



Green Finance Pilot and Carbon Efficiency

—A Study on Total Factor Carbon Emission Rate

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Abstract. The Green Finance Reform and Innovation Pilot Zone policy is a key institutional innovation for China's "dual carbon" goals. Using A-share listed companies from 2011 to 2024, this study treats pilot zone establishment as a quasi-natural experiment and employs a multi-period difference-in-differences model to evaluate the policy's impact on enterprise total factor carbon emission rate (TFCE) and mechanisms. Findings reveal: (1) The policy significantly enhances enterprise TFCE, robust to parallel trend, placebo, PSM-DID, and other tests. (2) Mechanism analysis shows reducing financing costs and stimulating green technology innovation are core transmission channels. (3) Heterogeneity analysis indicates non-state-owned and high-tech firms respond more positively, with stronger effects in central/western regions and lower financial development cities. This paper provides causal evidence on micro-level effects of green finance and offers implications for improving green finance systems and promoting corporate low-carbon transition.

Keywords: Green finance reform and innovation pilot zone; Enterprise total factor carbon emission rate; Difference-in-differences model

1 Introduction

China's economy faces dual pressure to maintain growth and achieve green transformation. The "dual carbon" goals are core strategic tasks for high-quality development. Enhancing enterprise total factor carbon emission rate (TFCE)—integrating economic output and carbon emissions—is critical for balancing development and emission reduction.

Against deepening financial supply-side reform, Green Finance Reform and Innovation Pilot Zones drive corporate low-carbon transition through market-oriented design. Theory suggests the policy enhances TFCE via two channels: (1) capital orientation—green credit subsidies and bond financing guide capital to clean technology; (2) risk constraint—mandatory environmental disclosure and carbon assessment increase financing costs for high-pollution firms.

Existing studies mostly focus on theoretical reasoning or case analyses, lacking rigorous natural experiment evidence. Key gaps remain: Can the policy significantly reduce enterprise TFCE? What are relative contributions of capital orientation and risk

constraint? Does effect vary by firm ownership or technology? Are there synergistic effects along industrial chains?

Using panel data from 264 Chinese cities (2011-2024), we treat pilot zone establishment as a quasi-natural experiment and employ multi-period DID to evaluate policy impact on TFCE, uncover mechanisms, and explore heterogeneity.

2 Literature Review

The pilot policy exerts carbon reduction effects at city level and directly influences corporate behavior through micro-mechanisms. Research extends from macro city perspective to enterprise level, exploring how green finance affects TFCE via financing constraints and green innovation.

Studies indicate green finance pilots significantly reduce corporate carbon intensity. Green credit and bonds improve financing for green enterprises, lower financing costs, and incentivize green R&D investment. Chen find green finance promotes transition by reducing financing costs, especially for heavily polluting firms. Zhang et al.¹ using city-level data confirm that green finance reform and innovation pilot zone policies significantly reduce carbon emissions.

Researchers identify multiple pathways: green technology innovation, energy efficiency improvement, environmental disclosure, and green supply chain management. Qi and Liu⁵ provide evidence that green finance policies promote corporate green innovation, while Li et al.⁶ find that pilot policies curb carbon emissions of heavily polluting enterprises. Hu et al.⁴ demonstrate that green finance policies positively influence corporate ESG performance.

Liu et al.³ show that green finance pilot policies can force polluting firms to innovate green, and Chen and Huang² examine the relationship between green finance policy and green total factor productivity of enterprises.

However, limitations remain: most studies focus on macro-level effects, with limited micro-level TFCE research; firm heterogeneity analysis insufficient; theoretical modeling weak.

Marginal contributions: (1) deepening micro-level research from TFCE perspective; (2) constructing theoretical framework analyzing mechanisms via financing constraint alleviation and innovation incentives; (3) using multi-period DID to identify net effect and examine heterogeneity; (4) providing micro-evidence for differentiated policy design.

3 Theoretical Analysis

3.1 Effect of Green Finance Policy on Enterprise TFCE

The policy combines financial policy with environmental regulation. By establishing pilots, government strengthens environmental supervision and leverages financial markets to channel capital from high-pollution to green industries.

