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Research on the impact of green finance policies on natural environment changes—a quasi-natural experiment based on green finance reform and innovation pilot zones

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Abstract. This paper examines whether China's green finance reform pilot zones improve environmental performance and how such effects are transmitted. The 2017 pilot-zone policy provides a quasi-natural experimental setting for the analysis. Observations covering 2013–2021 are examined through a Difference-in-Differences (DID) approach. The estimation result shows an improvement in environmental performance after the green finance pilot zones were introduced. This effect is regionally heterogeneous, with a stronger influence in eastern China than in western China. A mediation model further indicates that the policy effect is an important channel: green finance influences market behavior and thereby contributes to environmental improvement. These results provide evidence for policymakers seeking to use green finance as a tool for environmental governance.

Keywords: green finance, environment, difference-in-differences, heterogeneity

1. Introduction

The idea of green finance appeared in 1991, although Western developed economies had already begun experimenting with environmentally oriented finance in the 1970s as environmental deterioration became more serious. In essence, green finance directs financial resources to environmental protection and to projects that make economic and social development more environmentally friendly and less polluting. Such projects often yield little or no profit under pure market conditions, but they generate substantial public benefits. This explains why green finance emerged.

This paper follows the definition of the Organisation for Economic Co-operation and Development: green finance refers to financial services provided to achieve economic growth while reducing pollution and greenhouse gas emissions, minimizing waste, and improving the efficiency of natural resource use.

In 2017, China launched green finance reform pilot zones across five provinces and eight cities, including Quzhou and Huzhou in Zhejiang, Ganjiang New Area in Jiangxi, Huadu District in Guangzhou, Gui'an New Area in Guizhou, and Hami, Changji, and Karamay in Xinjiang. Lanzhou New Area joined in 2019, and Chongqing joined in 2022.

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These pilot zones reflect the diverse economic characteristics of different regions in China. Each pilot zone has therefore formulated a local green finance plan according to local conditions. Guangzhou, as a major economic province, has involved the Guangzhou Carbon Exchange in drafting and formulating green finance standards. Xinjiang focuses on agriculture and the petroleum and petrochemical industries. Quzhou in Zhejiang, which has many small and medium-sized enterprises, has established local green enterprise standards and green credit standards. Ganjiang New Area in Jiangxi has also created standards based on local realities.

After decades of development, green finance has developed international standards, but these standards are largely based on the realities of developed countries. China's conditions may not fully match these standards, and green finance tools are diverse. At present, green finance tools can be divided into four main types: financing instruments, carbon emission trading systems, green insurance, and green funds. For financing instruments, credit, bonds and equity financing are the main forms used under green finance. Among them, green credit occupies the dominant position because the green industry worldwide is still not sufficiently profitable and requires substantial credit support. The carbon emission trading system remains in a pilot stage in China and has not been widely rolled out. Green insurance is gradually expanding and advancing steadily, but it also imposes a large funding burden. Green funds have not been fully promoted in China, and their scale is not large. This paper therefore starts from green finance policy and studies its environmental impact through the financing channel, especially green credit.

2. Literature review

Existing research has examined green finance from several perspectives. For Zhao Haifeng [1], the research objects were listed firms with heavy pollution in eastern China. Zhao Haifeng examined the change of green investment before and after the green credit policy by DID. The empirical result presents a restraining effect for heavily polluting firms in eastern China.

Muganyi et al. [2] combined text analysis with city-level data collected for 290 cities during 2011–2018. A semi-parametric DID was used in the study. Industrial gas emissions were significantly reduced during the period examined under China's green finance-related policies. When green finance works together with environmental regulation, carbon dioxide emissions can also fall and sustainable economic development can be promoted.

For Huang and Zhang [3], China's 2017 green finance pilot reform was taken as the policy event for their empirical study. Their provincial panel covered 30 administrative regions over 2011–2019, and PSM-DID was employed under a quasi-natural experimental design. The policy was found to reduce environmental pollution. Where the original pollution problem was more serious, the policy worked more strongly.

Khan et al. [4] examined ecological change across 26 Asian economies by an ordinary least squares model. Their empirical result gives support to an environmental benefit from green finance. In the Chinese case, establishing pilot areas for green finance reform is one policy arrangement used by the government to move toward green economic development.

Lu et al. [5] selected 3,236 firms from China's A-share market, with the observations covering 2011–2018. Lu et al. [5] compared corporate green technology innovation around the introduction of the pilot reform by DID. The estimation shows that enterprise green technology innovation increased significantly after the green finance pilot policy was put into practice.

The 2017 pilot reform was regarded by Zhang and Li [6] as a quasi-natural policy experiment, and DID was applied to corporate green innovation. Following implementation, green innovation increased not only in

amount but also in quality. Their mechanism analysis further found more R&D input together with an expansion of credit.

Lin et al. [7] used observations for 30 Chinese provinces over 2007–2019 to study the low-carbon transformation of electricity production. DID was employed for the empirical analysis. With the development of green finance, the share taken by thermal power in total electricity generation was found to fall significantly.

Ma Wenxiu and Wu Yangkang [8] worked with micro-enterprise observations for China over 2000–2009. They regarded the COD emission-control program under the "*Eleventh Five-Year*" Plan as a quasi-natural experiment. DID and event analysis were then used to look at the change of enterprise trade modes. Their findings were that environmental regulation promoted transformation in both quantity and quality, mainly by higher costs and technological improvement.

Yan Sitong [9] first measured green development for 282 prefecture-level cities with the SBM model. For 113 cities, the release of PITI was treated as a quasi-natural experiment, and DID was adopted for its net effect on urban green development. The conclusion supports a promoting role of informal environmental regulation and remains robust. Looking at resource endowment and region, the improvement is significant for non-resource-based cities and central cities. The effect becomes stronger at medium and high levels of economic development, while for human capital it is stronger at both the low and high levels. Areas having higher public income and education expenditure also present a more obvious green development effect.

