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The Impact of the green Finance Reform and Innovation Pilot Zone on the Low-Carbon Transformation of High-Energy-Consuming Enterprises

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Abstract: Whether green finance policies can drive the low-carbon transformation of high-energy-consuming industries is a crucial issue under the "dual carbon" goals. This paper uses the green finance reform and innovation pilot zones established in batches since 2017 as a quasi-natural experiment. Based on panel data from 814 listed companies in six major high-energy-consuming industries in the A-share market from 2011 to 2024, we employ a multi-period difference-in-differences (DID) approach to examine the impact of green finance policies on the environmental protection investment intensity of high-energy-consuming enterprises. Both the baseline regression and the robust estimation using staggered DID (Callaway-SantAnna, Sun - Abraham) fail to find a significant average treatment effect. However, heterogeneity analysis reveals a clear differentiated picture: the policy significantly enhances the environmental protection investment intensity in the electricity and heat industry (+1.19 percentage points, p=0.037), but has a significant negative effect on the non-metallic mineral products industry (-0.45 percentage points, p=0.027). Large-scale enterprises exhibit a positive marginal effect at the 10% statistical level (p=0.063), while small-scale enterprises show a negative marginal effect at the 10% statistical level (p=0.057), suggesting a potential "Matthew effect" in the policy. The policy synergy test indicates that the environmental protection investment promotion effect is significantly stronger in enterprises classified as heavy pollution (interaction term p=0.013). Placebo tests and time counterfactual tests support the robustness of the baseline conclusions. The findings of this paper suggest that the effects of green finance policies are highly heterogeneous. Policy design needs to pay attention to industry adaptation and differences in enterprise size to avoid unintended consequences that may arise from a "one-size-fits-all" approach.

Keywords: Green finance reform and innovation pilot zone; High-energy-consuming industry; Low-carbon transformation; Multi-period difference-in-differences; Heterogeneity Analysis.

1. Introduction

To achieve the goals of carbon peak and carbon neutrality, the green and low-carbon transformation of high-energy-consuming industries is a crucial step. Chinas six major high - energy-consuming industries - petroleum processing, chemical raw materials, non-metallic minerals, ferrous metal smelting, non-ferrous metal smelting, and electric power and heat - contribute nearly 50% of the countrys total energy consumption and a significant share of carbon emissions. However, the low-carbon transformation of high-energy-consuming enterprises faces significant financial constraints: the research and development of green technologies, equipment updates, and energy efficiency improvements all require large-scale long-term investment, while the traditional financial systems preference for credit to high -carbon industries may pose obstacles to transformation.

The Green Finance Reform and Innovation Pilot Zone is an important institutional arrangement initiated by the Peoples Bank of China and six other ministries and commissions in 2017. The first batch of pilot zones were established in five provinces and autonomous regions, namely Zhejiang, Jiangxi, Guangdong, Guizhou, and Xinjiang. In 2019, the pilot zone was expanded to Lanzhou, Gansu Province, and in 2022, it was further extended to Chongqing. The pilot zone aims to guide the allocation of financial resources towards green and low-carbon sectors through policy tools such as green credit, green bonds, and environmental information disclosure. A natural question arises: Has this policy effectively promoted the low-carbon transformation of high-energy-consuming enterprises?

Existing literature has extensively discussed the economic effects of green finance reform and innovation pilot zones, but it mainly focuses on dimensions such as green credit allocation efficiency and alleviation of corporate financing constraints (Wang Xin and Wang Ying, 2021; Li Qingyuan and Xiao Zehua, 2020) [1,2]. Independent analyses specifically targeting high-energy-consuming industries are extremely limited. The policy environment faced by high-energy-consuming enterprises is fundamentally different from that of general manufacturing industries: on the one hand, they are the core targets of "forced transformation" by green finance policies; on the other hand, they may face tighter financing constraints due to the "brown" label. The policy effects under this dual pressure require independent empirical testing.

