Do Carbon Financial Market Pilots Enhance Enterprise New Quality Productive Forces? A Quasi-Natural Experiment

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Abstract

In the contemporary competitive landscape, enterprises strive to bolster their competitiveness through technological innovation and structural upgrading. The carbon financial market pilot (CFMP) policy serves as a critical instrument to incentivize emission reduction and foster green technology adoption, thereby enhancing firm's competitive edge. Using CFMP as a quasi-natural experimental setting, the current research explores its effect on the development of new quality productive forces (NQPF) relying on balanced panel samples of listed firms covering 2011 to 2022. Methodologically, this study applies double machine learning techniques, multi-period difference-in-differences, two-way fixed effects models, and multiple robustness tests, as well as heterogeneity analyses. Our findings reveal that CFMP significantly promotes NQPF, with the key innovation being the identification of crucial mediating channels: mitigating information asymmetry and lowering financing costs, particularly by reducing equity financing costs. Further analysis shows that CFMP enhances enterprises' core competitiveness, with the mediating effect of NQPF in market performance and their short-term policy effects more prominent in fiscal performance and innovation capability. Furthermore, the effect features greater intensity in lower competition intensity, large enterprises, and state-owned enterprises operating in areas lacking stringent environmental constraints. This study sheds light on the part played by carbon finance mechanisms in shaping corporate competitiveness and green transformation. Policy implications include establishing a special green development fund for NQPF, building a national unified carbon finance information platform, implementing hierarchical and targeted support for enterprises of different types, and strengthening policy coordination between CFMP, green finance, and environmental subsidies to avoid overlapping or conflicting objectives.

Keywords: *financial resource allocation, new quality productive forces (NQPF), carbon financial market, low-carbon development, core competitiveness*

JEL Classification*:* G13, O30, Q54

Article history: Received: February 2025; Accepted: March 2026; Published: July 2026

1 INTRODUCTION

The Paris Agreement, rolled out in 2015, established a clear framework for global climate action, with a central goal of limiting the rise in the global average temperature to well below 2°C—

https://doi.org/10.7441/joc.2026.02.05

preferably to 1.5°C. It also provides guidelines for the carbon emission trading system (Wang & Zhang, 2024). According to the International Energy Agency (IEA)'s March 2024 report, China's carbon emissions in 2023 were approximately 1.26 billion metric tons, accounting for around 33.7% of the global total. Meanwhile, issues such as the shift in the economic growth pace, transition between old and new growth drivers, and resource and environmental constraints overlap, pose significant challenges for high-quality development. Against this backdrop, the proposal of New Quality Productive Forces (NQPF) has further clarified the green requirements for high-quality development. Specifically, NQPF takes technological innovation and management optimization as its core, aiming to reduce pollutant emissions in production and improve production efficiency. It also provides a direction for resolving the conflict amid economic growth and environmental governance.

To guide the green transformation of enterprises, the Chinese government encourages green management practices through means such as environmental legislation and regulatory guidelines. In 2011, the National Development and Reform Commission (NDRC) issued the Notice on Launching the Pilot Work of Carbon Emission Rights Trading, approving eight areas, embracing Beijing and Shanghai, to establish carbon financial markets. This notice has become a highly representative innovative tool. Unlike traditional environmental regulations, the Carbon Financial Market Pilot (CFMP) policy integrates market incentives and environmental management, with carbon emission rights as its trading target. These rights are essentially credit transactions with financial attributes (Gu et al., 2022). CFMP not only assigns a clear value to carbon emissions through market mechanisms but also restricts enterprise emission behaviors through trading rules. In the past, enterprises mostly focused on asset expansion and short-term profits, paying little regard to efficient energy utilization and green transition. Since the carbon market incorporated enterprise carbon emissions into transaction management, it has greatly promoted green management practices, driving firms to participate in ecological governance and facilitating endogenous structural adjustment.

Against the backdrop of a maturing carbon finance market, enterprises are increasingly prioritizing energy efficiency gains and emission reduction targets, while actively pursuing innovative technologies and production processes (Hunady & Chyláková, 2024). This shift aligns closely with the developmental logic of NQPF. Theoretically, promoting NQPF creates a practical approach balance the conflicting demands between economic growth and ecological regulation. In reality, however, NQPF initiatives are often characterized by high upfront investment, long payback periods, and elevated operational risks. Without external support—in particular, guidance and guarantees from the government—rational enterprise decision-makers often lack the motivation to take the initiative in its cultivation. Thus, how to enhance NQPF by driving management practices has become a key issue that requires focused attention.

The existing literature on CFMP's economic effects mostly holds two perspectives. According to the first perspective, cost-compliance consequences will result from environmental legislation. To be more precise, environmental rules raise enterprise costs, diminish their green management practices, and impair their production capacity (Yuan & Xiang, 2018; Wu & Hu, 2020; Xia et al., 2022; Arshad et al., 2025). However, the second perspective argues that

https://doi.org/10.7441/joc.2026.02.05

effective environmental legislation can encourage green management practices and partially or completely offset the expenses incurred by businesses (Xie et al., 2022; Hu et al., 2021; Zhang & Xi, 2024). Thus, as a significant environmental control policy, how does CFMP affect enterprise NQPF, and what is its mechanism? What are the impacts of CFMP on enterprises' core competitiveness and their dynamic effects? These problems are presently being examined and confirmed in further detail. Against this research backdrop, we draw on 2011–2022 microdata of Chinese A-share listed enterprises, using the CFMP as a quasi-natural policy shock. A multi-period difference-in-differences (DID) model is deployed for assessing the pilot's effects on enterprise NQPF, its underlying mechanisms, and associated economic consequences.

This work enriches relevant studies through four primary contributions. First, we construct a firm-level NQPF evaluation index system and conduct the first systematic assessment, expanding research on the micro-effects of carbon financial markets. Integrating NQPF into the analytical framework both broadens the dimension of understanding environmental regulatory policies and provides rich background support for future evaluations of CFMP effectiveness. Second, we unpack the black box of CFMP's influence on enterprise NQPF by thoroughly testing its core logic centered on reducing information asymmetry and easing financing constraints. Third, we innovate through heterogeneity analysis across three dimensions: provincial environmental regulation intensity, industry competition level, and enterprise characteristics including ownership and size, clarifying differentiated impacts to support targeted productivity development and competitive advantage consolidation for distinct regions, industries, and firms. Fourth, we split enterprises' core competitiveness into market performance, financial performance, and innovation capability to separately test CFMP's impacts, NQPF's mediating role, and the policy's short and long-term dynamic effects, offering valuable insights for CFMP optimization and institutional construction.

The subsequent layout of this work is well-arranged as follows. Section 2 constitutes theoretical grounding and hypothesis design, analyzing the influence mechanism of CFMP on enterprise NQPF and putting forward a theoretical hypothesis. Section 3 introduces data sources and research methodologies, including all the econometric models we have employed, variable definitions and measurements, samples, and data sources. Section 4 presents the empirical findings and provides a detailed interpretation of the results. Section 5 delves into the key discoveries, while Section 6 concludes the study and delivers relevant policy insights.

2 LITERATURE REVIEW AND HYPOTHESES STATEMENTS

2.1 ECONOMIC EFFECTS OF CFMP

Under the carbon finance market mechanism, when enterprises included in the pilot programs face emission reduction pressure from carbon emission quota constraints, they typically adopt two approaches to achieve compliance. First, they adjust production volume in the short term or purchase carbon emission quotas to control emissions. Second, they invest in green technology development in the long term to reduce carbon emissions at the source. Although green technological innovation increases enterprise innovation costs in the short term, Porter's theory posits that environmental constraints can force enterprises to innovate and, conversely,

https://doi.org/10.7441/joc.2026.02.05

reduce long-term costs. In other words, when the compensation effect brought by innovation covers and exceeds the initial cost input, enterprises will proactively increase investment in green innovation, thereby improving their environmental performance (Ge et al., 2023; Liu & Wang, 2023). Additionally, a study by Chaobo and Qi (2024) shows that CFMP can help cities break free from the carbon lock-in dilemma, with industrial structure upgrading playing a key mediating role in this mechanism. However, some studies present a different perspective, arguing that the carbon emission reduction effect of the policy is mainly achieved through optimizing energy consumption (Lin & Huang, 2022; Xuan et al., 2020; Mebrek & Louail, 2025).