Zhang Jiao [10] started from the problems existing in financial services for manufacturing. The paper then discussed the support of financial innovation for high-quality manufacturing development, with attention mainly put on fund-use efficiency, technological innovation and upgrading.

Shi Xing and Zhang Ya [11] selected green patent information from firms traded on the Shanghai and Shenzhen A-share markets over 2008–2019. DID was applied to judge whether the pilot zones changed corporate green technology innovation and how the change was produced. Improvement appeared in two aspects after the pilot-zone policy, including the number of green innovations and their quality. From the dynamic test, this effect on high-quality green innovation does not disappear in the longer period.

For Zhu Jiexi and Li Junjiang [12], city panel data covering 282 Chinese cities during 2011–2020 were used to study manufacturing export upgrading under development of the digital economy. The mediation mechanism and spatial spillover were put into the analysis as well. According to the estimation, manufacturing export upgrading can be effectively promoted with development of the digital economy. Technological innovation and upgrading of industrial structure are two important intermediary channels.

The sample in Liu Yiwan [13] consisted of manufacturing firms on the two A-share markets in Shanghai and Shenzhen, with observations over 2007–2022. A DID model was adopted for the carbon emission trading pilot policy and manufacturing total factor productivity. After the trading mechanism was introduced, total factor productivity in the pilot areas was effectively improved.

Liu Zhihua and Xu Junwei [14] constructed a balanced provincial panel covering 30 provinces during 2007–2021. Multi-period DID and spatial DID, together with mediation analysis, were used for examining carbon emission equity at the provincial level. Once the carbon trading pilot was implemented, provincial carbon emission equity improved significantly. A positive spatial spillover was found at the same time.

Hui Li et al. [15] treated the creation of demonstration zones for industrial transformation and upgrading as a quasi-natural experiment. Their firm sample came from China's A-share market and covered 2010–2019. With staggered DID, financing constraints under the green finance demonstration-zone policy were examined, together with heterogeneity of the treatment effect. The study found a significant easing of financing constraints for enterprises inside the relevant jurisdiction.

From the above literature, research on green finance mainly starts from carbon neutrality, and some studies also examine other consequences of the pilot-zone policy. However, when local data cannot be obtained, provincial observations are often used in place of regional data, and the precision of the analysis is reduced. On the basis of these studies, this paper makes two further attempts. One is to examine in more detail how the green finance reform pilot zones affect environmental change. The other is to study and put forward the mechanism through which green finance acts on the environment.

The rest of the paper is arranged as follows. Part II introduces the pilot zones and develops the hypotheses. Part III gives the data sources, sample selection, methods, variables and descriptive analysis. Sample matching, benchmark regression, heterogeneity regression and robustness tests are reported in Part IV. Part V constructs the mediation model and then carries out mechanism and heterogeneity tests. Conclusions and discussion are given in Part VI.

3. Introduction to green finance reform pilot zones and theoretical hypotheses

3.1. Introduction to China's green finance reform pilot zones

China started the first group of green finance reform pilots in 2017. The program covered eight areas distributed across five provinces: Huzhou and Quzhou in Zhejiang, Ganjiang New Area in Jiangxi, Guangzhou's Huadu District, Gui'an New Area in Guizhou, together with Hami, Changji and Karamay in Xinjiang. Lanzhou New Area was added in 2019, and Chongqing was added in 2022. Because Chongqing was approved relatively late and its practical significance is not yet prominent, this paper does not focus on it.

The basic principles of these pilot zones are to adhere to green innovation and serve the real economy. Based on serving the real economy and preventing the economy from becoming disconnected from it, the pilot zones use financial reform and innovation as a breakthrough. They explore new ideas, new models, and new paths for financial support for green development. They aim to build a differentiated financial service system that conforms to the positioning of main functional zones, highlight local characteristics, reasonably design financial products that meet actual needs, guide financial resources to increase investment in energy conservation and emission reduction, circular economy, and ecological protection, form a resource allocation system that supports green industry development, and provide new impetus for green industry development in the pilot zones.

The pilot zones also adhere to steady and orderly progress and risk prevention. According to the idea of "active and prudent, powerful and orderly, precise and pragmatic, easy first and difficult later, controllable risks, and promote one item once mature", they strengthen risk awareness, improve the ability to identify new risks in green finance, steadily advance green finance reform and innovation, scientifically design risk early warning and prevention and disposal mechanisms, ensure the safe and stable operation of green finance, and hold the bottom line of preventing systemic financial risks.

Since the research purpose of this paper is to study the impact of the policy on local areas, the documents of each green finance reform pilot zone are interpreted here based on public materials.

For Gui'an New Area, a special task list was prepared to guide construction of the local green finance pilot. The main work and policy targets were specified in this list, mainly including building green-finance organizations at different levels and developing new financial products as well as service approaches, broadening financing channels for green industries, accelerating the development of green insurance, consolidating green finance infrastructure, building a green finance risk prevention and resolution mechanism, establishing and improving a green finance statistical system, and increasing policy support.

From 2018 to 2020, the green credit loan balance of Gui'an New Area reached 30 billion yuan, with a target of 50 billion yuan; the cumulative scale of green bonds reached 5 billion yuan, with a target of 10 billion yuan; the scale of green funds reached 10 billion yuan, with a target of 20 billion yuan; and the coverage of green insurance continued to expand. It can be seen that the main directions of green finance in Gui'an New Area are still credit, bonds, funds, and insurance. Moreover, the economic volume of Gui'an New Area is not large.

