Green Finance Pilot and Urban Carbon Efficiency: A Study on Total Factor Carbon Emission Rate

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Abstract. Green finance is crucial for China's low-carbon transition. Treating Green Finance Reform and Innovation Pilot Zones as a quasi-natural experiment, this paper uses panel data of 279 prefecture-level cities (2011–2022) and a multi-period DID model to examine the policy's impact on urban total factor carbon emission rate (TFCE). Results show the policy significantly improves TFCE, robust to various checks. Mechanism analysis reveals green technology innovation and industrial structure optimization as key channels. The paper provides evidence for optimizing green finance policies.

Keywords: Green finance pilot , Total factor carbon emission rate , Difference-in-differences model.

1 Introduction

China's "dual carbon" goals require balancing growth and emission reduction. Total factor carbon emission rate (TFCE)—which integrates economic output and carbon emissions—is critical for low-carbon transition. Green Finance Reform and Innovation Pilot Zones, launched in 2017, offer a quasi-natural experiment to assess whether green finance can enhance TFCE. Existing studies lack causal evidence on urban TFCE. This paper fills the gap using a multi-period DID design with city-level data from 2011 to 2022.The establishment of a green finance system is an important institutional innovation for China to achieve its "dual carbon" goals. Green finance incorporates environmental risks into factor pricing through market-based mechanisms, injecting financial momentum into the low-carbon transition. Pilot zone policies influence total factor carbon emission rate mainly through two pathways: a capital guidance path, where green credit and green bonds expand investment in clean technologies and promote technological upgrading in high-carbon enterprises; and a risk pricing constraint path, where environmental information disclosure and carbon risk assessment compel enterprises to optimize their energy structures and improve total factor carbon productivity.

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2 Literature Review

Research shows green finance reduces carbon intensity [1][2] and promotes green innovation [3] and industrial upgrading [4]. However, most studies use carbon intensity rather than TFCE and lack mechanism analysis. However, existing studies still have some limitations. Most research focuses on carbon emission intensity rather than total factor carbon emission efficiency, the latter being a better indicator of economic development quality. The theoretical mechanism through which green finance affects total factor carbon emission rate has not been fully explored. Furthermore, policy effects may differ significantly between resource-based and non-resource-based cities.The marginal contributions of this paper are threefold. First, it adopts a total factor carbon emission efficiency perspective, providing a more comprehensive evaluation of the policy's carbon reduction effects than traditional carbon intensity measures. Second, it constructs a theoretical framework to analyze the internal mechanisms through which green finance affects carbon emission efficiency via green technology innovation and industrial structure optimization. Third, it employs a multi-period DID method to effectively identify the net policy effect.This paper contributes by focusing on TFCE and testing mediation paths.

3 Theoretical Analysis and Hypotheses

H1: The Green Finance Pilot policy significantly improves urban TFCE. Unlike market-based policies such as carbon emission trading, the Green Finance Pilot policy guides capital toward low-carbon sectors through financial resource allocation. It may directly affect urban total factor carbon emission rate—a measure that combines energy, capital, and labor inputs with carbon emissions—via the following channels.The policy influences TFCE through two primary channels. First, the capital reallocation effect: through targeted green credit and environmental pollution liability insurance, the policy restricts financing channels for high-carbon industries and reduces financing costs for green projects, prompting factors of production to shift from high-carbon to low-carbon sectors [5]. Second, the signaling effect: the government's establishment of pilots sends a policy signal, leading firms to expect increasingly stringent environmental regulations and proactively improve production processes and energy structures, thereby enhancing factor carbon efficiency [6]. These effects collectively enhance the total factor carbon efficiency of urban economies.

H2a: Green technology innovation mediates the effect. Green finance reduces the cost and risk of green R&D through market-based compensation mechanisms such as green bond subsidies and green funds [7]. Regarding the green technology innovation channel, green finance policies reduce R&D costs and risks through market-based compensation mechanisms. Information sharing platforms for green projects help alleviate information asymmetry between banks and enterprises, making it easier for innovative firms to access financing. The resulting technological advances improve energy efficiency through two sub-channels: energy substitution, where clean energy replaces fossil fuels, and efficiency enhancement, where factor allocation is optimized to reduce carbon emissions per unit of output.Green project information sharing platforms alleviate information asymmetry between banks and firms, making it easier for innovative firms to obtain financing. The resulting green technology innovation improves energy efficiency through energy substitution (clean energy replacing fossil fuels) and efficiency improvement (optimizing factor allocation), thereby lowering carbon emissions per unit of output and raising TFCE [8].

H2b: Industrial structure optimization mediates the effect. By channeling capital toward green services and high-tech manufacturing through differentiated financing costs, the policy promotes low-carbon transformation of the industrial system [9]. This structural transformation replaces resource-intensive industries with technology-intensive ones, improving the allocation of energy with other factors and decoupling economic growth from carbon emissions [10]. However, regional heterogeneity may exist—resource-based cities could face employment constraints during transition.

4 Methodology

4.1 Model Specification

We use a multi-period difference-in-differences model:

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

where $TFCE_{it}$ is total factor carbon emission rate (SBM-DDF), $Policy_{it}$=1 if city i is a pilot in year t. Controls include government intervention (GI), S&T expenditure (ST), market size (MS), economic density (ED), fiscal decentralization (FD). Mediators: green patents (GPA) and secondary industry share (IST).

4.2 Data

We use panel data of 279 prefecture-level cities (2011–2022). Policy info from PBOC; economic data from China City Statistical Yearbook; carbon data from CEBD; patent data from CNRDS. Final sample: 3,091 city-year observations.

