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Carbon Trading and Digital Transformation of Enterprise

-- Quasi-natural Experimental Evidence from Carbon Trading Pilot

Songwei Wang, Xiujuan Zheng

Anhui University of Finance and Economics, Bengbu 233030, China

Abstract

Under the background of "double carbon" and the era of digital economy, it is of great significance to study whether carbon emission trading can promote the digital transformation of enterprises. According to "Porter Hypothesis", proper environmental regulation can promote enterprises to increase investment in technology research and development, and the improvement of enterprise's technology level will help to realize transformation and upgrading. However, whether the carbon emission trading mechanism can trigger the "Potter effect" and realize the digital transformation of enterprises is still lacking in experience and evidence. Therefore, with the help of the quasi-natural experiment of carbon emissions trading pilot, based on the panel data of A-share listed companies from 2008 to 2020, this paper evaluates the impact, mechanism and heterogeneity of carbon emissions trading on the digital transformation of enterprises through double difference method. The findings are as follows: First, carbon emission trading has promoted the digital transformation of enterprises in pilot provinces and cities. Second, the accumulation of technological capital of enterprises plays an intermediary role. As a market-driven environmental regulation, carbon emission trading can promote the digital transformation of enterprises by forcing enterprises to increase investment in technology research and development. Third, compared with enterprises in coastal and eastern regions, carbon emissions trading has a greater role in promoting the digital transformation of enterprises in inland and central regions, and carbon emissions trading can promote the digital transformation of small-scale enterprises, but it has no impact on the digital transformation of large-scale enterprises. Further analysis shows that the financing constraints of enterprises play a regulatory role, and high financing constraints inhibit the promotion of carbon emission trading to the digital transformation of enterprises.

Keywords

Carbon Emission Trading; Digital Transformation; Technological Innovation; High-quality Development.

1. Introduction

China's economy has long relied on the development mode of over-investment and high pollution. How to achieve low-carbon environmental protection and high-quality economic development is a big problem. In terms of environmental protection, China government has already explored the governance of carbon emissions, and gradually established a market-oriented environmental regulation-carbon emissions trading system. China's carbon emission trading system can be divided into three stages: in the embryonic stage from 2002 to 2010, it participated in CDM projects and sold emission reductions to developed countries. In the pilot stage from 2011 to 2020, in 2011, the National Development and Reform Commission issued

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the Notice on Launching the Pilot Work of Carbon Emission Trading, and identified seven pilot provinces and cities such as Shenzhen, Shanghai and Hubei, and the carbon emission trading market was officially launched. In 2016, Fujian Province was identified as a pilot province for carbon emission trading. After 2017, China's carbon emissions trading entered a growth stage, and the issuance of the National Carbon Emissions Trading Market Construction Plan (Power Generation Industry) marked the start of the national carbon trading system. In order to effectively cope with global warming, alleviate the environmental deterioration in China and realize the transformation of economic development mode, President Xi Jinping made a solemn commitment to the world at the United Nations General Assembly in 2020 to "achieve peak carbon dioxide emissions by 2030 and carbon neutrality by 2060". Subsequently, the Tenth Five-Year Plan clearly pointed out that the carbon emission trading mechanism should be improved as an important means to achieve the goal of "double carbon".

According to the White Paper on the Development of Digital Economy in China, the overall scale of digital economy in China will reach 39.2 trillion yuan in 2020, and the growth rate far exceeds the GDP growth rate. With the continuous progress of a series of digital technologies such as artificial intelligence, blockchain, cloud computing and big data, under the goal of "double carbon", emerging digital technologies are gradually integrated with green and low-carbon production. For high-carbon emission industries, digital information technologies such as Internet of Things, cloud computing and distributed management can be applied to production, transportation, trading and other aspects, reducing carbon emissions in production and operation stages, and also facilitating the tracing and positioning of carbon footprint. In addition, by integrating digital networks to build smart grid, the carbon footprint can be further reduced, thus achieving the effect of carbon emission reduction[1]. Obviously, the development of digital economy plays a key role in China's goal of "double carbon"[2]. Therefore, the digital economy is an important support for China's economic development and the main direction of high-quality economic transformation. Enterprises are the main body of the economy and society. To achieve low-carbon and high-quality economic development, we must guide enterprises to change from the original extensive development mode with high pollution and low efficiency to the direction of technology and efficiency. Under the background of the global rise of digital economy, enterprises should seize the development opportunity of the digital age and carry out digital transformation to realize a sustainable business development model. Enterprise transformation is not easy, so under the background of "double carbon" and digital economy, how to promote the digital transformation of enterprises and take the development path of technological progress and low carbon and environmental protection is an important topic that needs to be discussed and studied urgently, which is of great significance to the high-quality development of China economy.