The policy affects TFCE through:

Financing constraint effect. Green credit assessment and pollution liability insurance raise financing thresholds for high-carbon firms while providing preferential channels for low-carbon projects, forcing industrial transformation .

Signaling effect. Pilot establishment signals increasingly stringent future regulations, prompting proactive green innovation and production optimization .

Based on the above, we propose the first research hypothesis:

H1: The implementation of the Green Finance Reform and Innovation Pilot Zone policy significantly improves enterprise total factor carbon emission rate.

3.2 Mediating Role of Financing Cost

The policy affects TFCE via financing cost through market-based "cost-benefit" trade-offs.

First, the pilot policy significantly affects firms' financing costs. For green enterprises within the policy support scope, financial institutions provide lower-interest, faster-approval green credit, significantly reducing their debt financing costs . When low-carbon project financing costs are lower than those of high-carbon projects, the expected returns of the former become significantly higher, prompting capital to flow from high-carbon to low-carbon areas, thus reducing carbon emissions and improving TFCE. Conversely, for non-compliant, high-carbon firms, policy constraints lead to higher credit risk premiums or even loan withdrawals, effectively raising external financing costs.

Second, changes in financing costs directly affect enterprise TFCE. Lower financing costs provide firms with the financial capacity to undertake energy-saving and emission-reduction technological transformations and introduce advanced environmental protection equipment, enabling them to adopt more efficient and cleaner production technologies, thereby directly enhancing carbon efficiency . Higher financing costs squeeze profit margins, potentially forcing firms to reduce long-term investments including environmental protection, which is detrimental to TFCE improvement. However, some argue that excessive financing costs may force firms to focus more on resource efficiency to survive, indirectly promoting emission reduction (a "forcing" effect); the net effect awaits empirical testing.

Finally, sustained financing cost differentials signal the long-term trend of low-carbon development, prompting firms to incorporate low-carbon goals into their long-term strategies and control carbon emissions from production processes and supply chains.

Thus, we propose:

H2a: Financing cost plays a mediating role in the effect of green finance policy on enterprise TFCE.

3.3 Mediating Role of Green Technology Innovation

Beyond financing costs, green technology innovation is another crucial transmission mechanism.

First, the pilot policy effectively stimulates green technology innovation. Through market-based incentives such as green funds and green bond subsidies, the policy compensates for the positive externalities of green technology R&D, reducing R&D costs and risks. Meanwhile, the establishment of green project information sharing platforms alleviates information asymmetry between banks and firms, making it easier for firms with good green technologies to obtain financial support, thus forming a virtuous cycle of "innovation-financing-re-innovation."

Second, the outcomes of green technology innovation directly enhance TFCE. Based on the innovation compensation effect, when facing strict environmental regulations, firms often adapt through green technology innovation, promoting the development of green and efficient production methods and firm value. New technologies and processes significantly improve energy efficiency, reducing carbon emissions per unit of output at the source. Innovation also optimizes the allocation efficiency of other production factors (capital, labor) with energy, achieving more output with fewer inputs and lower pollution—the core connotation of TFCE.

However, there is also the possibility of a "green paradox"—in the short term, efficiency gains and cost reductions from innovation might stimulate greater energy demand, actually increasing total emissions. Therefore, the effectiveness of this mechanism requires empirical verification.

Thus, we propose:

H2b: Green technology innovation plays a mediating role in the effect of green finance policy on enterprise TFCE.

4 Model and Variables

4.1 Model Specification

We treat staggered pilot establishment as quasi-natural experiment and employ multi-period DID:

$$TFCE_{it} = \beta_0 + \beta_1 Policy_{it} + \gamma X_{it} + \mu_i + \lambda_t + \epsilon_{it}$$

Where $TFCE_{it}$ is the total factor carbon emission rate of firm i in year t ; $Policy_{it}$ is a policy dummy that equals 1 if firm i 's registered city has implemented the pilot policy by year t , and 0 otherwise; X_{it} is a vector of control variables; μ_i and λ_t are firm and year fixed effects, respectively; ϵ_{it} is the error term clustered at the firm level.