In terms of economic effects, an increasing number of studies have confirmed CFMP in improving enterprises' TFP. For instance, Pan et al. (2022) find that the policy yields significant TFP gains for enterprises, with these improvements persisting post-implementation. Zhou and Qi (2022) further note that policy-induced positive outcomes for green TFP is particularly pronounced in regions with stringent economic penalty mechanisms. Even though current studies have extensively verified the dual environmental and economic repercussions of CFMP, research on how this policy affects the NQPF at the micro-level remains relatively scarce.

2.2 HYPOTHESES STATEMENTS

From the perspective of the resource-based view, enterprise NQPF is a heterogeneous core resource composed of high-quality human capital, advanced technology, and green production capacity, which constitutes the foundation of sustainable competitive advantage (Barney, 1991). Dynamic capability theory further highlights that enterprises need to continuously integrate and reconfigure internal and external resources to adapt to environmental changes (Teece et al., 1997). CFMP, as a market-oriented environmental policy, provides external institutional support for enterprises to accumulate green resources and enhance dynamic capabilities. Meanwhile, the institutional theory suggests that policy tools shape enterprise behavior through regulatory pressure and market incentives (DiMaggio & Powell, 1983). CFMP integrates policy constraints and market mechanisms, guiding enterprises to adjust resource allocation toward green and innovative directions.

Enterprise NQPF takes innovation as its core driving force. It exhibits typical characteristics such as high technology, high efficiency, high quality, and green development. Compared with traditional productive forces, the cultivation and development of NQPF are marked by capital intensity, long time horizons, and high-risk characteristics. That is, enterprises cannot promote NQPF implementation without long-term and stable financial support. However, in practice, when enterprises undertake innovation and other green management activities, they often encounter two core constraints. First, moral hazard arises from information asymmetry. Second, capital constraints resulting from income fluctuations. Based on this, Figure 1 clearly presents the theoretical mechanism framework of how CFMP affects enterprise NQPF.

The external environment is a key variable affecting enterprise green management practices. Among these factors, CFMP establishes economic incentive mechanisms through price signals. Its core goal is to guide the market to optimize green and low-carbon industrial layouts and

https://doi.org/10.7441/joc.2026.02.05

energy use patterns. Specifically, regarding the functional paths of this policy on enterprise NQPF, analysis can be conducted from both the supply side and the demand side.

From the supply side, the carbon finance market opens up new financing channels for enterprises. By selling carbon emission rights or carbon credits, enterprises can secure funds dedicated to energy conservation and emission reduction projects as well as low-carbon technology R&D, which provides key financial support for the national NQPF (Wu et al., 2024). Additionally, carbon financial futures instruments enable enterprises to hedge risks from carbon emission cost fluctuations, enhancing the stability and predictability of their production and operation plans and fostering a sound operational environment for NQPF development.

From the demand side, the dual guidance of market and policy jointly drives the development of enterprise NQPF. On the one hand, rising environmental awareness among consumers has significantly expanded market appetite for low-carbon and carbon-neutral goods. This shift in consumer preferences compels firms to align their NQPF development with evolving market demands (Kartal et al., 2024). On the other hand, as a prominent policy-fueled regulatory instrument, CFMP imposes clear emission reduction obligations on enterprises, directly stimulating demand for carbon financial products and services (Lin & Liu, 2024). Meanwhile, price signals formed within the carbon finance sector capture the shortage of carbon allowances, guiding firms to dynamically adjust their operational strategies and accelerate the low-carbon transition of production activities (Feng et al., 2024).

When the carbon market reaches supply-demand equilibrium, the pilot policy anchors the true value of carbon emission rights via market-oriented pricing mechanisms, helping enterprises scientifically evaluate emission reduction costs and benefits and further optimizing resource allocation efficiency in the low-carbon sector. As the carbon finance market expands, it is expected to attract more investors and enterprises, thereby injecting greater impetus into the development of enterprise NQPF. Given the above discussion, subsequent theoretical hypotheses are established.

H1 CFMP can significantly improve enterprise NQPF.

CFMP can improve enterprise NQPF through a key path: alleviating information asymmetry. Specifically, the policy establishes a standardized information environment through multiple mechanisms and reduces market information barriers.

An information transmission framework centered on mandatory information disclosure is required. Enterprises participating in the carbon finance market must first meet access standards and then systematically disclose carbon emission-related information in a unified and standardized format and scope, which include actual emissions, implemented emission reduction measures, and emission reduction effects. This mandatory disclosure pushes firms to enhance the standardization and transparency of their information. The Interim Provisions on the Administration of Carbon Emission Rights Trading further clarifies the carbon emission trading management framework through administrative regulations and sets rigid standards for the authenticity and completeness of carbon emission data to ensure information quality at the institutional level. Strict supervision and punishment mechanisms should be established to consolidate information credibility. Regulatory authorities verify the accuracy and authenticity of enterprises' carbon emission data via regular inspections and random spot checks. Enterprises violating information disclosure requirements—forging or tampering with data—face legal disciplinary measures, including fines and revocation of trading qualifications (Yan & He, 2024). This strong constraint prevents information distortion. Multi-entity participation forms an information-sharing network. The carbon finance market covers multiple stakeholders, including government regulatory authorities, pollution control entities, and emission reduction enterprises. The collaborative participation of these entities builds a multi-party interconnected information exchange platform. Enterprises can obtain industry trends and benchmark against peer practices through the platform. They then optimize management strategies and adjust production decisions. This largely resolves the information asymmetry dilemma in traditional markets (Gu & Zhao, 2025). In light of the foregoing analysis, the following mediating effect hypothesis is postulated.

H2 CFMP improves enterprise NQPF by alleviating information asymmetry.

CFMP drives the improvement of enterprise NQPF by resolving capital constraints, supported primarily by the market-oriented trading mechanism it establishes. On the carbon finance market platform, enterprises with surplus carbon allowances gain economic benefits through trading and transferring allowances, while high-carbon enterprises purchase allowances to cover emission gaps. This process reduces high-carbon enterprises' rent-seeking costs for allowances, creates additional income for low-carbon enterprises, directly internalizes carbon emission externalities, and realizes a Pareto improvement where low-carbon enterprises benefit, high-carbon enterprises comply with regulations, and overall emission reduction efficiency improves, ultimately optimizing resource allocation significantly (Xie & Yu, 2024; Shu et al., 2024).

Further analysis indicates that market-oriented mechanisms of the carbon finance market, such as quota trading income and compliance requirements, enhance enterprises' transaction participation enthusiasm and promote their proactive integration into the low-carbon trading system. For high-carbon enterprises participating in the market, a multi-level supervision network naturally emerges, comprising government supervision based on policy rules, peer supervision among high-carbon enterprises, and market supervision by investors and consumers driven by low-carbon preferences (Garcia-Sanchez et al., 2025; Romero-Castro & Miramontes-Viña, 2025). Under this system, high-carbon enterprises are more inclined to achieve compliant emission reduction through such transactions and build a positive low-carbon development image. This reputation effect strengthens investors' trust and long-term investment willingness, easing enterprises' equity financing constraints and reducing equity financing costs, thereby providing equity capital support for NQPF development (Pineda Perez & Grijalvo, 2025).

Notably, China's banking credit activities exhibit distinct policy-driven traits. Guided by CFMP, banks more proactively allocate credit resources to low-carbon enterprises and use transition financial instruments to provide tailored support for high-carbon enterprises with low-carbon transformation potential (He & Zhang, 2024). Theoretically, CFMP can reduce both short-and

https://doi.org/10.7441/joc.2026.02.05

long-term corporate debt financing costs by optimizing credit resource allocation and enhancing risk-hedging tools. Furthermore, the cost-reduction effect is expected to be more pronounced for long-term debt, which typically involves larger capital needs, extended maturities, and stricter risk control standards. However, due to policy transmission lags, the slow adjustment of bank credit allocation and bond financing pricing, as well as substantial heterogeneity in corporate financing structures, CFMP's impact on debt financing costs has not reached statistical significance.

H3 CFMP improves enterprise NQPF by reducing financing costs.