According to "Porter Hypothesis", proper environmental regulation can promote enterprises to increase investment in technology research and development, and the improvement of enterprise's technology level will help to realize transformation and upgrading[3]. Under the background of "double carbon", as a market-oriented environmental regulation, the carbon emission trading mechanism is an important driving force to realize enterprise transformation and upgrading and high-quality economic development. However, there are few studies on the impact of carbon trading on enterprise transformation. Liu et al(2020) measures enterprise transformation by total factor productivity, and the study finds that carbon emission trading can promote enterprise transformation and upgrading[4]. In addition, carbon trading also has a significant impact on the green innovation of enterprises and promotes the green upgrading of enterprises[5]. Although the above scholars confirmed that carbon emissions trading can promote the transformation and upgrading of enterprises, they failed to discuss the impact of carbon emissions trading on the digital transformation of enterprises in combination with the trend of the digital economy. As a market-oriented environmental regulation, carbon emission

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trading can trigger the "Potter effect" and promote the digital transformation of enterprises, but there is still a lack of experience and evidence. In view of this, this paper intends to study whether carbon emission trading can help promote the digital transformation of enterprises under the background of "double carbon". If carbon emission trading promotes the digital transformation of enterprises, what is the mechanism? Is the policy effect heterogeneous? This paper will study and discuss these problems.

The marginal contributions of this paper are as follows: firstly, the current research on carbon emission trading is mostly focused on the macro level. This paper takes micro-enterprises as the research subject and the digital transformation of enterprises as the breakthrough point, which broadens the research horizon. Secondly, this paper combines the environmental regulation policy with the digital transformation of enterprises, and studies the influence, mechanism and heterogeneity of carbon emission trading on the digital transformation of enterprises by using the double difference method, which enriches the relevant theoretical research of environmental regulation and digital economy to some extent. Finally, the conclusion of this paper provides experience reference for the improvement of carbon emissions trading and the transformation and upgrading of enterprises, and provides new explanations and evidence for the high-quality economic development.

2. Theoretical Analysis and Research Hypothesis

In the era of digital economy, digital information technology will be organically combined with enterprise production to promote low-carbon and efficient production of enterprises, and digitalization has gradually become the transformation direction of enterprises: big data and cloud computing technology can monitor and analyze all aspects of energy production, optimize energy supply efficiency, thus reducing production costs and ecological damage; In the industrial field, artificial intelligence technology can realize green intelligent manufacturing and realize efficient and sustainable manufacturing mode; In the field of transportation, in addition to building new energy vehicles to reduce carbon emissions, it can also realize the intelligence of vehicles and transportation networks. On the other hand, in terms of carbon emission treatment, the previous treatment methods were mainly capture, utilization and storage technology, but the price was expensive and the burden was heavy for small-scale enterprises with low returns. By using digital technology, enterprises can improve ecological carbon fixation efficiency and real-time carbon monitoring. The application of digital technology will help enterprises to "control the increment" and "control the stock" of carbon emissions, so as to realize carbon emission reduction[6]. Under the dual pressure of carbon emissions trading and government environmental supervision, enterprises will carry out green and low-carbon production to reduce compliance costs. The application of digital information technology in production and management processes can improve resource allocation efficiency and reduce unit energy consumption, thus achieving carbon emission reduction and improving production efficiency[7]and the green products produced by enterprises have high added value and high market competitiveness, which can further expand the profits of enterprises. Therefore, affected by carbon emissions trading, enterprises will carry out digital transformation in order to achieve green and low-carbon production.

The digital transformation of enterprises needs the support of R&D funds[8]. Proper environmental regulation can force enterprises to increase R&D investment, and with the improvement of enterprise's technical level, the income generated can make up for the compliance cost. This technological advantage can lay the foundation for future enterprise transformation and upgrading[9]. As a market-oriented environmental regulation, carbon emissions trading, in order to prevent excessive carbon emissions, some enterprises are included in the key control targets, and they will carry out technological innovation to improve

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their production technology. On the other hand, some enterprises that are included in carbon trading because of excessive carbon emissions will be affected by the income incentive of carbon emissions trading, that is, they will sell excess carbon quotas through emission reduction to obtain additional profits, and enterprises will increase investment in technological innovation[10]. Therefore, under the incentive of carbon emissions trading, the trend of enterprise R&D innovation has gradually formed, and the accumulation of technical capital provides R&D funds for digital transformation, which is conducive to enterprises to seize the development opportunities of digital economy and realize their own digital transformation[11].