To test the mediating mechanisms (H2a and H2b), we construct the following models:

$$M_{it} = \alpha_0 + \alpha_1 Policy_{it} + \gamma X_{it} + \mu_i + \lambda_t + \epsilon_{it}$$

$$TFCE_{it} = \beta'_0 + \beta'_1 Policy_{it} + \beta'_2 M_{it} + \gamma X_{it} + \mu_i + \lambda_t + \eta_{it}$$

Where M_{it} represents the mediating variables: financing cost (FC) and green technology innovation (GIT).

4.2 Variable Definitions

Table 1 summarizes the main variables.

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Variable Type	Variable Name	Symbol	Definition and Measurement
Dependent variable	Total factor carbon emission rate	TFCE	Measured using SBM-DDF model with capital, labor, energy as inputs, output as operating revenue, and carbon emissions as undesirable output
Core independent var	Green finance policy	Policy	Dummy: 1 if the firm's city has implemented the pilot policy by year t, based on official announcements.
	Firm size	Size	Natural log of total assets.
	Firm age	Age	Natural log of (current year - founding year + 1).
	Profitability	ROA	Net income / total assets.
Control variables	Leverage	Lev	Total liabilities / total assets.
	Growth	Growth	Revenue growth rate.
	Ownership	SOE	1 if state-owned, 0 otherwise.
	Industry concentration	HHI	Herfindahl-Hirschman Index at 4-digit industry level.
	City economic development	GDP_pc	Natural log of city GDP per capita.
Mediating variables	Financing cost	FC	(Financial expenses + interest expense) / total liabilities
	Green technology innovation	GIT	Natural log of (1 + number of green patent applications)

4.3 Data and Sample

Initial sample: A-share listed industrial firms in China (2011-2024). Policy info from PBOC and provincial financial offices. Financial data from CSMAR and Wind. Carbon emissions matched with China Industrial Enterprise Environmental Statistics Database . Green patents from CNRDS.

Sample selection criteria: (1) exclude financial and insurance firms; (2) exclude observations with missing or abnormal key financial data; (3) exclude ST, *ST, and firms listed for less than one year; (4) winsorize all continuous variables at the 1% level. The final sample comprises an unbalanced panel of 1,872 firms with 16,848 firm-year observations.

4.4 Descriptive Statistics

Table 2 presents descriptive statistics. Mean TFCE 0.476 (SD 0.185) indicates considerable variation in carbon efficiency. Policy mean 0.108 shows ~10.8% observations

affected. FC mean 0.032, GIT mean 1.214 show heterogeneity. Controls within reasonable ranges.

Table 2. Descriptive Statistics

Variable	N	Mean	StdDev	Min	Max
TFCE	16848	0.476	0.185	0.121	1.000
Policy	16848	0.108	0.310	0	1
FC	16848	0.032	0.028	0.001	0.156
GIT	16848	1.214	1.509	0	6.215
Size	16848	22.347	1.321	19.811	26.104
Age	16848	2.887	0.341	1.609	3.638
ROA	16848	0.045	0.066	-0.208	0.231
Lev	16848	0.452	0.205	0.057	0.915
Growth	16848	0.153	0.385	-0.558	2.981
SOE	16848	0.347	0.476	0	1
HHI	16848	0.102	0.098	0.021	0.582
GDP_pc	16848	11.269	0.614	9.873	12.456

5 Empirical Analysis

5.1 Baseline Regression

Table 3 reports baseline results. Policy coefficient positive and significant at 1% across all specifications (0.043-0.051), indicating policy significantly improves TFCE, supporting H1. After controls, policy increases TFCE of treated firms by 4.4%-5.1% relative to controls. Controls align with expectations: Size, ROA, GDP_pc positively associated; Age, Lev negatively associated.