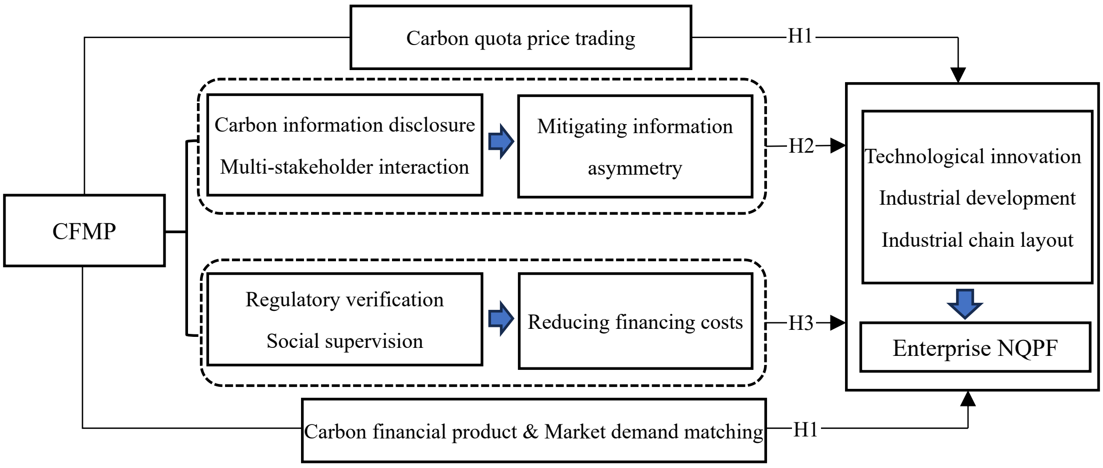

Fig. 1 - Theoretical mechanism framework Source: own research

3 DATA AND METHODS

3.1 VARIABLE SELECTION AND DATA SOURCE

3.1.1 EXPLAINED VARIABLES

Drawing on scholarly works in this field (Färe et al., 2007; Coomes et al., 2019; Lyu et al., 2023; Zhang et al., 2024), NQPF features two core elements, two aspects of basic connotation, and three key characteristics. Its primary driving force is scientific and technological innovation, with original and disruptive breakthroughs enabled by advanced technological evolution, innovative factor optimization and deep industrial iteration. Green development acts as a defining feature, given that NQPF represents inherently green productive forces aligned with carbon peaking, carbon neutrality targets, and ecological priority. The core connotation of NQPF centers on upgrading three components and their efficient coordination: high-quality innovative laborers, advanced intelligent means of labor, and new-type factors such as high-quality materials and data. NQPF features advanced technology, high efficiency and superior quality, with improved TFP as its core marker. It is realized through traditional industry transformation, strategic emerging industry expansion and future industry deployment while emphasizing the independent controllability, safety, and efficiency of industrial and supply chains. Based on the above context and the research of Wang et al. (2021), this study frames a multi-level evaluation index system (see Table 1). New-quality producers are high-quality

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innovative talents with competence in technological innovation, future industry development, and industrial chain layout. New-quality materials of production are enterprises' advanced technologies and equipment, reflecting their R&D input, future industry support, and industrial chain resource allocation capacity. New-quality objects of producers are high-quality materials and new-type production resources, reflecting technological innovation application, future industry resource allocation, and industrial chain environmental protection. Optimized combination denotes the efficient matching of these three components, reflecting an enterprise's comprehensive NQPF level. The entropy weight method is adopted for hierarchical weighting, which is theoretically justified by its ability to objectively reflect the relative importance of each indicator based on information entropy without subjective interference (Li et al., 2022). This method avoids the bias of subjective weighting and ensures the reliability of the NQPF index.

Table 1 - The index system of enterprise NQPF

Target layer	Primary index	Secondary index	Three-level index	Measurement method	Stats
NQPF (1.000)	New quality producers (0.276)	Scientific and technological innovation (0.113)	Share of highly educated workforce (0.007)	Bachelor's degree or above/Number of employees	+
			Proportion of R&D personnel (0.015)	Number of R&D personnel/Employees	+
			Proportion of R&D salary (0.029)	R&D expenses - employee compensation/Revenue	+
			The proportion of training expenses (0.062)	Staff training expenses/Revenue	+
		Future industrial development (0.154)	The proportion of executives with a digital background (0.084)	Digital background numbers of executives/Number of executives	+
			The proportion of senior executives with R&D background (0.016)	Number of senior executives with R&D background/Number of senior executives	+
			The proportion of executives with an environmental protection background	Number of executives with environmental background/Number of executives	+

https://doi.org/10.7441/joc.2026.02.05

		(0.054)		
	Industrial chain layout (0.010)	Executive industry chain attention (0.010)	Ln (1+ industrial chain supply chain word frequency)	+
	Scientific and technological innovation (0.154)	Proportion of R&D expenses (0.075)	R&D expenses (excluding R&D compensation)/ Revenue	+
		Proportion of digital intangible assets (0.079)	Digital intangible assets/Intangible assets	+
New quality materials of production (0.314)	Future industrial development (0.154)	Artificial intelligence adoption (0.084)	Equipment book value per employee	+
		Penetration of industrial robots (0.016)	Robot installation density	+
		Proportion of environmental investment (0.054)	Environmental investments/Total assets	+
New quality objects of producers (0.193)	Industrial chain layout (0.006)	Supply chain concentration (0.004)	Average transaction ratio of the top five customers and suppliers	-
		Supply chain stability (0.002)	Supply-demand fluctuation deviation	-
	Scientific and technological innovation (0.128)	Digital technology innovation (0.055)	Ln (1+ Number of digital patent applications)	+
		Green technology innovation (0.072)	Ln (1+ Number of green patent applications)	+
	Future industrial development (0.064)	The proportion of data assets (0.059)	Data asset scale / firm market valuation	+
		Data element application (0.005)	Ln (1+ Data element utilization word frequency)	+
	Industrial chain layout (0.002)	Pollution emission intensity (0.001)	Sulfur dioxide emissions/Revenue	-
			Chemical oxygen demand/Operating income	-
		Carbon emission intensity (0.001)	Carbon emissions/Revenue	-
Optimized combination	Scientific and technological	Innovation efficiency (0.011)	Ln (1+ patent filings)/ln (1+ R&D spending)	+

https://doi.org/10.7441/joc.2026.02.05

(0.217)	innovation (0.170)	Digital real industry technology integration (0.069)	Ln (1+ Number of industrial technology integration)	+
		Industry-university-research cooperation (0.091)	Ln (1+ Number of patents for industry-university-research cooperation)	+
	Future industrial development (0.033)	Digital transformation of enterprises (0.030)	Digital transformation index	+
		ESG performance of enterprises (0.003)	ESG score of enterprises	+
	Industrial chain layout (0.014)	Supply chain efficiency (0.014)	Ln (365/Inventory turnover)	-

Note: The weight of each index is in parentheses, and three decimal places are reserved.

3.1.2 CORE EXPLANATORY VARIABLES

CFMP represents a manually coded dummy variable as combined effect term of $\boldsymbol{treat_i}$ and $\boldsymbol{post_t}$. Specifically, $\boldsymbol{treat_i}$ is single binary construct indicating whether a region has enacted CFMP, while $\boldsymbol{post_t}$ is year-period dummy serving taken as a measure for the pilot year. The value of $\boldsymbol{post_t}$ is 1 if the year is the one after the implementation of the pilot year. In 2013, the Chinese government launched CFMP in Shenzhen, with Beijing, Tianjin, Guangdong, and Shanghai introducing the regulatory policy within the same year. Hubei and Chongqing rolled out their CFMP in 2014, while Fujian became the final pilot region in 2016. These carbon emission trading schemes have formed valid treatment and control groups for empirical analysis.

3.1.3 CONTROL VARIABLES

To improve the precision of the estimator of treatment effects influenced by omitted variables, this study uses control variables at both prefecture-level city and company levels. At the corporate level, the variables used include business size (***Size***), leverage ratio (***Lev***), growth rate (***Growth***), ownership ratio of the top shareholder (***Top1***), board size (***Boa***), proportion of independent directors (***IO***), and audit opinion (***AO***). Furthermore, at the prefecture-level city level, per capita regional GDP (***Rgdp***), regional education spending (***Edu***), and year-end number of mobile phone subscribers (***Tel***) are chosen as control variables. Table 2 shows the particular meanings of the dependent, independent, as well as control variables.

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Table 2 - Definitions of variables and their units

Variable types	Variable names	Variable symbols	Variable definition
Explained variable	NQPF of enterprises	Npro	Table 1
Explanatory variable	Pilot carbon financial market policies	CFMP	If the city initiates the pilot carbon financial market, the value is 1; otherwise, it is 0.
Control variable	Company size	Size	Total assets
	Leverage ratio	Lev	Total liabilities to total assets ratio
	growth	Growth	Total revenue growth rate
	The proportion of the largest shareholder	Top1	Largest shareholder's shareholding ratio
	Board size	Boa	Number of directors
	Proportion of independent directors	IO	Institutional shareholdings / Total outstanding shares
	Audit opinion	AO	Issuing an unqualified opinion is 1, otherwise 0
	Gross regional product per capita	Rgdp	GDP/resident population
	Regional education expenditure	Edu	Education expenditure
	Total mobile phone users by the end of each year	Tel	Year-end mobile user scale

3.1.4 MECHANISM VARIABLES

The information asymmetry. CFMP mitigates information asymmetry by boosting information disclosure and price discovery functions. Reduced information asymmetry lowers financing frictions and guides resource clustering in innovative fields, forming a key intermediary that links the policy to enterprise NQPF.