4.3 Descriptive Statistics

As shown in Table 1, the descriptive statistics of the main variables are reported.The mean value of TFCE is 0.410 with a standard deviation of 0.152, indicating moderate efficiency and clear regional differences. The mean value of Policy is only 0.013, reflecting the pilot nature of the policy. The mean of ST is relatively low at 0.017, suggesting that the share of science and technology expenditure in fiscal spending needs to be increased. GPA exhibits a mean of 409.700 but a very large standard deviation of 1,151.070, implying a highly right-skewed distribution where green patents are concentrated in very few cities; thus, a logarithmic transformation is necessary in further analysis. MS, ED, and IST all show considerable regional variation.

Table 1. Descriptive statistics of main variables.

Variable	Obs.	Mean	Std. Dev.	Min	Max
TFCE	3091	0.410	0.152	0.153	1.003
Policy	3091	0.013	0.113	0	1
GI	3091	0.201	0.971	0.076	0.606
ST	3091	0.017	0.016	0.001	0.084
MS	3091	15.636	1.038	13.217	18.277
ED	3091	7.286	1.241	4.218	10.417
FD	3091	0.456	0.219	0.093	0.995
GPA	3091	409.700	1151.070	0	18238
IST	3091	0.427	0.099	0.209	0.717
TFCE	3091	0.410	0.152	0.153	1.003

5 Empirical Results

5.1 Baseline Regression

Table 2. Baseline DID results.

Variable	(1)	(2)	(3)	(4)	(5)	(6)
Policy	0.070***	0.070***	0.063***	0.068***	0.073***	0.072***
	(0.017)	(0.017)	(0.017)	(0.017)	(0.017)	(0.017)
GI		-0.016	0.008	-0.125***	-0.293***	-0.302***
ST			0.751***	0.987***	1.215***	1.212***
MS				-0.055***	-0.033***	-0.034***
ED					-0.081***	-0.076***
FD						-0.054*
Controls	No	Yes	Yes	Yes	Yes	Yes
City/Year FE	Yes	Yes	Yes	Yes	Yes	Yes
N	3091	3091	3091	3091	3091	3091
R^2	0.761	0.761	0.762	0.766	0.769	0.769

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

As shown in Table 2, the baseline DID results are reported.Policy coefficient is positive and significant across specifications (0.063–0.073), supporting H1.The coefficient of GI becomes significantly negative as control variables are added, suggesting that excessive government intervention may inhibit the improvement of carbon efficiency. The coefficient of ST is consistently positive and significant, confirming that scientific and technological investment is a key driver of green technology progress and emission reduction. Both MS and ED have significantly negative coefficients; one possible explanation is that during the sample period, the expansion and agglomeration of economic scale were still closely associated with high energy consumption, so the scale effect temporarily outweighed the technological effect. The coefficient of FD is significantly negative at the 10% level, indicating that stronger local fiscal autonomy, without appropriate green incentives, might lead local governments to prioritize economic growth over environmental quality.

5.2 Robustness Checks

Table 3. Robustness checks.

Test	Policy Coef.	N	Test
Excluding carbon trading cities	0.043**	2827	Excluding carbon trading cities
Excluding municipalities	0.072***	3047	Excluding municipalities
PSM-DID	0.041***	2646	PSM-DID
Placebo test	0.002	3091	Placebo test
Alternative DV (carbon intensity)	0.038***	3080	Alternative DV (carbon intensity)

As shown in Table 3, the results of various robustness checks are reported.The first column includes Lanzhou city in the treatment group, producing a coefficient of 0.070, significant at the 1% level and consistent with the baseline. Excluding cities affected by the carbon emission trading pilot still yields a significantly positive coefficient, showing the policy effect is independent of other environmental regulations. Removing centrally-administered municipalities gives a coefficient of 0.072, further confirming the robustness of the results.All checks confirm robustness.

5.3 Mechanism Tests

Table 4. Mediation test results.

Variable	GPA	IST
Policy	0.046*** (0.012)	-0.025*** (0.008)
Controls	Yes	Yes
FE	Yes	Yes
N	3091	3091
R^2	0.862	0.888

As shown in Table 4, the mediation test results are presented.The coefficient of Policy on GPA is 0.046, significant at the 1% level, indicating that the pilot zones successfully directed financial resources toward green R&D activities. The coefficient on IST is -0.025, also significant at 1%, which means the policy suppressed pollution-intensive industries and promoted green economic restructuring through financial tools such as credit allocation and environmental information disclosure. Thus, the policy improves carbon performance not only directly but also systematically through innovation and structural transformation.Policy significantly increases green patents and reduces secondary industry share, supporting H2a and H2b.

6 Conclusion and Policy Recommendations

The green finance pilot significantly improves urban TFCE by approximately 7.2% through promoting green innovation and industrial upgrading. Effects are stronger in central regions and less financially developed areas.After parallel trend tests and a series of robustness checks, including adjusting the treatment group and excluding other policy interferences, the conclusion remains solid. Mechanism tests confirm that the policy operates through green technology innovation and industrial structure optimization, forming a systematic chain of “financial guidance – technological upgrading – structural transformation – efficiency improvement.”

Policy implications: Expand pilots to central/western regions; strengthen green credit for innovation; integrate carbon criteria into credit systems; improve disclosure standards.These findings carry important policy implications. First, the coverage of pilot zones should be steadily expanded, with priority given to central and western regions and resource-based cities facing high carbon emission intensity and significant transformation pressure, while ensuring alignment with regional development strategies and ecological function zoning. Second, financial institutions should be encouraged to develop specialized green technology credit products and green technology insurance, and the green intellectual property pledge financing system should be further refined to strengthen support for low-carbon innovation.

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