Research on the Path and Countermeasures for the Green Transformation and Upgrading of Heavy Pollution Enterprises Driven by the Pilot Policies of Low Carbon Cities

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Keywords: Low carbon city pilot policy, Green transformation and upgrading, Difference-in-difference model

Abstract: In order to achieve China's carbon emission goals, the central government proposed a pilot policy for low-carbon cities, promoting the harmonious development of low-carbon environmental protection and economic development, and giving heavy polluting enterprises the mission of accelerating green transformation and upgrading. The research sample of this paper is the data of A-share listed companies in Shanghai and Shenzhen in China from 2007 to 2020. By constructing a difference-in-difference model, this paper examines the two paths and mechanisms of low-carbon policies driving the green transformation and upgrading of heavily polluting enterprises, and on this basis, it conducts robustness tests and heterogeneity analysis. The research finds that the implementation of low-carbon city policy significantly affects the investment decisions of heavily polluting enterprises on fixed assets and research and development(R&D), and the effect of this policy on investment strategies of enterprises of different ages, sizes, ownership and carbon emission intensity is different. This paper discusses the logical relationship and path mechanism between the pilot policies of low-carbon cities and the green transformation and upgrading of enterprises. The policy enlightenment obtained has an important role in how the country can achieve the green transformation of economy by driving the transformation and upgrading of heavily polluting enterprises under the "dual carbon" goal.

1. Introduction

Following the Kyoto Protocol and the Paris Agreement, China, as the world's second largest economy entity and the largest carbon dioxide emitter, first proposed the medium and long-term strategic goal of "achieving carbon peak by 2030 and carbon neutrality by 2060" at major conferences such as the General Debate of the United Nations General Assembly and the Climate Ambition Summit in 2020. Under the sub goal, in order to seek a win-win low-carbon economic development path of reducing greenhouse gas emissions and economic development, the Central Committee systematically planned and made overall arrangements, and a series of low-carbon policies came into being. A series of opinions issued by the Central Committee aimed at achieving carbon peak and carbon neutrality, have guided the implementation of the green and low-carbon transformation policy system of China's economy and society, and launched a series of policies to promote the harmonious development of low-carbon environmental protection and economic development.

These measures further challenge the development of heavy polluting enterprises in the future, and meanwhile have become important opportunities and levers for the green and high-quality development of heavy polluting enterprises in China. Since the reform and opening up, the development model on which China's heavily polluting enterprises rely for survival has generally been high in energy consumption and heavy in pollution, resulting in serious environmental pollution and ecological degradation. In 2017, the CO_2 emissions increased 2.36 times compared with 2000 [1](Fu Hua et al., 2021), and heavily polluting enterprises have become the main economic body of China's carbon emissions. At the same time, in recent years, the production efficiency of China's heavily polluting enterprises has further declined [2](Ding Wenjun and Du Zhiming, 2018), which

  DOI: 10.25236/ssce.2022.051

has become a key reason for dragging down macroeconomic growth [3](Ren Shenggang et al., 2019). The heavy polluting enterprises in the transition period are faced with the trade-off and coordination between energy consumption, carbon dioxide emissions and economic efficiency [4](Shao Shuai et al., 2019). Under the dual background of increasingly serious environmental problems and high-quality development, the green transformation and upgrading of heavily polluted enterprises are imminent. Therefore, China's heavily polluting enterprises should change their development mode through production technology innovation and elimination of backward production capacity. The series of low carbon policies represented by the pilot policies for low carbon cities not only reflect the country's commitment to the optimization and upgrading of urban energy structure, the transformation and upgrading of urban industrial structure, and the upgrading of urban innovation capability from a macro perspective [5](Wang Jing, 2021), but also officially open a new chapter in the history of "China's governance" with the core of corporate green transformation and upgrading governance. As important emitters of greenhouse gases and a core economic entities in the R&D, innovation of low-carbon scientific and technological products, enterprises must be important participants and backbone in urban low-carbon construction [6](Xiong Guangqin, 2020).

