefore, enterprise digital transformation has become a powerful driving force to promote the construction of a beautiful and strong socialist country, accelerating the pace and depth of this process. It has injected new vitality into the city for sustainable development while realizing the goal of green and low-carbon development for enterprises, and has helped the economy and society to develop with high quality. However, the high sunk costs, technological uncertainty and positive externalities in the process of enterprise digital transformation have led to the common dilemma of "unwillingness to change, not daring to change"[1]. Against this backdrop, the low-carbon city pilot policies may alleviate the transformation constraints of enterprises from the three dimensions of cost compensation, risk sharing and capacity building through the reinforcement of environmental regulations, green financial incentives and information infrastructure support. For example, targeted green credit support in pilot areas may reduce the financing costs of digital technology transformation. Therefore, clarifying the causal relationship between low-carbon pilot policies and enterprise digital transformation can provide a direct basis for optimizing the design of green financial policies and promoting energy saving and emission reduction among enterprises. It is also of great practical significance in advancing the implementation of China's dual-carbon strategy.

2. Literature Review

2.1. Green Impact on Corporate Behavior Finance Policies

Most of the existing studies have found that green financial policies can have some impact on enterprise behavior. Specifically for each policy: the green credit policy promotes corporate green innovation, and its effect increases with the strengthening of regional environmental enforcement and intellectual property rights protection (Wang & Wang, 2021), while the policy promotes the level of corporate environmental social responsibility by increasing the cost of capital, narrowing the external channels of financing, and enhancing corporate environmental concerns (Si & Cao, 2022). In addition, the green bond policy forces the green transformation of brown enterprises by increasing the credit spreads of brown bonds (Chen et al., 2021), significantly improves the level of green innovation of issuers (Wang & Feng, 2022) and reduces the level of carbon emissions of enterprises (Yu et al., 2022); for the pilot zone of green financial reform and innovation, the policy can promote green innovation of enterprises through the percentage of long-term borrowing of enterprises and improve the debt structure of enterprises. For the green financial reform and innovation pilot zone, the policy can promote green innovation through the proportion of long-term corporate borrowing, improve corporate debt structure (Li & Liu, 2021), and motivate corporations to fulfill their environmental social responsibilities (Shen & Liao, 2020), while reducing pollution emissions through the downsizing of the production scale of heavily polluting corporations (Cui et al., 2023); in addition, the pilot policy for low-carbon cities

[1]According to the "2023 China Manufacturing Digital Transformation Research", 68% of enterprises believe that "lack of a clear digital transformation roadmap" is the main obstacle, and 55% of enterprises have postponed their transformation plans due to "insufficient capacity of the internal technical team". At the same time, the Ministry of Education's "Digital Economy Talent Demand Forecast Report (2023)" pointed out that China's digital technology talent gap of 11 million people, of which the shortage of artificial intelligence, big data analysis and other core areas accounted for more than 40%, which further exacerbated the difficulty of enterprise transformation.

can reduce carbon emissions by reducing the consumption of electricity by corporations and upgrading the level of technological innovation (Zhang, 2020), and the policy effect is more significant for state-owned enterprises and enterprises in heavily polluted areas (Chen et al., 2022; Dong et al., 2024); at the same time, the policy improves the level of green technological innovation by significantly increasing the scientific and technological talents of enterprises and alleviating the constraints of financing (Guo et al., 2023), and produces a significant spillover effect, which significantly stimulates the green innovation activities of enterprises in peer cities (Tian & Liu, 2021). Other studies have pointed out that environmental protection tax reform pushes large and medium-sized enterprises to innovate in green technology, but has no significant impact on small-sized enterprises (Wen & Zhong, 2020).

2.2. Factors Influencing the Digital Transformation of Enterprises

In terms of the factors affecting the digital transformation of enterprises, academics have conducted a large number of prospective studies, and have achieved relatively fruitful results. Specifically, Li & Liang (2020) pointed out that successful digital transformation should rely on a solid digital technology foundation, increase the financial investment in digital transformation, build a system for attracting and educating digital talents, and create a support platform for digital transformation. In addition, the digital transformation of enterprises also needs a policy system to support and guide (Zhang & Luan, 2022), and to play the role of the government (Han et al., 2021), Shi et al. (2021) pointed out that the government should accurately implement policies for enterprises in different regions and industries, guide enterprises to enhance their awareness of the transformation, and strengthen the construction of the data governance and regulatory system. Pei et al. (2023) also noted that Solidly promoting digital transformation requires the joint efforts of enterprises and the government, and the government should actively guide enterprises to increase their digital transformation efforts, build an incentive mechanism to drive the digital transformation of enterprises, accelerate the promotion of the construction of new infrastructures, and cultivate a digital talent team to provide all-round and multi-level protection for promoting the digital transformation of enterprises. In addition, Zheng & Jiang (2022) concluded through the questionnaire analysis that improving the efficiency of production services is the main driving force of enterprise digital transformation, and talent and cost are the prominent problems faced by digital transformation; at the same time, enterprise scale growth and digital transformation is a two-way coupling and interaction process, and the cooperation between the enterprise and scientific research institutions is essential to promote the integration of the digital economy. Finally, the awareness and culture of enterprise digital transformation are also very critical, and enterprises should cultivate a new culture of digital transformation, strengthen the consensus of digital transformation within the enterprise (Pei et al., 2023), and imbibe the concept of digital transformation and innovative development (Zhao & Ding, 2021).

In general, the current academic research on the impact of green finance policies on corporate behavior focuses on reducing corporate carbon emissions, promoting corporate green innovation and increasing total factor productivity. However, there is a relative lack of literature directly studying the impact of low-carbon city pilot policies on enterprise digital transformation. Only Zhao et al. (2023)'s study examines the impact of R&D expenditures on innovative technologies on enterprise digital transformation, but it lacks discussion on the role of green policies in promoting digital transformation among enterprises.

Therefore, the possible marginal contributions of this study are as follows: First, in the context of the "dual-carbon" goal, this study focuses on policies such as the pilot low-carbon city policy and its impact on enterprise digital transformation. This enriches research on the determinants of enterprise digital transformation. Secondly, we have developed a framework for the influence mechanism between low-carbon city pilot policies and enterprise digital transformation. This enriches research on the mechanisms linking these two areas. Third, based on the heterogeneity analysis of enterprise types, industries, and life cycles, it provides decision-making references for the government to differentiate the formulation of green financial policy tools and guide various types of subjects in participating in the digital low-carbon transformation. The rest of this paper is organized as follows: Section 3 is the theoretical analysis and research hypotheses, Section 4 is the research design and variable description, Section 5 is the empirical analysis and discussion, Section 6 is the expansive analysis, and Section 7 is the conclusion and policy recommendations.

3. Theoretical Analysis and Research Hypotheses

In terms of objectives, our study seeks to answer the following questions: First, does the low-carbon city pilot policy significantly contribute to the digital transformation of enterprises, and what is the marginal impact of the implementation of this policy on the digital transformation of enterprises? Second, in what ways do they influence firms' digital transformation? Is there a mediating and moderating role? Third, is there significant heterogeneity in the impacts of firms' digital transformation? To answer these questions, we need to construct a theoretical framework for understanding the impact of green, low-carbon city pilot policies on enterprise digital transformation.