In addition, when the financing constraints of enterprises are large, there is a great pressure on capital turnover. At this time, it is difficult for enterprises to share or transfer the risks and costs of investment through external financing, and enterprises may choose to reduce production to meet environmental requirements instead of transforming investment to achieve emission reduction and profitability[12]. Then, the high investment cost and operational risk caused by the large financing constraints will lead enterprises to reduce the allocation of internal funds in R&D investment, and at the same time, it is difficult to make up the gap of R&D funds from external financing channels, which will eventually weaken the promotion of carbon emissions trading to the digital transformation of enterprises.

In view of the above analysis, this paper puts forward the following assumptions:

H1: Carbon emission trading can promote the digital transformation of enterprises.

H2: Carbon emission trading promotes the digital transformation of enterprises by encouraging enterprises to increase the accumulation of technical capital.

H3: High financing constraints will weaken the promotion of carbon emissions trading to the digital transformation of enterprises.

3. The Research Design

3.1. Sample Selection and Data Sources

In this paper, the panel data of A-share listed companies from 2008 to 2020 are selected as samples, and the data are all from WIND database. In this paper, the microscopic data of enterprises in the screening are processed as follows: first, enterprises with ST and ST* and enterprises with missing data are deleted; Secondly, due to the particularity of financial industries, the samples of enterprises with industry codes of J66, J67, J68 and J69 are excluded. Thirdly, because the carbon trading market in Chongqing is small and the compliance rate is low, this paper does not consider the sample of enterprises in Chongqing; Finally, the continuous variables in the sample data are truncated by 1% and 99%.

3.2. Empirical Model and Variable Description

3.2.1. Model Design

The double difference method can control the differences between the treatment group and the control group before carbon trading and the influence of other synchronic factors, and properly solve the endogenous problems in empirical analysis. In order to investigate the influence of carbon emissions trading on the digital transformation of enterprises, this paper uses the quasi-natural experiment of carbon emissions trading and adopts the double difference method to estimate the effect. The double difference model set in this paper is as follows:

$$\mathrm{DCG}_{pcit} = \alpha_0 + \alpha_1 \mathrm{DID} + \alpha_2 X + \gamma_t + \mu_i + \delta_c + \eta_p + \varepsilon_{\mathrm{pcit}} \quad (1)$$

DCG represents the digital transformation of I enterprises in C industry in P province during T period; The interactive item DID is the interactive item of the grouping virtual variable Treat

ISSN: 2688-9323

and the reform Time virtual variable time, which is used to indicate the size of the processing effect. X indicates the control variables, including the enterprise size, asset-liability ratio, return on equity, the age of the enterprise, the size of the board of directors, and the shareholding ratio of the largest shareholder.

In order to investigate the influence mechanism of carbon emission trading on digital transformation of enterprises, In this paper, the three-step method is used to test the mediation effect of technological innovation[13]. On the basis of model (1), the following model (2) and model (3) are constructed. Among them, RD is the intermediary variable, namely technical capital accumulation, and the other variables are consistent with the above. If it is met simultaneously, the regression coefficient of the interaction term DID in model (1) is significant, the regression coefficient of the interaction term DID in model (2) is also significant, and the regression coefficient of RD in model (3) is significant, then there is a mediation effect. If the regression coefficient of the interaction term DID in model (3) is significant and is lower than the regression coefficient of the interaction term DID in model (1), there is a partial mediation effect, and if not significant, there is a complete mediation effect.

$$RD_{pcit} = \chi_0 + \chi_1 \mathrm{DID} + \chi_2 X + \gamma_t + \mu_i + \delta_c + \eta_p + \varepsilon_{pcit} \tag{2}$$

$$\mathrm{DCG}_{pcit} = \theta_0 + \theta_1 \mathrm{DID} + \theta_2 \mathrm{RD}_{pcit} + \theta_3 X + \gamma_t + \mu_i + \delta_c + \eta_p + \varepsilon_{pcit} \tag{3}$$

After verifying the "Porter effect", this paper introduces the variable of financing constraint (FC) to investigate whether the financing constraint inhibits or strengthens the promotion of carbon emissions trading to the digital transformation of enterprises, that is, the regulatory effect of financing constraint. In this paper, financing constraints and policy dummy variable DID are interacted to build the following model:

$$\begin{aligned}\mathrm{DCG}_{pcit} = \beta_0 + \beta_1 \mathrm{FC}_{pcit} * \mathrm{DID} + \beta_2 \mathrm{DID} + \beta_3 \mathrm{FC}_{pcit} * \mathrm{Treat} + \beta_4 \mathrm{FC}_{pcit} * T\mathrm{ime} \\ + \beta_3 X + \gamma_t + \mu_i + \delta_c + \eta_p + \varepsilon_{pcit}\end{aligned} \tag{4}$$