Different from other environmental regulations in China, the implementation method of the pilot policy for low-carbon cities is to explore the mode of decoupling economic growth from carbon emissions by selecting different types, different development stages, and different resource endowments. Fu Yun (2008) found that the basic way to achieve low carbon development of China's social economy is to implement low carbon economy to the level of urban economy and to establish a low carbon development concept based on low energy consumption, low emissions, high efficiency and efficiency, and a Chinese green social and economic development model with carbon neutral technology [7]. Wang Jiajia (2010) pointed out that organizing economic activities through low-carbon economy theory is a specific behavior to implement the national green development goals in practice, and the core idea of low-carbon cities is to achieve green and sustainable development of urban economy[8]. Therefore, this policy emphasizes the economic behavior of various economic entities in cities whose targets are at the micro level, and requires economic entities to take their scientific and technological innovation as the technical support for policy implementation, in order to achieve the basic goal of developing urban economy, science and technology and promoting a harmonious society.

This paper takes A-share listed enterprises in Shanghai and Shenzhen Stock Exchanges of China as the research object, explores the impact mechanism and realization path of low-carbon city pilot policies to promote green transformation and upgrading of enterprises from the two paths of "fixed asset investment strategy transformation" and "research and development investment strategy transformation", and provides reference and inspiration for exploring low-carbon environmental policies that adapt to green transformation and upgrading of enterprises.

The main marginal contributions of this paper are boiled down to three points: First, based on the investment perspective within enterprises, this research further explores how the macro policy of low-carbon city pilot will affect the investment decisions of enterprises at the micro level. As the first study to test the sample data of A-share listed companies in Shanghai and Shenzhen, this paper provides an empirical basis for a more comprehensive understanding of the implementation effect of the low-carbon city pilot macro comprehensive environmental policy; Second, this paper analyzes the theoretical mechanism of the policy to promote low-carbon transformation and upgrading of heavily polluting enterprises by influencing enterprise investment decisions. On the basis of existing researches, the external causes of enterprise transformation and upgrading are studied from the perspective of national low-carbon policy, which enriches the research on the impact of external causes of development on enterprise transformation and upgrading, provides theoretical basis and experience reference for a series of decisions made by heavily polluting enterprises seeking transformation and upgrading, analyzes and verifies the micro effect generation mechanism of macro environmental policies from the perspective of policy goal orientation and enterprise transformation and upgrading; Third, this paper analyzes the heterogeneity of the samples of size, age, ownership and the sample enterprises in different carbon emission intensity industries through the heterogeneity

test. On the basis of existing researches, this paper studies the external causes of enterprise transformation and upgrading from the perspective of national low-carbon policy, which enriches the research on the impact of external causes of development on enterprise transformation and upgrading. At the same time, it analyzes and verifies the micro effect mechanism of macro environmental policies from the perspective of policy goal orientation and enterprise transformation and upgrading.

2. Literature review

2.1. Research on the effect of policies of low-carbon city pilot

According to historical researches, domestic and foreign scholars have conducted normative and empirical studies on the macro and micro effects of low-carbon city pilot policies from multiple perspectives, and tested the implementation effect of national low-carbon pilot work.

Chen Nan (2018) assessed the effectiveness of the three batches of policies from 2010 to 2015 on the economic impact of 70 pilot cities from the perspective of the role of regional economy at the macro level by building the effectiveness evaluation index system of special environmental regulations[9]. The conclusion is that the implementation of low-carbon pilot has a positive effect on regional economic development. Based on this, this paper also combs the effects of low-carbon city pilot policies into macro and micro levels. The macro effects of policies can be divided into the impact on the regional environment and the impact on the regional economy. The low carbon city policy can promote the improvement of regional environmental quality. Song Hong (2019), in order to test whether the implementation of the low carbon city pilot policy is beneficial to air governance, used difference-in-difference model to examine the path of the policy to significantly reduce the air pollution in the pilot area is to promote the transformation of heavily polluting enterprises, change the industrial structure, promote the technological innovation of heavily polluting enterprises, etc., and then reduce pollution emissions [10]. Chu Guodong (2017) and Zhou Di (2019) all used the DID to evaluate the effect of low-carbon pilot policies, and reached the consistent conclusion that the carbon intensity per unit GDP, electricity consumption intensity or other energy consumption intensity of low-carbon pilot cities are lower than those of non pilot cities after the implementation of the policy [11-12]. As for the regional economy, the characteristics of the pilot policy for low-carbon cities are to promote the economic development of the pilot region by putting forward carbon emission requirements for the economic entities in the pilot cities to promote the transformation and upgrading of the economies in the cities. Shi Daqian et al. (2018)compared the governance model of the low carbon city pilot policy with that of the smart city pilot policy, and concluded that the main focus of the low carbon city pilot policy is the "carbon reduction" and other low carbon measures in the high carbon industry to improve the energy use efficiency of the whole city[13].