3.1. Analysis of the Direct Effects of Pilot Low-Carbon City Policies on the Enterprises' Digital Transformation

As an important driving force for the country to achieve the "dual-carbon" goal, the pilot green low-carbon city policy promotes the green transformation of enterprises through multi-dimensional measures such as optimization of the energy structure, green financial support, and empowerment of digital technology under the dual-track mechanism of "policy incentive + market-driven", according to the resource base theory. According to the resource-based theory, the pilot low-carbon city policy reduces the cost of transformation through targeted support of green credit, financial subsidies, and other tools. At the same time, the construction of low-carbon cities leads to a better inflow of technological knowledge, higher levels of human capital (Wang et al., 2023b), and improved allocation efficiency of resources (Chen et al., 2024), while also easing the financing constraints of enterprises (Guo et al., 2023). This policy-driven resource replenishment mechanism enhances by alleviating resource constraints and the willingness of their enterprises to digitally transform and enhance digital transformation. In addition, according to signaling theory, the government's policy support for enterprises in the pilot region can send positive signals to investors, which helps attract more venture capital and improve the enterprises' digital technology innovation capability. Finally, from the perspective of institutional pressure mechanism, environmental regulation is likely to force enterprises to respond technologically. Zhao et al. (2023) argued that the pilot policy of low-carbon cities significantly increases the compliance cost of enterprises through carbon emission quota assessment, mandatory environmental information disclosure, etc. In response to the policy pressure, enterprises may accelerate measures such as production and technological change to turn the pressure into an opportunity for digital transformation that reduces carbon emissions for enterprises through digital transformation. Finally, Porter's hypothesis suggests that environmental regulations will increase the willingness of enterprises to innovate in green technology, generate relevant innovation performance to offset the environmental costs of enterprises, and promote technological innovation to realize the digital transformation of enterprises. The following hypothesis is proposed:

H1: Low-carbon city pilot policies contribute to the digital transformation of enterprises.

3.2. Mediating Effects of Financing Constraints

Because of the large up-front capital investment, long cycle, uncertainty of input and output, and technological uncertainty on the way to enterprise digital transformation, many enterprises have a weak willingness to digitally transform. Therefore, a certain amount of financial support must be supplemented to solve the path dependence and capital market imperfections and other market failures faced by enterprises on their way to digital transformation. As a kind of "soft constraint" environmental regulation policy, local governments often encourage enterprises to save energy and reduce emissions through incentives such as tax breaks and subsidies (Zhang et al., 2022). In addition, according to resource base theory, enterprises that receive government credit support or subsidies can effectively alleviate their own financing constraints (Guo et al., 2023; Xu & Cui, 2020), which reduces the cost of transformation, and thus increases the willingness of enterprises to digital transformation. This leads to the following hypothesis:

H2: Low-carbon city pilot policies facilitate digital transformation by easing corporate finance constraints.

3.3. Moderating Effects of Government Capacity

In order to promote the digital transformation of enterprises to achieve high-quality urban development, it is necessary for local governments to formulate appropriate laws and regulations according to local conditions. According to the theory of diffusion of innovation, as an authoritative organization, the government can accelerate the adoption of new technologies by enterprises through demonstration effects, incentives and policy guidance. For example, tax incentives, financial subsidies and other incentives can encourage digital transformation of enterprises. Secondly, governments with strong overarching and public service delivery capabilities can build and maintain high-quality information and communication technology (ICT) infrastructures, such as high-speed broadband networks and 5G base stations, which are the basic conditions for enterprises to carry out digital transformation (Wang & He, 2023). Additionally, according to the theory of regulation, a government with sound governance capacity and effective public service mechanisms can improve the quality of public services and the proportion of livelihood expenditures. This can lead to continuous optimization of the factor endowment structure and the development of a supportive environment for enterprises (Wang et al., 2023a). For example, the government can improve the digital technology level of the workforce through the reform of the education system to provide high-quality talent for the digital reform of enterprises. Additionally, a proactive government places greater emphasis on the construction of regulatory capacity, risk control, and the regulatory environment, thereby better protecting enterprises' digital patents (Wang et al., 2023a). Take Shenzhen, a city with top-ranked government capability, as an example. Its carbon market liquidity has ranked first nationwide for many consecutive years, with a cumulative trading volume of 65.7 million tons of carbon allowances and a total transaction value of 1.463 billion yuan, accounting for approximately 2.5% of the total allowance scale of the seven national carbon trading pilot programs. Shenzhen has actively responded to national policies by deeply integrating digital technologies with traditional industries. This integration has promoted the reduction of resource and energy consumption in traditional industries and enterprises, facilitated their transformation and upgrading, optimized industrial chain structures, and ultimately achieved the goal of energy conservation and emissions reduction. From this, we propose the following hypothesis:

H3: Government capacity can positively moderate the positive facilitation of digital transformation by piloting low-carbon city policies.

4. Research Design and Description of Variables

4.1. Sample Selection and Data Sources

This paper takes listed companies in China from 2000 to 2022 as the research object, and the data required for the empirical study from the Cathay Database (CSMAR), China Research Data Service Platform (CNEDS) and annual reports of listed companies. The following treatments are made with reference to established studies:

1) financial industries are excluded; 2) ST and *ST data are excluded; 3) samples with missing main variables are excluded; 4) all continuous variables are winsorized at the upper and lower 1% levels to handle outliers.

4.2. Variable Setting

4.2.1. Core Explanatory Variable: Low-Carbon City Pilot (DID)

The core explanatory variables in this paper are the three batches of low-carbon city pilots established by the National Development and Reform Commission. As there is a crossover of the cities that will be piloted in the first two batches, the year of implementation of the pilot city policy is determined with reference to Song et al. (2019).

4.2.2. Explained Variable: Digital Transformation (DT) of Enterprises

Generally speaking, the digital transformation of enterprises not only includes the application of digital technologies such as "artificial intelligence", "cloud computing", "big data", "blockchain" and so on, but also involves the production and operation mode and decision-making of enterprises, in order to promote the digitalization of enterprises to achieve higher quality and efficiency in the production process. At present, it is difficult to measure the digital transformation of enterprises, and there is no unified measurement index in the academic community. Drawing on the research of Wu et al. (2021), this paper uses Python crawler technology to collect and organize the annual reports of all A-share listed enterprises on the Shanghai Stock Exchange and Shenzhen Stock Exchange. It then analyzes the degree of transformation based on the word frequency of "enterprise digital transformation" in these reports[2]. Then, the Java PDFbox library is used to extract all the text content of these reports, so as to build up a data pool, which provides the basis for the subsequent feature word screening. Subsequently, using the thesaurus, text analysis was conducted to count the keyword frequency for each listed company. The data were classified to calculate the total word frequency, and logarithmic processing was applied to the results.

4.2.3. Control Variables

In order to improve the precision of the research in this paper, the factors that can influence the digital transformation of enterprises that have been confirmed by reference to existing studies are included in the control variables. These include: enterprise gearing ratio debt_asset_ratio (total liabilities/total assets) (Hu et al., 2023); Board size Boardsize (Huang et al., 2023); enterprise age (ln(current year − year of enterprise listing + 1)), enterprise size (ln(total assets of enterprise + 1)) (Wang & Wang, 2023); book-to-market ratio BM (total assets/market capitalization), Tobin's Q (market value of the firm/replacement cost of the firm's assets) (Wu et al., 2021). All variables are defined as shown in **Table 1**.

[2]Words related to digital transformation include artificial intelligence, business intelligence, image understanding, investment decision aid systems, intelligent data analytics, intelligent robotics, machine learning, deep learning, semantic search, biometrics, face recognition, voice recognition, identity verification, autonomous driving, natural language processing, big data, Data Mining, Text Mining, Data Visualization, etc.

Table 1. Definition of variables.

Typology	Name (of a thing)	Notation	Define
Explanatory variable	Enterprise Digital Transformation	DT	Logarithmization based on text and word frequency
Core explanatory variables	Low-carbon city pilot policy	DID	0 - 1 variable, 1 indicates that the company is in a pilot city after the policy is implemented
Control variable	Corporate gearing	debt_asset_ratio	Total liabilities/total assets
	Board size	Boardsize	Unit: persons
	Total assets of the enterprise	size	ln(total business assets + 1)
	Age of business	Age	ln(current year − year of listing of the enterprise + 1)
	Tobin's Q	Q	Market value of the company/Replacement cost of the company's assets
	Book-to-market ratio	BM	Total assets/market capitalization
Intermediary variable	Financing constraints	KZ	KZ index
Moderator variable	Government capacity	lngc	ln(total local fiscal expenditures for the year/gross domestic product for the year)

4.2.4. Mediating Variables (KZ)

Referring to Gao et al. (2021), the KZ index is selected to measure corporate financing constraints.[3]

4.2.5. Moderating Variable: Government Capacity (lngc)

Government capacity refers to the extent to which a government is actually able to perform its duties and functions, and it covers how the government carries out its tasks and the means by which it achieves these goals. It usually includes the following aspects: policy formulation and implementation capacity, social governance capacity, economic development promotion capacity, public service delivery capacity, and legal and regulatory arrangements. Referring to the idea of Hou et al. (2024), this paper adopts fiscal expenditure efficiency to measure government capacity, defined as the ratio of total local fiscal expenditure in the current year to gross domestic product in the same year, followed by logarithmic transformation.