Information differences between capital suppliers, ranging from investors to financial institutions, and thus evade direct observation by enterprises. Given this, this study uses securities market trading behavior as a proxy. It uses individual stock trading data to measure the degree of information asymmetry between uninformed and informed traders regarding company value. This measurement indirectly reflects the information differences between the capital supply and demand sides. This approach aligns with the research idea of Bharath et al. (2009), which infers information differences between financing parties through market trading characteristics.

For the specific quantification of information asymmetry, this study draws on the metrics developed by Amihud et al. (1997), Amihud (2002), and Pástor & Stambaugh (2003) using

https://doi.org/10.7441/joc.2026.02.05

daily trading data. The first principal factor of the initial metrics is extracted to capture common variation related to information asymmetry, which is then used to construct the composite information asymmetry index (ASY). The benefits of this index are that it avoids the one-sidedness of a single indicator and retains core information variation through principal component analysis. From an economic perspective, holding remaining determinants steady, intensified information asymmetry corresponds to reduced stock liquidity and a larger ASY index value. As such, the index effectively captures the level of information asymmetry. Furthermore, analysts' deep analysis, interpretation, and public disclosure of corporate information help mitigate information asymmetry between firms and external investors. This study adopts analyst coverage (Asym) as the surrogate for information imbalance, where greater analyst following indicates higher corporate information transparency. Using the median annual industry-level analyst coverage as the threshold, firms are classified into high-transparency (Asym > P50) and low-transparency (Asym < P50) subsamples, followed by subgroup regression analysis.

Corporate financing costs. By improving the risk pricing efficiency of low-carbon projects, the policy directly influences enterprises' debt and equity financing costs. Such costs directly determine enterprises' capacity for sustained investment in NQPF cultivation areas, including green technology R&D and digital transformation. Given the divergent impacts of different financing channels on long-term innovation investment, this study further distinguishes between debt and cost of equity capital.

Consistent with Pittman and Fortin (2004), firm-level debt costs are quantified as current financial expenses relative to total liabilities at the reporting date. Long-term debts cover current portions of non-current debts, long-term borrowings, corporate bonds, long-term payables, and other non-current liabilities, while short-term debt is defined as current loans stated on the balance sheet, a specification designed to accurately capture cost variations across different debt tenors. For equity financing costs, we draw on Easton (2004) and adopt the PEG and MPEG models. We calculate two metrics denoted as R1 and R2 separately based on price-earnings ratios and market earnings growth rates, using the formula provided in Equation (1). This dual-method framework fully captures investors' risk premium assessments of firms' low-carbon transition and innovation potential.

$$r_{PEG} = \sqrt{(EPS_2 - EPS_1)/P_0} \tag{1}$$

In contrast to the PEG model, the MPEG model incorporates dividend factors. The specific formula is presented in Equation (2):

$$r_{MPEG} = \sqrt{(EPS_2 + r_{MPEG} \times DPS_1 - EPS_1)/P_0} \tag{2}$$

Here, $\boldsymbol{EPS_1}$ and $\boldsymbol{EPS_2}$ represent expected earnings per share for the next year and two years, respectively. $\boldsymbol{P_0}$ represents the current stock price. $\boldsymbol{DPS_1}$ represents the dividend per share for the future period. The dividend payout ratio is calculated using the median of the company's dividend payout ratio over the previous three years.

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3.1.5 DATA AND SAMPLE

Given that CFMP is a China-based regional pilot program, this analysis uses panel data from 283 prefecture-level spanning 2011 to 2022. Urban-level data are mainly collected from the official *China City Yearbook* (2011–2022), which contains datasets on economy, population, industry, and environmental pollution, while firm-specific data are retrieved from CSMAR database. We filter the initial research sample in accordance with the steps listed below: (1) excluding financial institutions to retain non-financial A-share firms and mitigate extreme value effects; (2) removing ST* and PT* samples; (3) eliminating observations that violate accounting norms such as negative asset-liability ratios or fixed assets; (4) excluding samples with missing key variables. This filtering yielded 23,551 observations. Summary statistics are provided in Table 3.

Table 3 - Descriptive statistics of the regression analysis variables Source: own research

Type	Variable	Obs	Mean	Stv. Dev.	Min	Max
Explained variable	NQPF	23,551	12.962	8.419	0.960	72.013
Core explanatory variable	CFMP	23,551	0.364	0.481	0.000	1.000
Control variables	Size	23,551	22.449	1.335	19.918	26.426
	Lev	23,551	0.446	0.201	0.065	0.894
	Growth	23,551	0.150	0.388	-0.572	2.486
	Top1	23,551	35.67	15.302	8.930	75.490
	Boa	23,551	2.140	0.198	1.609	2.708
	BI	23,551	37.39	5.288	33.330	57.140
	AO	23,551	0.989	0.103	0.000	1.000
	Rgdp	23,551	11.44	0.522	8.773	13.056
	Edu	23,551	14.44	1.098	9.906	16.276
	Dig	23,551	7.034	0.935	3.219	8.397

3.2 ECONOMETRIC MODEL

3.2.1 CORE IDENTIFICATION STRATEGY

Following Acemoglu and Angrist (2001), the multi-period DID model works well to resolve endogeneity concerns in counterfactual settings. Fixed effects of prefecture cities and years are added to mitigate individual and time-varying confounders. The baseline model is shown in Equation 3.

$$NQPF_{it} = \alpha_0 + \alpha_1 CFMP_{it} + \beta_1 Controls_{it} + \eta_i + \theta_t + \varepsilon_{it} \quad (3)$$

Here, $\boldsymbol{\eta_i}$ and $\boldsymbol{\theta_t}$ represent time-invariant city factors and yearly fixed controls. ε_{it} denotes the random disturbance that accounts for unobserved confounders. Furthermore, $\boldsymbol{\alpha_1}$ is the key parameter reflecting CFMP's policy effect.

https://doi.org/10.7441/joc.2026.02.05

3.2.2 MECHANISM EFFECT MODEL

This study constructs a mediating mechanism model below.

$$Mediator_{it} = \eta_0 + \eta_1 CFMP_{it} + \beta_2 Controls_{it} + \eta_i + \theta_t + \varepsilon_{it} \tag{4}$$

The ***Mediator**$_{it}$* indicates information asymmetry and financing costs. The remaining parameters align with the definitions in Equation (3).

4 EMPIRICAL RESULTS

4.1 BASELINE ESTIMATION ANALYSIS RESULTS

Table 4 presents the baseline regression results. Column (1) shows that the coefficient of CFMP on enterprise NQPF registers at 0.466 and attains 5% statistical significance without control variables, a positive and significant effect that persists following the gradual inclusion of firm-level and regional-level controls. The R-squared of the regression models increases gradually from 0.228 (Column 1) to 0.263 (Columns 5–6) with the sequential inclusion controlling for firm-specific and city-specific factors. This incremental change is statistically significant, illustrating the introduction of relevant controls effectively improves the model's explanatory power for enterprise NQPF. The stable R-squared upon adding a complete set of controls confirms the robustness of the CFMP coefficient. This finding confirms that CFMP facilitates enterprise NQPF development through the pricing effect and supply-demand matching mechanism, thus supporting H1.