From a micro perspective, the requirements of the policy on the pollutant emissions of pilot cities are shown in that the peak pollutant emissions of enterprises in cities must be reduced, so stimulating enterprises to innovate production technologies, change investment strategies and other series of economic activities can reduce energy consumption and pollution discharge in the production and operation process. Xu Jia (2020) found that the role of low-carbon city pilot policies on pollutant emissions is mainly shown in the restrictions on carbon emissions [14]. The micro object of the policy is the production and operation process of heavily polluting enterprises whose main energy consumption structure is high carbon energy, such as thermal power generation, steel manufacturing and other production processes. Zhuang Guiyang (2020) found that, in order to achieve the goal of controlling greenhouse gas emissions at the city level, the pilot policy of low-carbon cities is mainly aimed at reducing carbon emissions of enterprises with high energy consumption and pollution emissions in some industries [15]. Based on this, further requirements are put forward for updating the enterprise production system. In this process, enterprises will be induced to carry out green technology innovation and green production system construction. Song Hong (2019) investigated the effect of the implementation of pilot policies of low-carbon cities on enterprises' green technology innovation through the method of DID, and measured the technological innovation level of enterprises in pilot cities and pilot cities respectively with the patent index of industry and enterprise

level, and reached the conclusion that the implementation of pilot policies of low-carbon cities can promote enterprises' green technology innovation [10].

To sum up, domestic scholars have conducted a lot of discussions on the micro effects of the pilot policies for low-carbon cities, which mainly focus on the design logic and practical research. Therefore, there is a lack of empirical research on the micro investment strategies of enterprises.

2.2. Research on the influencing factors of green transformation and upgrading of enterprises

According to historical researches, the influencing factors of enterprise transformation and upgrading can be divided into external and internal motivation. At present, some researches have considered that the external causes of green transformation and upgrading of enterprises mainly include tax burden, resource and environmental policies, etc. Horbach (2018) discussed the role of carbon tax in promoting enterprise production technology innovation and green transformation by analyzing and studying the regulatory effectiveness of "hard" regulatory measures such as the Renewable Energy Law (Yang, 2019). Huang Jiqiang (2021) found that the reduction of tax burden has significantly improved the total factor productivity of heavily polluting enterprises. From the perspective of heterogeneity, he found that: for larger enterprises and state-owned enterprises, the reduction of tax burden has a more significant role in promoting the total factor productivity of small-scale enterprises and non-state-owned enterprises [17]. Finally, he concluded that the reduction of tax burden can significantly improve the operating income and net asset income of enterprises, and improve the operating efficiency of enterprises. The internal motivation of enterprise transformation and upgrading mainly includes investment strategy, energy consumption structure, technological innovation and internal management, etc. According to the research of Guo Pibin (2021), the green transformation and upgrading of energy-oriented enterprises is caused by the joint action of the internal resource development pressure and external environmental competition pressure, while corporate responsibility innovation and the improvement of dynamic capability are a dynamic process of mutual promotion and mutual influence, and the dynamic improvement of both will further promote the green transformation and upgrading of enterprises [18]. Finally, the green transformation and upgrading of enterprises are realized through the two main paths of green process innovation and green product production innovation in the production system. Brandt (2016) analyzed the role of green entrepreneurs' proficiency in the three skills of profit, communication and integrity in the process of green energy transformation, and found that entrepreneurs with the above talents can promote the green transformation and upgrading of enterprises [19].