The marginal contributions of this paper are reflected in three aspects. Firstly, from a research perspective, it is the first time to focus the policy evaluation of the green finance reform and innovation pilot zone on high-energy-consuming industries, filling the research gap in this area. Secondly, in terms of methodology, it employs both traditional TWFE and robust estimators such as Callaway-SantAnna and Sun - Abraham staggered DID [3,4], ensuring that the conclusions are not affected by the negative weight bias caused by staggered treatment timing. Thirdly, in terms of findings, it reveals significant heterogeneity in policy effects - directional differentiation between industries and scales - providing empirical evidence for the design of differentiated green finance policies.

2. Institutional Background and Theoretical Analysis

2.1. Pilot Zone for Green Finance Reform and Innovation

In June 2017, the Executive Meeting of the State Council decided to establish pilot zones for green finance reform and innovation in Zhejiang, Jiangxi, Guangdong, Guizhou, and Xinjiang, marking the transition of Chinas green finance from top-level design to local practice. Based on their respective economic structures and resource endowments, each pilot zone explores differentiated paths for the development of green finance: Huzhou and Quzhou in Zhejiang focus on the construction of a green finance standard system and information sharing platform; Ganjiang New Area in Jiangxi focuses on the innovation of green credit and green insurance products; Huadu District in Guangzhou, Guangdong promotes the integration of green finance with the construction of the Guangdong-Hong Kong-Macao Greater Bay Area; Guian New Area in Guizhou explores green finance to support ecological poverty alleviation; and Hami, Changji, and Karamay in Xinjiang combine the positioning of the Silk Road Economic Belt to develop green finance.

The core policy tools in the pilot zone include: green credit guidelines and statistical systems, facilitation of green bond issuance, environmental information disclosure requirements, standards for identifying green enterprises and projects, and mechanisms for monitoring and assessing green financial risks. These tools influence corporate behavior through two channels: the "incentive channel" by reducing the financing costs of green projects and encouraging enterprises to increase environmental protection investment and research and development of green technologies; and the "constraint channel" by raising the requirements for environmental information disclosure and risk assessment, making it more difficult for high-pollution and high-emission enterprises to obtain financing, and forcing them to transform.

2.2. The uniqueness of high energy-consuming industries

High energy-consuming industries exhibit three distinct characteristics. Firstly, they exhibit strong asset specificity. Production equipment in industries such as petroleum processing, chemical raw materials, non-metallic minerals, and metal smelting is highly specialized. Transformation implies large-scale asset replacement, with extremely high sunk costs. Secondly, they have a high dependence on energy. The electric power and thermal power industries are inherently energy conversion sectors, and their low-carbon transformation involves fundamental adjustments to the energy structure. Thirdly, they face tight financing constraints. Under the dual pressures of the "dual carbon" goals and green finance policies, high energy-consuming enterprises may face the risk of banks withdrawing or cutting off loans, exacerbating financing constraints.

These characteristics imply that the impact of green finance policies on high-energy-consuming enterprises may not be a simple linear promotion, but rather depends on the interaction of multiple factors such as the enterprises own transformation capabilities, industry technology characteristics, and regional financial environment.

2.3. Research Hypothesis

Based on the aforementioned analysis, this paper proposes the following hypothesis:

H1: The policies of the green finance reform and innovation pilot zone have increased the environmental protection investment intensity of high-energy-consuming enterprises.

H2: The policy effect exhibits significant heterogeneity across different property rights, enterprise sizes, industry types, and regions.

3. Research Design

3.1. Data sources and sample selection

The micro-level panel data for enterprises in this paper are all sourced from the CSMAR database, with the research sample covering the period from 2011 to 2024. The data tables relied upon for the study include: annual tables of basic information for listed companies, a financial indicator database, a corporate governance database, as well as detailed tables for projects under construction and management expenses, which are used to calculate indicators related to corporate environmental protection investment.

The sample screening process is as follows: (1) retain A-share listed companies on the Shanghai and Shenzhen stock exchanges; (2) exclude ST, *ST, and PT companies; (3) exclude financial companies; (4) based on the 2012 industry classification by the China Securities Regulatory Commission, screen for six major high-energy-consuming industries: C25 Petroleum processing, coking, and nuclear fuel processing industry, C26 Chemical raw material and chemical product manufacturing industry, C30 Non-metallic mineral product industry, C31 Ferrous metal smelting and rolling processing industry, C32 Non-ferrous metal smelting and rolling processing industry, D44 Electricity and heat production and supply industry; (5) exclude observations with missing key variables. Ultimately, 814 companies and 7,011 company-year observations are obtained.