Table 4 - Baseline regression results Source: own research

Variable	(1)	(2)	(3)	(4)	(5)	(6)
CFMP	0.466**	0.559**	0.551**	0.550**	0.550**	0.482**
	(0.222)	(0.219)	(0.218)	(0.219)	(0.222)	(0.221)
Size		1.170***	1.333***	1.333***	1.325***	1.326***
		(0.132)	(0.139)	(0.141)	(0.141)	(0.141)
Lev		-2.546***	-3.046***	-3.049***	-2.978***	-2.998***
		(0.707)	(0.715)	(0.715)	(0.716)	(0.716)
Growth			0.474***	0.470***	0.446***	0.448***
			(0.134)	(0.134)	(0.134)	(0.134)
Top1			-0.062***	-0.062***	-0.063***	-0.063***
			(0.010)	(0.010)	(0.010)	(0.010)
Boa				-0.069	-0.087	-0.085
				(0.828)	(0.827)	(0.827)
BI				0.028	0.028	0.028
				(0.027)	(0.027)	(0.027)
AO					1.534***	1.541***
					(0.546)	(0.544)
lnrgdp					-0.020	0.119
					(0.351)	(0.340)
lnedu						0.822*

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						(0.447)
lndig						-0.745
						(0.503)
Year fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
City fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
Constant	12.792***	-12.380***	-13.674***	-14.549***	-15.631***	-23.855***
	(0.156)	(2.813)	(2.837)	(3.409)	(5.289)	(8.548)
Observations	23,551	23,551	23,551	23,551	23,551	23,551
R-squared	0.228	0.252	0.263	0.263	0.263	0.263

Note: Enterprise-level clustering standard errors are presented in parentheses. $p<0.01$, $p<0.05$, and $p < 0.1$ are marked as ***, **, and *, individually. The same below.

4.2 ROBUSTNESS CHECK RESULTS

4.2.1 COMMON TREND TEST AND DYNAMICS EFFECTS

Figure 2 presents the parallel trend test results. All pre-policy estimated coefficients fail to reach the 10% statistical significance threshold, which verifies that no systematic differences exist between the treatment and control groups before policy enforcement.

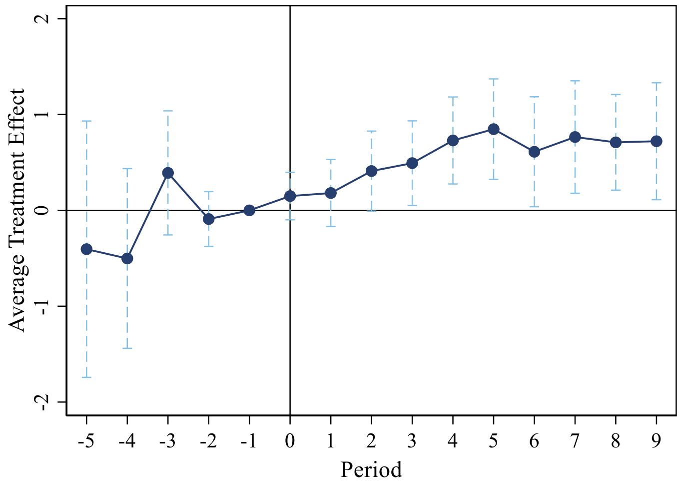

Fig. 2 - Common trend test result. Source: own research

4.2.2 CONSIDER THE IMPACT OF HETEROGENEOUS TREATMENT EFFECTS

Temporal group differences-driven time-varying heterogeneous treatment effects may distort average treatment effects; thus, we apply Bacon decomposition to investigate time-heterogeneous resilience characteristics (Goodman-Bacon, 2021). According to Table 5, the corresponding weight for the poor control group is just 0.056. Hence, the negative attribute of the flawed control group does not interfere with the therapy of CFMP.

https://doi.org/10.7441/joc.2026.02.05

Table 5 - The results of Bacon decomposition Source: own research

Treatment Group vs Control Group	parameter	weight
Later Treatment vs Early Control	0.397	0.056
Early Treatment vs Later Control	-0.203	0.018
Timing vs Never Treatment	0.070	0.786
Timing vs Already Treatment	-0.732	0.140

4.2.3 PLACEBO TEST

Worryingly, bias from unobservable factors may still affect treatment effect estimates; thus, following Chetty et al. (2009), this study employs time and spatial placebo tests to verify whether baseline results are driven by random factors, as illustrated in Figure 3.

This study constructs a fake treatment group by artificially advancing the policy implementation time for the time placebo test. Repeated estimations show that the placebo coefficients all include 0 within the 95% confidence interval, confirming that the improvement of enterprise NQPF is not driven by long-term time trends or other time-varying confounding factors but is closely associated with CFMP.

For the spatial placebo test, this study constructs a virtual treatment group by randomly permuting pilot areas and substituting them into the benchmark model for regression, with 500 repetitions of this virtual experiment. The results approximate a normal distribution with a small two-tailed p-value, confirming that spatial differences for pilot zones relative to their non-pilot counterparts are not driven by random factors. This further validates that CFMP's effect on promoting enterprise NQPF is policy-directed rather than a spurious correlation from spatially omitted variables.

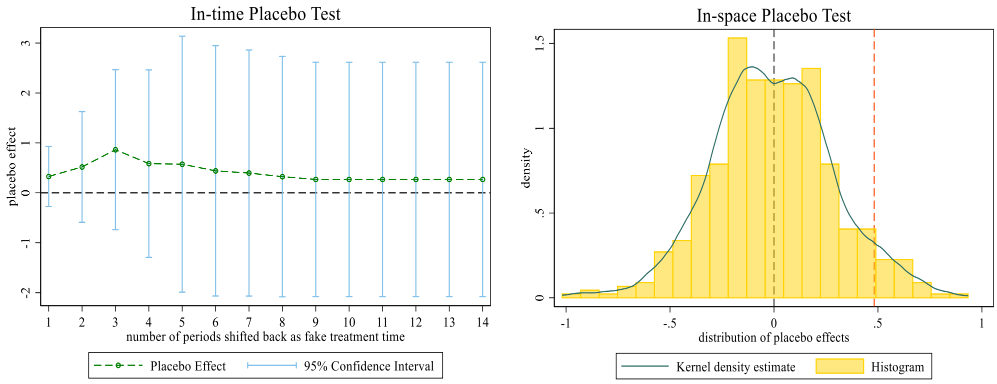

Fig. 3 - Placebo test results. Source: own research

4.2.4 MATCHING METHOD

PSM-DID. While the DID method estimates the overall treatment influence, CFMP is not a strict natural experiment, and potential selectivity bias may remain (Ho et al., 2007). This study applies nearest neighbor matching (1:1), kernel matching, as well as caliper matching (caliper = 0.05), as illustrated in Columns (1)–(3) in Table 6. Regression coefficients remain

https://doi.org/10.7441/joc.2026.02.05

significantly positive across all matching methods, confirming that causal inference is insensitive to matching method choices and, thus, highly robust.

Entropy Balancing. Pilot areas as treatments and non-pilot areas as controls, covariate differences may confound enterprise NQPF development. To further validate the baseline results, we adopt the entropy balancing method (Hainmueller, 2012), which controls the first moment of covariates and performs weighted regression to enhance the comparability of sample characteristics. Illustrated in Table 6, Column (4), the marginal effect of CFMP continues to be robust and positive.

Table 6 - Results of matching method test Source: own research

Variable	(1) Kernel density matching	(2) 1:1 nearest neighbor matching	(3) Caliper matching	(4) Entropy balance
CFMP	0.431**	0.605*	0.431**	0.372*
	(0.164)	(0.306)	(0.161)	(1.966)
Controls	Yes	Yes	Yes	Yes
Year fixed effects	Yes	Yes	Yes	Yes
City fixed effects	Yes	Yes	Yes	Yes
Constant	-27.922*	-63.684	-25.285*	-5.656
	(14.216)	(38.165)	(12.897)	(-0.277)
Observations	18,489	6,454	18,489	23,551
R-squared	0.283	0.386	0.280	0.199

4.2.5 EXCLUDE THE INTERFERENCE OF OTHER POLICIES IN THE SAME PERIOD

Consider the implications of the development of industrial robots. Industrial robot development promotes automation and intelligence, which may affect enterprise production efficiency and, thus, NQPF. We use provincial industrial robot installation density (IRD_policy) as its proxy, and Table 7 Column (1) shows that CFMP still notably fosters enterprise NQPF, confirming robust results.

Low-carbon city pilot policy. City-level low-carbon development may synergize with CFMP to influence enterprise technological innovation directions. Low-carbon city pilot catalogs were officially launched by the NDRC across three batches in 2010, 2012 and 2017; thus, this study adds a dummy variable for the policy's implementation year (IRD_policy) to the baseline model to control its impact. Column (2) of Table 7 shows that the CFMP coefficient remains significantly positive, confirming result robustness.

4.2.6 OTHER ROBUSTNESS TESTS

To exclude the impact of COVID-19, we estimate using the 2011–2019 sample, with regression results summarized in Table 7 Column (3). To control for other regional environmental policies, we add provincial-year fixed effects, and the regression results are shown in Column (4) of Table 7. To control for residual correlation across firms within the same industry-year due to common external shocks, we follow Cameron et al. (2011) and adopt industry-year two-way

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clustering treatment. The corresponding regression results are displayed in Table 7, Column (5). All results confirm the robustness of core regression outcomes.