3.2.2. Description of Variables

Interpreted variable. DCG of enterprise digital transformation is selected as the explained variable. The digital transformation of enterprises can be divided into two levels: one is "underlying technology", which mainly includes artificial intelligence, blockchain, cloud computing and big data; The second is "practical application", that is, the application of digital technology[14]. Firstly, based on the classic literature, government documents and related research reports related to digital transformation, this paper sorts out the keywords in all directions in the above two levels and arranges them into a thesaurus; Secondly, Python is used to crawl the annual report text of listed companies in Shanghai and Shenzhen A-shares, and according to the above-mentioned keyword library, the keyword frequency of digital transformation is extracted through Java PDFbox library; Finally, the word frequency of each keyword is summed up to measure the digital transformation of enterprises. Because the data obtained by keyword frequency summation has the characteristics of "right bias", this paper deals with it logarithmically, and finally gets the overall index DCG of digital transformation. The greater the DCG, the higher the degree of digital transformation of enterprises.

Explain variables. The interactive item DID of the grouping virtual variable Treat and the Time virtual variable time is used as the core interpreted variable to represent the processing effect. For the grouped dummy variable Treat, enterprises in the pilot provinces and cities of carbon emission trading are selected as the treatment group (Treat=1), and enterprises in other

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provinces and cities are selected as the control group (Treat=0). As for the dummy variable of policy Time, this paper considers that the policy has a certain lag from the beginning to the effect. Therefore, if the implementation time of carbon trading in pilot provinces and cities is before June of that year, it is considered that carbon trading was implemented in that year, that is, Time=1; otherwise, it is considered that carbon trading was implemented in the next year, that is, Time=0.

Intermediate variable. The technological capital accumulation RD is selected as the intermediary variable. In this paper, the intensity of R&D investment, that is, the proportion of R&D expenditure in the total assets of enterprises, is used as a proxy variable for the accumulation of technical capital[11]In order to investigate the influence path of technology capital accumulation in carbon emission trading on the digital transformation of enterprises.

Regulating variable. Select financing constraint FC as the adjustment variable. At present, there is no specific financial index to directly measure the degree of financing constraint of enterprises. This paper uses SA index to measure the degree of financing constraint of enterprises. KZ and WW index contain many endogenous financial variables, but SA index has no endogenous problems. Because the SA index is negative, this paper takes the absolute value of SA index as the proxy variable of financing constraint FC. The greater the absolute value of SA index, the greater the degree of financing constraint for enterprises.

Control variables. This paper controls the following variables: enterprise scale (Size), asset-liability ratio (Lev), return on net assets (ROE), enterprise age (firm), board size (Borad) and shareholding ratio of the largest shareholder (Top1). Considering that the digital transformation of enterprises may also be affected by the region, industry and economic cycle where enterprises are located, this paper further controls the provinces, industries and time variables.

3.2.3. Descriptive Statistics

The main explained variables, variable names, definitions and descriptive statistics are shown in Table 1 below.

Table 1. Descriptive statistics

variable	Definitions	Average	SD	Min	Max
DCG	Keyword frequency ratio	30448	1.029	1.258	0.000
Size	Ln (total assets at the end of the period)	30448	22.092	1.291	19.810
Lev	Total liabilities/total net assets	30448	0.419	0.207	0.050
ROE	Net profit/net assets	30448	0.072	0.120	-0.563
FirmAge	Ln (year-year of establishment +1)	30448	2.807	0.372	1.609
Board	Ln (number of directors)	30448	2.136	0.198	1.609
Top1	Number of shareholders holding the most shares/total number of shares of the company	30448	0.350	0.149	0.088
FC	SA index	30448	3.752	0.253	3.086
RD	R&D investment/total assets	30448	0.018	0.021	0.000

4. Empirical Analysis

4.1. Benchmark Regression

The influence of carbon emissions trading on the digital transformation of enterprises is shown in Table 2, and (1)-(4) in the table are the benchmark regression results. Column (1) and column (2) did not join the fixed effect of industry and region, but controlled individuals and time. Column (3) and column (4) simultaneously control the individual, time, industry and regional fixed effects. (4) On the basis of controlling the fixed effects of individuals, time,

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industries and regions, adding a series of control variables, the coefficient of interactive item DID is 0.1565, which is significant at the level of 1% and greater than 0, and the adjustment R is also greater than the first three columns. Therefore, after controlling the fixed effects of individuals, time, industries and regions, the model fitting effect is better and the results are more robust. This paper will further test the robustness below. Finally, according to the regression results, carbon emissions trading has a significant positive effect on the digital transformation of enterprises, so it is assumed that H1 is established.