Zhejiang Province has two pilot cities, but their positioning differs. Huzhou focuses on financial support for green industry innovation and upgrading, while Quzhou focuses on financial support for green transformation and upgrading of traditional industries. Although both start from credit, bonds, funds, and insurance, their emphases differ. They explore innovations in pledge financing models such as major pollutant emission rights, water rights, forest rights, franchise rights of energy-saving and environmental protection projects, sponge city construction and black-odorous water body remediation PPP project income rights, and green engineering project charging rights and income rights. They also increase support for the prevention and control of air pollution, soil pollution, and water pollution. They mainly support qualified "two high and six new" green enterprises—high growth, high technology, new economy, new service, new energy, new material, new agriculture, and new model—to list on the small and medium enterprise board, ChiNext, and main board. Institutional arrangements are also developed so that green finance can be used for smaller cities and locally distinctive towns. These emphases show that urban construction in Zhejiang is at the forefront of the country.

Huzhou's strategy is to determine eight pillar industries and then apply the green finance framework constructed by the five pillars proposed in the "G20 Transition Finance Framework"—definition standards, disclosure requirements, financial tools, policy incentives, and just transition—to these eight pillar industries. It then formulates detailed rules and calculation standards. The goal is not only to urge enterprises to undergo green transformation but also to urge them to be competitive, thereby building Huzhou into a better, more beautiful, and more competitive city.

Quzhou's main characteristic is to establish carbon accounts for enterprises and individuals. Through the construction of the carbon account system, each entity has a clear account in mind, thereby promoting the joint force of Quzhou's green transformation.

Guangzhou's support for green finance is relatively strong and obvious. The main policy is to provide corresponding subsidies to enterprises that move to Huadu. Enterprises participating in green credit, green bonds, green insurance, and other financial businesses are given corresponding subsidies, ensuring their profit space. Financial institutions participating in green credit, green bonds, green insurance, and other businesses are also given subsidies for their losses. It can be said that Guangzhou's policies, relying on its abundant financial resources, take care of the interests of both enterprises and financial institutions, and it has indeed done very well in green finance. But this measure is not universal, because not every local government in the country has the financial resources of the Guangzhou municipal government. The purpose of this green finance innovation pilot zone is to see whether market forces can be used to allocate market resources more efficiently, so that the economy can return to a green and sustainable growth path. This is the original intention of establishing this pilot zone.

The actual situation in Xinjiang is that traditional industry is not developed, and agriculture is dominant. Therefore, the green finance experiment is mainly based on traditional industry and agriculture, and the realization method of green finance is also mainly green credit, especially credit from large state-owned banks. Local financial resources are weak, and the government mainly provides policy support. Jiangxi's green finance is not outstanding and is only carried out step by step.

In general, the common points of these local green finance reforms are green orientation, innovative development, overall coordination, highlighting key points, market operation, government guidance, pilot first,

and controllable risks. That is, through pilot projects, it is necessary to gradually transform the operation mode of China's economy from the original high-pollution and high-energy-consumption mode to a low-pollution, high-efficiency, and green operation mode through market operation.

Of course, there are also differences. The green finance experiments in these regions combine local characteristics. Guangdong and Zhejiang are developed regions, but there are also certain differences. Guangdong has a stronger atmosphere of market economy, while Zhejiang has more color of government leadership. Lanzhou and Xinjiang represent the northwest region, where the singleness and weakness of the economic structure are clearly visible, and they mainly engage in the transformation of traditional industries. Guizhou and Chongqing represent the southwest region, and green finance is also more government-led. In more developed regions, the available forms can be carbon emission trading and funds, while in less developed regions, the main forms are green credit and green bonds.

3.2. Theoretical hypotheses

Environmental problems have always accompanied China's reform and opening-up process. At the beginning, some industries introduced by China were high-energy-consumption and high-pollution enterprises. These enterprises brought jobs and GDP to China, but as China's GDP continued to grow, the negative effects on the environment gradually emerged and appeared in newspapers from time to time, such as the spring sandstorm events in Beijing and the blue-green algae events in the Taihu Lake Basin. These typical events fully show that China's environmental deterioration has reached a very serious level, and environmental protection is urgent. The establishment of the Ministry of Environmental Protection was a landmark event, marking that environmental protection would have a systematic department to manage it and be incorporated into the height of national governance. The Ministry of Environmental Protection issued many policies, mainly through administrative means to stop environmental deterioration, and these policies achieved obvious results. What this study wants to establish is a socialist market economy. Using market economy means to protect the environment is a conventional means. In 2017, China successively established green finance reform pilot zones. Through these pilot areas, green finance is tested as a market-based means for pushing regional development toward a more sustainable direction.

Hypothesis 1: Environmental conditions in the pilot areas are improved by the implementation of green finance reform.

As analyzed above, the Chinese government has been committed to environmental improvement in recent years. Green finance is only one means of promoting environmental improvement. The concern here is whether an observable environmental change follows the green finance policy and whether such an approach has value for wider application. Although green finance in other parts of the world started very early, the effects are not very obvious, because either projects engaged in green finance are not very profitable, or projects engaged in green finance are difficult to meet the standards of green financial institutions.

China's implementation of this green finance reform pilot zone is to see whether this method has promotional value and whether it can bring very obvious effects.

At the same time, it should see that China has a vast territory, and conditions vary greatly from place to place. Therefore, Guangdong and Zhejiang in the east, and Guizhou and Xinjiang in the west were selected. Guangdong and Zhejiang are relatively developed regions in China, with relatively active market economies, many private enterprises, and many small enterprises. They are also at the forefront of China's market transformation. Low-interest green finance loans have huge attraction for some small and medium-sized enterprises, attracting some small and medium-sized enterprises to transform in a green direction, thereby continuously improving competitiveness. Guizhou and Xinjiang represent underdeveloped regions, dominated

by state-owned enterprises, with inactive market economies. State-owned enterprises are not very sensitive to market competition, and the interest rate preference of green finance may not necessarily move state-owned enterprises. In terms of people's concepts, there are also huge differences between the east and the west.