3.2. Variable definition

3.2.1. Dependent variable

This article uses environmental investment intensity to measure the investment of enterprises in low-carbon transformation, defined as the amount of environmental investment divided by total assets.

3.2.2. Core explanatory variables

The core explanatory variable in this paper is the difference-in-differences interaction term did = treat × post, representing the policy of the green finance reform and innovation pilot zone. Here, treat is a dummy variable for the treatment group, taking the value of 1 if the province where the enterprise is registered belongs to the green finance reform and innovation pilot zone, and 0 otherwise; post is a dummy variable for the policy time point, taking the value of 1 if the year is greater than or equal to the year when the province was first included in the pilot zone. Since the policy was implemented in three batches (the first batch of five provinces in 2017, Gansu in 2019, and Chongqing in 2022), post varies across different treatment groups.

3.2.3. Control variables

Based on existing research, this paper controls the following variables: firm size (Size, natural logarithm of total assets), asset-to-liability ratio (Lev), return on assets (ROA), asset turnover (ATO), cash flow ratio (Cashflow), revenue growth rate (Growth), Tobins Q (TobinQ), board size (Board), proportion of independent directors (Indep), proportion of shares held by the largest shareholder (Top1), firm age (FirmAge), proportion of shares held by institutional investors (INST), and proportion of shares held by management (Mshare). All continuous variables are winsorized at the 1% and 99% quantiles.

3.3. Model Setting

This paper employs a staggered difference-in-differences (Staggered DID) model to estimate the impact of the green finance reform and innovation pilot zone policy on the low-carbon transformation of high-energy-consuming enterprises. The benchmark model is set as follows:

$$Y_{it} = \alpha + \beta did_{it} + \gamma \, Controls_{it} + \mu_i + \lambda_t + \varepsilon_{it} \quad (1)$$

Among them, Yit represents the dependent variable (environmental protection investment intensity), didit denotes the treatment variable, Controlsit signifies the control variable vector, μi stands for firm-specific fixed effects, λt indicates year-specific fixed effects, and εit represents the random error term. The standard error is clustered at the firm level.

Due to the staggered timing of treatment, the traditional TWFE estimator may suffer from a "negative weight" bias (Goodman-Bacon, 2021) [5]. To address this, this paper also employs the staggered DID robust estimator proposed by Callaway and SantAnna (2021) and Sun and Abraham (2021) for supplementary testing.

4. Empirical results

4.1. Descriptive statistics

Table 1 reports the descriptive statistics of the main variables. The mean value of environmental investment intensity is 0.0069, with a standard deviation of 0.0162, indicating that the proportion of environmental investment in total assets of high-energy-consuming enterprises is on average less than 1%, and there are significant differences among enterprises. The treatment group accounts for 27.6% (245 companies) of the sample, and observations with DID=1 account for 18.1% (1,268).

4.2. Benchmark DID regression

Table 2 reports the benchmark DID regression results. Models M1 to M3 use environmental investment intensity as the dependent variable, gradually incorporating control variables.

Table 1. Baseline regression results

did	0.00176	0.00156	0.00126
	(1.105)	(0.976)	(0.796)
Controls	No	Partial	Full
Firm FE	Yes	Yes	Yes
Year FE	Yes	Yes	Yes
N	6684	6684	6684
R^2	0.001	0.004	0.009

Note: The t-value is indicated in parentheses, and the standard error is clustered at the firm level. *** p<0.01, ** p<0.05, * p<0.1.

The benchmark regression results indicate that the coefficient of did is not significant in all three models (all p > 0.25). When environmental investment intensity is taken as the dependent variable, the did coefficient ranges from 0.0013 to 0.0018, with limited economic significance (approximately 18% to 26% of the mean). This result suggests that, on average, the green finance reform and innovation pilot zone policy has not significantly increased the environmental investment intensity of high-energy-consuming enterprises, and hypothesis H1 is not supported.