Under the guidance of the national goal of carbon peak and carbon neutralization, the research on the micro effects of low-carbon policies has become a frontier topic in the academic community. It can be seen from the existing literature that the research on the micro effects of pilot policies for low-carbon cities is relatively scattered at present. However, most of the studies on the transformation and upgrading of enterprises are based on the explanations of internal and external pressures and motivations, and few of them use empirical research to explore the path of transformation and upgrading of enterprises and other economic individuals. In addition, existing studies either explore the governance effects of low-carbon policies or analyze the factors that affect the transformation and upgrading of enterprises, but few studies combine the two to test the relationship between them. Therefore, from the perspective of industrial adjustment in the choice of enterprise investment strategies, this paper discusses the theoretical framework for enterprises to promote transformation and upgrading through the two paths of "transformation of fixed asset investment strategies" and "transformation of research and development investment strategies". The main research methods used is empirical analysis. And it is innovative to explore the path and mechanism provided by the national macro low-carbon policies for the transformation and development of microeconomic individuals.

3. Theoretical mechanism

Starting from the requirements of low carbon policy on enterprise carbon emissions, this paper discusses the micro effect, mechanism and transmission path of low carbon city pilot stimulating enterprise transformation and upgrading to achieve certain carbon emissions targets from fixed asset

investment strategy and research and development strategy.

3.1. Change of fixed asset investment strategy

Zhuang Guiyang (2020) pointed out that, in order to achieve the goal of controlling greenhouse gas emissions at the city level, the pilot policy of low-carbon cities is mainly aimed at low-carbon development of enterprises in key areas of high energy consumption and high pollution emissions in cities [15]. Therefore, under the supervision of the low carbon city pilot policy, the heavily polluting enterprises will update the green production system by reforming and restructuring the production system, updating the original backward technology equipment and purchasing new high-end equipment; Meanwhile, since most production and operation sites are seriously polluted, enterprises will take the decision to close the heavily polluted operation sites, which will significantly reduce the investment in fixed assets of enterprises for upgrading equipment in the original production and operation sites and the original heavily polluted production system. Therefore, it is an important way for enterprises to seek transformation and upgrading for enterprises to change their fixed asset investment strategies caused by the pilot policies of low-carbon cities. Therefore, assumption 1 of this paper is as follows:

Hypothesis 1a: The implementation of the national low-carbon city pilot has increased the investment in fixed assets of enterprises;

Hypothesis 1b: The implementation of the national low-carbon city pilot has reduced the investment in fixed assets of enterprises.

3.2. Change of R&D investment strategy

Song Hong (2019) investigated the effect of the implementation of low-carbon city pilot policies on green technology innovation of enterprises through difference-in-difference model, and selected the patent index at the enterprise level to measure the technological innovation level of enterprises in the pilot cities [10]. And he concluded that the implementation of low-carbon city pilot policies has a promoting effect on the construction of green production system and green technology innovation of enterprises. Therefore, driven by the pilot policy, the heavily polluting enterprises, starting from the production system that will cause serious environmental pollution, seek green transformation and upgrading of the production system through technological innovation by increasing research and development expenditure on production technology and reduce greenhouse gas emissions in the production system. That is, enterprises change their original research and development strategies, increase innovation and research expenditure on production technology, so as to achieve the carbon emission reduction goal and realize transformation and upgrading. Therefore, the following assumptions are proposed:

Hypothesis 2: The pilot implementation of national low-carbon cities effectively increases the research and development investment of enterprises.

4. Research Design

Hu Ridong(2018) pointed out that DID is an econometric method used to evaluate the effect of policy implementation. Its basic idea is to regard the implementation of new policies and institutional changes as a "quasi experiment" of an exogenous economic system [20]. However, the implementation of the national low carbon city pilot policy may have a significant difference in the fixed asset investment and research and development investment of heavily polluting enterprises in pilot cities and non-pilot cities. Therefore, the implementation of this policy can be regarded as a "quasi natural experiment" and a DID model can be built to evaluate its effects. Based on this, this paper takes the second batch of low carbon city pilot projects in China in 2012 as a policy shock, tests the green transformation and upgrading of heavily polluting enterprises under the low carbon development goals by evaluating their policy effects and taking enterprises in the pilot cities after the implementation of the low carbon city pilot policies in 2012 as the experimental group, and enterprises in non-pilot cities after the implementation of the policy in 2012 served as the control group to construct a difference-in-difference model to quantitatively evaluate the effect of low-carbon

city policies on enterprises' investment in fixed assets and R&D:

4.1. Model construction

(1) The impact of policies on the investment decisions of heavy polluting enterprises in fixed assets.

$$Inv_{it} = \beta_0 + \beta_1 Policy_c \times Post_t + \lambda X_{it} + \mu_i + \mu_t + \varepsilon_{it} (1)$$

(2) The impact of policies on investment decisions of research and development of heavily polluting enterprises.

$$R\&D_{it} = \beta_0 + \beta_1 Policy_c \times Post_t + \lambda X_{it} + \mu_i + \mu_t + \varepsilon_{it} (2)$$

The explained variable in equation (1)$Inv_{i,t}$represents Fixed assets investment of enterprise i in year t, expressed by the proportion of the difference between the cash paid and the cash recovered by the enterprise for the construction and disposal of fixed assets and other long-term assets in the total assets of the enterprise.

The explained variable in equation (2)$R\&D_{i,t}$represents R&D investment proportion of enterprise i in year t, expressed by the proportion of R&D expenditure investment in total assets of the enterprise.

Explanatory variable$Policy_c \times Post_t$is a dummy variable before and after the policy pilot. If the city where company i's office address is located was included in the second batch of low-carbon city pilot list by the state in 2012, the value is 1, otherwise it is 0.

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Referring to the research of Dong et al (2022), we use to represent a series of control variables. In this paper, eight enterprise level control variables are selected, and the measurement methods are as follows: (1) Enterprise size is Size, and the original data of the sample's total assets are expressed by natural logarithms; (2) Growth opportunity, measured by the sustainable growth rate of the sample; (3) Age of enterprise, expressed by the years of establishment of the sample; (4) Leverage ratio, expressed as the ratio of total liabilities divided by total assets of the sample; (5) Enterprise ownership; (6) The operating cash flow Cfo is expressed by the logarithm of the ratio of the cash income of the main business divided by the total assets of the sample; (6) The profitability Tobinq is expressed by the ratio of the sample profit before interest and tax divided by its total assets; (7) Return on assets Roa is expressed as the ratio of the sample's net profit before interest and tax divided by its total assets; (8) Share is the shareholding ratio of the top ten shareholders. In addition, drawing on the research of Xu Jia et al. (2020), this paper selects six control variables that affect urban carbon emissions at the city level: (1) GDP at the level of economic development, expressed in urban per capita GDP; (2) Population density, expressed as the ratio of total population at the end of the year to urban area; (3) Industrial structure Struc, indicating the industrialization level by the proportion of the output value of the secondary industry in the city; (4) The level of urbanization is expressed by the urbanization rate of the city; (5) Energy consumption structure Estr, expressed by the proportion of coal consumption in total energy consumption; (6) Foreign direct investment (Fdi) is expressed as the ratio of urban foreign direct investment to GDP[14].

In addition, in order to control other unobservable inherent characteristics of the enterprise and macro environmental change factors that only change with the year, this paper adds the fixed effect of the individual enterprise and the fixed effect of the year, as well as the random disturbance term.

4.2. Data source

This paper takes the data of A-share listed companies in Shanghai and Shenzhen from 2007 to 2020 as the object of research and analysis, obtains the original data of the explained variables and all enterprise level control variables from CSMAR and the data of the city level control variables from China Urban Statistical Yearbook (2008-2020), and then processes the collected original data as follows: (1) Screen out the sample data of ST or * ST; (2) Screen out companies that were established

in the same year and were PT and delisted during the observation period; (3) Remove the missing sample data of all major variables; (4) Exclude financial, real estate and other service industries, only the sample of listed companies in key industries with high energy consumption and high pollution emissions, such as electric power, thermal power, manufacturing and waste treatment, is retained; (5) Winsorize all continuous variables in the model at 1% and 99% quantiles; (6) The initial fixed asset investment of enterprises was due to rigid demand, so the sample data of the initial 3 years of the sample enterprises were screened out.

Table 1 Major variables describe statistical characteristics.