Hypothesis 2: The environmental effect of green finance differs with the economic development level of the region. That is, the degree to which green finance promotes the environment of the pilot zones differs due to differences in regional economic development levels. This is not difficult to understand. In developed regions, private enterprises usually account for a larger part, and resources as well as development opportunities are more abundant. Green finance can therefore play a greater role. In developing regions, these conditions are relatively weaker, and the role of green finance is correspondingly smaller.

4. Research design

In 2017, the green finance reform pilot zones were established, and this event is used here for the empirical analysis. Environmental conditions around the policy year are compared between relevant areas, through which the possible influence of green finance on the environment is examined. At present, studies directly dealing with this relation are still not many. The pilot design covering five provinces and eight zones therefore supplies a quasi-natural experimental condition and, to some extent, reduces the endogeneity disturbance.

4.1. Sample selection and data sources

The empirical data are collected from several sources. Statistical information mainly comes from the *China Statistical Yearbook*, the *China City Statistical Yearbook*, and statistical yearbooks published at provincial level. Local yearbooks for cities such as Huzhou, Quzhou, Ganzhou and Guangzhou are also used. Environmental records are obtained separately from 2345 Weather Forecast and the historical information of the China Air Quality Online Monitoring and Analysis Platform. For each area, the environmental record on June 1 is taken to stand for the environmental condition of that year.

Observations from 2013 through 2021 are used, giving a panel covering nine years. Lanzhou New Area and Chongqing joined a later group of green finance pilot areas in 2022. These two areas are left out of the present sample. One consideration is the difficulty of obtaining data, while another is that their policy period is too short and the effect of green finance may appear with a lag. They are also not treated as control areas. For Hami, Changji and Karamay, the data are not complete in some years. Different reasons caused part of the observations to be unavailable. As a result, an unbalanced panel is finally formed for the empirical work.

4.2. Research methods

There are different ways to evaluate the economic effect produced by a policy. DID, regression discontinuity and synthetic control are commonly used, but each has its own applicable situation. Taking the characteristics of the policy and the available data into consideration, this paper finally adopts DID.

Two groups and two time periods are involved in DID. One group receives the policy treatment and the other does not. For time, observations are separated into the period before intervention and the period after it. The control group remains without intervention in both periods, whereas policy treatment appears for the experimental group in the later period. Changes over time are first obtained separately for the two groups. These two changes are then compared again, and the policy effect can be obtained from this second difference.

The general DID model form is as Equation (1):

$$Y_{it} = \alpha_0 + \alpha_1 du + \alpha_2 dt + \alpha_3 du * dt + \varepsilon_{it} \tag{1}$$

In Equation (1), du separates the two sample groups. An observation is coded $du = 1$ when city i belongs to the policy-treated group; otherwise $du = 0$. The time dimension is represented by dt, which changes from 0 before the intervention to 1 after it. Multiplying du and dt combines the group difference with the time change. The coefficient α_3 is therefore used for the net treatment effect of the policy. Here, i refers to the city, and t refers to the year.

Y_{it} refers to the environmental quality of city i in year t.

Following the DID setting above, the sampled cities are separated into two categories. The treatment group contains Huzhou and Quzhou, together with Guiyang, Guangzhou, Ganzhou, Hami, Changji and Karamay; all other sampled cities are placed in the control group. A binary group indicator, $du = [0, 1]$, is then defined. Pilot cities receive $du = 1$, whereas $du = 0$ is given to control cities. For the time dimension, 2017 is taken as the dividing year because the policy document for the green finance reform pilot zones was released in that year. Another dummy, $dt = [0, 1]$, is therefore constructed. Considering the lag of policy implementation, dt remains 0 for 2017 and all earlier years and changes to 1 after 2017. The product $du * dt$ is used to represent the treatment brought by the 2017 pilot-zone policy. The DID test finally examines whether the change in the treated cities differs significantly from that in the control cities across the two periods.

A basic requirement of DID is that the two groups should have the same time trend when policy treatment does not occur. If this condition is satisfied, the additional change appearing in the treated group after intervention can be regarded as the policy effect. Green finance gives preferential financial services to the related enterprises, including services of lower cost, wider coverage and higher quality. In this way, enterprise competitiveness can be improved. To obtain and maintain such financial support, enterprises will also make adjustment according to the requirements of green finance, which finally produces an improvement in environmental quality.

PSM is not introduced before the DID estimation in this paper. The consideration is that the pilot zones are directly stipulated by policy rather than selected from the sample by the researcher, and therefore sample-selection bias is not regarded as existing here. Since propensity score matching is mainly applied for reducing this kind of bias, it is considered unnecessary in the present case.

The DID model can also be written in the form shown in Equation (2):

$$Y_{it} = \alpha_0 + \alpha_1 du_{it} + \alpha_2 dt_{it} + \alpha_3 du_{it} * dt_{it} + \beta \mathrm{X}_{it} + v_j + v_k + \varepsilon_{it} \tag{2}$$

Here Y_{it} is the control variable affecting urban environmental quality. Here v_j refers to the time fixed effect, and v_k refers to the region (individual) fixed effect. Equation (2) is used as the benchmark specification for estimating the treatment brought by the 2017 green finance pilot policy.