4.3. Modeling and Preliminary Statistical Analysis

In this paper, we use panel data of listed companies in China from 2000 to 2022,

[3]The steps for calculating the KZ Index are as follows: collect each company's data on gearing, and Tobin's Q value.net cash flow from operations, cash dividends, cash holdings, Compare the ratio of these financial data to total assets at the beginning of the period, as well as the gearing ratio and Tobin's Q value, with the median of the same industry for the same year. Each financial ratio is assigned a value based on the comparison: if a ratio is below the industry median, it is labeled 1; if it is above or equal to it, it is labeled 0. The five assigned values are summed up to obtain the KZ index.

and conduct preliminary statistical analysis of the collected data before setting up the required econometric model, so as to provide the basis for the set econometric model. Table 2 demonstrates the descriptive statistics results of all variable series.

Table 2. Descriptive statistics of variables.

Variables	Sample size	Minimum value	Maximum values	Average value	(Statistics) Standard deviation	Upper quartile	Kurtosis	Skewness
DT	16167	0	6.38	1.83	1.49	1.61	0.44	2.28
DID	16167	0	1	0.75	0.44	1	−1.13	2.28
debt_asset_ratio	16167	0.01	8.75	0.31	0.217	0.2797	10.057	359.9
Boardsize	16167	0	17	8.03	1.457	9	0.023	4.04
size	16167	17.64	27.121	21.876	1.075	21.748	0.715	4.186
Age	16167	0	3.401	1.69	0.915	1.791	−0.29	2.286
Q	16167	0.024	121.48	2.79	3.103	2.005	10.7	275.1
BM	16167	0.008	1.38	0.561	0.225	0.562	0.094	2.553
lngc	16167	−13.91	−4.68	−6.49	1.09	−6.49	0.004	2.20
KZ	16167	−12.9	11.52	0.65	2.61	0.98	0.72	4.19

Source: Author's calculations.

According to the research needs, this paper constructs the following econometric model and digital transformation as the explanatory variable: low carbon city pilot policy as the core explanatory variable

$$DT_{i,t} = \beta_0 + \beta_1 DID_{i,t} + \sum_{i=1}^{6} n_i Controls_{i,t} + \mu_t + \epsilon_{it} \quad (1)$$

where the subscript i denotes firms, t is time, $DT_{i,t}$ denotes the degree of digital transformation of firm i during period t; $DID_{i,t}$ is a binary (0 - 1) variable that equals 1 if firm i is located in a pilot city after the implementation of the policy during period t; $Controls_{i,t}$ denotes a series of control variables; μ_i is an individual firm fixed effect; and ϵ_{it} is an exogenous perturbation term, which is assumed to be independently and homoscedastically distributed. According to the previous analysis, this paper expects β_1 to be positive to test hypothesis H1.

5. Empirical Analysis and Discussion

5.1. Baseline Regression

The examined direct impact is estimated first based on Model (1). The specific regression results are shown in Table 3. From the parameter estimation results, the following characteristics are observed:

Table 3. Impact of digital transformation of low-carbon city pilot policies on enterprises.

Variables	DT		
	(1)	(2)	(3)
DID	0.459***	0.131***	0.021
	(11.99)	(3.32)	(0.51)
Boardsize		0.021***	0.025***
		(2.66)	(3.21)
debt_asset_ratio		−0.126**	−0.138**
		(−2.20)	(−2.42)
Age		0.273***	0.158***
		(17.49)	(7.00)
BM		0.115**	−0.016
		(2.57)	(−0.30)
size		0.315***	0.246***
		(18.05)	(13.49)
Q		0.008**	0.003
		(2.36)	(0.77)
Constant	1.490***	−5.835***	−4.364***
	(51.32)	(−15.87)	(−11.38)
Hausman test	5.36**	409.61***	106.23***
R-squared	0.011	0.129	0.147
Observations	16,166	16,166	16,166
yearfix	NO	NO	YES
idfix	YES	YES	YES

Note: *** denotes that the hypothesis test is statistically significant at 99% confidence level, ** denotes that it is statistically significant at 95% confidence level; * denotes that it is statistically significant at 90% confidence level, and in parentheses are the t value. Source: Author's calculations.

First, for the core independent variable (DID), the coefficient is positive and remains significant both before and after adding the control variables, indicating that the implementation of the low-carbon city pilot policy has a positive promotion effect on the digital transformation of enterprises. After adding the control variables, the regression coefficient of DID is 0.131, indicating that the implementation of the policy will increase the degree of digital transformation of enterprises by 13.1% in the next year. This verifies that hypothesis H1 is valid.

Second, observing the coefficients of the control variables and their significance, we find that firm growth, total firm size, firm age, book-to-market ratio, and board size all significantly and positively contribute to firm digital transformation, while gearing significantly inhibits firm digital transformation.

Third, after adding the control variables, the model passed the Hausman test, indicating that the model was chosen correctly.

5.2. Robustness Tests

5.2.1. Parallel Trend Test

The double difference method requires that the control group and the treatment group satisfy the parallel trend assumption, and the results are shown in Figure 1. Before the implementation of the policy, the regression coefficient for the low-carbon city pilot (DID) was not significantly different from 0, indicating that there is no significant difference in the digital transformation of enterprises between the two groups. This satisfies the parallel trends assumption, and after the implementation of the policy, the coefficient (DID) is significantly different from 0 at the 5% significance level, indicating that the degree of digital transformation in the treatment group has risen significantly compared to the control group, indicating that the policy has a sustained promotional effect on the digital transformation of enterprises in low-carbon city pilots.

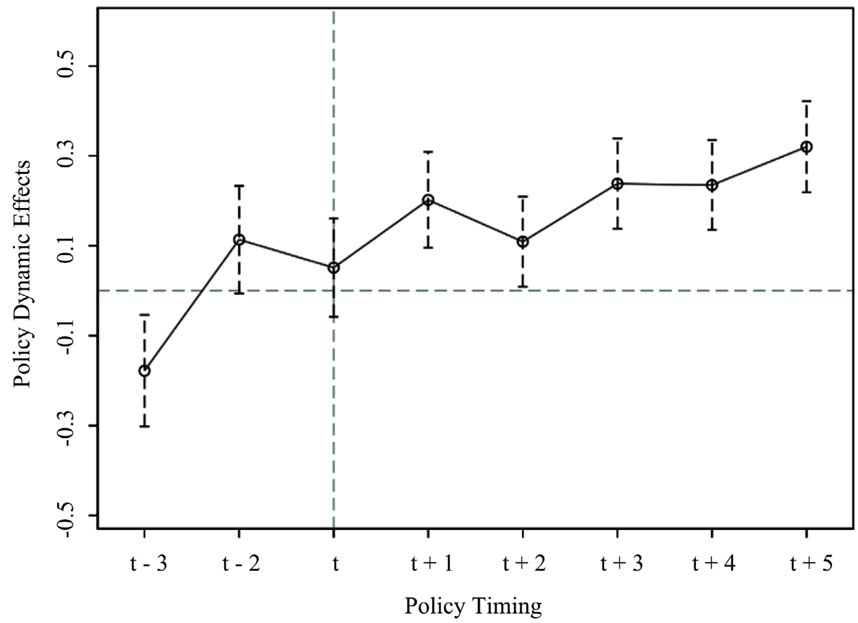

Figure 1. Parallel trend test.