Change the estimated model of the policy effect. Double machine learning, formally, reduces estimation bias from limited key control variables and avoids model misspecification (Yang et al., 2020). Column (6) of Table 7 presents the double machine learning results, where CFMP's coefficient on enterprise NQPF is markedly positive with 1% statistical confidence, further validating a steady causal mutually reinforcing effect.

Table 7 - Results of the series robustness testing Source: own research

Variable	(1) Exclude industrial robot development	(2) Rule out pilot policies for low-carbon cities	(3) Eliminate the impact of COVID-19	(4) Add provincial-year fixed effect	(5) Change the clustering level	(6) Double machine learning model
CFMP	0.466**	0.473**	0.370*	0.482**	0.482*	2.033***
	(0.222)	(0.219)	(0.201)	(0.221)	(0.249)	(0.412)
IRD_policy	0.044					
	(0.210)					
LCC_policy		-0.169				
		(0.244)				
Controls	Yes	Yes	Yes	Yes	Yes	Yes
Year fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
City fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
Constant	-23.913***	-24.230***	-27.966***	-23.855***	-23.855*	0.671***
	(8.775)	(8.508)	(8.717)	(8.548)	(12.384)	(0.036)
Observations	23,551	23,551	16,517	23,551	23,551	23,551
R-squared	0.261	0.263	0.242	0.263	0.263	-

4.3 RESULTS OF MECHANISM ANALYSIS

4.3.1 INFORMATION ASYMMETRY

The mechanism analysis on information asymmetry is shown in Table 8. Column (1) shows CFMP's coefficient is significantly negative reaching the 1% statistical standard, signifying that the policy constrains information asymmetry. Column (2) shows that CFMP reaches positive statistical significance at 10%, which verifies that regulation improves information transparency, which, in turn, mitigates information asymmetry. Columns (3)–(4) demonstrate that CFMP's promotion of enterprise NQPF is more pronounced under higher information transparency. CFMP alleviates information asymmetry through enhanced information disclosure and price discovery, reducing financing frictions and directing resources to innovative sectors to foster NQPF development. These results provide empirical support for H2.

Table 8 - Mechanism analysis results of mitigating information asymmetry Source: own research

Variable	(1) ASY	(2) Asym	(3) Asym>P50	(4) Asym<P50
CFMP	-0.081***	0.411*	0.678**	0.259
	(0.021)	(0.228)	(0.337)	(0.341)
Controls	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes
City FE	Yes	Yes	Yes	Yes
Constant	7.071***	-5.130	-27.249	-22.984
	(0.668)	(3.511)	(12.728)	(12.417)
Observations	23,551	23,551	11,815	11,736
R-squared	0.429	0.361	0.305	0.268

4.3.2 FINANCING COSTS

Table 9, Columns (1) to (2), reports estimated evidence for different time horizons debt financing costs, respectively. In terms of coefficient direction, CFMP exhibits a negative impact on enterprises' debt financing costs; nonetheless, these estimated results are statistically insignificant. Notably, the absolute value of the coefficient for long-term debt financing costs (0.045) exceeds that of short-term counterparts (0.005), which is consistent with theoretical expectations: long-term liabilities typically involve greater capital requirements, longer maturities, and stricter risk control standards. The diverse risk management tools provided by CFMP could more effectively hedge against long-term risks, thereby alleviating enterprises' long-term capital constraints and enabling them to scale up resource allocation for technological breakthroughs, green transformation, and production equipment upgrading, ultimately promoting NQPF development. Although the empirical findings of this study do not demonstrate statistical significance, the relative variation in the coefficient of long-term financing costs still offers certain empirical insights into the policy transmission mechanism of CFMP.

Table 9, Columns (3) to (4), presents the empirical outcome for equity financing costs. CFMP's coefficient obtains a negative estimate significant at the 1% level, signifying the policy notably lessens enterprises' equity financing costs. This is because CFMP strengthens market confidence in enterprises' future potential—enterprises participating in carbon finance transactions cultivate a low-carbon development image, and this reputation effect enhances investors' willingness to pay and investment enthusiasm. The reduced equity financing costs provide enterprises with more financial support for technological innovation, talent introduction, and equipment upgrading, thereby promoting enterprise NQPF.

Overall, CFMP has significantly reduced enterprises' equity financing costs, thereby promoting enterprise NQPF, with these results providing empirical support for H3.

https://doi.org/10.7441/joc.2026.02.05

Table 9 - Mechanism analysis results of financing cost Source: own research

Variable	(1)	(2)	(3)	(4)
	Debt financing cost		Equity financing cost	
	shortdebt	longdebt	R1	R2
CFMP	-0.005	-0.045	-0.010***	-0.013***
	(0.049)	(0.072)	(0.004)	(0.004)
Controls	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes
City FE	Yes	Yes	Yes	Yes
Constant	2.535	-12.513***	0.245*	0.036
	(1.782)	(2.653)	(0.125)	(0.148)
Observations	23,551	23,551	23,551	23,551
R-Square	0.597	0.710	0.200	0.147

4.4 RESULTS OF THE HETEROGENEOUS EFFECTS ANALYSIS

Given that CFMP mainly targets heavy-polluting enterprises, its effects are associated with industry competition intensity, enterprise-specific characteristics, and provincial factors such as policy implementation intensity. We, thus, conduct heterogeneity analysis across three dimensions: provincial governance, industry competition intensity, and enterprise micro-characteristics.

Table 10 - Results of heterogeneity analysis Source: own research

Variable	(1)	(2)	(3)	(4)	(5)	(6)
	ER=1	ER=0	State-owned enterprises (SOE)=1	SOE=0	Size=1	Size=0
CFMP	0.363	0.649**	0.545*	0.208	0.844**	0.192
	(0.350)	(0.277)	(0.289)	(0.353)	(0.408)	(0.337)
Controls	Yes	Yes	Yes	Yes	Yes	Yes
City FE	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes
Constant	-12.690	-33.047***	-31.886**	-33.358**	-39.176***	-52.648***
	(12.281)	(10.885)	(12.874)	(13.602)	(10.458)	(8.527)
Observations	11,253	12,298	10,232	13,319	11,785	11,767
R-squared	0.253	0.273	0.302	0.307	0.202	0.222

Provincial governance. While higher provincial environmental regulation intensity is generally expected to enhance policy effectiveness. Following Deng & Yang (2019), this study constructs a provincial environmental regulation intensity index via text analysis of government

https://doi.org/10.7441/joc.2026.02.05

work reports and uses Python for word segmentation and counts the frequency of keywords including terms such as environmental protection, energy conservation, and emission reduction; it then assigns a value of 1 to provinces where the environmental regulation intensity exceeds the average and 0 otherwise. Table 10, Columns (1) to (2), shows that CFMP's positive impact on enterprise NQPF is more significant in provinces with lower environmental regulation intensity. This may be because enterprises in high-regulation regions have already completed basic transformation, leaving limited room for NQPF improvement through the carbon market. In contrast, enterprises in low-regulation regions have greater potential for upgrading green technology and improving production efficiency. The carbon price signals and financing support brought by the carbon market can more directly drive their transition from extensive development to green and efficient development, thereby enhancing the incremental effect of the policy.

Enterprise micro-characteristics. Distortions in the efficiency of intra-industry financial resource allocation primarily stem from ownership discrimination and scale discrimination. Table 10 examines CFMP's heterogeneous impact on enterprise NQPF across ownership and scale. Columns (3)−(4) reveal a remarkably positive influence of CFMP on SOEs NQPF, as SOEs benefit from implicit government guarantees that reduce financial friction and financing costs. Columns (5)−(6) show CFMP's promotion of NQPF is more pronounced for larger enterprises, driven by economies of scale that lower their financing costs.

Industry competition intensity. CFMP's impact on enterprise NQPF exhibits heterogeneity across different industrial competition structures. This study uses the Herfindahl-Hirschman Index (HHI) to measure industrial competition, calculated as $HHI = \sum_{i=1}^{n}(X_i/X)^2$, where $\boldsymbol{X_i}$ represents operating income, the book value of owners' equity, total assets, and revenue from principal activities, and X denotes the total industry value of the corresponding indicators. The mean HHI across these indicators is used as the threshold to split the sample into high-HHI (weak competition) and low-HHI (intense competition) subsamples. Table 11, Columns (1) to (8), shows that CFMP exerts a more pronounced promoting effect on enterprise NQPF in low-competition industries. The underlying mechanisms lie in leading enterprises in low-competition industries holding core scarce resources covering capital endowments and technological strengths, boasting sound conditions for low-carbon transition, and efficiently capturing carbon finance policy dividends through inter-industry synergies. In contrast, enterprises in high-competition industries face squeezed profit margins and inter-firm competitive pressures, struggling to allocate limited resources to long-term low-carbon technological innovation, which hinders the full conversion of carbon finance policy dividends into actual NQPF improvements.