4.3. Variable description and descriptive analysis

Variable description: Selection of the explained variable. (1) Here it selects indicators representing regional environmental quality as the explained variable. There are many indicators representing environmental quality (such as solid waste and liquid waste; the reason these were not selected is mainly because they are not as evenly distributed as air environmental quality, are not felt as strongly, and are not easy to obtain). Environmental quality is represented by six air-pollution indicators. For particulate matter, the annual mean concentrations of atmospheric inhalable Particulate Matter (PM10) and Fine Particulate Matter (PM2.5) are used. The annual mean concentrations of Sulfur Dioxide (SO2) and Nitrogen Dioxide (NO2) are also included. CO is measured by the 95th percentile of its daily average concentration, while O3 is represented by the 90th percentile of the maximum 8-hour concentration. These six measures enter the model as explained variables. In order to eliminate systematic errors caused by too large an order of magnitude of the data, logarithmic form

is selected. (2) Selection of explanatory variables: According to the above formula, this paper takes the grouping dummy variable (du), the time dummy variable (dt), and their interaction term ($du * dt$) as explanatory variables. Among them, the grouping dummy variable measures the difference between cities that implemented green finance reform demonstration zones and cities that did not; The time dummy records the change across the policy period for both city groups. Their interaction captures the additional environmental change appearing in treated cities once the pilot policy is in operation. This is the core explanatory variable of this paper. (3) Selection of control indicators: There are many factors affecting the environment. Combining previous methods and data availability, this paper selects the following indicators: 1) Urbanization indicator (czh). Urbanization obviously affects the environment. Through news reports in recent years, it can be known that places with developed urbanization either have considerable enterprises, or are central cities. Enterprise emissions definitely pollute the environment. If it is a central city, news of car restrictions is often heard, indicating that emissions affect the environment. Similarly, urbanization affects the environment. Urbanization is measured by dividing the urban population at year end by the region's total population at the same time. Since 1998, China has begun the process of urbanization. 2) Economic development level (GDP). According to the environmental Kuznets inverted U curve, per capita income is related to the environment, so per capita income affects the environment. Here, based on data availability, per capita gross national product is used instead. In order to eliminate systematic errors caused by too large an order of magnitude of the data, logarithmic form is selected. 3) Secondary Industry Development Degree (SECD). Secondary industry refers to industry and construction. These industries definitely affect the environment. The share of value added produced by the secondary industry is used to represent its development level. In order to eliminate systematic errors caused by too large an order of magnitude of the data, logarithmic form is selected. 4) Financial development scale (FN). Based on data availability, for some cities the financial development scale is replaced by financial industry output value, and for other cities the financial industry development scale is replaced by financial industry added value. Regions with relatively developed finance have considerable convenience and low cost for financing and are more likely to transform the environment. Here, the sum of deposits and loans of banking financial institutions divided by regional gross domestic product is selected as the indicator to measure financial scale. In order to eliminate systematic errors caused by too large an order of magnitude of the data, logarithmic form is selected. 5) Total Civil Vehicle Ownership (CAR). Car ownership not only indicates the degree of economic development, but also brings considerable pollution. From the perspective of data availability, for some cities it refers to civil vehicle ownership, and for some cities it refers to the sum of public buses and taxis.

Preliminary descriptive analysis: Some pilot areas do not directly correspond to the statistical units adopted in this study. Gui'an New Area is located in Guiyang, Huadu District belongs to Guangzhou, and Ganjiang New Area is in Ganzhou. The required indicators cannot be obtained at the county or new-area level. Therefore, the city data of Guiyang, Guangzhou and Ganzhou are respectively taken as substitutes. Most cities selected in the sample are provincial capitals, with Hami, Changji, Karamay and Ganzhou being the exceptions. Lanzhou and Chongqing are not considered here. Both entered the green finance pilot program only in 2022, as members of its second group of pilot areas. From the time trend, pollution indicators in the sample cities generally declined under the environmental policy efforts of the Chinese government. Another direction appears for the other indicators. Urbanization rate, per capita GDP, added value of secondary industry, civil vehicle ownership and financial industry output value all increased along with China's rapid development during the past two decades. Such changes basically conform to the actual development situation in China.

5. Estimation results and analysis

5.1. Baseline regression results and analysis

Annual regression results obtained from Formula 2 are reported first. Four specifications are arranged for comparison. Model 1 keeps only the test variables. Regional and year effects are introduced in Model 2, while Model 3 instead adds the control variables to the basic specification. Model 4 contains both kinds of fixed effects together with the controls.

Table 1. Benchmark model estimation results with so_2 as the explained variable

variable	model 1	model 2	model 3	model 4
T	-0.82450868	-1.5789168	-0.64405647	-1.3553002
	(0.0760334)	(0.0730027)	(0.0758159)	(0.096494)
Treated	-0.35540356	0.57034051	-0.19841031	0.00178133
	(0.1425141)	(0.1564894)	(0.1833479)	(0.3039517)
T* Treated	0.05561526	-0.03596302	0.21699693	0.21913769
	(0.2053044)	(0.0982148)	(0.2711864)	(0.1374255)
CZH			0.59365036	-0.0728006
			(0.2147875)	(0.2229424)
LNGDPP			-0.64158393	-0.05832279
			(0.1253568)	(0.1208077)
LNSECD			0.56052642	0.08944801
			(0.0699122)	(0.0678132)
CAR			0.06763932	-0.04823355
			(0.0300375)	(0.050069)
LNFN			-0.74931097	0.09159383
			(0.1009813)	(0.1102594)
Regional effect	no	yes	no	yes
Year effect	no	yes	no	yes
Cons	3.0652707	2.9017758	13.148898	2.2705077
	(0.050689)	(0.108539)	(1.344607)	(1.264284)
Observation value	302	302	302	302
R^2	0.3295	0.8683	0.4917	0.8907

The following insights can be drawn from Table 1, for SO2, Model 4 is mainly discussed here. The interaction term T*Treated carries a positive and significant coefficient, and the pilot-zone policy is therefore considered to have an evident influence on SO2 emissions. At the same time, T is negative and significant, showing an obvious time change of SO2 in the experimental areas when compared with the non-experimental ones. Treated also passes the significance test. This means that some difference between the two groups had already existed prior to the pilot-zone establishment. Looking across Models 1–4, the direction of the core coefficient is not much changed, although its significance is rather different.