Variable	N	Mean	Std	Min	Max
Inv	14655	0.0622	0.0750	-0.1014	0.5582
R&D	14655	0.0213	0.01852	0.0033	0.1153
Policy×Post	14655	0.2232	0.4154	0	1
ROA	14655	0.5226	0.4396	-0.0081	0.8915
Own	14655	0.3583	0.2668	0	1
Cfo	14655	0.7022	0.5990	0.0093	17.8916
Lev	14655	0.4226	0.2076	0.0072	1.3583
Tobinq	14655	0.3887	0.1821	-0.6121	10.1444
Age	14655	15.0452	5.6203	0.4503	31.6172
Size	14655	12.1081	1.2792	9.4197	22.4773
InGDP	14655	0.4278	0.7231	0.0099	0.5282
Struc	14655	47.6622	8.6522	29.836	62.1703
Estr	14655	9.1026	1.3393	6.6557	11.0324

Table 1 shows the descriptive statistical results of each variable. The average value of investment in fixed assets of enterprises is 0.0622, the maximum value is 0.5582, and the minimum value is -0.1014. The average value of R&D investment in research and development of enterprises is 0.0213, the maximum value is 0.1153, and the minimum value is 0.0033. It can be seen that there are significant differences between the investment in fixed assets and research and development of heavily polluted listed enterprises in China. Meanwhile, the differences of other control variables of the sample are also obvious.

5. Empirical results analysis

5.1. Analysis of benchmark regression results

Table 2 shows that in the regression model where the enterprise fixed asset investment is the explained variable, no matter whether the control variable is added or not, the DID variable Pilot × Post's estimation coefficient is always negative, and it has passed the 1% significance level test, indicating that the pilot policy for low-carbon cities effectively reduces the fixed asset investment of enterprises. This result is consistent with the expectation in Hypothesis 1 that the enterprises' fixed asset investment reduced due to the closure and parallel operation of pollution facilities is greater than the fixed asset investment for the improvement and restructuring of the production system. In the regression model where the enterprise R&D investment is the explained variable, no matter whether the control variable is added or not, the DID variable Policy × Post's estimation coefficient is always positive, and has passed the 1% significance level test. It shows that under the influence of the environmental regulation policy of low-carbon city pilot, the R&D investment of enterprises has

increased significantly, which is in line with the expectation of Hypothesis 2. From the overall perspective, the pilot policies for low-carbon cities can, to a certain extent, promote the green transformation and upgrading of enterprises by reducing the fixed asset investment of enterprises in polluting facilities and operating sites and increasing the investment in production technology R&D and innovation.

Table 2 Benchmark Regression Results of the Impact of Low Carbon City Pilot Policies on Fixed Assets Investment and R&D Investment of Enterprises.

	(1)	(2)
	Inv	*R&D*
Policy ×Post	-0.0495***	0.0179***
	(0.0056)	(0.0065)
ROA	-0.0871**	0.0491**
	(0.0399)	(0.0336)
Grow	0.0103*	0.0135**
	(0.0550)	(0.0750)
Own	-0.059	0.057
	(0.2131)	(0.3843)
Cfo	0.0404***	0.0152***
	(0.0010)	(0.0038)
Lev	-0.2186***	-0.0111***
	(0.0084)	(0.0050)
Tobinq	0.0392**	-0.0568**
	(0.0132)	(0.0402)
Age	0.0033***	-0.0001***
	(0.0016)	(0.0005)
Size	0.0134***	0.0019***
	(0.0023)	(0.0011)
Share	0.0003***	-0.0002***
	(0.0002)	(0.0001)
InGDP	-0.0194***	0.1286***
	(0.0036)	(0.0048)
Pdensity	-0.0029***	0.0314***
	(0.0013)	(0.0021)
Struc	0.0002***	-0.00006***
	(0.0002)	(0.0005)
Urban	-0.0382**	0.0372**
	(0.0422)	(0.0134)
Estr	-0.0143***	-0.0005***
	(0.0063)	(0.0014)
Enter\Year	Y	Y
adj. R^2	0.372	0.383
N	14387	14387

Note: The standard error of variable estimation coefficient is shown in brackets, and * * *, * * and * represent respectively p<0.01, p<0.05 and p<0.1, the same for the following tables.