Table 11 - Results of heterogeneity analysis of industry competition intensity Source: own research

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Variable	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
CFMP	-0.156	0.661**	-0.047	0.559*	-0.401	0.741**	-0.226	0.701**
	(0.367)	(0.282)	(0.350)	(0.298)	(0.367)	(0.298)	(0.368)	(0.286)
Controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
City FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Constant	-24.574*	-18.724*	-33.481***	-19.494*	-26.669**	-18.066	-30.284**	-18.050
	(13.223)	(10.868)	(12.562)	(11.652)	(12.690)	(11.677)	(13.292)	(11.183)
Observations	6,992	16,541	8,189	15,344	8,520	15,016	7,245	16,293
R-squared	0.350	0.278	0.365	0.271	0.343	0.283	0.346	0.281

4.5 FURTHER ANALYSIS

4.5.1 ANALYSIS OF THE ECONOMIC CONSEQUENCES OF CORPORATE COMPETITIVENESS

Firm core competitiveness, which is defined as firms' comprehensive capability to gain and sustain market competitive advantages, serves as a pivotal indicator for measuring policy outcomes (Prahalad & Hamel, 2009; Wernerfelt, 1984). NQPF is a critical transmission mechanism linking policies to firm core competitiveness, and whether its enhancement translates into sustainable competitive advantages is a key criterion for assessing policy effectiveness. Accordingly, this study empirically assesses the direct role of CFMP on firms' NQPF and whether such influence translates into long-lasting competitive advantages.

Mechanistically, CFMP relies on carbon pricing and constraint-incentive mechanisms to effectively alleviate information asymmetry between firms and the capital market, reduce firms' green financing costs, and drive NQPF development. NQPF embodies cutting-edge technological attributes, efficient resource allocation capabilities, high-quality product supply capacity, and green low-carbon development foundation; these constitute the core support for firms to build technological barriers, expand market share, reduce operational costs, and shape green brand images, ultimately contributing to the continuous improvement of firms' core competitiveness (Tian et al., 2025).

While diverse indicator systems exist for measuring firm core competitiveness, no unified standard has been established. This study comprehensively evaluates firm core competitiveness across technological innovation, market performance, operational efficiency, green advantages, and brand value. Drawing on existing studies (Tobin, 1969; Lang & Stulz, 1994; Aghion & Griffith, 2008; Bournakis & Mallick, 2018), it selects representative indicators from financial performance, market performance, and innovation capability, adopting return on total assets (ROA), Tobin's Q and TFP as proxy variables, respectively. This study empirically examines CFMP's impact on firm competitiveness alongside the intermediary function of firms' NQPF.

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Among them, the model specifications are as follows:

$$COM_{it} = \mu_0 + \mu_1 CFMP_{it} + \beta_3 Controls_{it} + \eta_i + \theta_t + \varepsilon_{it} \quad (5)$$

$$NQPF_{it} = \alpha_0 + \alpha_1 CFMP_{it} + \beta_4 Controls_{it} + \eta_i + \theta_t + \varepsilon_{it} \quad (6)$$

$$COM_{it} = \gamma_0 + \gamma_1 CFMP_{it} + \lambda_2 NQPF_{it} + \beta_5 Controls_{it} + \eta_i + \theta_t + \varepsilon_{it} \quad (7)$$

Here, $\boldsymbol{COM_{it}}$ denotes the core competitiveness of the firm, $\boldsymbol{NQPF_{it}}$ is the mediating variable, and other variable definitions are identical to those illustrated above.

As shown in the results of Table 12, Columns (1), (3), and (5) show that CFMP exerts a significant positive total effect on Tobin's Q, ROA, and TFP_GMM without the mediating variable. Column (2) documents a positive effect significant under the 1% threshold of CFMP on NQPF, verifying the core explanatory variable's positive effect on the mediating variable. Columns (2), (4), and (6) indicate a significantly positive coefficient of NQPF on Tobin's Q, demonstrating NQPF's partial mediating role. In contrast, NQPF's coefficients on ROA and TFP_GMM are insignificant, with no substantial difference between CFMP's direct and total effects, which confirms the latter's direct impact on these two indicators and NQPF's non-involvement in their transmission paths. These results reveal heterogeneous policy impact paths on firm competitiveness across dimensions: market performance indicators are affected by the mediating effect of firms' external characteristics, while financial performance and innovation capability indicators rely more on the policy's direct effect.

Table 12 - Regression results of the economic consequences of corporate competitiveness Source: own research

Variable	(1) TobinQ	(2) TobinQ	(3) ROA	(4) ROA	(5) TFP_GMM	(6) TFP_GMM
CFMP	0.086*	0.081*	0.004**	0.004**	0.053*	0.053*
	(0.045)	(0.045)	(0.002)	(0.002)	(0.029)	(0.029)
NQPF		0.013***		0.000		0.000
		(0.002)		(0.000)		(0.002)
Controls	Yes	Yes	Yes	Yes	Yes	Yes
City FE	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes
Constant	11.387***	11.694***	-0.157**	-0.155**	2.667***	2.672***
	(1.517)	(1.512)	(0.066)	(0.066)	(0.993)	(0.995)
Observations	22,095	22,095	23,543	23,543	21,844	21,844
R-squared	0.307	0.311	0.320	0.320	0.268	0.268

4.5.2 DYNAMIC EFFECT ANALYSIS

As shown in Table 13, pre-policy ROA and TFP_GMM coefficients are insignificant across all periods, satisfying the dynamic DID model's parallel trend assumption, while Tobin's Q coefficients are significant in two pre-policy periods and fail the test. Post-policy, the short term (1–2 years) witnesses the policy exert a positive impact on all metrics; the most prominent short-term effect is on ROA, which is attributed to policy dividends such as green financing

https://doi.org/10.7441/joc.2026.02.05

interest subsidies and carbon asset trading gains directly boosting firms' current financial performance. In the long run (3–5 years), the constructive role of the policy in boosting ROA and TFP_GMM persist until the 4th year post-implementation, with TFP_GMM demonstrating stronger long-term sustainability, while the impact on Tobin's Q lacks stability. This is because TFP, as a long-term indicator reflecting firms' fundamental production capacity, relies on incremental inputs such as technological innovation and production process optimization, and CFMP-driven transformation requires 3–4 years to translate into sustained production efficiency improvements. In contrast, ROA is a short-term profitability indicator linked to current profits; long-term transformation cost provisions and diminishing marginal returns of policy dividends rapidly erode profits, leading to faster policy effect attenuation. The insignificance of both indicators' coefficients from the 5th year onward is most likely a phased result of the short sample observation window or incomplete release of firms' low-carbon transformation long-term effects, instead of complete policy effect disappearance.

Table 13 - Results of dynamic effect analysis Source: own research

	(1) TobinQ	(2) ROA	(3) TFP_GMM
pre_5	-0.188	0.006	-0.015
	(0.123)	(0.005)	(0.102)
pre_4	-0.207*	-0.001	0.103
	(0.116)	(0.005)	(0.087)
pre_3	-0.161*	-0.005	0.011
	(0.090)	(0.004)	(0.061)
pre_2	-0.059	-0.003	-0.013
	(0.038)	(0.002)	(0.022)
current	0.081*	0.004**	0.043**
	(0.044)	(0.002)	(0.020)
post_1	0.105*	0.006***	0.061**
	(0.058)	(0.002)	(0.026)
post_2	0.062	0.008***	0.046
	(0.072)	(0.002)	(0.031)
post_3	0.038	0.005**	0.064*
	(0.063)	(0.003)	(0.035)
post_4	0.065	0.006**	0.063*
	(0.060)	(0.003)	(0.036)
post_5	0.061	0.001	0.039
	(0.057)	(0.003)	(0.038)
post_6	0.061	0.001	0.054
	(0.061)	(0.003)	(0.040)
post_7	0.007	-0.004	0.061
	(0.068)	(0.003)	(0.041)
post_8	-0.096	-0.008***	0.062

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	(0.068)	(0.003)	(0.043)
post_9	-0.068	-0.005	0.006
	(0.062)	(0.003)	(0.047)
Constant	11.584***	-0.161**	2.691***
	(1.529)	(0.067)	(1.002)
Observations	22,095	23,543	21,844
R-squared	0.307	0.321	0.269

5 DISCUSSION

This study's conclusions align with the mainstream view that carbon markets promote green innovation (Wu et al., 2025), as results suggest CFMP significantly enhances enterprise NQPF by weakening information imbalance and alleviating financing pressures. First, the policy improves corporate carbon information disclosure quality and strengthens transparency with external stakeholders, which mitigates adverse selection risks during eco-friendly innovation and facilitates the market recognition of carbon-reduction technologies and financial support (De Blick et al., 2024). Second, CFMP provides low-cost financing channels for low-carbon projects through carbon financial instrument innovation (Lu et al., 2023); enterprises participating in carbon market transactions send environmental compliance signals via carbon quota surpluses or emission reduction certifications, enabling them to obtain credit market interest rate concessions and ultimately alleviating funding bottlenecks in NQPF cultivation.