5.2.2. Placebo Test

In order to exclude the influence of unobservable factors or omitted variables on the experimental results, and to ensure that the policy effect is not due to randomization, this paper conducts a placebo test. Random sample of the same proportion in the same year as the policy implementation is taken as the "pseudo" treatment group, while the remaining enterprises serve as the control group. The random regression is then repeated 500 times. The kernel density plot of the final estimated coefficients and their *p*-values for the low-carbon city pilot policy is shown in Figure 2. The results show that most of the estimated coefficients are clustered around zero and the vast majority of the *p*-values are above the $p = 0.1$ straight line, which suggests that the difference between the treatment and control groups is not significant in the placebo test, thus enhancing the robustness of the results.

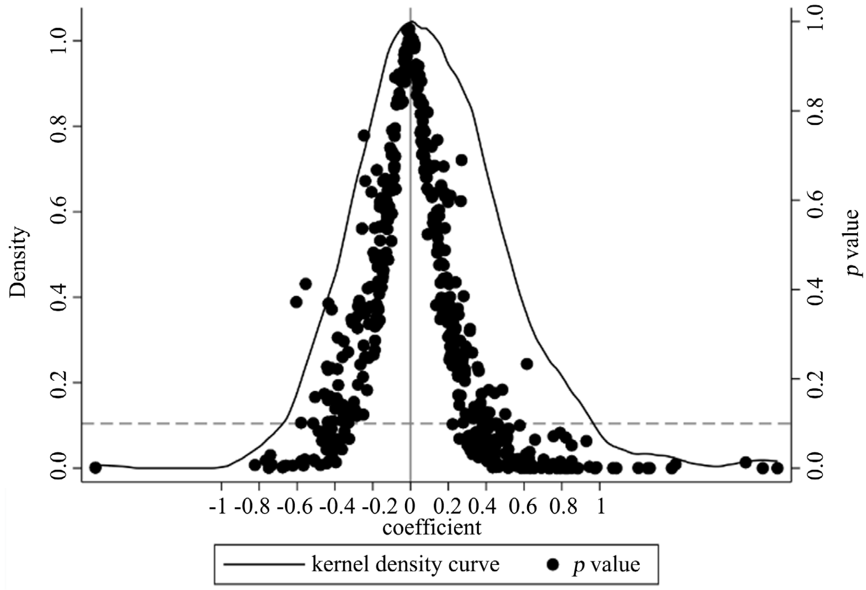

Figure 2. Placebo test.

5.2.3. Substitution of Explanatory Variables

In order to further demonstrate the robustness of the conclusion that the low-carbon city pilot policy promotes the digital transformation of enterprises, this paper replaces the explanatory variables with the help of the digitization index from the CSMAR database. The regression results are shown in Table 4 for the low-carbon city pilot policy. The results, shown in columns (1) and (2) of Table 4, indicate that the low-carbon city pilot policy significantly promotes enterprises' digital transformation at the 1% and 5% significance levels, both before and after adding the control variables.

Table 4. Robustness test of on digital transformation of enterprises low-carbon city pilot policies.

Variables	DT_index		DT
	(1)	(2)	(3)
DID	4.047***	1.804***	0.1067**
	(17.54)	(8.02)	(2.16)
Boardsize		0.037	0.0349***
		(0.82)	(3.27)
debt_asset_ratio		0.205	−0.1853**
		(0.63)	(−2.43)

Continued

Age		2.138***	0.2768***
		(23.98)	(13.28)
BM		−0.057	0.0396
		(−0.22)	(0.66)
size		2.099***	0.3419***
		(21.10)	(14.74)
Q		0.084***	0.0070
		(4.37)	(1.52)
Constant	34.508***	−13.376***	−6.4609***
	(197.21)	(−6.38)	(−13.25)
Observations	16,166	16,166	8416
R-squared	0.023	0.194	0.135
yearfix	NO	NO	NO
idfix	YES	YES	YES

Note: *** denotes that the hypothesis test is statistically significant at 99% confidence level, ** denotes that it is statistically significant at 95% confidence level; * denotes that it is statistically significant at 90% confidence level, and in parentheses are the t value. Source: Author's calculations.

5.2.4. Rule out Competing Hypotheses

During the sample period, a number of green policies and digital transformation policies were introduced concurrently. The impact of these policies may lead to bias in the regression coefficient of the low-carbon city pilot policy on corporate digital transformation, resulting in erroneous experimental outcomes. Therefore, considering that the smart city pilot policy may have a positive effect on corporate digital transformation and thus introduce bias into the experimental results, this paper eliminates the influence of this policy on the experiment. Specifically, we exclude city samples that were simultaneously affected by both the low-carbon city pilot policy and the smart city pilot policy after their implementation, retaining only the listed company samples influenced solely by the low-carbon city pilot policy. The regression results are shown in column (3) of **Table 4**. The results indicate that, at the 5% significance level, the coefficient of the DID (Difference-in-Differences) term is significantly positive, demonstrating that the low-carbon city pilot policy significantly promoted corporate digital transformation.

5.3. Endogenous Treatment

In the above section, we explored the impact of low-carbon city pilot policies on the digital transformation of enterprises. However, these policies may introduce modeling biases that create endogeneity problems, resulting in biased and inconsistent results when estimating the parameters of the baseline regression model.

In addition, although this paper controls a series of variables affecting the digital transformation of enterprises, there is still a possibility that some important explanatory variables may be omitted and thus lead to endogeneity problems. For this reason, this paper will add control variables and use the PSM-DID model for endogeneity.

5.3.1. Consider Omitted Variables

Asset turnover (Total Asset Turnover = Sales Revenue/Average Total Assets) is a core indicator of an enterprise's operational efficiency, reflecting the comprehensive ability of an enterprise to utilize its assets to generate revenue, and also directly affecting the enterprise's cash flow generation ability. Digital transformation requires enterprises to adjust their asset structure dynamically, and a higher asset turnover ratio means that they usually have more stable cash flow, better asset allocation capabilities, and process management efficiency. Therefore, asset turnover rate characterizes the agility of enterprise resource reallocation and provides a key financial guarantee for enterprise digital transformation. Referring to Bai et al. (2022), we add the control variable of asset turnover ratio, and the results of the estimated parameters are shown in column (2) of **Table 5**. The results show that the coefficient before DID is significantly positive at the 1% significance level, indicating that the low-carbon city pilot policy significantly facilitates enterprise digital transformation.

Table 5. Endogenous treatment of firms' digital transformation by piloting low-carbon city policies.

Variables	DT		
	(1)	(2)	(3)
DID	0.1308***	0.130***	0.0687***
	(3.32)	(3.29)	(3.77)
Boardsize	0.0213***	0.0211***	0.0096***
	(2.6646)	(2.63)	(2.60)
debt_asset_ratio	−0.1263**	−0.130**	−0.0561**
	(−2.2043)	(−2.27)	(−2.12)
Age	0.2734***	0.271***	0.1207***
	(17.4911)	(17.35)	(16.58)
BM	0.1152**	0.118***	0.0266
	(2.5687)	(2.63)	(1.28)
Size	0.3149***	0.318***	0.1172***
	(18.0546)	(18.22)	(14.52)
Q	0.0079**	0.00779**	0.0042***
	(2.3559)	(2.30)	(2.72)

Continued

asset_turnover_ratio		0.0670***	
		(2.85)	
green_cognition			0.0170***
			(3.12)
Constant	−5.8346***	−5.943***	−2.0388***
	(−15.8716)	(−16.09)	(−12.00)
Observations	14,323	14,323	14,323
R-squared	0.129	0.130	0.106
idfix		Yes	Yes
yearfix		NO	NO
Estimation method	PSM-DID	Adding control variables	Adding control variables

Note: *** denotes that the hypothesis test is statistically significant at 99% confidence level, ** denotes that it is statistically significant at 95% confidence level; * denotes that it is statistically significant at 90% confidence level, and in parentheses are the t value. Source: Author's calculations.