4.3. Parallel Trends Test and Event Study

The parallel trends assumption is a prerequisite for the validity of Difference-in-Differences (DID) estimation. This paper employs the event study method for testing, with the year before policy implementation as the baseline period. Regarding the intensity of environmental protection investment, the ex-ante coefficients are not significantly different from zero, and the joint test $\chi^2(5)=1.140$ (p=0.338), indicating that the parallel trends assumption cannot be rejected. It is worth noting that the ex-post coefficients exhibit a marginal positive trend starting from t+3 (t+3: p=0.056, t+5: p=0.095), suggesting that the policy may have a lag effect, but the overall Average Treatment Effect (ATT) is not significant (p=0.147).

4.4. Staggered DID robust estimation

Considering the potential negative weighting issue that may arise from advancing policies in three batches, this paper further employs the estimators of Callaway-SantAnna (2021) and Sun-Abraham (2021) for robustness testing [6].

Table 2. Average treatment effect results of three DID estimators

Dependent variable	estimator	ATT	SE	p-value	95% CI
Environmental protection investment intensity	TWFE	0.001	0.001	0.373	[−0.002, 0.004]
Environmental protection investment intensity	Callaway-Sant'Anna	0.003	0.002	0.147	[−0.001, 0.008]
Environmental protection investment intensity	Sun-Abraham	0.001	0.002	0.417	[−0.002, 0.005]

The three estimators consistently indicate that the green finance reform and innovation pilot zone policy has no statistically significant average treatment effect on the environmental protection investment intensity of high-energy-consuming enterprises. The point estimates of Callaway-SantAnna and Sun -Abraham are slightly larger than those of TWFE, but the standard errors are also larger, and all confidence intervals include zero. The parallel trends test was not rejected at the 5% level under both the CS and SA frameworks (CS: p=0.226, SA: p=0.085).

4.5. Heterogeneity analysis

Although the average effect is not significant, the policy effect may exhibit significant differences across different types of enterprises. This article conducts a heterogeneity analysis from four dimensions: property rights, enterprise size, industry type, and region [7].

4.5.1. Heterogeneity of property rights nature

The samples were divided into two groups based on the nature of property rights: state-owned enterprises (SOEs) and non-SOEs. The results showed that the difference-in-differences (DID) coefficient was positive in the SOE sub-sample (0.0038, p=0.168) and negative in the non-SOE sub-sample (-0.0013, p=0.496), indicating a directional differentiation but neither reaching a 5% significance level.

4.5.2. Heterogeneity in enterprise size

Enterprises are divided into two groups: large-scale and small-scale, based on the median of the full sample. This is the most enlightening finding: in the sub-sample of large-scale enterprises, the did coefficient is +0.0046 (p=0.063), which is marginally significantly positive at the 10% statistical level; in the sub-sample of small-scale enterprises, the did coefficient is -0.0035 (p=0.057), which is marginally significantly negative at the 10% statistical level. Both coefficients are marginally significant at the 10% level and have opposite directions, suggesting that green finance policies may have a "Matthew effect" - while promoting large enterprises to increase environmental protection investment, they have a crowding-out effect on small enterprises.

4.5.3. Industry heterogeneity

The regression results for each of the six major high-energy-consuming industries reveal significant directional differentiation. The did coefficient for the electric power and heat industry (D44) is +0.0119 (p=0.037), which is significantly positive at the 5% level, indicating that green finance policies have significantly increased the environmental protection investment intensity of electric power and heat enterprises. The did coefficient for the non-metallic mineral products industry (C30) is -0.0045 (p=0.027), which is significantly negative at the 5% level. The did coefficients for the remaining four industries (petroleum processing, chemical raw materials, ferrous metals, and non-ferrous metals) are not significant.

4.5.4. Regional heterogeneity

The DID coefficients for the sub-samples from the eastern, central, and western regions are all insignificant, indicating no systematic differences in policy effects across regions.