Table 2. Benchmark regression

variable	(1)	(2)	(3)	(4)
DID	0.1602***	0.1522***	0.1658***	0.1565***
	(8.4650)	(8.1055)	(8.7094)	(8.2736)
_cons	0.9803***	-3.5467***	0.9787***	-3.4424***
	(146.9654)	(-10.8709)	(146.4347)	(-10.5630)
Control variable	NO	YES	NO	YES
Industry fixed	NO	NO	YES	YES
Individual fixation	YES	YES	YES	YES
Time fixed	YES	YES	YES	YES
Region fixed	NO	NO	YES	YES
N	30448	30448	30448	30448
adj. R^2	0.7002	0.7047	0.7059	0.7100

Note: "* * *", "* *" and "*" represent the significance levels of 1%, 5% and 10% respectively; The value of t in brackets is calculated by robust standard error. similarly hereinafter.

4.2. Robustness Test

4.2.1. Parallel Trend Test

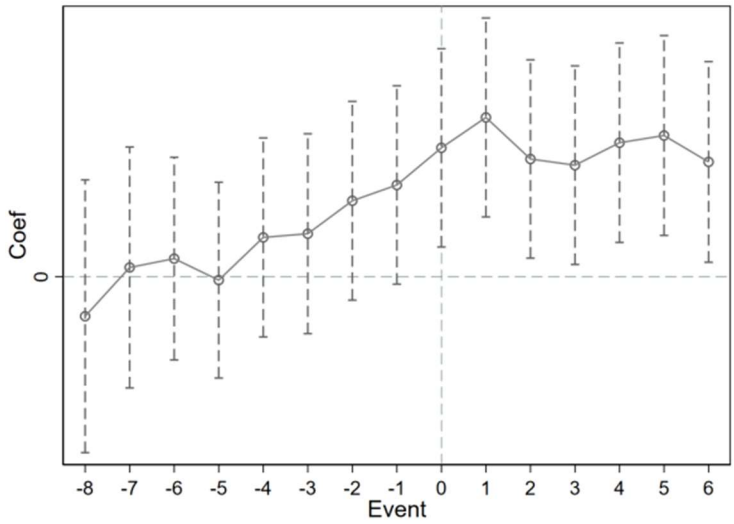

Figure 1. Parallel trend test

The premise of using the double difference method is to meet the parallel trend hypothesis, that is, the result variables of the treatment group and the control group cannot have a significant change trend with time before the policy is launched. Because there may be great differences in the development degree of enterprises in pilot provinces and cities and non-pilot provinces and cities, it is particularly important for enterprises to start digital transformation before the implementation of carbon emissions trading. This paper constructs the time difference variable between the years before and after carbon trading and the current year of carbon trading. If

ISSN: 2688-9323

there is no significant upward trend in the digital transformation of enterprises in pilot provinces and cities and non-pilot provinces and cities before the current year of carbon trading, then the regression result of this paper is stable. Under the 95% confidence interval, the test result of parallel trend is shown in Figure 1 below. Before the implementation of carbon emissions trading, the confidence interval contained 0, indicating that there was no significant difference in digital transformation between the control group and the treatment group, while after the implementation of carbon emissions trading, the confidence interval was different from 0 and significantly positive, indicating that with the opening of carbon emissions trading, enterprises gradually carried out digital transformation, which verified the parallel trend hypothesis.

4.2.2. Placebo Test

Although the benchmark regression obtained that carbon emissions trading can promote the digital transformation of enterprises and verified the parallel trend hypothesis, is the digital transformation of enterprises affected by other unobservable factors? Therefore, this paper carries out a placebo test. Firstly, the year is randomly selected as the experimental year of carbon emission trading in provinces and a pseudo-time dummy variable is generated. Secondly, enterprises in seven provinces are randomly selected as processing groups and pseudo-grouping virtual variables are generated; Thirdly, the pseudo-grouping virtual variables and pseudo-time virtual variables are interacted to generate pseudo-policy virtual variables, and repeated regression is carried out for 500 times to obtain the interaction coefficient; Finally, the adjoint probability p value of regression coefficient and its distribution are combined to draw the nucleation density map. The placebo test is shown in Figure 2 below, showing an approximate normal distribution. As shown in the figure, the estimation coefficient of pseudo-policy dummy variable is concentrated around 0, while the true value of 0.1565 is at the right end of the figure, which is far from each other. In addition, based on the level of 10%, most of the estimated coefficients of pseudo-policy dummy variables are above the dotted line of 10%, indicating that their regression is not significant. Therefore, the benchmark regression result of this paper is obviously a minimum probability event at the level of 99%, so the influence of other unobservable factors on the digital transformation of enterprises can be ruled out, which shows that the regression result of this paper is robust.