The green cognition of corporate executives also significantly influences the digital transformation of enterprises. Strategic cognition theory suggests that the subjective perceptions of senior management play a crucial role in shaping business operations and decision-making, with executives' perceptions and understanding of the external environment driving corporate behavior. Existing research has shown that, under the "dual carbon" goals, executives with strong green awareness tend to steer their companies toward greener and more sustainable development paths. Given that digital transformation inherently possesses characteristics of low carbon and environmental sustainability, firms led by executives with strong green cognition are more likely to adopt digital transformation as a means to achieve energy conservation and emission reduction goals. Following established practices, this paper measures executive green cognition based on corporate annual reports. Using text analysis methods, we select 19 keywords reflecting managerial attention to green issues across three dimensions: green competitive advantage cognition, corporate social responsibility cognition, and external environmental pressure perception. These keywords include terms such as energy conservation and emission reduction, environmental protection departments, environmental strategies, environmental inspections, environmental philosophies, low-carbon environmental protection, and environmental management institutions. Using Python software, we conducted keyword extraction, frequency analysis, and statistical processing from the sample firms' annual reports. The frequency of these keywords was used to calculate executive green cognition, which was then log-transformed for further analysis. By incorporating executive green cognition as a new control variable, the final regression results are shown in column (3) of Table 5. At the 1% significance level, the pilot policy for low-carbon cities significantly promoted enterprise digital transformation. Simultaneously, executive green cognition also significantly facilitated enterprise digital transformation at the 1% significance level.

5.3.2. Propensity Score Matching (PSM-DID)

Propensity score matching is a method used to reduce selection bias between treatment and control groups in observational studies. Its core idea is to simulate a randomized experimental environment and improve the credibility of causal inference by estimating the probability of each sample entering the treatment group and then matching individuals with similar characteristics in the treatment and control groups based on their scores. Since PSM-DID can mitigate the issue of biased coefficients of key explanatory variables caused by model specification errors to some extent, this paper adopts the PSM-DID method to reassess the coefficients of explanatory variables.

In order to verify the reliability of the matching results, this paper carries out the balance test. The final results are shown in Figure 3. They indicate that the standard errors of each variable in the control and treatment groups are significantly reduced, and the absolute value of the standard deviation is less than 5%. Therefore, the double-difference balance assumption is satisfied. The final results of the estimation of the parameters using PSM-DID are shown in column (1) of Table 5: at 1% significance level, the coefficient before DID is significantly positive and the coefficient is 0.1308, which indicates that the implementation of the pilot policy of low carbon cities will make the digital transformation of enterprises increase by 13.08%.

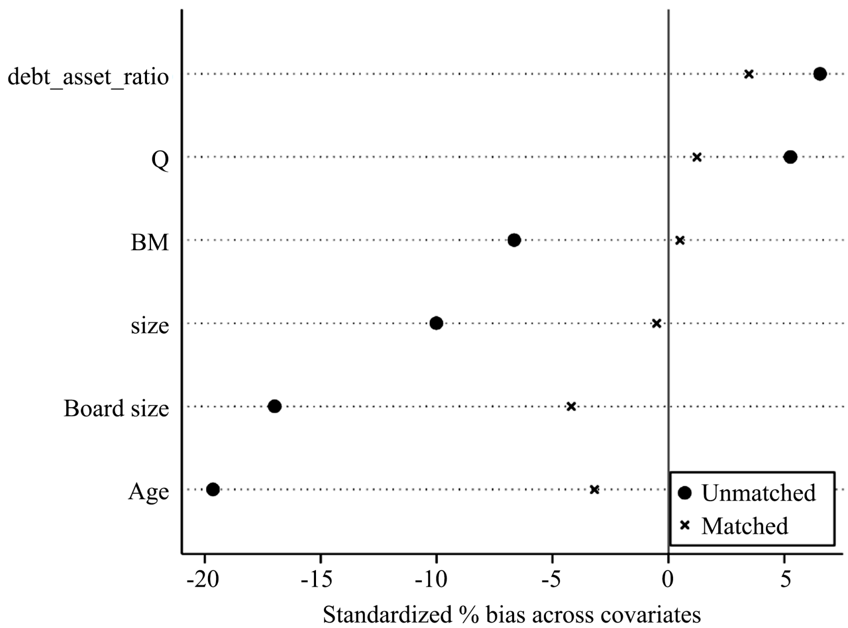

Figure 3. PSM-DID balance test.

6. Expanded Analysis

The above study has obtained empirical evidence that promotes digital transformation of enterprises. Based on the above theoretical analysis, in the positive promoting effect of the low-carbon city pilot policy on enterprise digital transformation, financing constraints play a mediating role, while government capacity plays a positive moderating role. This section will delve into the mechanism of action between low-carbon city pilot policies and enterprise digital transformation, and examine whether there is any heterogeneity in the effects between the two.

6.1. Analysis of Intermediary Mechanisms

In order to test the mediating role, this paper will use the improved two-step method proposed by Jiang (2022) and apply the following model (2) to test the mechanism:

$$KZ_{i.t} = \beta_0 + \beta_1 DID_{i.t} + \sum_i^{\circ} n_i Controls_{i.t} + \mu_i + \epsilon_{it} \quad (2)$$

where $KZ_{i.t}$ denotes the financing constraints, and the meanings of the other variables remain unchanged, where we expect β_1 to be positive to verify H2.

In Table 6, column (1) and column (2) report the mediating effect of financing constraints. From the results before and after adding control variables, at the 1% significance level, the coefficients before DID are significantly positive, suggesting that the pilot policy of low carbon cities significantly alleviates the financing constraints of firms, which is largely consistent with previous literature (Zhen, 2021; Zhang et al., 2022). Meanwhile, referring to previous literature, Xu et al. (2023) found that the higher the enterprise financing pressure, the more difficult the digital transformation. And Hua & Yu (2023) and Chen & Peng (2024) also found that easing corporate financing constraints can promote corporate digital transformation. Therefore, H2 holds.

Table 6. Analysis of mediating effects.

Variables	KZ	KZ	DT
	(1)	(2)	(3)
DID	1.0128***	0.5972***	0.131***
	(9.56)	(6.12)	(3.32)
Constant	−0.1023	−17.3789***	−5.835***
	(−1.27)	(−22.99)	(−15.87)
Controls	NO	YES	YES
yearfix	NO	NO	NO
idfix	YES	YES	YES
Observations	16,166	16,166	16,166
R-squared	0.007	0.194	0.129

Note: *** denotes that the hypothesis test is statistically significant at 99% confidence level, ** denotes that it is statistically significant at 95% confidence level; * denotes that it is statistically significant at 90% confidence level, and in parentheses are the t value. Source: Author's calculations.

6.2. Analysis of Regulatory Mechanisms

For further analysis, to test the moderating role played by government capacity, the paper constructs model (3) by further introducing an interaction term based on Equation (1):

$$DT_{i.t} = \beta_0 + \beta_1 DID_{i.t} + \beta_2 lngc_{i.t} + \beta_3 lngc_{i.t} \times DID_{i.t} + \sum n_i Controls_{i.t} + \mu_i + \epsilon_{it} \quad (3)$$

where $lngc_{i.t}$ denotes the level of government capacity in the region where the i-th firm is located during period t, and the meanings of the other variables remain unchanged. This paper expects $\beta 3$ to be positive in order to validate H3.

In Table 7, columns (1) and (2) of Table 7 report the moderating effect of government capacity. From the results, it can be seen that after adding control variables, at the 5% and 1% significance levels, the low-carbon city pilot policy still plays a significant role in promoting the digital transformation of enterprises. Additionally, the coefficients for the interaction term are significantly positive at the 5% significance level. This indicates that government capacity positively moderates the effect of the low-carbon city pilot policy on the digital transformation of enterprises. Therefore, H3 is supported.