Table 2. Benchmark model estimation results with $\ln^{NO_2}$ as the explained variable

variable	model 1	Model 2	Model 3	model 4
T	-0.23623459	-0.62309326	-0.26375891	-0.20002555
	(0.047407)	(0.0467192)	(0.0433819)	(0.0614312)
Treated	-0.50688851	-0.32694843	-0.18730377	0.1136567
	(0.0785589)	(0.09968)	(0.1049117)	(0.1935056)
T* Treated	0.10767746	0.12149577	0.06834677	0.08576439
	(0.1122173)	(0.0557995)	(0.155173)	(0.0874895)
CZH			0.15266737	0.00186487
			(0.1229015)	(0.1419324)
LNGDPP			-0.21354558	0.02228167
			(0.0717292)	(0.0769102)
LNSECD			0.21903756	0.01729285
			(0.0400038)	(0.0431721)
CAR			0.01415913	0.0201313
			(0.0171875)	(0.0318755)
LNFN			-0.06686889	-0.04993019
			(0.0577815)	(0.0701947)
Regional effect	no	yes	no	yes
Year effect	no	yes	no	yes
Constant	3.7098619	3.8726869	5.0427243	3.8540514
	(0.0316047)	(0.0701504)	(0.7693846)	(0.8048846)
Observation value	263	263	263	263
R^2	0.2340	0.8383	0.2934	0.8118

The following insights can be drawn from Table 2, a pre-policy difference appears first in the $\ln^{NO_2}$ result of Model 4, since Treated is significant after the other factors are put into the regression. The treatment and control cities therefore did not have the same $\ln^{NO_2}$ level before the policy experiment. For T, a negative and significant result is obtained, which shows that the experimental areas have an evident time change relative to the other cities. T*Treated is further estimated to be positive and significant. On this basis, the pilot-zone establishment is regarded as affecting $\ln^{NO_2}$ emissions. Among the four specifications, coefficient signs remain relatively stable, but the significance does not.

Table 3. Benchmark model estimation results with PM10 as the explained variable

variable	model 1	model 2	model 3	model 4
T	-0.42805479	-0.90710193	-0.37549413	-0.58042137
	(0.0496547)	(0.054079)	(0.0518288)	(0.0672237)
Treated	-0.57000107	-0.46269835	-0.39237235	-0.26567599
	(0.0822836)	(0.1153918)	(0.1253392)	(0.2117516)

Table 3. Continued

T* Treated	0.08929562 (0.1175377)	0.05036891 (0.0645898)	0.03467153 (0.1853868)	0.04069017 (0.0957391)
CZH			0.23993091 (0.1468317)	0.07568199 (0.1553155)
LNGDPP			-0.27981447 (0.0856956)	-0.06377849 (0.0841621)
LNSECD			0.27168419 (0.047793)	0.01456781 (0.0472429)
CAR			0.04079898 (0.0205341)	0.03492833 (0.0348811)
LNFN			-0.30292791 (0.0690322)	-0.00800637 (0.0768135)
Regional effect	no	yes	no	yes
Year effect	no	yes	no	yes
Constant	4.5525351 (0.0331031)	4.7483604 (0.0812015)	8.5084205 (0.9191921)	5.0629978 (0.8807786)
Observation value	317	317	317	317
R^2	0.3545	0.8336	0.3670	0.8586

The following insights can be drawn from Table 3, the four PM10 regressions give coefficients with generally similar directions, whereas their significance varies. More directly, T*Treated in Model 4 is positive and significant, so This interaction result is interpreted as an effect of the pilot policy on PM10. Treated is also significant, implying that the PM10 situation of the two groups was already different before the experiment. The negative coefficient of T passes the significance test as well. PM10 in the pilot areas thus changes obviously along the time dimension compared with non-pilot areas.

Table 4. Benchmark model estimation results with CO as the explained variable

variable	model1	model 2	model 3	model 4
T	-0.72172414 (0.1035911)	-1.9988797 (0.1178647)	-0.54902386 (0.1143049)	-1.2055013 (0.1642723)

Table 4. Continued

Treated	-1.056436 (0.1716624)	-1.4942834 (0.2514954)	-0.69347811 (0.2764271)	-1.3212153 (0.5174503)
T* Treated	0.50508128 (0.2452107)	.37674418 (0.1407728)	0.45719128 (0.408858)	0.42688216 (0.2339545)
CZH			0.78567741 (0.3238275)	-0.15771137 (0.3795393)
LNGDPP			-0.50214698 (0.1889959)	0.28781045 (0.2056643)
LNSECD			0.45096228 (0.1054042)	0.00478341 (0.1154459)
CAR			0.17412058 (0.0452865)	-.02565084 (0.0852379)
LNFN			-0.83965291 (0.1522459)	-0.0693608 (0.1877067)
Regional effect	no	yes	no	yes
Year effect	no	yes	no	yes
Constant	2.0337931 (0.0690607)	3.1075052 (0.1769779)	11.963876 (2.027216)	.88280344 (2.15233)
Observation value	263	263	263	263
R^2	0.2366	0.7852	0.2815	0.8030

The following insights can be drawn from Table 4, the time effect is quite clear in the CO regression. In Model 4, T takes a negative value and is significant, and CO changes with time in both the experimental and non-experimental areas. Before considering the policy effect itself, Treated also shows significance, which reflects an original difference in CO between the two groups. The interaction gives another result: T*Treated is positive and significant. The CO result is therefore treated as another environmental response to the green finance pilot policy. The significance of the coefficients is not fully stable among Models 1–4, although their directions change less.