4.6. Placebo test

4.6.1. Randomly assign treatment groups

By randomly shuffling the treatment group assignments 500 times and re-estimating the DID model, we obtained the empirical distribution of placebo coefficients. The true DID coefficient (0.00126) falls in the middle of the random coefficient distribution and does not significantly deviate from zero. This result suggests that the baseline results are unlikely to be driven by random factors.

4.6.2. Time counterfactual test

The policy time was uniformly advanced by 2 and 3 years to construct artificial policy timings. For environmental protection investment intensity, the artificial DID coefficients for the advanced 2-year and 3-year periods were both insignificant (p=0.250 and p=0.157), supporting the notion that the policy effect did not stem from pre-existing trends.

4.7. Policy coordination test

This paper further examines whether green finance policies have a synergistic effect with the attributes of heavily polluting industries. The interaction term between the difference-in-differences (DID) and the heavily polluting industry group is added to the benchmark model [8].

The interaction terms between heavy pollution group 2 and group 3 are highly significant (p<0.01) in the dimension of environmental protection investment intensity, indicating that among enterprises with higher levels of heavy pollution, the promotional effect of green finance policies on environmental protection investment is stronger. This finding supports the logic of "targeted policy implementation" in green finance policies - policy effects are more pronounced in enterprises with higher levels of pollution [9].

Table 3. Results of policy coordination test

Dependent variable	Policy variable	Interaction coefficient	p-value
Environmental protection investment intensity	Heavy pollution group 2	0.006	0.002
Environmental protection investment intensity	Heavy pollution group 3	0.006	0.001

5. Robustness Test

This article conducted the following robustness tests to ensure the reliability of the conclusions:

Firstly, robust estimation using staggered DIDs. As mentioned earlier, the results of the Callaway-SantAnna and Sun-Abraham estimators are consistent with TWFE, with no significant average treatment effect found, ruling out the interference of negative weight bias [10].

Second, the parallel trends test. The parallel trends hypothesis of environmental protection investment intensity is supported.

Third, placebo test. The placebo test of 500 random allocation treatments indicates that the true coefficient does not significantly deviate from the random distribution; the environmental protection investment intensity passes the test in the time counterfactual test.

6. Conclusion and Suggestions

6.1. Conclusion

This paper uses the green finance reform and innovation pilot zone as a quasi-natural experiment, and based on the panel data of 814 listed companies in six major high-energy-consuming industries in A-shares from 2011 to 2024, employs a multi-period Difference-in-Differences (DID) method to examine the impact of green finance policies on the low-carbon transformation of high-energy-consuming enterprises. The main conclusions are as follows:

Firstly, the policy of the green finance reform and innovation pilot zone has not significantly increased the environmental protection investment intensity of high-energy-consuming enterprises on average. The TWFE, Callaway-SantAnna, and Sun -Abraham estimators unanimously support this conclusion.

Secondly, the policy effect exhibits significant industry and scale heterogeneity. The environmental protection investment intensity in the electric power and heat industry has seen a notable increase (+1.19 percentage points), while that in the non-metallic mineral products industry has significantly decreased (-0.45 percentage points). Large-scale enterprises exhibit a positive marginal effect at the 10% statistical level, whereas small-scale enterprises show a negative marginal effect at the same level, suggesting that the policy may exhibit a "Matthew effect".

Thirdly, the policy effect is more pronounced in enterprises with higher levels of heavy pollution, indicating that green finance policies have a certain degree of precision in implementation.

Fourthly, the specific mechanism through which green finance policies influence the low-carbon transformation of high-energy-consuming enterprises still requires further exploration.

6.2. Suggestions

The findings of this paper offer the following policy implications. Firstly, the effects of green finance policies are highly heterogeneous, and a "one-size-fits-all" policy design may lead to unintended consequences - while promoting the transformation of some enterprises, it may exacerbate the difficulties of others. Secondly, policies should pay attention to differences in enterprise size, providing supporting support for transformation financing for small and medium-sized enterprises to avoid the "Matthew effect". Thirdly, industry characteristics should be taken into account in policy design. Industries with clear technological transformation paths, such as electricity and heat, may be more likely to benefit from green finance policies, while industries with unclear transformation paths, such as non-metallic minerals, require additional technical support.

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