Table 7. Analysis of moderating effects.

Variables	DT	
	(1)	(2)
DID	0.1258**	0.1527***
	(2.18)	(2.60)
lngc × DID	0.0163**	0.0203**
	(2.08)	(2.54)
lngc	0.0495***	0.0396***
	(6.61)	(5.20)
Boardsize		−0.0054***
		(−3.39)
debt_asset_ratio		0.0347***
		(2.69)
Age		0.0057**
		(2.07)
BM		−0.0149
		(−0.99)
size		−0.0212***
		(−7.96)
Q		0.0056***
		(4.02)

Continued

Constant	0.4509***	0.8639***
	(8.11)	(11.24)
yearfix	NO	NO
idfix	YES	YES
Observations	13,257	13,257
R-squared	0.072	0.082

Note: *** denotes that the hypothesis test is statistically significant at 99% confidence level, ** denotes that it is statistically significant at 95% confidence level; * denotes that it is statistically significant at 90% confidence level, and in parentheses are the t value. Source: Author's calculations.

6.3. Heterogeneity Analysis

6.3.1. Heterogeneity of Enterprise Life Cycles

It has been found that due to the difference in the life cycle of the enterprise, the goals set by the enterprise will also be different. Therefore, drawing on the division of the life cycle of enterprises by Huang et al. (2016), this paper divides the life cycle of enterprises into the growth period, maturity period, and decline period based on the cash flow of enterprises. From **Table 8**, the pre-DID coefficients for firms in the growth and maturity periods are positive and significant at the 1% level, while those for firms in the decline period are not significant at the 10% level. This suggests that there is heterogeneity in the impact of the life cycle on the digital transformation of firms. The Low Carbon City Pilot policy more significantly promotes the digital transformation of growing and mature firms. This may be explained by the fact that firms in the growth stage have market expansion and competitiveness improvement as their core objectives, while mature firms seek to extend their life cycle through innovation. Both tend to adopt digital transformation to capture efficiency gains or new growth points. For declining companies, on the other hand, the strategic focus is usually on short-term survival, and management may be more concerned with immediate financial returns than long-term investments. The longer payoff cycle of digital transformation does not match the strategic priorities of declining firms. In addition, the p-value of Fisher's within-group difference test is 0.1, indicating that at the 10% significance level, the difference in the life cycle of the firms leads to significant heterogeneity in the effect of the digital transformation of the pilot low-carbon city policy on the firms.

Table 8. Life cycle heterogeneity.

Variables	DT		
	Growing	Maturity	Recession
DID	0.223***	0.111*	0.117
	(3.48)	(1.76)	(0.43)

Continued

Constant	0.639***	0.629***	0.154
	(5.26)	(5.02)	(0.31)
Controls	YES	YES	YES
yearfix	NO	NO	NO
idfix	YES	YES	YES
Group	Not Recession		Recession
Fisher test (p)		0.1	
Observations	6807	6538	591
R-squared	0.120	0.091	0.079

Note: *** denotes that the hypothesis test is statistically significant at 99% confidence level, ** denotes that it is statistically significant at 95% confidence level; * denotes that it is statistically significant at 90% confidence level, and in parentheses are the t value. Source: Author's calculations.

From the discovery, we advise that: First, Improve the Enterprise Lifecycle Identification Mechanism. It is recommended that a dynamic evaluation system be built that enables the precise identification of enterprises in the decline phase through regular diagnostics, providing data support for targeted policy interventions. Second, a Categorized Governance Incentive Scheme for Digital Transformation should be implemented. For growth and mature-phase enterprises, strengthen market incentive mechanisms. For example, incorporate the application of digital technologies into the carbon emission trading accounting system, allowing enterprises to exchange additional quotas based on their digital decarbonization achievements. However, for enterprises in the decline phase: adopt a step-by-step intervention strategy of "feasibility assessment—resource restructuring—targeted support," focusing on supporting the digital transformation of production processes rather than disruptive innovation, to avoid resource misallocation.

6.3.2. Heterogeneity of Industries in Which Operate Firms

In addition, the difference in the industries in which the enterprises are located further affects the effect of the low-carbon city pilot policy on the digital transformation of enterprises. From the regression results in **Table 9**, the pre-DID coefficients of enterprises located in non-heavily polluted industries are positive and significant at the 1% significance level, while the pre-DID coefficients of enterprises located in heavily polluted industries are not significant. This suggests that there is heterogeneity in the impact of the industry on the digital transformation of firms. The low-carbon city pilot policy more significantly promotes the digital transformation of firms located in non-heavily polluting industries. This may be explained by the fact that firms in heavily polluted industries have highly solidified production equipment and processes, and digital transformation requires disruptive reconfiguration of production lines, involving more serious technical difficulties and sunk costs. At the same time, heavy-polluting industries face stricter environmental regulations and need to prioritize resources to meet compliance requirements, crowding out the financial and technological resources needed for digital transformation. In addition, heavily polluting industries face greater financing constraints due to their high environmental risks, making it more difficult for them to obtain green credits and bonds. The above factors together lead to a low willingness to digitally transform companies in heavily polluting industries. In addition, the p-value of Fisher's within-group difference test is 0.08, indicating that at the 10% significance level, the differences in the industries where the enterprises are located lead to significant heterogeneity in the effects of the digital transformation promoted by the low-carbon city pilot policy on the enterprises.

Table 9. Heterogeneity of industries in which firms operate.

Variables	DT	
	NO	YES
DID	0.183***	0.0269
	(3.97)	(0.32)
Constant	−5.855***	−5.538***
	(−13.53)	(−6.60)
Controls	YES	YES
yearfix	NO	NO
idfix	YES	YES
Fisher test (p)	0.08	
Observations	10,608	2604
R-squared	0.137	0.105

Note: *** denotes that the hypothesis test is statistically significant at 99% confidence level, ** denotes that it is statistically significant at 95% confidence level; * denotes that it is statistically significant at 90% confidence level, and in parentheses are the t value. Source: Author's calculations.

Based on this, the following policy recommendations and solutions are proposed: Firstly, targeted support measures should be implemented for heavy-polluting industries, such as providing special funds and subsidies to encourage the adoption of environmentally friendly technologies and digital solutions, while strengthening employees' digital skills training to enhance their technical application capabilities. Secondly, stricter yet flexible environmental standards and incentive mechanisms, such as tax incentives and green certification rewards, should be tailored for these industries to reduce their transformation costs and improve market competitiveness. Additionally, cooperation platforms involving the government, enterprises, and research institutions should be established to promote technology sharing and innovation, especially in developing digital transformation solutions applicable to heavy-polluting industries, thereby accelerating the application of advanced technologies. Finally, the development of green financial tools, such as green bonds and carbon trading markets, should be promoted, along with supporting the implementation of pilot projects and the widespread dissemination of successful cases to stimulate broader participation.

6.3.3. Heterogeneity of Enterprise Types

Finally, from the perspective of enterprise type, it is also possible that differences in enterprise type may affect the effectiveness of the low-carbon city pilot policy on the digital transformation of enterprises. From the regression results in Table 10, the pre-DID coefficients of technology-intensive enterprises are positive and significant at the 1% significance level, while the pre-DID coefficients of enterprises located in labor-intensive and capital-intensive types are not significant. This suggests that there is heterogeneity in the impact of firm type on the digital transformation of firms, and that the Low Carbon City Pilot Policy more significantly promotes the digital transformation of technology-intensive firms. This may be explained by the fact that technology-intensive firms usually already have a high level of technology and continue to invest in R&D activities, have a strong innovation capacity, and have less difficulty and stronger willingness to digitally transform. In contrast, since labor-intensive firms mainly rely on a large amount of labor rather than advanced technology for production, the main challenges faced by such firms in implementing digital transformation include the lack of necessary technical support and sufficient capital investment. At the same time, capital-intensive enterprises have a large number of fixed assets, and the cost of adapting the use of such equipment once it is in place is high. Although low-carbon city pilot policies encourage energy efficiency and carbon emission reduction, capital-intensive firms may find it difficult to quickly change their existing production model to take full advantage of the benefits of these policies, resulting in a low willingness to digitally transform. In addition, the p-value of Fisher's within-group difference test is 0.02, indicating that differences in firm types lead to significant heterogeneity in the effect of the low-carbon city pilot policies on the digital transformation of firms at the 5% significance level.