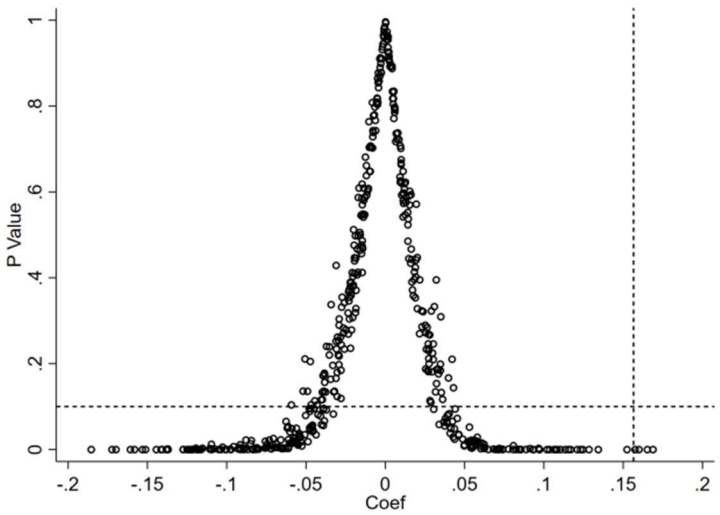

Figure 2. Placebo test

4.2.3. PSM-DID

China carbon emissions trading was implemented in three batches in 2013, 2014 and 2016, but the randomness in the selection of pilot cities is not strong, which may lead to a great difference

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in the development level and digitalization level between enterprises in pilot cities and non-pilot enterprises, resulting in errors in the regression results. In order to improve the robustness of the regression results in this paper, this paper matches the samples of the enterprises in the treatment group with the samples of the enterprises in the control group with more similar development level by means of tendency score matching and phase-by-phase matching. Column (1) and column (2) are the regression results of estimating the model (1) after two matching methods, namely, K-nearest neighbor matching and kernel matching. As can be seen from the following table, the coefficient of DID is 0.1471 under the K-nearest matching mode, which is significant at the level of 1%. Under the nuclear matching mode, the coefficient of DID is 0.1570, which is still significant at the level of 1%. Therefore, under the two matching methods, the estimated values of DID coefficients are significantly positive, indicating that the regression results in this paper are robust and credible.

Table 3. PSM-DID

variable	(1)	(2)
DID	0.1471***	0.1570***
	(7.5263)	(8.2827)
_cons	-3.5748***	-3.4694***
	(-10.2496)	(-10.6092)
Control variable	YES	YES
Individual fixation	YES	YES
Fixed time	YES	YES
Industry fixation	YES	YES
Regional fixation	YES	YES
N	28263	30384
adj. R^2	0.7106	0.7097

4.3. Analysis of Intermediary Effect

Through the above demonstration, the carbon emission trading mechanism, as a market-oriented environmental regulation, can promote the digital transformation of enterprises. This part will verify and analyze the transmission mechanism, and investigate the influence path of carbon emission rights to promote the digital transformation of enterprises.

The test results of intermediary effect are shown in Table 4 below. Column (1) is the regression result of model (1), that is, the influence of carbon emission trading on the digital transformation of enterprises. The correlation coefficient and significance have been explained in the previous article, so I will not repeat them here. (2) The column is the regression result of model (2), which examines whether carbon emissions trading will encourage enterprises to increase investment in technology research and development. According to the results, the DID coefficient is 0.0005, which is significant at the level of 10%, indicating that carbon emissions trading has significantly improved the accumulation of technology capital of enterprises. (3) Column is the regression of model (3) by introducing the accumulation of technical capital into model (1). The DID coefficient of 1.1547 is significant at the level of 1%, and compared with the cross-item coefficient of column (1), the DID coefficient of column (3) is reduced, while the coefficient of RD is 3.6478, which is significant at the level of 1%, so there is some intermediary effect. It shows that carbon emissions trading can promote the digital transformation of enterprises by enhancing the accumulation of technological capital, so it is assumed that H2 is verified.