5.2 Parallel trend test

To ensure the unbiased estimation, the experimental group and the control group should meet the parallel trend assumption. The parallel trend assumption of this policy in this paper means that, in terms of time trend, the fixed asset investment and research and development investment in the experimental group and the control group were basically flat before the implementation of the second

batch of urban pilot projects in 2012, but after 2012, there is no parallel trend. The figure above shows that the trend of enterprise fixed asset investment and R&D investment in pilot areas and non-pilot cities can keep parallel before 2012. However, the two types of investment of enterprises in pilot cities had obvious trend changes compared with enterprises in non-pilot cities after 2012. Therefore, the robustness test results of the parallel trend of enterprise investment levels in pilot cities and non-pilot cities before and after the implementation of the policy are consistent with the parallel trend assumption of this paper.

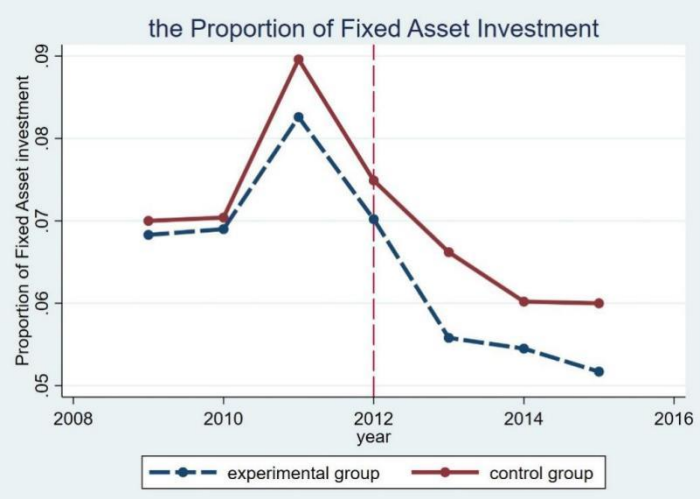

Figure 1 Fixed asset investment of enterprises at the city level before and after the implementation of the pilot policy for low-carbon cities.

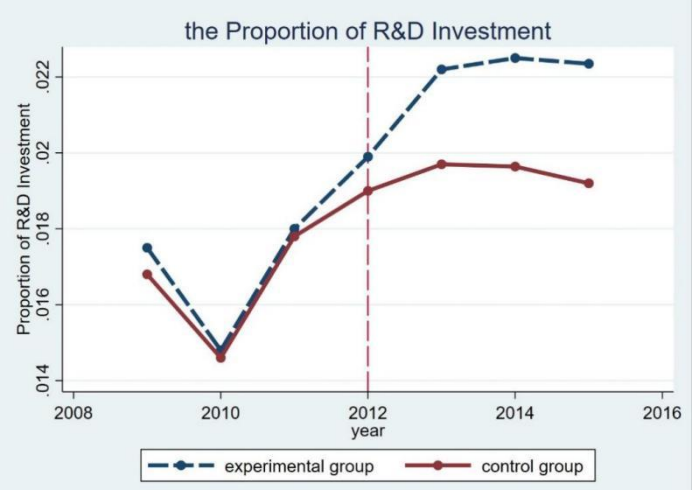

Figure 2 Investment in research and development assets of enterprises at the city level before and after the implementation of the pilot policy for low-carbon cities.

6. Heterogeneity analysis

6.1. Heterogeneity analysis of enterprises in different carbon emission intensity industries

This paper refers to the research of Xu Jia (2021), and divides the sample enterprises into high carbon emission industry group and low carbon emission industry group. The critical point of grouping is the median of the ratio of total carbon emissions of each sample industry to industry GDP. Then each group conducts DID regression respectively [14]. The results in Table 5 show that for the heavy pollution industry with low carbon emissions, the estimated coefficient of Inv is -0.0153 and the coefficient of R&D is 0.0723, both of which fail the 10% significance test. For the high carbon emission industry, the estimated coefficient of Inv is -0.0532, and the estimated coefficient of R&D is 0.0723, and the estimated values of the two explained variables are significant at the 5% confidence

level. It can be seen that the implementation of the policy will lead to significant differences between the two types of investments of enterprises in different carbon emission industries, and make the impact of enterprises in high carbon industries on the two types of investments more significant than that in low carbon industries.

Table 5 Investigate the heterogeneity of different carbon emission intensity of enterprises.