Table 10. Heterogeneity of firm types.

Variables	DT		
	Labor	Capital	Technology
DID	−0.00420	0.122	0.273***
	(−0.06)	(1.13)	(4.59)
Constant	−5.057***	−5.557***	−5.938***
	(−6.01)	(−4.87)	(−10.50)
Controls	YES	YES	YES
yearfix	NO	NO	NO

Continued

idfix	YES	YES	YES
Group	Not Technology		Technology
Fisher test (p)		0.02	
Observations	3177	1799	7120
R-squared	0.080	0.071	0.163

Note: *** denotes that the hypothesis test is statistically significant at 99% confidence level, ** denotes that it is statistically significant at 95% confidence level; * denotes that it is statistically significant at 90% confidence level, and in parentheses are the t value. Source: Author's calculations.

Based on this, we suggest that: First, customized support programs should be provided for labor-intensive and capital-intensive enterprises. For instance, special funds or subsidies can be established to specifically support these enterprises in their investments in energy conservation, emissions reduction, and automation upgrades, thereby reducing the costs of their digital transformation. At the same time, efforts should be made to encourage the development of digital tools and technical solutions tailored to these enterprises, enhancing production efficiency and environmental friendliness. Second, education and training should be strengthened, with a particular focus on improving employees' digital skills and environmental awareness. By organizing training sessions, workshops, and other activities, necessary knowledge and skills can be imparted to employees, helping them adapt to the changes brought about by digital transformation. This is especially crucial for labor-intensive industries. Thirdly, cross-industry collaboration platforms should be established to promote exchanges and cooperation between technology-intensive enterprises and other types of businesses. Such collaboration can not only accelerate the application and diffusion of advanced technologies but also help labor-intensive and capital-intensive enterprises better understand how to leverage digital technologies to achieve their transformation goals.

7. Conclusions and Policy Recommendations

Along with the accelerated pace of building a modernized and beautiful socialist country, China is paying more and more attention to the protection and governance of the environment. Under the background of the "dual carbon" policy, many green policies have been put forward one after another, among which the pilot policy of low-carbon cities requires cities to realize high-quality development through green and low-carbon transformation, while enterprises, as the micro-body of the national economy, can effectively reduce carbon emissions, optimize the industrial structure, and significantly improve the characteristics of social production efficiency coincide with this goal. The characteristics of enterprise digital transformation coincide with this goal because it can effectively reduce carbon emissions, optimize industrial structure, and significantly improve social production efficiency. In this context, unlike general research, this paper innovatively studies the relationship between the pilot low-carbon city policy and the digital transformation of enterprises, and meticulously explores the mechanism and effect of promoting the digital transformation of enterprises, and summarizes the conclusions of the study as follows the policy.

First, pilot policies in low-carbon cities can significantly improve the digital transformation of firms. This conclusion still holds after a series of robustness tests such as replacing the explanatory variables, parallel trend test, placebo test, and endogeneity treatments such as adding control variables for omitted variables and adopting propensity to match score (PSM-DID).

Second, mechanistic studies have shown that pilot low-carbon city policies can alleviate corporate financing constraints and thus facilitate digital transformation, while government capacity plays a positive moderating role between the two.

Thirdly, the heterogeneity study shows that the promotion effect of the low-carbon city pilot policy on the digital transformation of enterprises varies by enterprise type, with the promotion effect being more significant among technology-intensive enterprises. Meanwhile, from the technology-intensive perspective of the industry in which the enterprises are located, the positive promotion effect of digital transformation is more significant. The pilot low-carbon city policy on the enterprises located in non-heavily poll industries is located in heavily polluted enterprises. In addition, from the perspective of the different life cycles of enterprises, the low-carbon city pilot policy has a more significant positive effect on the digital transformation of enterprises in growing and mature enterprises.

Based on the above empirical findings, this paper draws several insights as follows:

First, it is recommended that the coverage of the policy be expanded on the basis of the existing pilot projects, and that a "gradient + differentiation" promotion mechanism be established to avoid the mismatch of resources caused by the "one-size-fits-all" policy. In view of the heterogeneous characteristics identified in the study, priority should be given to expanding the policy to technology-intensive industrial agglomerations and regions with a concentration of non-heavily polluting industries, and at the same time establishing digital transformation demonstration zones in mature industrial parks.

Second, improving financing channels. For all types of enterprises, especially those facing financial bottlenecks in the process of digital transformation, the Government should introduce more targeted financial policies, such as setting up special funds and lowering the threshold for loans, to alleviate the problem of corporate financing constraints. At the same time, it should strengthen cooperation among financial institutions, encourage banks and other financial institutions to provide more flexible financing solutions for low-carbon projects, and strengthen the evaluation capacity of these projects to ensure the effective use of funds.

Thirdly, the role of the government should be played. As an authority, the government can, through demonstration effects, incentive mechanisms and policy guidance, create a favorable environment for the digital transformation of enterprises. At the same time, optimize the proportion of livelihood expenditures to improve the quality of public services and continue to optimize the structure of factor endowments and the development of the soft environment so as to provide enterprises with a good external environment. For example, the education system should be reformed to improve the digital technology level of the workforce construction and the maintenance of the necessary ICT infrastructure for the digital transformation of enterprises.

It is worth mentioning that although this paper reveals in depth the intrinsic relationship between low-carbon policies and enterprise digital transformation, there are still some limitations that deserve further in-depth research in the future. First, this paper uses a static panel for estimation and lacks the ability to capture the low-carbon city pilot policies' ability to have long-term dynamic impacts on enterprise digital transformation. More in-depth research in the future can start from a low-carbon city pilot policies perspective. In addition, although this paper derives the long-term dynamic impacts of low-carbon city pilot policies on enterprise digital transformation, two financing constraints and government capacity key mediating and regulating mechanisms, more mechanisms of the s effect on the digital transformation of enterprises on the way still need to be explored, such as green technological innovation and low-carbon city pilot policy "executives" green perceptions. Finally, this paper only explores the impact of low-carbon city pilot policies on enterprise digital transformation, and more in-depth research can be conducted on other related green policies in the future.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

References

Bai, F., Liu, D., & Dong, K. (2022). How Digital Transformation Affects Corporate Financial Performance—An Analysis of Multiple Mediation Effects Based on Structural Equations. *East China Economic Management, 36,* 75-87.

Chen, G., Ding, S., & Zhao, X. (2021). China's Green Financial Policies, Financing Costs and Green Transformation of Enterprises—Based on the Perspective of Central Bank's Collateral Policy. *Financial Research, No. 12,* 75-95.

Chen, S., Mao, H., & Sun, J. (2022). Low-Carbon City Construction and Corporate Carbon Reduction Performance: Evidence from a Quasi-Natural Experiment in China. *Journal of Business Ethics, 180,* 125-143. https://doi.org/10.1007/s10551-021-04886-1

Chen, X., Huang, Y., & Gao, Y. (2024). Can Urban Low-Carbon Transitions Promote Enterprise Digital Transformation? *Finance Research Letters, 59,* Article ID: 104807. https://doi.org/10.1016/j.frl.2023.104807

Chen, Y., & Peng, C. (2024). Confucianism and Corporate Digital Transformation: Evidence from China. *International Journal of Emerging Markets.* https://doi.org/10.1108/IJOEM-11-2023-1810

Cui, H., Wang, B., & Xu, Y. (2023). Green Financial Innovation, Financial Resource Allocation and Corporate Pollution Reduction. *China Industrial Economy, No. 10,* 118-136.