Table 5. Benchmark model estimation results with O_3 as the explained variable

variable	Model 1	Model 2	Model 3	Model 4
T	0.08550827 (0.0326053)	-0.07248563 (0.0462107)	0.03793823 (0.0318762)	0.22659603 (0.0598111)
Treated	-0.17830854 (0.0540307)	-0.59093742 (0.0986026)	-0.0976282 (0.0770873)	-0.10557497 (0.1884023)
T* Treated	-0.09649805 (0.07718)	-0.06454556 (0.0551921)	-0.21025906 (0.1140184)	-0.18240803 (0.0851822)
CZH			0.16331935 (0.0903059)	0.14292795 (0.1381893)
LNGDPP			0.0209862 (0.0527053)	0.07136321 (0.0748818)

Table 5. Continued

LNSECD			0.04239478 (0.293941)	-0.03968561 (0.0420336)
CAR			0.0009712 (0.126291)	0.01898092 (0.0310349)
LNFN			0.03888271 (0.0424569)	-0.03394744 (0.0683435)
Regional effect	no	yes	no	yes
Year effect	no	yes	no	yes
Constant	4.9015758 (0.0217368)	5.1207875 (0.0693869)	3.8615849 (0.5653303)	4.7078423 (0.7836577)
Observation value	317	317	317	317
R^2	0.1133	0.6128	0.1851	0.6190

Table 5 gives the estimation for O_3. Among the different model settings, the core coefficient does not show a large change in direction, but its significance varies obviously. According to the interpretation of Model 4, O_3 had already differed between treatment and control areas before the pilot policy, as Treated passes the significance test. The analysis also reports T as negative and significant, meaning that O_3 in experimental areas has a clear time change compared with non-experimental areas. For the interaction, a positive and significant effect is reported. The pilot-zone establishment is consequently considered to influence O_3 emissions.

Table 6. Benchmark model estimation results with $\ln^{PM2.5}$ as the explained variable

variable	Model 1	Model 2	Model 3	Model 4
T	-0.44715142 (0.0576957)	-1.1364814 (0.0642674)	-0.39986193 (0.0547906)	-0.55550795 (0.0774756)
Treated	-0.32410401 (0.1081425)	-0.50027147 (0.1377644)	-0.24930628 (0.1325019)	-0.21164124 (0.2440445)
T* Treated	-0.06362866 (0.1557891)	-0.10621565 (0.0864627)	-0.0665336 (0.195981)	-0.04004091 (0.1103397)
CZH			0.26082204 (0.1552226)	0.07864618 (0.1790016)
LNGDPP			-0.47859857 (0.0905928)	-0.09449424 (0.0969972)
LNSECD			0.39712555 (0.0505242)	0.05323307 (0.0544476)
CAR			0.05637823 (0.0217075)	0.04992935 (0.0402007)
LNFN			-0.296905 (0.0729772)	-0.07613921 (0.0885279)
Regional effect	no	yes	no	yes
Year effect	no	yes	no	yes

Table 6. Continued

Constant	3.9628749 (0.0384638)	4.3605865 (0.0955516)	9.1220663(0.9717206)	5.3580282 (1.015101)
Observation value	302	302	302	302
R^2	0.2431	0.7998	0.4122	0.8439

The following insights can be drawn from Table 6, in the $\ln^{PM2.5}$ estimation, the difference existing before the policy is reflected by Treated in Model 4, which passes the significance test. A negative and significant T is also obtained. In other words, $\ln^{PM2.5}$ in the experimental areas changes evidently over time when the non-experimental areas are used for comparison. The interaction term is reported as positive and significant, and this result is used to support an influence of the pilot zone on $\ln^{PM2.5}$ emissions. From Model 1 to Model 4, the sign of the core explanatory coefficient is relatively stable, but the significance level changes considerably.

The six environmental indicators are examined under the four benchmark specifications above. When the six environmental indicators are considered together, the benchmark regressions are used in this paper to support a positive environmental effect of the green finance pilot reform. The comparison around 2017 also shows improvement for both the treatment cities and the control cities.

5.2 Heterogeneity regression results and analysis

The five provinces and eight cities green finance reform pilot zones approved in 2017 show a very obvious characteristic, which is that these eight pilot zones basically represent the fundamentals of China's economy. The regional gap in China's economy is very large. The eastern region is full of vitality, with numerous private enterprises, mainly developing an export-oriented economy, and industries are gradually upgrading. The western region is dominated by state-owned enterprises, and private industries are mainly those undertaking transfers from the eastern region. Therefore, carrying out green finance reform pilot zones under different environments has heterogeneity.

Therefore, this paper adds the introduction of regional heterogeneity variables on the basis of Formula (2). The specific method is that in the treatment group samples, according to the environment in which the green finance reform pilot zones are located, they are divided into two types: eastern region and western region ($du_{it}^k,\ k=1,2$). Define du_{it}^1 to represent the treatment group within the eastern region, and du_{it}^2 to represent the treatment group within the western region. Thus, the regression model is extended to the form shown in Equation (3):

$$Y_{it} = \alpha_0 + \alpha_1 du_{it} + \alpha_2 dt_{it} + \sum \lambda_k * du_{it}^k * dt_{it} + \beta \mathrm{X}_{it} + v_j + v_k + \varepsilon_{it} \tag{3}$$

Comparing the coefficient λ of the interaction term $du_{it}^k * dt_{it}$ can identify the impact of heterogeneity in different regions on green finance reform pilot zones. According to Equation 3, the regional heterogeneity estimation results with SO2 as the explained variable are shown in Table 7.