ISSN: 2688-9323

Table 4. Mediating effect

variable	(1)	(2)	(3)
DID	0.1565***	0.0005*	0.1547***
	(8.2736)	(1.7616)	(8.1952)
RD			3.6478***
			(7.0543)
_cons	-3.4424***	0.0531***	-3.6361***
	(-10.5630)	(10.4913)	(-11.1593)
Control variable	YES	YES	YES
Individual fixation	YES	YES	YES
Fixed time	YES	YES	YES
Industry fixation	YES	YES	YES
Regional fixation	YES	YES	YES
N	30448	30448	30448
adj. R^2	0.7100	0.7918	0.7107

4.4. Heterogeneity Analysis

The difference of enterprise scale and enterprise location will affect the promotion of carbon emissions trading on enterprise digital transformation. Therefore, after discussing the policy effect and influence mechanism of carbon emissions trading on enterprise digital transformation, this paper will further analyze the heterogeneity of the impact of carbon emissions trading on digital transformation, which will help to analyze and understand the digital transformation of enterprises in different situations under carbon emissions trading and better put forward constructive opinions.

4.4.1. Heterogeneity of Enterprise Scale

Table 5. Differences in Enterprise Scale

variable	(1)	(2)
DID	0.2469***	0.0347
	(7.5769)	(1.2759)
_cons	-6.1632***	-0.8940
	(-9.9457)	(-1.5165)
Control variable	YES	YES
Individual fixation	YES	YES
Fixed time	YES	YES
Industry fixation	YES	YES
Regional fixation	YES	YES
N	14950	15165
adj. R^2	0.7387	0.7422

The size of the enterprise will affect the business decision and the use of funds, thus affecting the digital transformation of the enterprise. In this paper, the median total assets of enterprises at the end of the period is taken as the standard for dividing large and small enterprises, and enterprises below the median total assets at the end of the period are small-scale enterprises, and vice versa. Two sub-samples are grouped and regressed, and the regression results are shown in Table 5 below. (1) The column indicates the regression result of small-scale enterprises, and the DID coefficient is 0.2469, which is significant at the level of 1%; (2) The column indicates the regression results of large-scale enterprises, and the DID coefficient is not statistically significant. The regression results show that carbon emission trading can promote

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the digital transformation of small-scale enterprises, but it does not promote the digital transformation of large-scale enterprises. The reason is that large-scale enterprises rely more on the existing production methods and technical level, and it is difficult for large-scale enterprises to quickly adjust their business strategies and the direction of capital use because of the large number of management. However, small-scale enterprises have flexible operating mechanism, are more sensitive to market changes, and can adjust their strategic deployment in time. Under the influence of carbon emission trading, small-scale enterprises can realize digital technology transformation and reduce carbon emissions by increasing investment in technology research and development in time.

4.4.2. The Heterogeneity of Enterprise Location

Because of the unbalanced economic development in the eastern, central and western parts of China, as well as the coastal and inland areas, the policy effects of carbon emission trading will be different for such differences. Since Chongqing is the only pilot city in the western region, and the sample of enterprises in Chongqing has been eliminated in this paper, only the heterogeneity of carbon emission trading policy effects of enterprises in the central and eastern regions and inland and coastal regions is considered, and the regression results are shown in the following Table 6. According to the regression results in the following table, column (1) and column (3) are the regression results of enterprises in coastal and eastern regions, and the DID coefficients are 0.1228 and 0.1204, respectively, which are significant at the level of 1%; Column (2) and column (4) are the regression results of enterprises in inland areas and central areas, and the DID coefficients are 0.2044 and 0.2565, respectively, which are significant at the level of 1%. The regression results show that carbon emission trading plays a greater role in promoting the digital transformation of enterprises in inland and central regions than enterprises in coastal and eastern regions. The reason is that the innovation level, production technology and development mode of enterprises in central and inland areas are relatively backward compared with those in eastern and coastal areas. Therefore, under the incentive of carbon emissions trading, the central and inland areas have improved their technical level by increasing investment in technology research and development, and the digital transformation of enterprises is more obvious.

Table 6. Location Differences of Enterprises

variable	(1)	(2)	(3)	(4)
DID	0.1228***	0.2044***	0.1204***	0.2565***
	(5.1454)	(6.2145)	(5.4620)	(4.5847)
_cons	-3.6287***	-3.1534***	-4.2009***	-2.2494***
	(-8.7117)	(-5.8475)	(-10.3978)	(-3.0832)
Control variable	YES	YES	YES	YES
Individual fixation	YES	YES	YES	YES
Fixed time	YES	YES	YES	YES
Industry fixation	21877	5288	YES	YES
Regional fixation	0.6406	0.6351	YES	YES
N	19155	11285	21551	5047
adj. R^2	0.7038	0.7241	0.7204	0.6716

4.5. Further Analysis

According to the above analysis of intermediary effect, carbon emissions trading can force enterprises to accumulate technical capital, thus providing R&D financial support for the digital transformation of enterprises. However, financing constraints will affect the capital turnover of enterprises, thus affecting the allocation of R&D funds of enterprises, thus hindering the digital

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transformation of enterprises. Therefore, this paper will further analyze the transmission mechanism and investigate the regulatory effect of financing constraints on the impact of carbon emission trading on the digital transformation of enterprises.