Dong, Y., Sun, Z., Li, W. et al. (2024). How the Low-Carbon City Pilot Policy Reduces

Enterprise Carbon Emissions and Paves the Way for High-Quality Development: Evidence from a Quasi-Natural Experiment in China. *Environment, Development and Sustainability.* https://doi.org/10.1007/s10668-024-05724-w

Gao, J., Chu, D., & Lian, Y. (2021). Can ESG Performance Improve Corporate Investment Efficiency? *Securities Market Herald, No. 11,* 24-34, 72.

Guo, F., Yang, S., & Cha, I. (2023). Can Low-Carbon City Building Enhance Urban Green Technology Innovation?—Evidence from a Quasi-Natural Experiment. *Soft Science, 37,* 40-49.

Han, L., Chen, S., & Liang, L. (2021). Digital Economy, Innovation Environment and Urban Innovation Capability. *Research Management, 42,* 35-45.

Hou, Z., & Yu, J. (2024). Smart City, Government Governance Capacity and Fiscal Expenditure Efficiency. *Journal of Chengdu University (Social Science Edition), No. 5,* 45-57.

Hu, J., Yu, X., & Han, Y. (2023). Can ESG Ratings Promote Corporate Green Transformation?—Validation Based on Multi-Temporal Double Difference Method. *Research on Quantitative and Technical Economics, 40,* 90-111.

Hua, Z., & Yu, Y. (2023). Digital Transformation and the Impact of Local Tournament Incentives: Evidence from Publicly Listed Companies in China. *Finance Research Letters, 57,* Article ID: 104204. https://doi.org/10.1016/j.frl.2023.104204

Huang, B., Li, H., & Liu, J. (2023). Digital Technology Innovation and High-Quality Development of Chinese Firms—Evidence from Firms' Digital Patents. *Economic Research, 58,* 97-115.

Huang, H., Zhai, S., & Chen, J. (2016). Corporate Life Cycle, Financing Methods and Financing Constraints—A Study Based on the Moderating Effect of Investor Sentiment. *Beijing: Financial Research, No. 7,* 96-112.

Jiang, T. (2022). Mediating and Moderating Effects in Empirical Studies of Causal Inference. *China Industrial Economy, No. 5,* 100-120.

Li, H., & Liang, D. (2020). Mechanism, Path and Countermeasures of Enterprise Digital Transformation. *Guizhou Social Science, No. 10,* 120-125.

Li, R., & Liu, L. (2021). Green Finance and Corporate Green Innovation. *Journal of Wuhan University (Philosophy and Social Science Edition), 74,* 126-140.

Pei, X., Liu, Y., & Wang, J. (2023). Enterprise Digital Transformation: Drivers, Economic Effects and Strategy Choices. *Reform, No. 5,* 124-137.

Shen, L., & Liao, X. (2020). Green Finance Reform and Innovation and Corporate Social Responsibility—Evidence from Green Finance Reform and Innovation Pilot Zones. *Financial Forum, 25,* 69-80.

Shi, Y., Wang, Y., & Zhang, W. (2021). Digital Transformation of Chinese Enterprises: Current Situation, Problems and Prospects. *Economist, No. 12,* 90-97.

Si, L., & Cao, H. (2022). Can Green Credit Policy Improve Corporate Environmental Social Responsibility-Based on the Perspectives of External Constraints and Internal Concerns. *China Industrial Economy, No. 4,* 137-155.

Song, H., Sun, Y., & Chen, D. (2019). Evaluation of the Effect of Governmental Air Pollution Control—An Empirical Study from the Construction of "Low-Carbon Cities" in China. *Management World, 35,* 95-108, 195.

Tian, L., & Liu, C. (2021). "Peer" Institutional Pressure and Corporate Green Innovation: Spillover Effects of Environmental Pilot Policies. *Economic Management, 43,* 156-172.

Wang, G., Li, X., & Yang, T. (2023a). Fiscal Balance Restructuring and Digital Transformation of Enterprises: "Spring Rain" or "Counterproductive"? *Economic and Management Research, 44,* 3-24.

Wang, H., & He, H. (2023). The Impact of Fiscal Expenditure on the Digital Transformation and Upgrading of China's Manufacturing Industry—Based on Panel Data of 31 Regions from 2007 to 2021. *Industrial Technology and Economics, 42,* 13-21.

Wang, W., Wang, X., & Jiang, H. (2023b). Can Low-Carbon City Construction Accelerate the Knowledge Flow of Low-Carbon Technologies? *Science Research, 41,* 2204-2215.

Wang, X., & Wang, Y. (2021). Research on Green Credit Policy to Enhance Green Innovation. *Management World, 37,* 173-188, 11.

Wang, Y., & Feng, J. (2022). Research on Green Bonds to Promote Enterprises' Green Innovation. *Financial Research, No. 6,* 171-188.

Wang, Y., & Wang, Y. (2023). Corporate ESG Performance, Risk Taking and Green Technology Innovation. *Friends of Accounting, No. 10,* 94-102.

Wen, H., & Zhong, Q. (2020). Can Environmental Protection Tax Reform Pry Enterprises' Green Technology Innovation—Insights from the Change of China's Sewage Charge Collection Standard. *Journal of Guizhou University of Finance and Economics, No. 3,* 91-100.

Wu, F., Hu, H., & Lin, H. (2021). Corporate Digital Transformation and Capital Market Performance-Empirical Evidence from Stock Liquidity. *Management World, 37,* 130-144, 10.

Xu, G., Li, G., & Sun, P. (2023). Inefficient Investment and Digital Transformation: What Is the Role of Financing Constraints? *Finance Research Letters, 51,* Article ID: 103429. https://doi.org/10.1016/j.frl.2022.103429

Xu, J., & Cui, J. (2020). Low-Carbon City and Enterprise Green Technology Innovation. *China Industrial Economy, No. 12,* 178-196.

Yu, Z., Peng, Z., & Li, P. (2022). Research on the Impact of Green Finance Development on Regional Carbon Emission—Taking Green Credit, Green Industry Investment and Green Bond as Examples. *Financial Theory and Practice, No. 2,* 69-77.

Zhang, H. (2020). Can Pilot Low-Carbon City Policies Reduce Carbon Emissions?—Evidence from a Quasi-Natural Experiment. *Economic Management, 42,* 25-41.

Zhang, Y., & Luan, J. (2022). Digital Economy Enabling Rural Revitalization: Theoretical Mechanisms, Constraints and Promotion Paths. *Reform, No. 5,* 79-89.

Zhang, Z., Sun, Z., & Lu, H. (2022). Has the Low-Carbon City Pilot Realized the "Increase in Quantity and Quality" of Enterprise Green Technology Innovation? *Journal of Yunnan University of Finance and Economics, 38,* 85-98.

Zhao, D., & Ding, Y. (2021). Mechanisms, Paths and Countermeasures of Digitalization to Promote Rural Revitalization. *Journal of Hunan University of Science and Technology (Social Science Edition), 24,* 112-120.

Zhao, S., Zhang, L., & An, H. (2023). Has China's Low-Carbon Strategy Pushed forward the Digital Transformation of Manufacturing Enterprises? Evidence from the Low-Carbon City Pilot Policy. *Environmental Impact Assessment Review, 102,* Article ID: 107184. https://doi.org/10.1016/j.eiar.2023.107184

Zhen, Z. C. (2021). Did the National Low Carbon Strategy Increase the Total Factor Productivity of Enterprises?—A Quasi-Natural Experiment Based on Low-Carbon City Pilots. *Industrial Economics Research, No. 6,* 101-115.

Zheng, Q., & Jiang, W. (2022). Research on Digital Transformation of Manufacturing Enterprises under the Perspective of Digital Economy—An Empirical Analysis Based on Enterprise Questionnaire Survey. *Jiangsu Social Science, No. 1,* 137-149, 244.