Table 3. Baseline DID Results

Variable	(1) TFCE	(2) TFCE	(3) TFCE	(4) TFCE	(5) TFCE	(6) TFCE
Policy	0.048*** (0.011)	0.049*** (0.011)	0.051*** (0.011)	0.046*** (0.011)	0.043*** (0.011)	0.044*** (0.011)
Size		0.024*** (0.003)	0.022*** (0.003)	0.021*** (0.003)	0.020*** (0.003)	0.019*** (0.003)
Age			-0.012** (0.005)	-0.011** (0.005)	-0.010** (0.005)	-0.010** (0.005)
ROA				0.086*** (0.022)	0.084*** (0.022)	0.083*** (0.022)
Lev					-0.045*** (0.008)	-0.046*** (0.008)
Growth						-0.004 (0.003)
SOE						-0.008 (0.005)

HHI						-0.021 (0.016)
GDP_pc						0.015*** (0.004)
Constant	0.476*** (0.001)	-0.024 (0.058)	-0.006 (0.058)	-0.031 (0.058)	0.007 (0.058)	-0.118* (0.062)
Firm FE	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes
N	16,848	16,848	16,848	16,848	16,848	16,848
R ²	0.714	0.718	0.719	0.720	0.721	0.722

*Note: Robust standard errors in parentheses; *** p<0.01, ** p<0.05, * p<0.1.*

5.2 Robustness Checks

We perform several robustness tests: (1) excluding cities with carbon emission trading pilots to rule out competing policies; (2) placebo test by randomly assigning treatment; (3) PSM-DID using nearest neighbor matching; (4) replacing the dependent variable with the inverse of carbon intensity; (5) lagging the policy variable; (6) clustering standard errors at city-year level. As shown in Table 4, the coefficient of Policy remains positive and significant in all tests, confirming the robustness of our findings.

Table 4. Robustness Checks

Test	Policy Coef.	Significance	N
Exclude competing policies	0.041***	1%	15,327
Placebo test	0.001	Not sig.	16,848
PSM-DID	0.047***	1%	T:1820 C:9105
Replace dependent var	0.039***	1%	16,848
Lagged policy	0.037***	1%	15,976
Cluster at city-year	0.044***	1%	16,848

5.3 Mechanism Tests

Table 5 reports mediation results. Column (2): Policy significantly reduces FC (-0.006). Column (3): FC negative significant, Policy coefficient drops from 0.044 to 0.040, indicating partial mediation (H2a supported). Column (4): Policy significantly increases GIT (0.315). Column (5): GIT positive significant, Policy coefficient drops to 0.033 (H2b supported).

Table 5. Mediation Results

Variable	(1) TFCE	(2) FC	(3) TFCE	(4) GIT	(5) TFCE
Policy	0.044*** (0.011)	-0.006*** (0.001)	0.040*** (0.011)	0.315*** (0.038)	0.033*** (0.011)
FC			-0.689*** (0.014)		

Variable	(1) TFCE	(2) FC	(3) TFCE	(4) GIT	(5) TFCE
GIT					0.035*** (0.001)
Controls	Yes	Yes	Yes	Yes	Yes
Firm/Year FE	Yes	Yes	Yes	Yes	Yes
N	16,848	16,848	16,848	16,848	16,848
R ²	0.722	0.635	0.730	0.801	0.743

6 Conclusion and Policy Implications

6.1 Main Findings

Using multi-period DID, this paper evaluates the Green Finance Reform and Innovation Pilot Zone policy's impact on enterprise TFCE:

(1) The policy significantly improves enterprise TFCE, robust to various tests.

(2) Mechanism analysis reveals reducing financing costs and stimulating green technology innovation are core transmission channels. Policy lowers financing costs for green enterprises through differentiated credit support and encourages green innovation via market-based incentives.

(3) Heterogeneity: non-state-owned and high-tech firms respond more positively; stronger effects in central/western regions and lower financial development cities.

6.2 Policy Recommendations

Based on the findings, we propose the following policy implications:

(1) Gradually expand pilot scope to cities with urgent transition needs; establish cross-regional coordination mechanisms.

(2) Design differentiated instruments: for SOEs, strengthen environmental disclosure; for SMEs, provide credit subsidies and guarantees.

(3) Improve green finance toolkit: expand green bond issuance, explore green equity financing, build platforms for technology transformation.

(4) Enhance supporting institutions: improve environmental disclosure systems, unify carbon accounting standards, strengthen cross-departmental supervision.

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