	Inv		R&D	
	Low carbon industry	High carbon industry	Low carbon industry	High carbon industry
	(1)	(2)	(3)	(4)
Policy×Post	-0.0153**	-0.0532***	0.0723*	0.4122*
	(0.0122)	(0.0024)	(0.0516)	(0.0653)
Enter\Year	Y	Y	Y	Y
N	6764	7623	6764	7623
adj.R^2	0.365	0.393	0.375	0.295

6.2. Heterogeneity analysis of enterprises with different ownership

The ownership attributes of enterprises usually have different impacts on their investment strategies. Therefore, this paper draws on the research of Xu Jia(2020), and divides the sample enterprises into two groups according to the ownership of state-owned enterprises and non-state-owned enterprises. Based on the benchmark regression model, this paper examines whether the pilot policies of low-carbon cities will have a heterogeneous impact on the fixed asset investment and research and development investment of different types of enterprises [14]. The estimated results are shown in Table 6. The coefficient of explanatory variables in the state-owned enterprise group is significantly higher than that in the non-state-owned enterprise group, that is, the pilot policy for low-carbon cities can more significantly promote the change of state-owned enterprise assets to the two investment strategies, and the direction of action is to increase the investment in fixed assets and R&D.

Table 6 Examining the Heterogeneity of Enterprise Ownership.

	Inv		R&D	
	State-owned	Non-state-owned	State-owned	Non-state-owned
	(1)	(2)	(3)	(4)
Policy×Post	-0.4741***	-0.0156**	0.4120**	0.0492*
	(0.0123)	(0.0250)	(0.0463)	(0.0744)
Enter\Year	Y	Y	Y	Y
N	5864	8523	5864	8523
adj.R^2	0.362	0.349	0.352	0.259

7. Conclusions and policy implications

Based on the second batch of low-carbon city pilot policies implemented by the state in 2012, this paper uses micro enterprise data to test the two investment paths and mechanisms of low-carbon

policies driving the green and high-quality development of China's heavily polluting enterprises. Research findings:

(1) Low carbon city pilot has a significant negative impact on fixed asset investment of enterprises. From the enterprise level, the fixed asset investment of state-owned enterprises is more affected by the implementation of low-carbon city pilot policies than non-state-owned enterprises. From the urban level, the reduction of enterprise fixed asset investment is more obvious in economically developed regions and regions with high energy consumption; (2) The significant impact of low carbon city pilot policies on enterprise R&D investment is positive. From the perspective of enterprises, the impact on R&D assets investment of state-owned enterprises is greater than that of non-state-owned enterprises; From the urban level, the increase of enterprise R&D asset investment is more obvious in economically developed regions and regions with high energy consumption.

The conclusions of this paper provide the following policy implications to help the country further implement pilot policies and drive the green transformation and upgrading of heavily polluting enterprises:

First, the central government can summarize and refine the existing pilot methods and experience, and expand the implementation scope of low-carbon city pilot by forming typical cases and other methods. As the pilot policy of low carbon cities can promote enterprises to change their investment strategies for fixed assets, it is in line with the goal of enterprises to achieve green transformation and upgrading by closing, shutting down and transforming heavily polluting operating facilities and technological innovation and production systems, thus promoting the development of China's green low carbon economy. Therefore, the central government can summarize the experience of the pilot method with good implementation effect and follow the implementation method of "pilot first and then promotion", which will help to achieve China's "dual carbon" goal from the urban level. Second, the central government should further promote the national macro environmental policies to effectively stimulate the enthusiasm of innovation subjects in cities from the micro level. The research results show that enterprises are the main body of innovation in cities, and the implementation of the pilot policy of low-carbon cities will promote enterprises to increase their investment in technological innovation and R&D, thus contributing to the overall transformation and upgrading of the industry. Therefore, a reasonable coordination of low-carbon city pilot policies and other incentive policies of the state for investment in enterprises will help the macroeconomic regulation and microeconomic policies to coordinate and advance side by side. Meanwhile, when implementing this environmental regulation, each pilot region can guide enterprises to invest in green industry system and environmental protection technology research and development by formulating appropriate incentive policies. Based on these enterprises can cultivate new urban development drivers while improving their own R&D and innovation capabilities to achieve their own transformation and upgrading, ultimately promote the construction of low-carbon cities further.

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