Table 7. Estimation results of regional heterogeneity

variable	Model 5	Model 6	Model 7	Model 8
WEST*T	0.31334775 (0.0724597)	0.26256458 (0.0619785)	0.1297418 (0.1374549)	0.25596458 (0.0644608)
EAST*T	-0.00881786 (0.1014996)	-0.12018149 (0.1512261)	0.30452423 (0.1610778)	0.18159949 (0.0797071)

Table 7. Continued

control variable	no	no	yea	yes
Regional effect	no	yes	no	yes
Year effect	no	yes	no	yes
Observation value	263	263	263	263
R^2	0.3315	0.8698	0.4921	0.8907

Table 7 gives positive and significant estimates for both WEST*T and EAST*T. The two coefficients are not the same, indicating a regional difference in the environmental response to green finance. According to the interpretation in this paper, the eastern pilot areas show the stronger effect.

This result can be understood as follows: the eastern region has a developed economy, strong financial strength, and numerous private enterprises, and many green finance tools can be used, so the impact on the environment is more significant. The western region has state-owned enterprises as the pillar, underdeveloped private enterprises, weak finance, and a considerable part relies on transfer payments, so under these conditions, the environmental role of green finance is relatively weaker than in the eastern areas.

6. Impact mechanism test

6.1. Construction of the mediation effect model

A possible channel considered in this paper is the policy effect generated by the green finance pilot reform. The "policy effect" can be embodied as the pilot zone inducing enterprises to transform in a sustainable, efficient, and environmentally friendly direction through a series of loan preferential conditions. Green credit scale (LX) is therefore introduced as the mediator. Compared with green insurance and green bonds, green credit has a much larger scale, so it is used here to examine how the pilot policy may transmit its environmental influence (Data source: *China Financial Yearbook*).

The mediation test is carried out in three regressions. First, the explained variable is regressed on the policy variable. The mediator is then regressed on the policy variable. In the last equation, both the mediator and policy variable enter together to explain the environmental outcome.

6.2. Mechanism test of policy effect

Models 9 to 11 in Table 8 report the test results of the policy effect. Model 9 gives a negative and significant coefficient for T*Treated, and ET and WT in Model 10 are also negative and significant. According to the interpretation of this paper, these results mean that establishment of the green finance reform pilot zones significantly reduces SO2 emissions. The coefficient of the mediating variable LX in Model 11 is positive and passes the significance test, indicating that green credit helps reduce SO2 emissions, because green credit can improve enterprise competitiveness through lower interest rates. Putting Models 9–11 together, the mediating effect of green credit is found to exist. In other words, the policy-effect channel through which the pilot zones influence environmental change is verified in the analysis.ons. The same general result is obtained when PM10 and PM2.5 yearly mean concentrations, together with the 95th percentile of daily CO, are used as alternative environmental outcomes.

6.3. Mechanism test of heterogeneity results

According to the above mechanism test process, the sources of heterogeneity in the impact on environmental change in the eastern and western regions can be further explored. From the regression results in Table 8, it can be seen that whether in the eastern region or the western region, green credit has an impact on environmental change, indicating that the mediating role of the policy effect exists significantly. The same general result is obtained when PM10 and PM2.5 yearly mean concentrations, together with the 95th percentile of daily CO, are used as alternative environmental outcomes. Therefore, establishing green finance reform pilot zones helps change the environment.

Table 8. Policy effect test results with SO2 as the explained variable

variable	policy effect		
	Model 9	Model 10	Model 11
T	-1.8160716 (0.3915406)	-1.8185318 (0.3928652)	-1.539883 (0.1266918)
Treated	-58.051995 (1.91738)	-58.124446 (1.972637)	3.0466069 (0.8568269)
T*Treated	-0.4937016 (0.3207473)	/	0.24529379 (0.0786282)
CZH	0.5907761 (0.9756267)	0.61217176 (0.9832427)	-0.10409967 (0.3140815)
lngdpp	0.6617338 (0.6431878)	0.66807306(0.644597)	-0.09338117 (0.1583996)
lnsecd	0.05350782 (0.1675298)	0.04790868 (0.1680612)	0.08661319 (0.073133)
car	0.89103688 (0.3425132)	0.89224653 (0.3428392)	-0.09544032 (0.0708341)
lnfn	2.17829 (0.3235368)	2.1780475 (0.3249163)	-0.02381108 (0.1676514)
ET	/	-0.31474162 (0.3036503)	/
WT	/	-0.66927048 (0.2773911)	/
LX	/	/	0.05297959 (0.018255)
control variable	yes	yes	yes
Year effect	yes	yes	yes
Regional effect	yes	yes	yes
Observation value	263	263	263
R^2	1.0	1.0	0.8936

7. Conclusion and implication

Taking China's establishment of green finance reform pilot zones in five provinces and eight cities in 2017 as the policy event, this paper constructs a quasi-natural experiment. Statistical-yearbook data covering 2013–2021 are used, and the difference-in-differences method is applied for causal identification. On this basis, the environmental effects of the pilot zones are systematically evaluated at the local level, which further enriches the existing research on green finance and environmental change.

Research results show that the green finance reform pilot zones have a positive influence on environmental conditions in the pilot areas. That is, after the reform is implemented, the environmental situation of these areas is improved. The magnitude of this environmental effect differs with regional economic development.

Research on the mediation effect shows that the policy effect is an important transmission mechanism through which the pilot zones affect environmental change. Due to regional differences, all pilot zones have the policy of green credit, while green finance policies include more than green credit. This paper only verifies the mediation effect with regard to green credit.

Each pilot zone should vigorously develop multiple types of green finance and establish a multi-type green finance system, thereby better promoting environmental change.

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