The regression results of the moderating effect of financing constraints are shown in Table 7 below. The coefficient of DID is 0.0605, which is significant at the level of 1%, while the coefficient of interaction between financing constraints and DID is -0.6764, which is significant at the level of 1%. It shows that although carbon emissions trading can promote the digital transformation of enterprises, the financing constraints of enterprises will weaken the promotion of carbon emissions trading to the digital transformation of enterprises under carbon emissions trading. Suppose H3 is verified.

Table 7. Regulatory effect

variable	(1)
DDD	-0.6764***
	(-8.1787)
DID	0.0605**
	(2.3907)
Treat*FC	0.8018***
	(8.2312)
Time*FC	0.6125***
	(9.8830)
_cons	-3.8456***
	(-11.1482)
Control variable	YES
Individual fixation	YES
Fixed time	YES
Industry fixation	YES
Regional fixation	YES
N	30448
adj. R^2	0.7118

5. Conclusion and Enlightenment

Under the background of "double carbon" and the trend of digital economy, effectively evaluating the influence and internal mechanism of carbon emission trading on the digital transformation of enterprises can provide powerful experience and evidence for the high-quality economic development of China. Firstly, based on the micro-panel data of A-share listed companies from 2008 to 2020, this paper uses the pilot of carbon emission trading to carry out this quasi-natural experiment, and deeply analyzes whether the carbon emission trading mechanism can help the digital transformation of enterprises by using the double difference method, and carries out a series of robustness tests for the regression results. Secondly, this paper further analyzes the mechanism of the influence of carbon emission trading mechanism on the digital transformation of enterprises. Thirdly, this paper also analyzes the heterogeneous effect of carbon emissions trading on the digital transformation of enterprises. Finally, this paper further explores the regulatory effect of financing constraints on the digital transformation of enterprises. This paper draws the following conclusions: First, carbon emission trading can promote the digital transformation of enterprises. Developing digital economy is an important way to achieve high-quality economic development in China, and the digital transformation of enterprises is the embodiment of digital economic development.

ISSN: 2688-9323

Second, carbon emissions trading can promote the digital transformation of enterprises by forcing enterprises to increase investment in technological innovation. Third, the impact of carbon emissions trading on the digital transformation of enterprises is heterogeneous in different situations. For enterprises of different scales, carbon emission trading can promote the digital transformation of small-scale enterprises, but it has no significant effect on the digital transformation of large-scale enterprises. For enterprises with different locations, carbon emission trading plays a greater role in promoting the digital transformation of enterprises in inland and central regions than those in coastal and eastern regions. Fourth, the greater the financing constraints of enterprises, the more it will inhibit the promotion of carbon emission trading to the digital transformation of enterprises.

The conclusion of this paper can provide experience and evidence for the government to change the economic development mode and improve the national carbon emissions trading, and also provide inspiration for promoting the high-quality economic development of China. First, we will continue to develop and improve the carbon emission trading system, so as to promote enterprises' innovation ability, realize technological progress and lay a solid foundation for enterprise transformation. Second, the government should guide the development direction of enterprises, encourage the digital transformation of enterprises, and provide policy assistance to enterprises in digital transformation. Third, advocate enterprise innovation in the whole society, adhere to the innovation-driven development strategy, stimulate the technological innovation ability of enterprises, and promote the digital transformation of enterprises, so as to achieve a win-win situation of ecological environment improvement and high-quality economic development. Fourth, give financing expenses to enterprises that meet emission reduction standards, reduce the financing constraints of enterprises to alleviate the capital turnover problem of enterprises, and then promote enterprises to increase investment in technological innovation and realize digital transformation. Fifth, carbon emissions trading belongs to market-oriented environmental mechanism, and its effect depends on a perfect market mechanism, so the government should continue to improve the market mechanism and give play to the decisive role of the market in resource allocation. Fourth, the government should strengthen the enforcement of environmental protection and force enterprises to innovate in technology. Without environmental supervision, enterprises will tend to evade punishment, and it is difficult to promote the transformation of enterprise development mode. Fifth, we should pay attention to regional differences and enterprise scale differences, avoid the "one size fits all" environmental regulation strategy, and implement innovation subsidies according to local conditions to help enterprises transform digitally.

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