Contextually, CFMP's impact on enterprise NQPF exhibits heterogeneity: the policy effect is stronger in regions with weaker environmental regulation, prompting policymakers to consider policy overlap effects and regional return differences. However, large enterprises and SOEs possess richer technological and capital reserves for rapid adaptation, while other market players face higher transition costs due to resource constraints. Notably, SOEs lead in NQPF improvement, supported by robust policy execution and diversified financing tied to China's distinctive government-enterprise nexus (Wang et al., 2022). While CFMP's effect is more significant in weaker environmental regulation regions, this does not negate Porter's Hypothesis, whose core proposition focuses on the differential impacts of environmental regulation implementation (vs. non-implementation) on technological innovation and firm development. Building on this, this study further incorporates regional heterogeneity, noting that environmental regulation effects vary with intensity—for example, marginal effects of heterogeneous environmental regulations may overlap or offset in highly regulated regions. In contrast, this study consistently focuses on CFMP's own implementation effects and its specific impact pathways on enterprise NQPF.

Internationally, China's carbon finance market pilots and the EU Emissions Trading System (EU ETS) share similarities and differences in influencing corporate behaviors. Both impose cost constraints via carbon allowance scarcity and guide enterprises toward low-carbon technology R&D and production transformation through market-oriented mechanisms (Wang et al., 2025; Zheng et al., 2022). Three key differences emerge: first, the EU ETS relies on a mature carbon derivatives market to focus on risk transmission and carbon asset management,

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while China's pilots prioritize easing financing constraints. Second, the EU ETS covers predominantly private enterprises with profit maximization as the core decision objective, while Chinese SOEs, shaped by unique government-enterprise relations, exhibit both policy initiative and compliance rigidity. Third, the EU ETS is backed by a sound legal framework and cross-regional coordination, while China's pilots rely mainly on financing support and technology subsidies (Wei et al., 2025; Li et al., 2023). Additionally, CFMP does not operate in isolation but interacts with other policy tools. For example, green finance policies (e.g., green credit, green bonds) complement CFMP by providing targeted financial support for low-carbon projects, while environmental subsidies can reduce the short-term transition costs of enterprises, enhancing the policy synergy effect. However, potential policy conflicts may exist: excessive environmental subsidies may weaken the price signal of CFMP, reducing enterprises' incentives for long-term green innovation. Moreover, there is heterogeneity in CFMP design across pilot regions: for instance, Shenzhen and Shanghai have more flexible carbon quota allocation mechanisms and richer carbon financial instruments, while other regions focus more on compliance supervision. This study's conclusions verify the universal value of such market-oriented policies and offer empirical references and localized insights for China's carbon market optimization and emerging economies' carbon policy design.

This current study suffers from certain deficiencies in sample settings. Specifically, the analysis is based primarily on A-share listed firms traded on the Shanghai and Shenzhen stock markets, with National Equities Exchange and Quotations listed SMEs excluded, as well as local SOEs. This limitation means the conclusions may not be directly generalized to SMEs, which face more severe financing constraints and weaker technological capabilities. For SMEs, the impact of CFMP may be limited by their lack of access to carbon financial markets and insufficient green innovation resources. In other institutional environments (e.g., developed economies with mature carbon markets), CFMP's mechanism may differ because of differences in legal systems, market maturity, and enterprise governance structures. Additionally, in the sample of NQPF indicators, cutting-edge indicators such as the depth of AI application, digital disruptive innovation, and green disruptive technologies require further thorough consideration to more comprehensively measure the "new quality" dimension of NQPF development. Future research should expand the sample scope to verify the generalizability of the conclusions.

6 CONCLUSIONS AND POLICY IMPLICATIONS

The current research regards CFMP as a quasi-natural experimental setting and 2011–2022 microdata of China's public listed enterprises, aiming to explore the inherent link between carbon financial markets and enterprise NQPF as well as their underlying driving mechanism. Employing the double machine learning method, multi-period DID approach, two-way fixed effects model, robustness tests, and heterogeneity analysis, the key empirical results are as follows:

(1) CFMP significantly enhances enterprise NQPF, with this causal relationship verified through multiple robustness tests covering double machine learning, placebo tests and PSM-DID matching. Mechanistically, CFMP stabilizes the long-term capital supply for NQPF

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cultivation by regulating the carbon market's supply-demand balance and facilitating price discovery, thereby incentivizing enterprises to develop sustainable innovation and production upgrading.

(2) CFMP promotes NQPF through two key channels. On the one hand, it alleviates information asymmetry by establishing a standardized information environment via mandatory disclosure requirements and strict supervision, thereby reducing financing frictions. On the other hand, it integrates market-based mechanisms with regulatory oversight, CFMP reduces enterprises' equity financing costs, providing sustained financial support for high-investment, long-cycle NQPF cultivation activities such as green technology R&D and digital transformation.

(3) CFMP exhibits significant heterogeneous impacts across regions, industries, and enterprise types. The policy effect is more pronounced in regions with looser environmental regulations, as enterprises in these areas have greater green transformation potential and can directly benefit from carbon price signals and financing support. In low-competition industries, leading enterprises possess core resources and can efficiently capture policy dividends through inter-industry synergies, resulting in a more significant promotion effect. From the perspective of enterprise characteristics, large enterprises and SOEs benefit more: large enterprises leverage economies of scale to reduce financing costs, while SOEs gain advantages from implicit government guarantees and reduced financial frictions, both enhancing the efficiency of NQPF improvement.

(4) Further analysis shows that CFMP improves enterprises' core competitiveness: NQPF exerts a mediating effect only on market performance-oriented indicators, while financial performance and innovation capability are directly driven by the policy. Dynamically, the policy's short-term effects are more prominent in financial performance and innovation capability, while the long-term positive effects persist mainly in production efficiency, reflecting the characteristics of short-term financial dividend release and long-term production efficiency solidification.

Building on the above analyses, we propose targeted policy suggestions.

First, financial support and incentives should be enhanced to consolidate policy effectiveness. The government should establish a special green development fund for NQPF, providing long-term low-interest loans and equity investment for enterprises participating in CFMP. For enterprises with top 20% NQPF growth, a 3-year corporate income tax reduction should be implemented, and green innovation certificates need to be issued to enhance their market reputation.

Second, information and financing environments should be optimized to lower market costs. A national unified carbon finance information platform should be built, integrating data on carbon emissions, trading volume, and financing needs, and open free access to SMEs. Commercial banks should be encouraged to launch "carbon quota mortgage loans" and "green patent pledge financing" products, with the government providing risk compensation for non-performing loans.

https://doi.org/10.7441/joc.2026.02.05

Third, hierarchical and targeted support should be implemented to promote balanced development. For SMEs, a “green transition incubation program” should be set up to provide free carbon accounting training, technical consulting, and special subsidies for green equipment upgrading. For large enterprises and SOEs, carbon finance performance (e.g., carbon asset turnover rate, green R&D investment ratio) should be incorporated into their performance evaluation system.

Fourth, policy coordination and design optimization should be strengthened. A policy coordination mechanism should be established between CFMP, green finance, and environmental subsidies, avoiding overlapping or conflicting policy objectives. For pilot regions, differentiated policy designs need to be formulated based on local industrial characteristics: industrial-intensive regions should focus on carbon quota flexibility allocation, while technology-intensive regions should prioritize carbon financial instrument innovation.

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https://doi.org/10.7441/joc.2026.02.05